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Structural Performance of Grouted Sleeve Connectors With and Without Transverse Reinforcement For Precast Concrete Structure

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Abstract

This paper presents the performance of the proposed grouted sleeve connector with and without steel spiral as transverse reinforcement under incremental tensile load until failure. The connector utilized mild steel pipe as sleeve where the sleeve consists of external and internal sleeve with the diameter of the external sleeve is larger than internal sleeve. The mild steel pipe and the steel spiral are used to confine and reinforce the grout and the two discontinued bars spliced end-to-end configuration in the sleeve. The test shows that, there are two modes of failure which were bar slipped and bar fractured outside the sleeve. Eleven specimens out of fourteen shows satisfactory results as it failed due to bar fractured outside the sleeve and achieve satisfactory ultimate tensile capacity. The stiffness and the ductility of the connectors also satisfy. Grouted sleeve connectors with steel spiral perform better compared to connectors without a steel spiral. The test shows that the performance of the grouted sleeve connector with or without steel spiral was governed by grout-bar bond, anchorage length and confinement action provided by the sleeve and the steel spiral. The connectors have a potential to be used in connecting precast concrete structure.

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Keywords: component- component; grouted sleeve connector; transverse reinforcement; end-to-end; confinement action.

1. Introduction

Grouted splice sleeve connector is a designed mechanical coupler that filled with non-shrinkage grout as bonding material to splice reinforcement bars to ensure continuity during the load transfer. The connector will receive a reinforcing bar at each end and meet at mid-length as the grout is poured or injected into the sleeve.

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This type of connecter has been extensively in use for precast concrete structure where North America, Eupore and Japan are the earliest countries that use this method of connection to connect precast element such as a wall panel or column since it was invented by Alfred A. Yee in late 1960 for splicing reinforcement bars [1, 2]. Eriksson in 1960 also suggested the same idea of using cement grout as bonding material between the reinforcing bars and sleeve while Markested and Johansen in 1970 suggested of using steel pipe sleeve with resin mortar as bonding material for splicing deformed bar [3]. Grouted sleeve connector is relying on the bonding mechanism between the reinforcement bar and the grout where one of the factors governing the bonding is confinement. Confinement help in improving the bonding mechanism thus reduces the development length required in splicing reinforcement bar [2]. Confinement in sleeve connector can be done by confining the entire anchorage zone of splicing or confining the surrounding of individual bars by means such as transverse reinforcement, cylindrical steel pipe or aluminum sleeve [4,5,6]. Grouted sleeve connector allowed shorter development length for splicing of reinforcing bars as it is relying on the confinement action besides the grout strength [1].

It is essential to ensure the precast concrete connection system is not the weakest link among precast element, as it will affect the overall performance of the structure. It is important to prevent slippage of reinforcing bars in a critical location to ensure stability of structural system [7].Therefore, it is important to ensure that the structural performance of the grouted sleeve connector is able to maintain the integrity and continuity of the precast element with shorter development length as suggested in [1]. In precast connection system, the grouted sleeve connector should be the last element that will fail after other precast structure failed. Grouted sleeve connector in precast structure more likely tend to fail due to flexural failure rather than shear failure in which induces high tensile stress in the reinforcement bars. Therefore, the grouted sleeve connector is commonly test and evaluate based on its performance for tensile resistance under direct tensile test.

2. Significant Of Study

This paper presents the structural performance of grouted sleeve connectors with steel spiral as transverse reinforcement. The sleeve filled with grout as the bonding material between the reinforcing bar, steel spiral and the sleeve. Their performance was evaluated based on their load-displacement curves, ultimate tensile capacities, corresponding displacements at ultimate states and failure modes. This was to acquire the feasibility of the proposed connectors in precast concrete structure.

3. Experimental Procedure

3.1. Test Specimens

In this study, 14 specimens of grouted sleeve connectors were tested under direct tensile load where their tensile performance and failure modes were studied to acquire the factors that govern the performance of the connectors. The grouted sleeve connection specimens utilized circular hollow section (CHS) steel pipe as the sleeve wherein consists of an external sleeve and two internal sleeve steel pipes with 5 mm thickness as both having different diameters and connected by four M10 bolts at each end of sleeve. The length of the external sleeve was varied but the length of the internal sleeve was fixed at 50 mm and positioned at both ends in external sleeve. The internal sleeve was designed to act as anchors to provide resistance for the grout from slipping out from the sleeve. The steel spiral was made from R6 mild steel as the transverse reinforcement and Y16 high strength steel as the reinforcement bar. Two Y16 were spliced end-to-end configuration in the center of the R6 steel spiral, and bonded with sleeve connector by non-shrinkage Sika Grout-215. The two Y16s were spaced approximately 10mm apart from each other.

