

PERFORMANCE OF CS-SLEEVE UNDER DIRECT TENSILE LOAD, PART II: STRUCTURAL PERFORMANCE

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ABSTRACT: Tensile resistance of a sleeve connector used to connect between two structural components by confining grouted reinforcement bars relies on interaction among reinforcement bars, sleeve and grout. In this study, a total of nine specimens with different configurations, sizes of sleeves, reinforcement bars' surface conditions and also grouting materials were tested under direct tensile tests. This paper presents further discussion on the study of performance of CS-Sleeves, particularly on the load-displacement graphs and load-strain graphs of the specimens in order to acquire the structural performance of the specimens. The test data indicates that threads on reinforcement bar had significantly deteriorated the bonding mechanism between reinforcement bars and grout. None of the specimens achieved the required strength. However, the findings obtained from the study provide essential basis for future research in developing an adequate sleeve connector.

Keywords: *splice sleeve, grout, end-to-end connector, anchorage bond*

1.0 Introduction

A sleeve is a cylindrical mechanical steel coupler that utilized non-shrinking high early strength grout as filling material to splice reinforcement bars. The aim of the study is to develop an end-to-end sleeve connector that ensures continuity of the reinforcement bars at the minimum lapping length. The ultimate goals of developing a sleeve connector are (1) to minimize the usage of steel metal in the construction in order to reduce the construction cost, and (2) to speed up the erection process of precast wall panels. As a connection system for precast wall panels, the proposed sleeve connector should be able

to withstand the horizontal shear force and the flexural tensile force that are caused by lateral force, either contributed by wind load or seismic earth movement. In this preliminary study stage, a feasibility study was conducted on the proposed specimens to study their structural performance under direct tensile force.

The companion paper (Part I) emphasizes on the failure modes of the proposed specimens and their mechanisms of failure. This paper discusses further on the structural performance of the specimens through analyzing the load-displacement and the load-strain curves. The investigation concentrates on the parametric studies of the sleeve, which include investigating the effects of; (1) embedded length of the reinforcement bar in the grout, (2) sizes and diameters of the sleeve, (3) configurations of the sleeve, (4) load transferring medium or filling material used for the sleeve and also (5) surface condition of the reinforcement bars to the loading capacity of the sleeve.

2.0 Experimental Program

A total of nine specimens were proposed to be tested under direct tensile load in the laboratory. Figure 1 demonstrates the setup of the hydraulic actuator for direct tensile test. Specimens were placed vertically on the platform while the actuator grabbed on the reinforcement bars at both ends at 11MPa pressure. Then, as the testing launched, the arm of the hydraulic actuator moved upward, causing incremental pulling force onto reinforcement bars at opposite directions. The rate of pulling was 0.2kN/s throughout the testing. The data obtained from the testing consisted of load (kN), displacement (mm), steel strain ($\times 10^{-6}$ mm/mm) and also sleeve strain ($\times 10^{-6}$ mm/mm). The variation of load was plotted against displacement and strain reading for analysis.

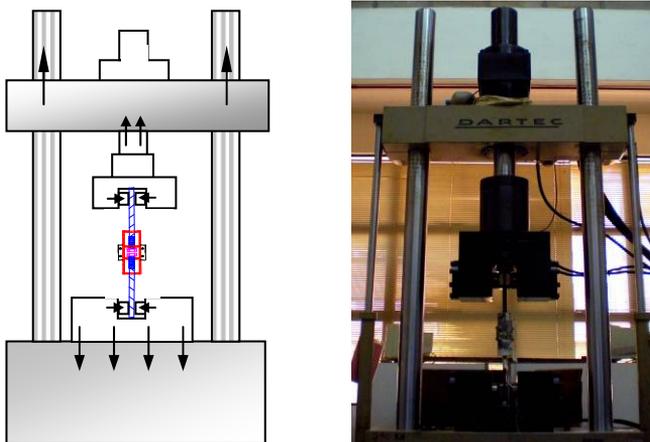


Figure 1: Tensile test were conducted in laboratory

2.1 Parametric Studies

2.1.1 Reinforcement bar embedded length

In this study, CS-Sleeves were tested under incremental tensile load to acquire their ultimate capacities and loading behaviour. A Y16 reinforcement bar was used as the control specimen to evaluate the structural performance of the proposed sleeves. The Y16 bar showed elastic behaviour (constant in load-displacement slope) before it yielded at 114.5kN load. Beyond that, its stiffness dropped drastically and it endured serious elongations (interpreted from drastic decrease of load-displacement slope after 114.5kN). The ductile behaviour could be observed through fluctuation of the load-displacement curve after it yielded. Y16 bar failed at ultimate capacity of 133.0kN, with the corresponding displacement of 61.62mm. Figure 2 shows the graph of load versus displacement for specimens CS-01, CS-02 and CS-03. The effects of different heights of the sleeves to the structural performance of the specimens were studied. Specimen CS-01 could sustain up to 98.4kN of loading with corresponding displacement of 8.72mm. Basically, it is almost impossible for a sleeve to produce perfect identical stiffness ratio as compared to the control specimen because; (1) the discontinuity of reinforcement bar, (2) the load were to be transferred among different materials, which include steel bar, grout, and sleeve. In other word, as the pulling force applied on the reinforcement bar, the load will be transferred from the reinforcement bar to the surrounding filling material (grout). The discontinuity of the reinforcement bar led to stress to be concentrated at the break point between them. The pulling force tends to break the grout, of which is weak in tensile, and causes it to split and slide out of the sleeve. Then, the sleeve plays essential role in preventing the grout from sliding out of it. Therefore, the stresses are transferred among the different material. Due to the reason that the loads were transferred among materials with different elastic modulus, CS-01 presented slightly less stiffness ratio as compared to control specimen. The gradual decrease in stiffness ratio of CS-01 triggered as the grout reached its compressive strength, when cracks and crushes initiated.

CS-01 presented an unusual increase in displacement (fluctuation) at 17kN. The comparison among other specimens with the similar failure mode, such as CS-02, CS-03, CS-06 and CS-09, shows that only CS-01 had such unusual fluctuation event occurred during loading period. It was suspected that the fluctuation was due to the slippage of the nut out of the reinforcement bar. The reason that load-displacement graph of the other specimens did not fluctuate is either (1) the nuts were yet to slip until the ultimate capacities of the specimens were reached, or (2) the slip and the displacement of reinforcement were unobvious.

The nut that clamped on the reinforcement bar in CS-01 was located too closely to the steel plate at the middle of the sleeve, causing such an unusual fluctuation in load-displacement graph. Poor working quality caused the nut was not precisely placed at the intended location in the sleeve. Figure 3 compares the locations of nuts in specimens CS-01 and CS-02, of which CS-01 had its nut placed closely to the steel plate at the middle of

the sleeve as compared to specimen CS-02. This led to the phenomenon that as if the nut directly contact onto the steel plates in the sleeve. Hence, it provided no tolerance for slippage of reinforcement bar.

