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INFLUENCE OF STEEL BARS FOR EXTERNAL CONFINEMENT ON COMPRESSIVE STRENGTH OF CONCRETE

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ABSTRACT : This paper examines the possible influence of external confinement on concrete by utilizing traditional steel bars. The test specimens were concrete cubes of 150 mm in size. Steel bars were bent and mounted surrounding the surface perimeter of the concrete cube, just like a belt. The diameters of steel bars were 6 and 8 mm. The belt was made of a steel bar and connected with a steel long nut. The results obtained from this investigation was the cubes confined externally with 8-mm diameter of steel bars had higher compressive strength than cube without external confinement. Spacing between the steel bars is affected by the concrete strengths compared with those using the smaller diameter of steel bars (6 mm). The closer the spacing of the steel bars, the higher the strength of the concrete cubes. The long nut provided a stronger connection than the steel bars. Thus, the application of these traditional steel bars as an external confining system for a possible future retrofitting method is recommended since it performed a significant contribution in providing effective confinement to concrete and further enhancing its compressive strength.

Keywords: *Compressive strength, Concrete, External confinement, Steel bars, Steel long nut, Retrofitting.*

1. INTRODUCTION

Confinement of concrete is well known to significantly improve the performance of concrete such as its compressive strength and ductility [1]. The confinement is normally implemented in concrete internally [2]. As internal confinement, it is manifested by the presence of transverse reinforcement [3]. For square sections, stirrups are the most popular type of transverse reinforcement [4]. Other innovative confinements are to introduce the use of high strength steel bars [5,6], use of steel fiber [7,8], interlocking steel bars [9], and FRP (fiber-reinforced polymer) [10].

There is a possibility of a building changing its function due to various reasons. The consequence of these changes is highly likely to create additional load to the building. This additional load increases the load carried by the concrete columns. Thus, it requires retrofitting effort to enhance its capacity. The easy way of retrofitting process is by introducing a confinement method externally since it does not require dismantling the concrete. In the study, the proposed retrofitting method uses traditional steel bars which are easily provided on-site. The steel bars are bent to follow the perimeter shape of the concrete and then connected using the steel long nut and it works just like a belt mechanism.

This initial research aims to find out the influence of traditional steel bars when used as external confinement on concrete before further extending its use to externally confine concrete columns. The main issues to be observed in the study are 1) how significant is the presence of the proposed external confinement method in improving the compressive strength of concrete, and 2) which parameters significantly influence the effectiveness of the proposed external confinement method in increasing the compressive strength of concrete.

It is expected that the proposed external confinement method can improve the compressive strength of the concrete cube and hence, it can further increase the axial compressive load capacity of the column. This proposed external confinement method can be an alternative effective and efficient method in increasing the compressive strength of the concrete column. As far as the author’s concern there has been no previous research and references on the use of traditional steel bars as external confinement for concrete [11]. Therefore, initial research on this proposed external confinement method using traditional steel bars for a possible retrofitting system on the column is needed to assess how effective it is in improving the compressive strength of concrete before can be used in columns.

Studies on retrofitting technique using external confinement for concrete columns which has been introduced earlier was the use of FRP (fiber-reinforced polymer) composite jacketing method by wrapping the perimeter surface of the columns [10]. Some of the advantages of this method are 1)its easiness in the installation; 2)there is no increase in cross-section; and 3)no increase in flexural or shear stiffness. However, the application of FRP jackets is generally very costly [12], and thus, it may not be a cost-efficient option for retrofitting in some cases. Hussain and Driver [13] and also Chapman and Driver [14] studied the behavior of concrete columns with external confining collars that use hollow structural sections (HSS) and connected by the bolt-nut system or by welding.

Hussain and Driver [13] conducted a test by imposing the axial static compressive load on the column specimens which were confined by the HSS collars. Test results indicated that columns with external confinement of HSS collars are potentially very suitable for rehabilitation of concrete columns to resist the earthquake loads because they can enhance their strengths and ductilities. Besides, the HSS collar can prevent concrete cover from premature spalling. The HSS collars welded at their ends exhibited a higher increase of compressive strength. This was also indicated by the effective core area which was about 1.95 times the corresponding area of those with bolted collars.

In 2011, research on a more practical external confining steel collars was conducted by Liu, Driver and Lubell [15]. The specimens were subjected to a combination of axial and lateral cyclic loading to determine the strength, ductility, and overall response of concrete short columns. To determine the effectiveness of the collars as a confinement system, the test results of the collared columns were compared to the corresponding test results of traditionally confined concrete column specimens.