As for Group D series (GD-series), the specimens were divided into two groups namely GD-60.3 and GD-76.1 according to the external sleeve diameter where the diameters are 60.3mm and 76.1mm. For GD-60.3 specimens, the internal sleeve was made from 48.5mm in diameter of steel pipe while for GD-76.1 group; the internal sleeve was made from 60.3mm in diameter steel pipe. The length of the internal sleeve is constant for all specimens in this series. The development lengths also varied from 100mm to 200mm with a 25mm step-up. Therefore, the external sleeve length varied from 210mm to 410mm with 50mm increments. GD-60.3 and GD-76.1 used steel spiral with 25mm and 45mm opening as the transverse reinforcement respectively. Finally, Group E series (GE-series) also added as the testing specimen and were divided into two groups namely GE-60.3 and GE-76.1 according the diameter of the external sleeve. Each series then consists of two specimens according to the development length of the reinforcement bars in the sleeve connectors without steel spiral as transverse reinforcement. The selected development lengths were 100mm and 200mm.

3.2. Test Setup

Fig. 2 shows the proposed sleeve specimens that were arranged vertically and tied using wires to the wooden frame to hold the specimen during the grouting process. Then, a Y16 bar was inserted and aligned to the center of the sleeve and the steel spiral until the bar from each end meet at mid-length of the sleeve. The Y16 bars then were tied to the wooden frame and finally the grout was poured into the sleeve manually at pourable state. Then, after the grout hardened and achieved at least minimum strength of 50 N/mm^2 the specimens were tested under incremental tensile load until failure. The specimens were placed vertically on the platform of the *DARTEC* hydraulic actuator and gripped onto the steel bars at a pressure of about 11MPa as in Fig. 3. Then, the actuator arm moved gradually upward, inducing tensile force at the rate of 0.5kN/s. The load variation against displacement was recorded during the test.