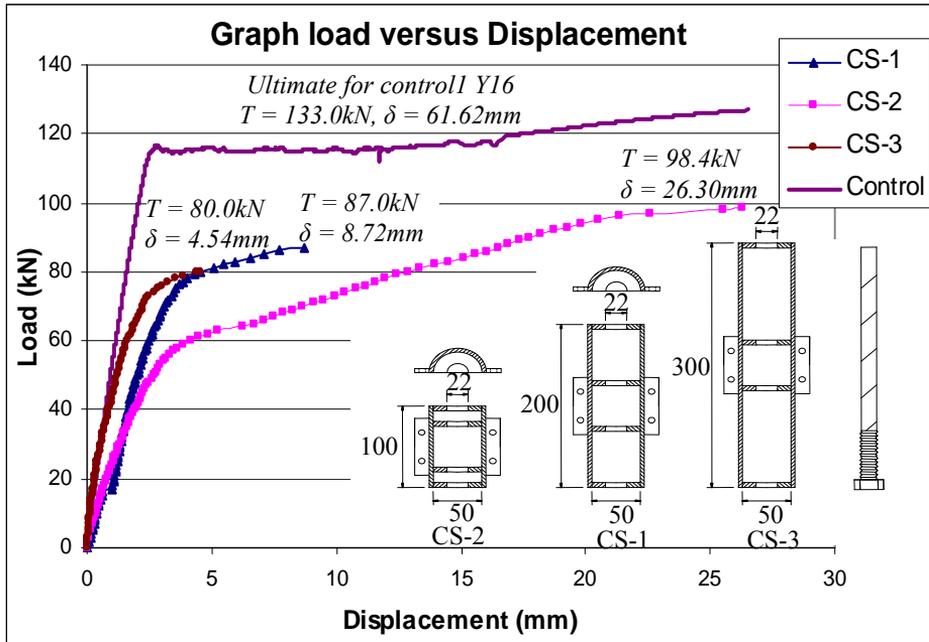


Figure 2: Graphs of load versus displacement of specimen CS-1, CS-2, CS-3 and control specimen 1Y16

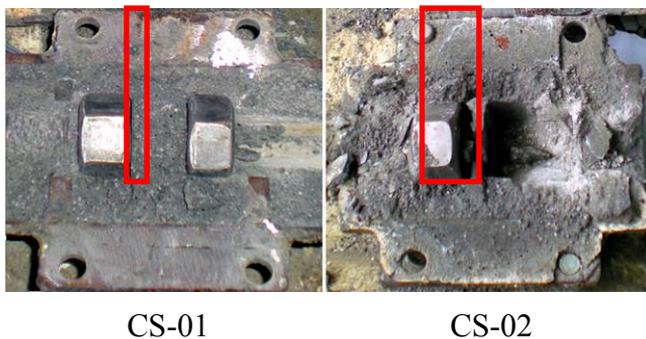


Figure 3: Comparison of volume/area ratio of specimen CS-01 and CS-02

As loading was applied on the reinforcement bar, the reinforcement slipped slightly before the interlocking mechanism between ribs on reinforcement bar and the grout keys between the ribs took effect. The steel plates that resisted the displacement of the nut provided no tolerance for the displacement. This induced stress onto the nut and eventually the threads on the nut that clamped onto the threaded reinforcement bar sheared off. As the nut sheared off and slipped out of the reinforcement bar, the reinforcement bar slipped suddenly as well. This led to sudden increase in displacement recorded in load-displacement data. This phenomenon was supported by the load-strain data obtained during the testing.

Figure 4 shows the load-strain graph of the mild steel sleeve that monitored the tensile condition of the sleeve throughout the testing. The strain of CS-01 sleeve increased linearly along with the incremental load before 17kN. Then, the strain reading dropped drastically after 17kN, of which exactly the same instant when the load-displacement graph fluctuated. It indicated the load was transferred directly from reinforcement bars to the sleeve, causing it to undergo tensile force as well. Then as the thread on the nut reached its shear capacity at 17kN, it slipped and could no longer transfer the load to the sleeve. Therefore, the mild steel sleeve was released from tensile force, which was indicated by the drastic decrease of the strain reading. Obviously, unless the nut was directly contact to the steel plate, it was not possible that the pulling force could transferred directly to the sleeve and developed a linear relationship between the respond of sleeve towards the loading applied on reinforcement bar.

The load-strain graph of CS-01 sleeve provides essential information on responds of the sleeve throughout the loading period. Figure 5 describes the responds of the CS-01 sleeve under loading. As the pulling force applied, the nut tended to move towards the direction of the force (Figure 5a). However, it was resisted by the steel plates in the middle of sleeve, causing the sleeve to endure tensile force directly (Figure 5b). This led to linear development of the strain reading as the pulling force increased. Then, as the incremental tensile force proceeded and reached the shear capacity of the threads at 17kN, the nut sheared off and could no longer transfer load to the middle steel plate of the sleeve. Hence, CS-01 sleeve was released from tensile force and reformed back to original condition (Figure 5c), and therefore, the strain reading dropped suddenly in great intense as showed in the load-strain graph.

Figure 6 presents the strain condition of the reinforcement bar in the sleeve. It also provides clues for the slip of the nut. At 17kN an unsmooth curve could be detected. It indicates a temporary retard of the strain development in reinforcement bar at the instant. At the instant, the nut sheared off and the reinforcement bar slipped slightly. This led to sudden relieve of the reinforcement bar from the tense applied onto it. Therefore, the development of strain condition in reinforcement bar retarded a while in load-strain graph in Figure 6.