The type of collars used by Liu, Driver and Lubell [15] consisted of two thick steel plates of 50 mm (2 inches) thick. They were cut in the form of an L letter. Two pieces of plates were connected by the structural bolt with a diameter of 25.4 mm (1 inch) following the required strength by the ASTM standard A490-14 [16]. The fabrication process was made using common tools and without any welding process such that it is more cost-effective when compared to the built-up HSS collars used in their previous study. Liu, Driver and Lubell [15] conducted a field test of concrete columns with external confinement made of solid steel plate collars subjected to a combination of axial and cyclic loading. The test results of these collared columns designed by Liu, Driver and Lubell [15] indicated no slip on the collars during testing even when spalling and destruction of concrete cover occurred between the collars. This could be an advantage for the application in the rehabilitation of the damaged columns exposed to earthquake loads.

Choi, Chung and Cho [17] studied the steel jacketing plates as external confinement on circular columns. Stainless steel plates were used for the jackets. Turn buckles and steel bands were used instead of clamps to introduce the external pressure on the steel jackets. A total of four turn buckles were installed at the top and the bottom of the steel jackets and turn-rolled out. Under that external pressure, the overlap line of each steel jacket was welded, and then five lateral strips were welded to reinforce the welding line. For the double-layered jacket, the lateral strips were used only on the outside jacket. This property of the new steel-jacketing method is beneficial because it does not disturb the original stiffness of the columns. The performance of the double-layered jacket was better for increasing ductility and energy dissipation capacity than the single-layered jacket. Thus, it seemed that the double-layered jacket is also effective for use in the retrofit of RC columns. Related to the column testing, it should be noted that the axial load placed on the column specimens was relatively low compared with that of other experiments. The newly proposed steel-jacketing method can be used to easily install steel jackets at any location on RC columns (bottom, middle, or top), and it is assessed to have several advantages over the conventional method. The new steel jackets can change the bonding failure of lap-spliced reinforcements from the splitting failure mode to pullout failure mode.

A comprehensive study on columns externally confined by L-shaped steel collars was carried out [18,19]. The test results obtained were the compressive strengths of the columns with steel collars which were 38 percent higher than the columns without confinement. The result has shown that the proposed analytical model can predict the behavior of externally retrofitted square concrete columns reasonably well.

From the study, it is found a promising result on the use of traditional steel bars as external confining collars for concrete. It is also very practical to apply since its installation is very simple. There is neither grouting nor welding are needed. This study can be developed further to provide a new innovative yet low-cost and simple external confinement method for concrete columns by using the traditional steel bars.

2. METHOD

This study aims to observe the impact of diameter and volumetric ratio of traditional steel bars when introduced as an external confining system for concrete in increasing its compressive strength. The test specimens were concrete cubes with the size of 150×150×150 mm in cross section with the assumption that the shape of the cube represents a square short column. The concrete compressive strength (f_c') was 20 MPa. Natural sand and crushed stone were used in concrete mixtures classified in Zone 2. The yield strength of steel bar f_y was 240 MPa. Two types of connection systems were used in the study. The first type was the lap splice of steel bars tied with steel wires (SBW) as shown in Fig. 1(a), whereas the second one was a steel long nut to connect the steel bars (SBL) as shown in Fig. 1b. As a control specimen, a cube without external confinement (C0A) was made. Details and types of external confinement studied are listed in Table 1. The steel bars were externally installed on columns surround their perimeter surfaces just like belts when concrete was three days of age. The compressive strength tests were carried out using a UTM when the specimens aged 7 days.

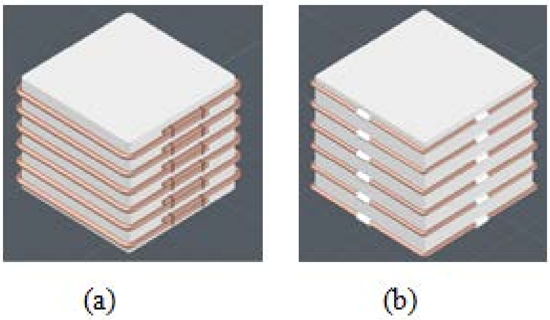

Fig.1 (a) External confinement with steel bars and steel wires, (b) External confinement with steel barsand steel long nuts.