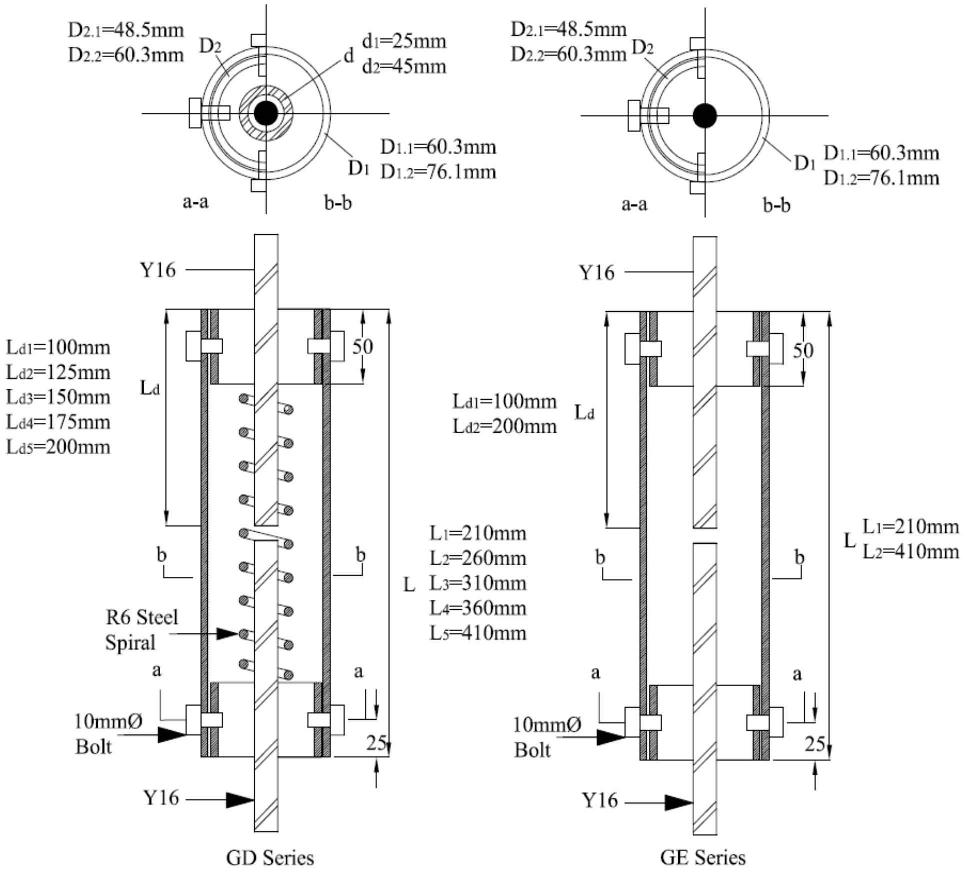


Fig. 1. Detail of Tested Grouted Sleeve Specimens

Fig. 2. Grouted sleeve connector prepared for grouting procedure

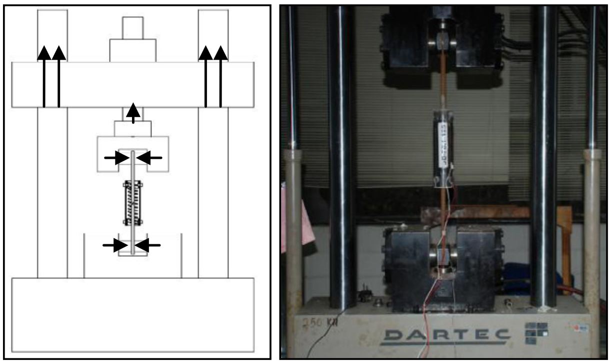


Fig. 3.Specimen on DARTEC machine ready to be tested for tensile test

4. Result and Discussion

The results were analyzed based on the development of plotted load-displacement graph in terms of the ultimate tensile capacity, P (kN), corresponding displacement at ultimate tensile capacity, ΔL (mm) and modes of failure.

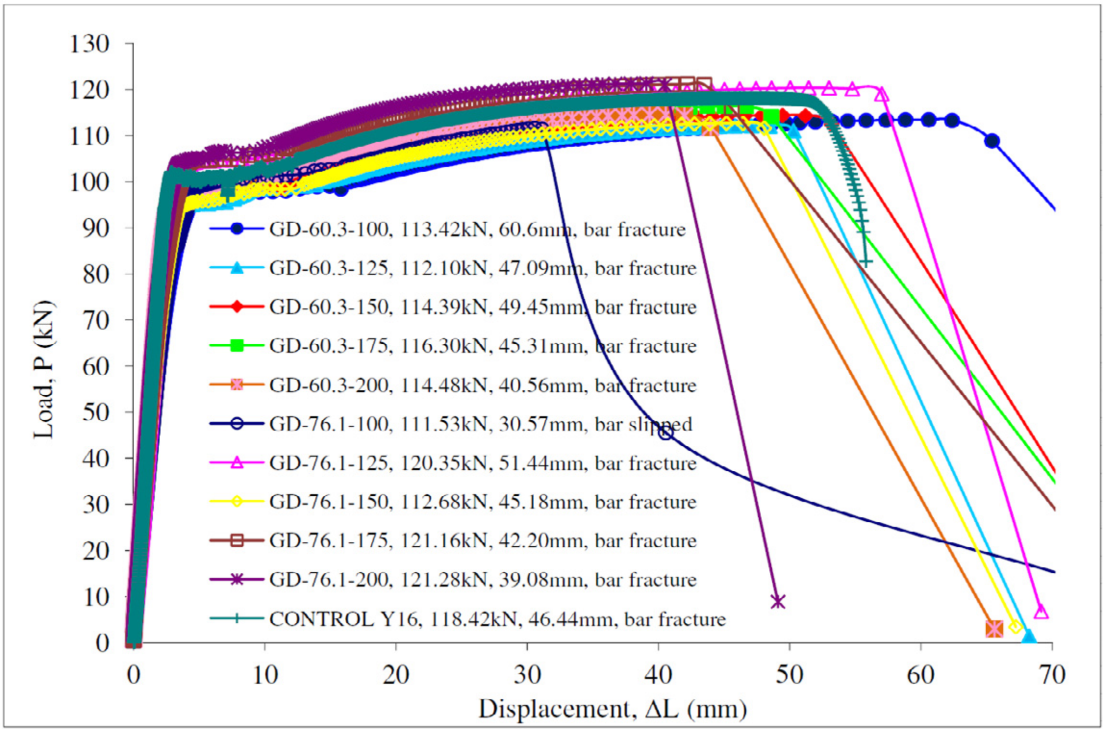
Table1 shows the test results for the proposed grouted sleeve connector for GD-series and GE-series. The recorded test results are based on the grout compressive strength, f_{cu} (N/mm^2), ultimate tensile capacity, P (kN), displacement at ultimate tensile capacity, ΔL (mm) and modes of failure. Fig. 4 shows the load-displacement graphs of the tested grouted sleeve connector under direct tensile load. The performance of the grouted sleeve connectors was compared to a single Y16 (Control Y16) reinforcement bar under direct tensile load. The result shows that, a single Y16 tested under direct tensile load is able to reach ultimate tensile capacity at 118.41 kN and the displacement at ultimate state was 46.44mm. The grouted sleeve connector can be classified as a satisfactory connector if it is able to generate bond strength higher than the tensile capacity of the spliced reinforcement bars. Therefore, the performance of the grouted sleeve connector can be determined if the grouted sleeve connector able to achieved ultimate tensile strength at par or higher than 118.41 kN. On the other hand, the performance also can be determined if the spliced bars in the connector fractured outside the grouted sleeve connector instead of slipping out from the connector.