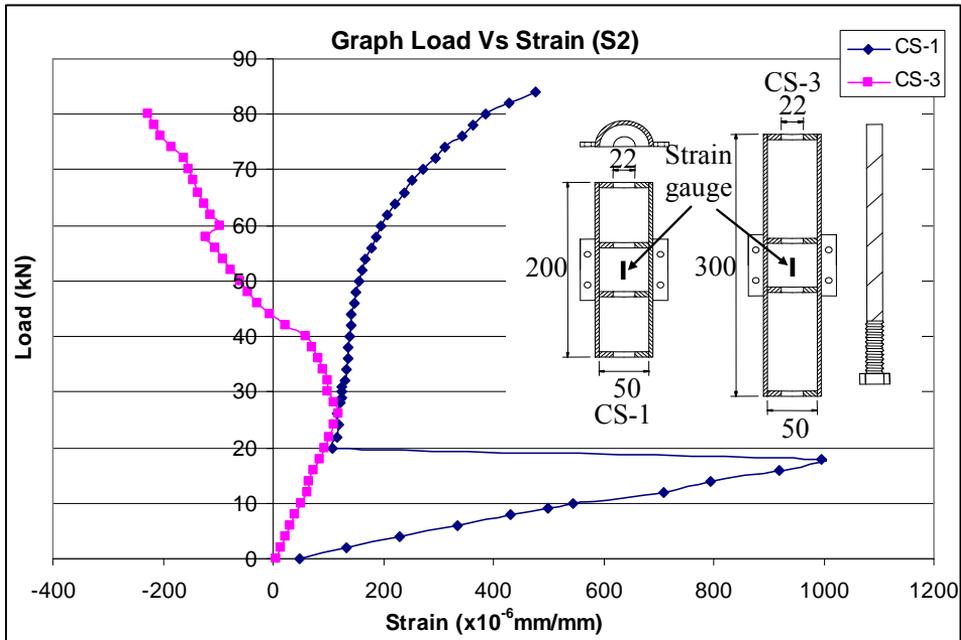


Figure 4: Graph load versus strain (S2) for specimen CS-01 and CS-03

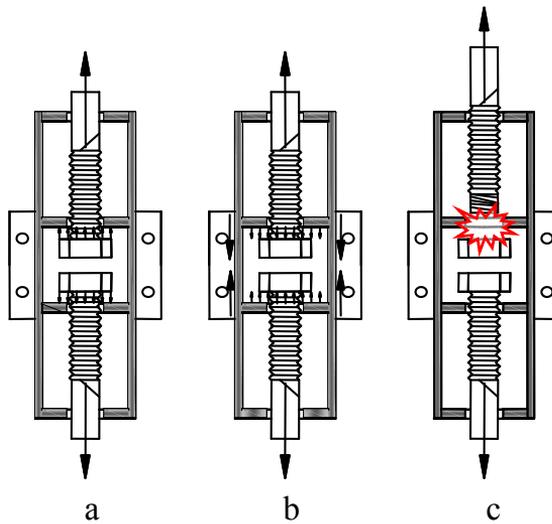


Figure 5: Mechanism of load transfer between reinforcement bar and sleeve

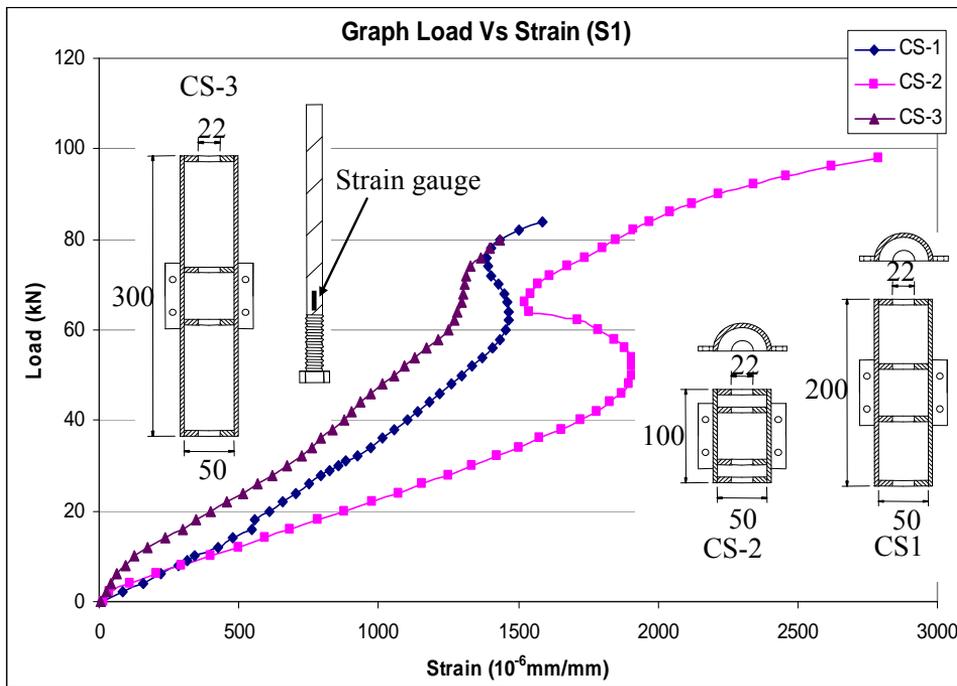


Figure 6: Graph load versus strain (S1) for specimen CS-01, CS-02 and CS-03

From the load-displacement graph in Figure 2, specimen CS-01 showed elastic behaviour for a short instant after 17kN before its stiffness started to decrease gradually at approximately 70kN load. The stiffness ratio was interpreted from the slope of load-displacement graph. The gradual decrease of stiffness ratio was governed by gradual increase of displacement, of which was contributed by (1) propagation and development of minor cracks and crushes of grout surrounding the reinforcement bar, (2) slight slip of reinforcement bar along the embedded length before the mechanical interlocking of between the ribs and the grout keys took effects, (3) slight elongation of reinforcement bar under tensile load, (4) damages and yielding of the threads.

Specimen CS-01 offered the ultimate loading capacity of 86.956kN with the corresponding displacement of 8.720mm. The results were unsatisfactory as it could only reached 65.4% of the required loading capacity. The causes of failure was discussed in *Part I* and was identified to be contributed by (1) poor bonding property between threaded reinforcement bar and surrounding grout and (2) low shear resistance capacity of the threads on reinforcement bar and the nut, causing the nut could not contribute in enhancing the effective bearing area to resist the slippage of reinforcement bar.

The reinforcement bars in specimen CS-02 had limited amount of length embedded in the grout (Figure 7). It led to less bonding capacity. Therefore, it showed the least stiffness ratio as compared to CS-01 and CS-03. This was interpreted from the instance when the displacement of the reinforcement bar accelerated (Figure 2). CS-02 underwent sudden increase in displacement at approximately 62kN load (the corresponding displacement was 5.1mm). The grout in the sleeve crushed at the instant. This caused the reinforcement bar to slip and directly contacted onto the steel plates in the sleeve. This explains the reason of sudden displacement at 62kN. The plates prevented the reinforcement bar from being pulled out of the sleeve. By then, the loading resistance of CS-02 was contributed by the strength of the nuts and the tensile resistance of the sleeve. Therefore, metallic ductile behaviour was observed from the load-displacement graph.

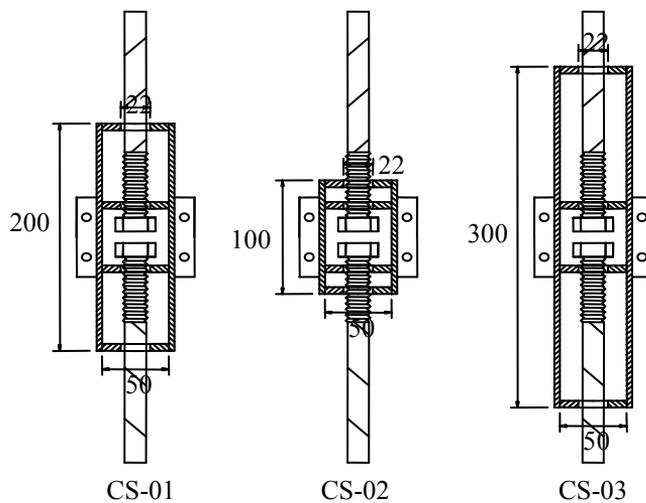


Figure 7: Details of specimen CS-01, CS-02 and CS-03

In this situation the displacement reading obtained from the testing was governed by (1) slight elongation of reinforcement bar, (2) slight deformation of steel plate in the sleeve, (3) slight elongation of steel sleeve, (4) crushing and slippage of the reinforcement bars, of which one of the reinforcement bars had its grout surrounding it crushed while another slipped slightly. The ultimate loading capacity of specimen CS-02 was 98.419kN. Due to crushing, it ended up with severe dislocation of the reinforcement bar at the end of testing. Similar as CS-01, the result obtained from specimen CS-02 was also unsatisfactory as it could only sustain up of 74% of the required strength. The factor that contributed to the failure were (1) crushes of grout, (2) shear resistance of the threads on the reinforcement bar and the nut.