Table 1 Specimens of external confinement

Specimen ID	Diameter of steel bar (mm)	Type of connection	Spacing of steel bars (mm)	Number of steel bar (pieces)
C0A	-	-	-	-
SBW-15	6	Wire	15	9
SBW-30	6	Wire	30	6
SBL6-10	6	Long nut	10	10
SBL6-30	6	Long nut	30	6
SBL8-20	8	Long nut	20	7
SBL8-40	8	Long nut	40	4

Steel bars of 6-mm diameter were tied using steel wires at their connections as can be seen in Fig. 2. The spacing between the steel bars was 15 mm (SBW-15) and 30 mm (SBW-30). Before steel bars were installed, the four corners of the cubes were made curved to eliminate any gaps between the steel bars and the concrete surface so that they could firmly attach to the cubes. While the steel bars connected using a steel long nut of 6 and 8 mm diameters as can be seen in Fig.3. The spacing between the steel bars of 6-mm diameter was 10 mm (SBL6-10) and 30mm (SBL6-30), and the steel bars of 8-mm diameter was 20 mm (SBL8-20) and 40 mm (SBL8-40).

Fig.2 External confinement with steel bars and wires

Fig.3 External confinement with steel bars and long nuts

The external confinement with steel long nut connection used two diameters of steel bars to study the performance of steel long nuts when connecting two different steel bar diameters under compressive load. The spacing of the steel bars with diameters of 6 and 8 mm was also different. This is due to the steel long nut diameter of 8 mm is bigger than 6 mm and hence, its spacing was adjusted to provide comparable volumetric ratios between them, and hence, the steel bar spacing was greater.

The steel bars can be connected using a steel long nut. Thus, both ends of the steel bars must be threaded. The installation of steel bars on the specimens require space to wind and tight up the steel long nut. Therefore, the surface of the concrete at the location of the steel long nut must be engraved, and thus, the steel bars can be firmly attached to the surface of the cube. This is due to the steel long nut diameter is greater than the steel bar diameter, and thus, allow the steel bars to touch tightly on the surface of the cube without any gap.

There is a special technique in the steel bar installation on the cube with the steel long nut connection, that is to bend the steel bars into an angle shape and then install them at each corner of the cube. To connect one steel bar to the other, a steel long nut is used as shown in Fig.3. This way makes it adjustable and flexible to the various column size.

3. TEST RESULTS AND DISCUSSION

The results of the compressive strength test of the cubes confined by the steel bars with steel wire and long nut connections are given in Tables 2 and 3. The results have indicated that the specimens with external confinement of steel bars with steel wire connection (SBW-15) had a compressive strength of about 10 percent higher than that without confinement (C0A). This value is very much higher than f_c' of 20 MPa. While the strength of specimen SBW-30 is less than C0A, although its strength exceeds the compressive strength of 20 MPa. That is because of the effect of spacing between steel bars in which the closer the spacing of the steel bars, the higher the compressive strength of the concrete cube. This confirms that the spacing of the steel bars affected the compressive strength of the concrete. This is due to the closer spacing of steel bars confines better the lateral expansion of the concrete. This can be confirmed from the compressive strength of specimen SBW-15 which is higher than that of specimen SBW-30. Fig. 4 shows that the condition of the steel wire connection after the completion of the test.

When the cube was loaded in compression, initial spalling occurred on the concrete surface, and then the cracks widened further. However, the concrete cube has not reached its ultimate capacity since the external confinement of steel bars still can resist the lateral expansion of concrete due to high compressive load.

When the axial compressive load for specimen SBW-30 was terminated before it completely collapsed. Even though the loading can be further continued, but due to safety reasons that the machine could be accidentally damaged since it almost reached its maximum capacity. Generally, when the specimen is subjected to compressive load failure, it could no longer carry the compressive load further, which is characterized by the abrupt degradation of the post-peak load. However, the specimens with external confinement of steel bars were different. When the cube is subjected to compressive loading though it has been failed, the cube is still able to carry the compressive load with gradual degradation. This is due to the presence of the external confinement that provides lateral passive pressure force to the concrete, such that the concrete is still able to withstand the load further despite it is already damaged. Additionally, the concrete cube compressive strength capacity also increases.