The direct tensile test results show that the tested grouted sleeve connectors have comparable load-displacement development to the Control Y16 as indicated by the load-displacement graphs in Fig. 4. The slope of the load-displacement graph indicates the initial stiffness of the grouted sleeve connector and the Control Y16. Based on best line method with linear relationship, the slope for grouted sleeve specimens were determined where GD-60.3 and GD-76.1 group shows that the stiffness increases as the development length of reinforcement bar increases. For GD-60.3 group, GD-60.3-100 specimen shows the lowest stiffness with a slope value of 25.888 and GD-60.3-200 shows the highest stiffness of 40.671, which were lower 38.97% and 4.12% respectively from the stiffness of Control Y16. As for GD-76.1group, specimens GD-76.1-100 show the lowest stiffness where the slope is 28.149 while GD-76.1-200 has the highest stiffness with a slope value of 39.121 that were lower 33.64% and 7.77% from Control Y16 stiffness respectively. This indicates specimens with longer development length (noted by the third notation in the specimens' name) behave almost identically to a single reinforcement bar as the continuity of the reinforcement is getting better. The load-displacement graph also indicate the spliced bar in the connectors able to yield as indicates by the decreasing slope of the load-displacement graph and then fluctuated until the connectors were failed due to bar fractured or bar slippage. The ultimate tensile capacity for tested grouted sleeve connectors ranged from the lowest of 102.17kN to 121.28kN where GE-76.1-100 and GD-76.1-200 specimen recorded the lowest and highest tensile capacity respectively. The ultimate tensile capacity of the grouted sleeve connecters also was inconsistent respect to the increases of reinforcement bar anchorage length in the grouted sleeve connector. However, all grouted sleeve connectors were able to give satisfactory result as the connectors were failed due to bar fractured outside the sleeve except for GD-76.1-100, GE-60.3-100 and GE-76.1-100 specimen where they were unsatisfactory as it failed due to bar slipped out from the sleeve. Apart from GD-76.1-125, GD76.1-175 and GD-76.1-200 that were able to achieve higher ultimate tensile strength than Control Y16, the ultimate tensile strength the rest of the connectors was lower than Control Y16. Nonetheless, as all tested connectors failed due to bar fractured except for GD-76.1-100, GE-60.3-100 and GE-76.1-100 specimen thus indicates that the connectors able to generate bond strength higher than the tensile capacity of the reinforcement bar resulting in satisfactory results. Despite GD-76.1-100, GE-60.3-200 and GE-76.1-20 specimen failed due to bar slippage, the connectors still able to generate sufficient bonding mechanism thus elongate before it failed due to bar slipped during strain-hardening process as the tensile capacity of the connector exceed the bond strength of grout-bar as shown in Fig 4. However, those three specimens still considered as unsatisfactory.