Among the specimens CS-01, CS-02 and CS-03, CS-03 had the longest embedded length of the reinforcement bar in the grout (Figure 7). Hence, it provided the largest stiffness ratio. CS-03's stiffness ratio was closed to the control specimen before reaching 45kN load. Then, the stiffness ratio decreased gradually. At 70kN, the degradation rate of the stiffness ratio accelerated due to rapid propagation of minor cracks and crushes in the grout. Its ultimate loading capacity was only 80.049kN (60.2% of the required strength). The corresponding displacement was 4.541mm. Although specimen CS-03 had the longest embedded length in the grout, it had the lowest loading capacity. The variation of ultimate load may due to poor quality of work, of which cause by poor compaction and improper bond between reinforcement bar and the grout. It was also noticed that the quality of thread also doubtful. Obviously, in CS-02, as the grout crushed, the specimen relied on the nut to give the resistance until it failed at 98.4kN. However, CS-01 had its nut sheared off at 17kN only. Therefore, the quality of the threads was not assured.

Figure 6 shows the load-strain graph of the reinforcement bars in specimens CS-01, CS-02 and CS-03. CS-02 underwent more severe strain throughout the testing because of the limited embedded length of reinforcement bar in the grout. Meanwhile, the reinforcement bars in CS-03 endured least strain as it had longer embedded length in grout. Obviously, the grout surrounding the reinforcement bar also took part in load resisting mechanism and could directly influence the stiffness ratio of the specimens. The load-strain graph also gave information that the stress in reinforcement bars in the specimens increase gradually until certain limits, then the strain reading dropped slightly. After that the strain reading increased again. This situation was due to the reason that the grout had reached to its yield, where minor cracks and slight slips occurred. The slight slip of reinforcement bar caused the instance release of reinforcement bar from the tension load. Soon after that, when the slight slip ended, the incremental load will lead further development of tension condition in reinforcement bars. Due to limited embedded length of the reinforcement bars in the grout for CS-02, it was noticed that it underwent slippage slightly earlier than the other specimens.

Figure 4 shows the load-strain graph that describes the tensile condition of mild steel sleeves of the specimens CS-01 and CS-03. The results obtained from the tensile test on a Y16 reinforcement bar showed that the maximum stress that could be sustained was 581N/mm². The elastic modulus of a high yield steel bar is 200GPa. Therefore, the reinforcement bar will yield at 2.905×10^{-3} mm/mm strain. The load-strain curve of the mild steel sleeve of specimen CS-03 showed negligible strain development. This indicated that the sleeve did not contribute in tensile resistance throughout the loading period. The poor bonding property between grout and threaded reinforcement bar led to improper distribution of stress in the sleeve. The reinforcement bars slipped before the sleeve could take part in resisting tensile force. Therefore, the mild steel sleeve did not take part in loading resisting mechanism.

The understandings obtained from the comparison of specimens CS-01, CS-02 and CS-03 were: (1) the thread on bar will influence the bonding mechanism between reinforcement bar and grout and this affects the bonding strength and ultimate loading

capacity of the specimens, (2) the nut could significantly increase the effective bearing area that resisted slippage of reinforcement bar. However, it should not rely on the threads to ensure it firmly attached onto the reinforcement bar due to (a) poor shear resistance of the threads, (b) the qualities of the threads were not assured, (3) the increase of embedded length can increase the stiffness ratio of the specimens, however, it did not increase the loading capacity of the specimens. Nevertheless, limited embedded length of reinforcement bar in grout will lead to early occurrence of acceleration of degradation rate for stiffness ratio. (4) The nut that clamped onto the reinforcement bar should not be located too closely contact to the steel plates in sleeve in order to prevent concentration of stress and to avoid direct transfer of stress from reinforcement bar to the plate.

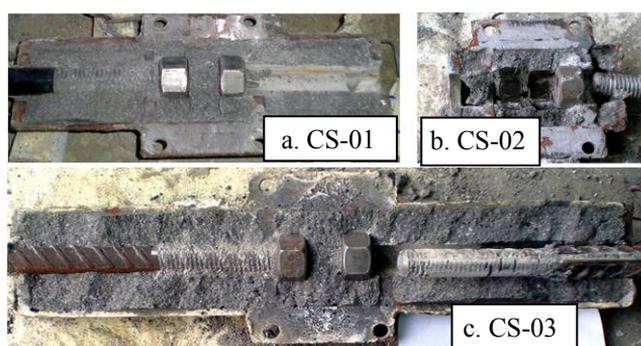


Figure 8: Failure mode of specimen CS-01, CS-02 and CS-03

The internal conditions and the failure modes of specimens CS-01, CS-02 and CS-03 are illustrated in Figure 8. Reinforcement bars of CS-01 and CS-03 slipped leaving behind the smooth surface of crushed grout keys. Meanwhile, the grout in CS-02 crushed, leaving behind the nut stuck at the opening of the steel plates due to failure of threads that hold the nut and reinforcement bar together.

2.1.2 Sizes of Sleeve

Figure 9 plots the graph of load versus displacement of specimens CS-01, CS-04 and CS-05. It studies the effects of different sizes of sleeve, in terms of cross sectional area, towards loading performance of the sleeve. Basically, despite of sudden displacement of specimen CS-01 at 17kN, the structural performance of the specimens appeared to be similar (ultimate loading capacity and stiffness ratio). It seems that the similarity in embedded length of reinforcement bars in grout-filled sleeve will lead to similar ultimate loading capacity, of which the specimens recorded 86.965kN, 85.272kN and 84.305kN

accordingly. Specimens CS-04 and CS-05 were also similar in stiffness ratio and the rate of decreasing rate of stiffness ratio. The load-displacement curve in Figure 8 showed that all the specimens underwent degradation of stiffness ratio as the pulling force reached 70kN. It was the instant where minor cracks and progressive shear failure occurred as the grouts in the sleeve had reached their capacities.