Table 2 The results of compressive strength tests of cubes with external confinement of steel bars and wires

Specimen ID	Diameter of steel bar (mm)	Spacing of steel bars (mm)	Compressive strength (MPa)
C0A	-	-	28.94
SBW-15	6	10	33.15
SBW-30	6	30	26.67

Fig. 4 The cube with external confinement of steel bars and wires after the completion of the test

Table 3 shows the test results of the cubes with external confinement long nut connection. The cube specimens long nut connection SBL6-10, that spacing steel bar of 6 mm and diameter is 10 mm have compression strength value higher than SBL6-30, because spacing of steel bar SBL6-10 are closer than SBL6-30. The same trend was observed for cube specimens with external confinement steel bar of 8 mm diameter SBL8-20, its spacing is 20 mm have compression strength value higher than SBL8-40 which its spacing is 40 mm.

Table 3 The results of compressive strength tests of cubes with external confinement of steel bars and steel long nuts

Specimen ID	Diameter of steel bar (mm)	Spacing of steel bars (mm)	Compressive strength (MPa)
C0A	-	-	14.51
SBL6-10	6	10	16.65
SBL6-30	6	30	13.56
SBL8-20	8	20	17.31
SBL8-40	8	40	14.76

The test results of the cubes confined by the steel bars and wires did not provide good compressive strength since it did not provide high lateral pressure to the concrete as shown in Fig.4. This was due to the steel wires failing to hold the lap splices of the steel bars and caused it to dislodge when confining the lateral expansion of the concrete. Based on this evidence, the steel long nut provides better performance for steel bar connection rather than that of steel wires. Long nut made of stainless steel with thread on the inside. The steel bars must be threaded to be able to connect with the steel long nuts. The steel long nuts were placed at mid of the sides of the specimens. According to Mander, Priestley and Park [20,21], the effect of confinement of square shape is more effective at the corners. Concrete pressure against the sides of the square confinement tends to deflect out the outer side of the concrete such that the cross-sectional area of concrete in the middle is ineffective.

Fig.5 Cube confined with steel bars of 6-mm diameter as external confinement with steel long nut connectors after the completion of the test

Fig.6 Cube confined with steel bars of 8-mm diameter as external confinement with steel long nut connectors after the completion of the test

The test results indicated that the compressive strengths of the specimens were below 20 MPa, either the specimen with or without external confinement. However, it was found that the steel long nuts used to connect the steel bars were not damaged and they were still able to provide the lateral pressure on the concrete. When the specimens were subjected to axial compressive loading, a few of the steel bar connections using the steel long nuts were detached as shown in Figs. 5 and 6. This was caused by the threaded parts of the steel bars that connect to the steel long nuts were not long enough to provide the good grips. The steel long nut connection is much stronger to withstand the lateral expansion from concrete than that of the steel wire connection. Thus, the steel long nut connection is a good connector for external confinement with steel bars.

The compressive strengths of SBL6-10 and SBL8-20 are the highest with the values of 12.85 and 16.17 percent, respectively, higher than specimen C0A. This shows that the closer the spacing of the steel bars, the higher the compressive strength of the concrete. The amount of steel bars as external confinement also affects the increase in strength of the concrete. This also shows that the compressive strength of SBL6-30 is higher than SBL6-10, and the compressive strength of SBL8-20 is higher than SBL-40. The diameter of the steel bars has also affected the strength of the specimens to withstand compressive forces. This is indicated from the compressive strength of SBL8-20 which is higher than SBL6-10.

The test results indicated that the proposed external confinement for concrete cube can be potentially used for further testing of column specimens on the laboratory scale. The compressive strength of the concrete cube confined with steel bars of 6-mm diameter as external confinement with steel long nut connectors after the completion of the test is lower compared with that of 8-mm steel bars.

The spacing of steel bars as external confinement has a major effect on the compressive strength of concrete. The connections of external confinement using the steel long nut are recommended since it can withstand the lateral expansion of concrete. To provide a better connection, the steel long nut is recommended to have a longer size to survive a higher compressive load or later a expansion of concrete.

4. CONCLUSIONS

From the test results and discussion, it can be concluded as follows:

1. The compressive strengths of specimens confined with steel bars connected either by using steel wires or steel long nuts have increased.
2. The external confinement of steel bars with steel long nut connector is strongly recommended because it is better in resisting the lateral force of concrete than the steel wires.
3. Steel bars should completely touch the surfaces of the specimens to provide perfect contact with concrete, and thus effective confinement.
4. The spacing of the steel bars significantly affects the concrete strength, the closer the spacing of steel bars, the higher the compressive strength of the concrete.
5. The diameter of steel bars also affects the compressive strength of concrete since the larger the diameter of the steel bars, the higher the compressive strength of the concrete.
6. The steel long nuts must have enough length to provide a better connection between the two steel bars when resisting the lateral expansion of the concrete.

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