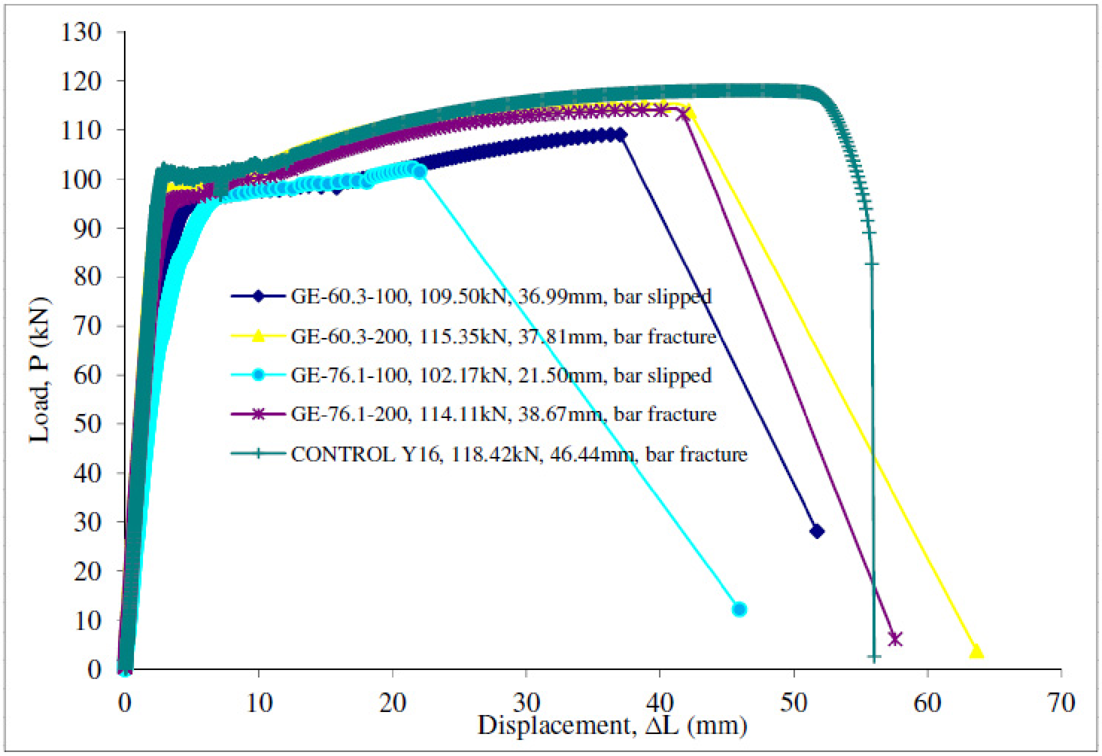
Bar slipped was due to grout-bar bond slip failure and bar fracture was due to tensile strength failure of the reinforcement bar. Grout-bar bond slip occur when the bonding strength between the grout and bar is insufficient thus leading to bar slipped as occurred in GD-76.1-100, GE-60.3-100 and GE-76.1-100 specimen as shown in Fig. 5a. The anchorage length for the reinforcement bar these three specimens can be considered as short anchorage length as it was only 100mm long. With such short anchorage length, the specimen was unable to generate sufficient bond stress to resist the spliced bar from being pullout from the sleeve connector. Short anchorage length means less shear area provided by the bars to generate bond stress to resist the pullout force. This lead to insufficient interlocking mechanism between the grout keys and bar ribs as the shear area is small thus the bar slipped before it's able to reached its ultimate capacity [9,10].

Table 1: Tensile Performance Of Proposed Grouted Sleeve Connector

Specimens	f_{cu} (N/mm^2)	P (kN)	ΔL (mm)	Modes of Failure
Control Y16		118.42	46.44	Bar fracture
GD-60.3-100	72.68	113.42	60.60	Bar fracture
GD-60.3-125	72.68	112.10	47.09	Bar fracture
GD-60.3-150	72.68	114.39	49.45	Bar fracture
GD-60.3-175	72.68	116.30	45.31	Bar fracture
GD-60.3-200	72.68	114.48	40.56	Bar fracture
GD-76.1-100	72.68	111.53	30.57	Bar slipped
GD-76.1-125	72.68	120.35	51.44	Bar fracture
GD-76.1-150	72.68	112.68	45.18	Bar fracture
GD-76.1-175	72.68	121.16	42.40	Bar fracture
GD-76.1-200	72.68	121.28	39.08	Bar fracture
GE-60.3-100	72.58	109.05	36.00	Bar slipped
GE-60.3-200	72.58	115.35	37.81	Bar fracture
GE-76.1-100	72.58	102.17	21.50	Bar slipped
GE-76.1-200	72.58	114.11	38.67	Bar fracture