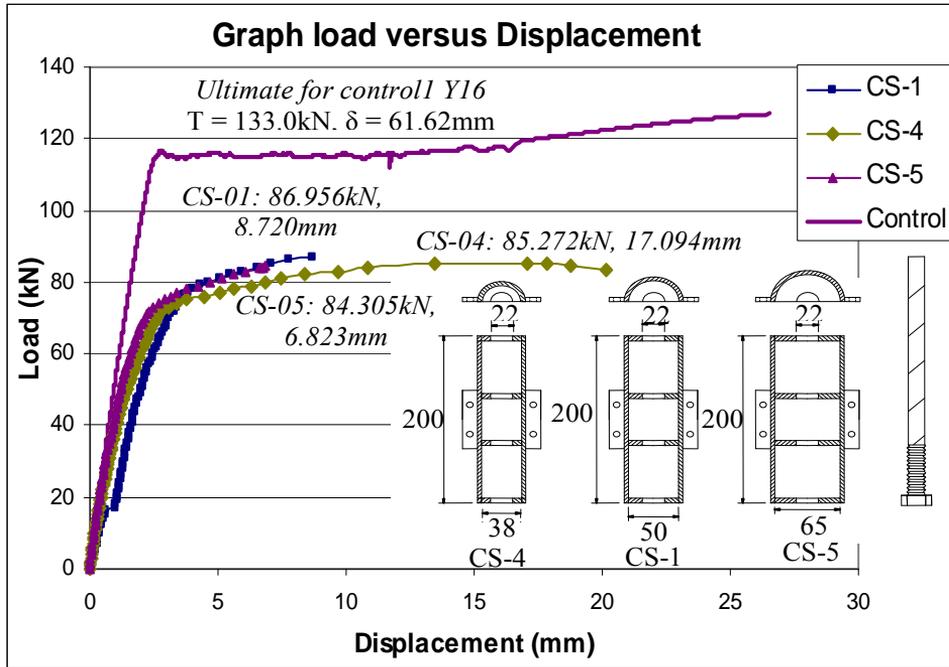


Figure 9: Graph load versus displacement of specimens CS-1, CS-4 and CS-5

Specimen CS-04 presented larger displacement among the specimens. The load-displacement curve indicated the occurrence of progressive crushing of the grout in it, of which was interpreted from the obvious sudden displacement represented by the plots in load displacement curve (at around 82kN loads).

As pulling force was applied onto the reinforcement bars at the opposite directions, the nuts that clamped onto them tended to displace together with the reinforcement bars towards the directions of the pulling forces. The interlocking effect of the nut caused distributed load onto the grout surrounding it (Figure 10a) and brought the grout to move along towards the direction as well. However, it was resisted by the steel plates at the middle of the sleeve. This induced compressive force onto the grout. The compression force deformed the grout and caused it to expand laterally. However, the lateral force was resisted by the circular sleeve. As the incremental gain larger, the lateral expansion also

gain intense and this confinement led to increase of compressive force, until it reached its extreme

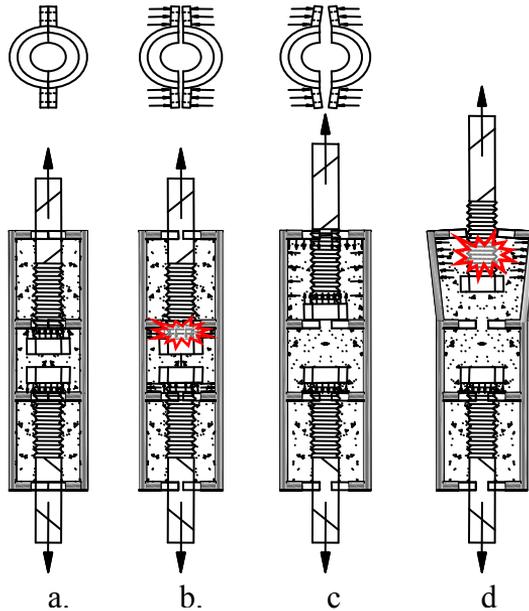


Figure 10: Failure mechanism of specimen CS-04

The grout crushed and large lateral force was generated at all direction (Figure 10b). This had forced semi-circular sleeve to expand towards the weaker axis, where the bolt and nut system gripped the together. Therefore, the opening of the middle steel plate in the sleeve gain larger until it exceeded the size of the nut. Then, the steel plates at the middle of the sleeve could no longer provide interlocking effect to the nut and reinforcement bar. As a result, the reinforcement bar, as well as with the nut, slipped out of the opening, inducing strong compressive force on the grout behind the steel plate (Figure 10c). This also triggered crushing on the grout as it had already exceeded the compressive capacity of the grout. At the meantime of compression, it also caused lateral expansion force. However, the double semi-circular sleeve could not generate enough resistance towards the expansion force as the bolt and nut system provided could only resist the lateral expansion at the middle of the sleeve. Therefore, the sleeve split and rotated outward slightly. The rotation split of the sleeve and the crushing of the grout caused large displacement of reinforcement bar (Figure 10d). Therefore, the specimen ended with 17.094mm displacement at ultimate loading capacity of 85.282kN (Fig 11).



Figure 11: Dislocation of reinforcement bar with nuts on it caused one end of sleeve to split

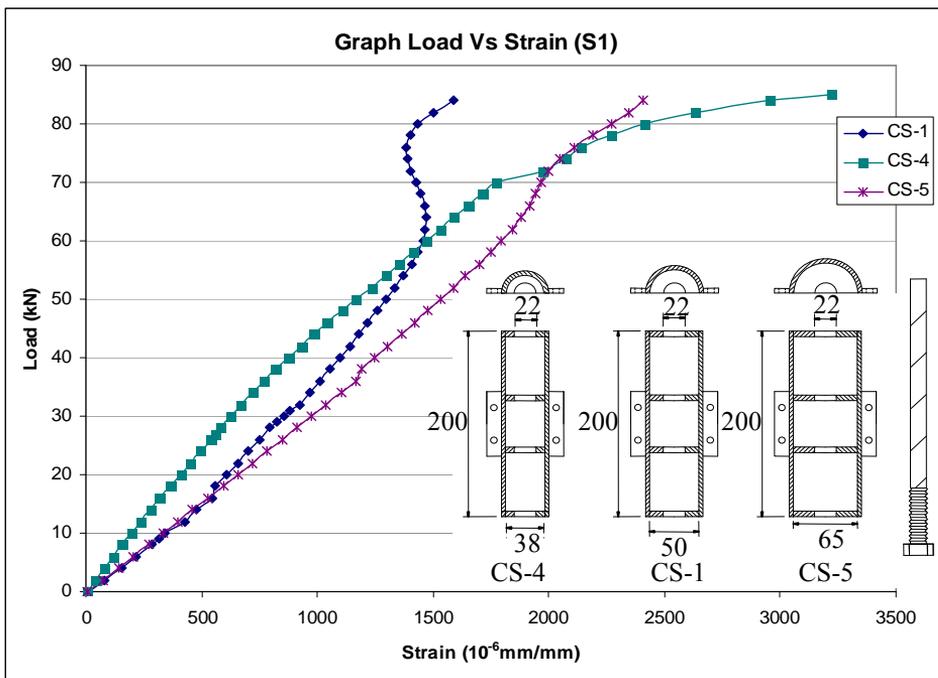


Figure 12: Load strain graph of reinforcement bars in CS-01, CS-04 and CS-05

Figure 12 plots the load-strain graph of the reinforcement bars in specimens CS-01, CS-04 and CS-05. It shows that specimens CS-01 and CS-06 slipped because their load-strain curve showed slight decrease of strain condition at around 80kN before further development of strain in reinforcement bars. They slipped before the reinforcement reached its yield.