a) GD-series grouted sleeve connector with transverse reinforcement



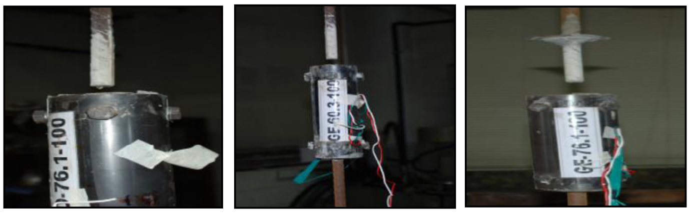
b) GE-series grouted sleeve connector without transverse reinforcement

Figure 4. Load-displacement graphs of grouted sleeve connectors

Bar fracture indicates the adequacy of the bond strength generated by the connectors thus outperformed the tensile capacity of the spliced reinforcement bar. Fig 5b shows the mode of failure for GD-60.3-100, GD- 76.1-125 and GE-60.3-200 where the bar fracture outside the sleeve. Although the anchorage length of GD-60.3-100 was 100mm long, this considered as short, the connector still able to generate bond strength that outperformed the tensile capacity of the bar. The bond strength was improved could be due to confinement action provided by the steel spiral and the steel pipe sleeve as the diameter of the spiral and the sleeve much smaller compare to GD-76.1-100 specimen. Other than that, the design of the the internal sleeve provide confinement stress as the internal sleeve block the motion of the grout form being pullout. This induced compression stress at the interface of the the internal sleeve surface and the grout thus generates confinement stress thus improve the bond strength. This characteristic is important for grouted sleeve connector without transverse reinforcement as the connector only relying on the bond strength to sustain the tensile load provided that the anchorage length of the spliced bar is adequate. This can be interpreted from the modes of failure of GE-series as the mode of failure changes from bar slipped at anchorage length 100mm long to bar fracture outside the sleeve at 200mm anchorage length. As the splice reinforcement bar in tension, it transmits the tensile stress to the surrounding grout them to the steel spiral and the to the sleeve wall. This generates confinement stress along the inner sleeve wall where this stress would provide normal pressure to the reinforcement thus increase the bond strength [8]. Meanwhile, the steel spiral will stretch and transverse tensile stress is developed where the stress provide confinement stress to the grout and spliced bar.

The tensile capacity recorded by all connectors that failed due to bar fracture ranged from 112.10kN and 121.28kN with a standard deviation of 3.24kN which equivalent to 557.47 N/mm^2 and 603.10 N/mm^2 in terms of tensile stress. For the purposes of design and safety, the ultimate tensile capacity of the reinforcement bar must be larger than the specified yield strength (f_y) [11]. As in [11], the yield strength of a high strength steel bar is should be at least 460 N/mm^2. Therefore, as the tensile stress of the connectors was ranged from 557.47 N/mm^2 and 603.10 N/mm^2 the connectors able to provide sufficient bond strength with the spliced bars as the bars were able to sustain ultimate tensile stress higher than specified by [11]. As for that, the connectors could be applied in the construction industry, as the tensile stress is at least 21.2% higher than the yield strength. Since, the tensile stress is higher than minimum yield strength of 460 N/mm^2, the quality of the reinforcement bars used in the connectors was still assured.

The ductility of the grouted sleeve specimens can be observed indirectly from the corresponding displacement of the sleeve at ultimate tensile states. The displacement endured by the connectors excluding the Control Y16 ranged from 39.08 mm and 60.60 mm. All connectors able to generate sufficient bonding strength thus enable the reinforcement bars to yield due to tensile stress endured as shown by the fluctuation in the load-displacement graphs. This also shows that the connectors able to provide tensile resistance as it exceeded the yielding point of the reinforcement bars. Although GD-76.1-100 specimen failed due to reinforcement bar slippage, the connector able to generate bonding strength just enough for the reinforcement bar to behave plastically. Based on the test result, it shows that, the ductility of GD-60.3-series is better than GD-76.1-series and GE-series. The possible factor is higher confinement stress developed with smaller diameter of the sleeve and steel spiral opening thus increase the bond strength. This contributes to smaller regions of confinement where this could improve the efficiency and the degree of the confinement stress confining the grout and the spliced reinforcement bars.



i. GD-76.1-100 ii. GE-60.3-100 iii. GE-76.1-100

a) Bar slipped

i. GD-60.3-100 ii. GD-76.1-125 iii. GE-76.1-200

b) Bar fracture

Fig. 5. Modes of failure in grouted sleeve connector

5. Conclusion

In this study, fourteen mild steel grouted sleeve connectors with and without steel spiral were experimentally tested under incremental direct tensile load. The grouted sleeve connector was designed to spliced two discontinues reinforcement bars. This finding is based on the direct tensile load conducted on reinforcement bar with 16 mm diameter only. Therefore, the findings are applicable for the bar size only for the time being..