Figure 13 illustrates the comparisons of failure modes for specimens CS-01, CS-04 and CS-05. The extreme pulling forces caused the threads on the nut and reinforcement

bar to fail, leaving the nuts remained in the sleeve while the reinforcement bars were pulled out of the sleeve (Figures 11a and 11b). On the other hand, specimen CS-04 underwent progressive crushes that led to severe lost of load transferring medium that ensure the continuities of the reinforcement bar, and therefore, it failed.



Figure 13: Failure modes of specimen CS-01, CS-02 and CS-05

The understandings obtained from this study are: (1) similarity of the embedded length of reinforcement bars in the grout-filled sleeve will cause similar structural performance, in terms of ultimate loading capacity, stiffness ratio, the degradation of stiffness ratio (triggered by the development of cracks and crushes in the grout), (2) the increase of cross sectional area of the sleeve does not contribute in increasing the loading capacity of specimens,

2.1.3 Configurations of sleeve

Figure 14 presents the graph of load versus displacement for specimens CS-01, CS-06 and CS-07. This study investigates the effects of steel plates welded in the sleeve to the ultimate loading capacity of the specimens. Specimen CS-01 had four steel plates welded on the semi-circular sleeves, two at both ends, while another two in the middle of the sleeve. Specimen CS-07 had only two steel plates welded at the both ends of the sleeve. Meanwhile, specimen CS-06 consisted of a pure steel cylinder without any steel plate welded on it (the specimens are as illustrated in Figure 13).

The ultimate loading capacities of specimens CS-01, CS-06 and CS-07 were 86.956kN, 40.922kN and 72.516kN respectively. These specimens failed in different manners (Figure 15). At ultimate state, the reinforcement bar in specimen CS-01 slipped and being pulled out of the sleeve; the grout in CS-07 crushed as it reached its compressive strength; the grout in CS-06 failed in tensile. It split and the grout slipped out of the sleeve. Therefore, it was observed that the configuration of the sleeve could

directly influence the loading capacity of the sleeve. The grout used for the sleeves were from the same mix, of which their compressive strengths were similar. However, specimen CS-07 failed in crushing while CS-01 did not.

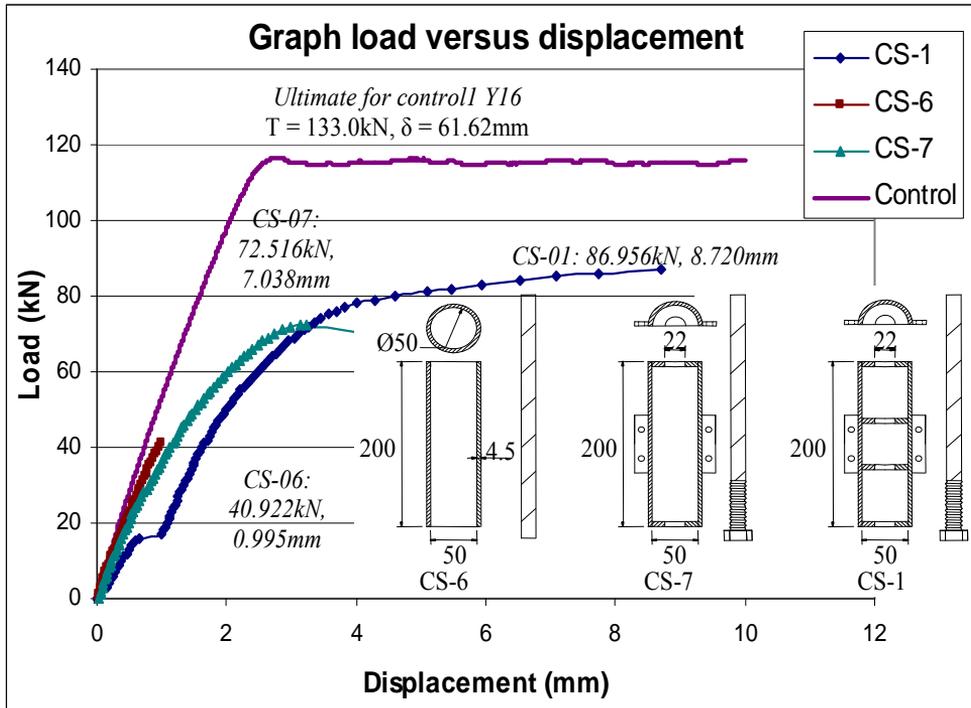


Figure 14: Graph load versus displacement of specimen CS-01, CS-06 and CS-07

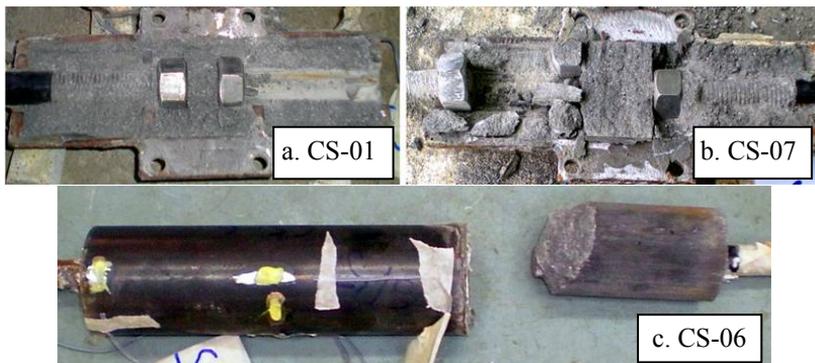


Figure 15: Comparison of failure modes of specimen CS-01, CS-06 and CS-07

Figure 16 plots the load-strain graph of the reinforcement bars in specimens CS-01, CS-06 and CS-07. None of the reinforcement bars yielded during the loading period. The reinforcement bars in specimen CS-06 showed as if did not contribute in load resisting mechanism as it recorded negligible development of strain reading. Improper configuration of sleeve unable to restrain the grout from slipped out of the sleeve. The grout was very weak in tensile and it relied on the friction between the sleeve and the grout to provide tensile resistance. As pulling force was applied, the stress concentrated at the discontinuity of the reinforcement bars. Then, the tensile resistance of the grout and the friction of the sleeve surface took part in preventing the grout from slipping out of the sleeve. Both of them were very weak and therefore, the specimen failed at very low loading

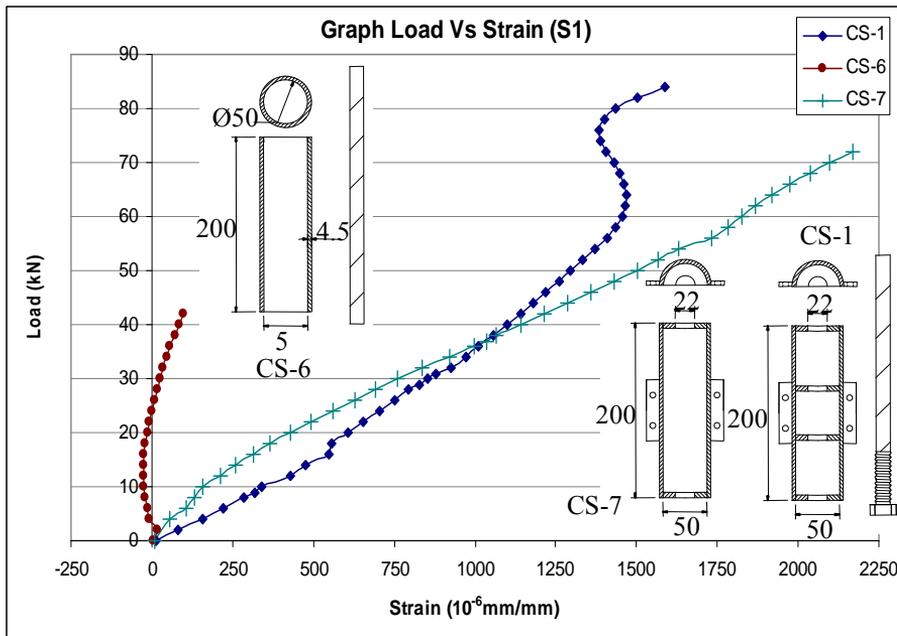


Figure 16: Load-strain graph of the reinforcement bars in specimens CS-01, CS-06 and CS-07

2.1.4 Load Transferring Medium

Figure 17 presents the graph of load versus displacement of specimen CS-01 and CS-08. The configuration of the sleeve for the specimens was similar except that CS-01 utilized grout (43.32N/mm²) while CS-08 utilized mortar (27.93N/mm²) as load transferring material. Specimen CS-01 could sustain up to 86.956kN while CS-08 offered 70.549kN of ultimate tensile resistance.

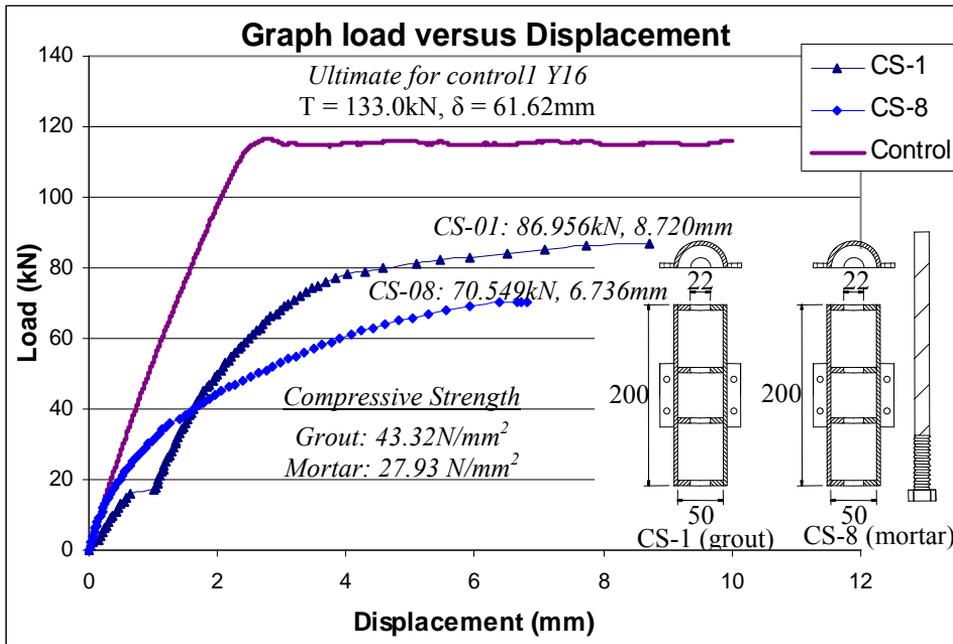


Figure 17: Graph load versus displacement of specimen CS-01 and CS-08

It was noticed that utilizing grout as bonding medium was at the advantage because (1) it offered higher compressive strength compared to mortar and this will significantly improve the bonding strength between grout and reinforcement bar, (2) it provide more reliable quality assurance during mixing as it only required certain amount of water, of which can be calculated and measured precisely before mixing. On the other hand, the mortar consisted of mixture of cement, water and sand. The dryness and humidity condition of the sand influenced the amount of water required and the amount of water required for mixing rely on the personal experience and the judgment of the individual who mix it., (3) the grout was easier to work with, as user can customize its grout condition whether in flowable state or stiffer state depend on the requirement of the work. In this situation, the grout was more easily workable under flowable state while injecting it into the sleeve, of which the mortar was unable to offer flowable properties for the

work, (4) the high strength grout that has self-compacting property that led to ease in compaction.

From the load-displacement graph in Figure 17, at initial stage, specimen CS-08 offered higher stiffness ratio as compared to specimen CS-01 as it underwent relatively less displacement as compared to CS-01. Then, the displacement development rate increased gradually until the load-displacement curve intercept with curve of CS-01 at approximately 1.5mm. The load resisting capacity of CS-08 was reaching its yield while CS-01 was yet to reach its capacity. Therefore, after the interception, CS-01 outperformed CS-08. Both the specimens underwent similar mode of failure, of which both of them had their reinforcement bar slipped out of the sleeve, while the nut remained inside the sleeve (Figure 18).

2.1.5 Surface condition of reinforcement bars

Figure 19 illustrates the graph of load versus displacement of specimens CS-01 and CS-09. This study investigated the effects of the threads towards the structural performance of the sleeve. CS-01 utilized threaded steel bar to be embedded in the sleeve, while CS-09 utilized deformed reinforcement bar in the sleeve. The result showed that deformed reinforcement bar provided better bonding properties. The thread on the reinforcement bars led to higher bearing/shear area and it had significantly affected the bonding capacity of the specimens. The grout keys between threads had limited shear areas to resist the pulling force and hence reinforcement bar slipped at 86.956kN as compared to specimen CS-09 of 101.795kN.



Figure 18: Comparison of bonding medium used in specimens CS-01 and CS-08

The mechanical interlocking property provided by the ribs on the deformed reinforcement bar not only enhance the bonding property of the specimen, it also led to higher stiffness ratio, of which it underwent slightly less displacement as compared to specimen CS-01 with threaded reinforcement.