The test results show that the modes of failure observed in the study consists of bar slipped out of the connectors and bar fracture outside the proposed grouted sleeve connectors. Bar slipped from the connectors due to inadequate bond strength while bar fracture due to bond strength higher than the ultimate tensile strength of the reinforcement bar.

The anchorage length of the spliced reinforcement bar governed the grout-bar bond strength weather with or without transverse reinforcement. Increase of anchorage length gives better performance as the modes of failure changes from bar slipped for anchorage length 100mm to bar fracture with 200mm long of anchorage length. The stiffness of the connectors also increases with the increasing anchorage length. Transverse reinforcement helps to improve the grout-bar bond performance of the grouted sleeve connector with short anchorage length as short as 100mm long provided that, the confinement stress is also adequate. However, it is suggested that the minimum anchorage length of the grouted sleeve connector with steel spiral as transverse reinforcement to be 125mm which is 7.8 times of the bar diameter.

The performance of the grouted sleeve connector without transverse reinforcement affected by the confinement action generates by the mild steel sleeve. The internal sleeve helps in generating the confinement stress through compression stress as it restrain the grout from being pullout from the sleeve thus improved the performance of the grouted sleeve connector without transverse reinforcement. The combination of confining using mild steel sleeve pipe and steel spiral improves the performance of the grouted sleeve connector. It enables grouted sleeve connector to have short anchorage length. Higher confinement stress generates by smaller diameter of the sleeve where steel sleeve with 60.3mm and 48.5mm as external and internal sleeve respectively with 25mm of steel spiral opening give better performance in-term of stiffness and ductility. Out of fourteen, eleven connectors show satisfactory results as they failed due to bar fracture and shows the possibility to be used in the pre-cast connection system.

References

[1] A. Einea , T. Yamane, and M.K Tadros, "Grout-filled pipe splices for precast concrete construction," PCI Journal, vol. 40 no.1, pp. 82-93, January-February 1995.

[2] J.H. Ling, A.B. Abd Rahman, I.S. Ibrahim , and Z. Abdul Hamid, "Behaviour of grouted pipe splice under incremental tensile load," Construction and Building Material J., vol 33, pp. 90-98, February 2012.

[3] Navaratnarajah V., "Splicing reinforcement bars with epoxy joints," Int. J. Adhesion and Adhesive, vol. 3 no. 2, G, pp. 271–350, April 1983.

[4] D. Darwin, and E.K. Graham, "Effect of deformation height and spacing on bond strength of Reinforcing Bars," ACI Structural Journal, pp. 646-657, November 1993.

[5] H.Y. Loh, Development of grouted spliced sleeve and its performance under axial ternsion, Msc, University Technology Malaysia, 2008.

[6] J.H. Ling, A.B. Abd Rahman, and Z. Abdul Hamid, "Performance of corrugated aluminium sleeve connector under direct tensile load," 2nd. Engineering Conference on Sustainable Engineering (ENCON 08), Kuching, Sarawak, Univerisity Malaysia Sarawak (UMS), 18-19 December 2008.

[7] P. Soroushian, K.B. Choi, G.H, Park, and F. Aslani, " Bond of deformed bars to concrete: Effects of confinement and strength of concrete," ACI Material Journal, vol.88 no.3, pp. 227-232, May-June 1991.

[8] L.J. Malvar, "Bond of reinforcement under controlled confinement," ACI Material Journal, vol. 89 no 6, November-December 1992.

[9] F.J. Brenes, Anchorage of grouted vertical duct connections for precast bent caps, PhD, University of Texas, Austin, 2005.

[10] K.L. Dahl, High strength grouted coupler, U.S Patent No. 6,192,647, 2001.

[11] BS8110:Part 1: 1997, British Standard Institution, 2nd Edition, March 1997.