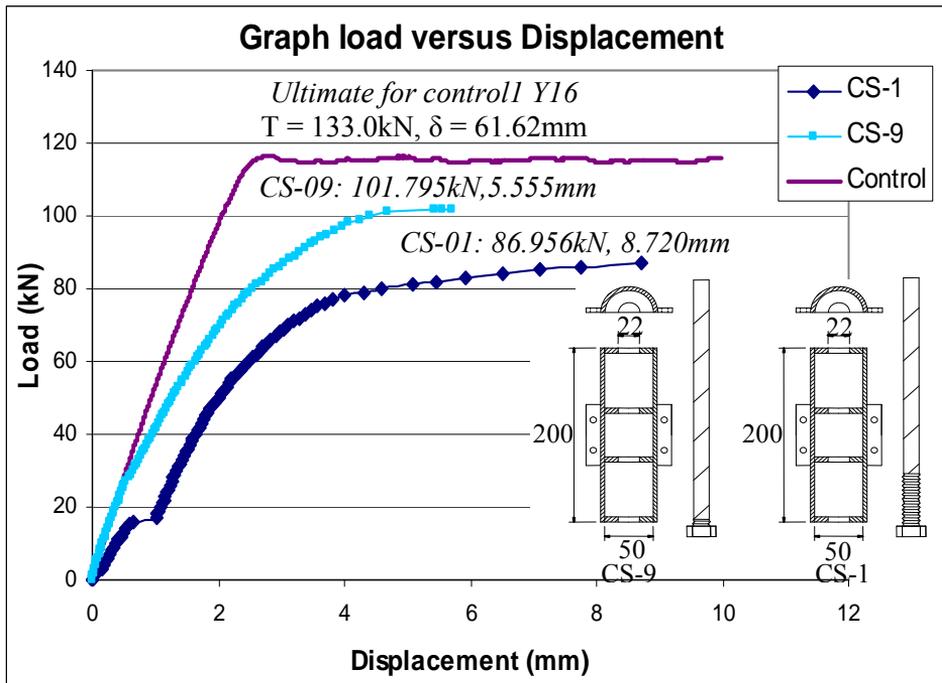


Figure 19: Graph of load versus displacement of specimen CS-01 and CS-09

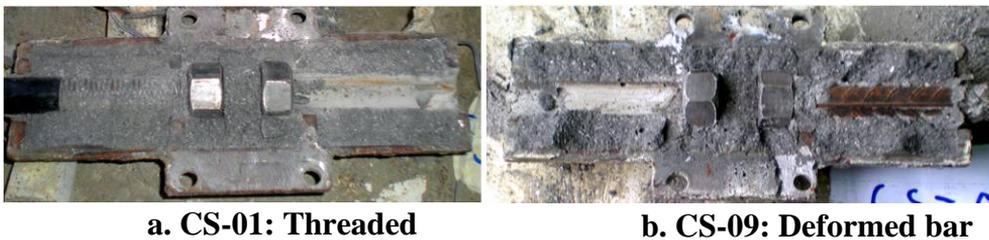


Figure 20: Failure modes of specimen CS-01 and CS-09

Figure 19 shows the graph of load versus displacement of specimens CS-01 and CS-09. This study investigates the effects of the threads towards the loading performance of specimen. Threaded reinforcement bars were embedded in specimen CS-01, while ordinary reinforcement bar was used in specimen CS-09. The outcomes showed that specimen CS-09, with ordinary rib pattern, had outperformed the threaded reinforcement bar in specimen CS-01. This was due to the strong mechanical interlocking between bar ribs and grout keys. CS-09 presented higher stiffness ratio as compared to CS-01 because it had better bonding property. Specimens CS-01 and CS-09 underwent similar failure

mode, of which both of the specimens had their reinforcement bars slipped and being pulled out of the sleeve (Figure 20).

The understanding obtained from the study are (1) reinforcement bar rib pattern should not be threaded in order to ensure optimum performance of bonding mechanism other wise it will affect the bond property between grout and reinforcement bar, (2) better bonding property will lead to high stiffness ratio of the specimen. Figure 21 illustrates the plots of all the specimens of this study and obviously, specimen CS-09 offered the best structural performance (101.795kN), while specimen CS-06 gave the least loading capacity of 40.922kN.

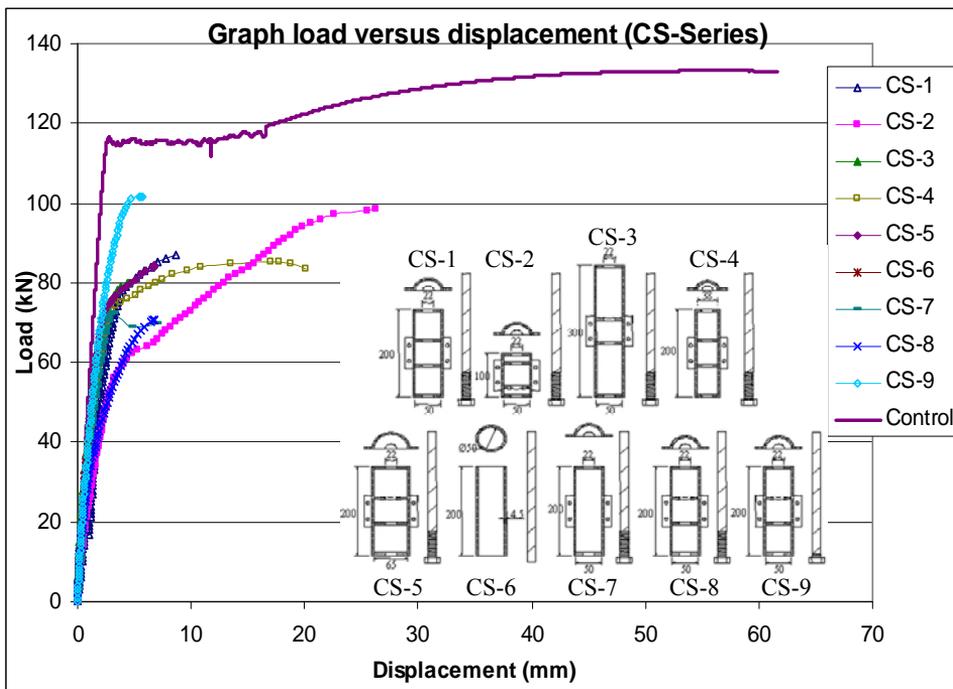


Figure 21: Load-displacement graph of all the specimens in the study

3.0 Conclusions

In this study, nine specimens of CS-Sleeve were used as sleeve connectors and tested under direct tensile test. None of the specimens provided satisfactory structural performance. The maximum loading capacity of the CS-sleeve was 76.5% of the required

strength. However, it provides important basis for future study and development of the sleeve connector. It can be concluded that:

- i. Threads on the reinforcement bar significantly decrease the bonding capacity of the sleeve.
- ii. The existence of the nut attached on the reinforcement bar could enhance the bonding capacity as it has significantly increase the bearing area to resist the slip of reinforcement bar, provided that it is firmly attached on the reinforcement bar throughout the loading period.
- iii. The surface condition of the sleeve is essential to prevent the grout from slipping out of the sleeve.
- iv. The usage of grout as filling material is more practical due to more reliable quality and ease in workability.
- v. The diameter of the sleeve contributes very minor effect to the loading capacity of the sleeve.
- vi. The embedded length of the reinforcement bar in the sleeve increases the stiffness ratio and bonding capacity between reinforcement bar and the grout.

Acknowledgement

The authors gratefully thank the CREAM (Construction Industry Research Institute of Malaysia) and CIDB (Construction Industry Development Board) for the financial support under research grant Vot. 73713. The experimental programs were conducted at the Structural and Material Laboratory of Faculty of Civil Engineering, Universiti Teknologi Malaysia. The contribution of the technical staffs are acknowledged.

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