Journal of Insights in Basic and Applied Sciences
مجلة رؤى في العلوم الأساسية والتطبيقية
ISSN: 3106-1737
Volume 2, Issue 3, 2026, Pages: 175-184
Journal homepage: https://jibas.com.ly/index.php/jibas/en

Study of Shear Strength Resistance in Confined Concrete Beams

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دراسة مقاومة قوة القص في الكمرات الخرسانية المحصورة

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Received: May 28, 2026	Accepted: June 27, 2026	Published: July 21, 2026

Abstract:
High strength concrete provides high strength than a normal concrete but less ductility. Over-reinforcing the concrete beam tends to lower the ductility which lead to structures fail without good warning. In order to avoid these kinds of brittle failures Euro codes and other standards does not allow designers to over-reinforce the concrete beam. Even though the code does not allow over-reinforcing, sometimes the designers may need to over-reinforce the beam due to certain limitations. Therefore, the purpose of this research is to increase the ductility of the beam by introducing helical reinforcement in the compression area.
In this research is to study the behavior of reinforced concrete beams with a single and double steel helical confinement in the compression zone. The investigation will be about the flexural behavior of the confined the reinforced concrete beams with respect to ultimate shear strength. The reinforced concrete beams were under-reinforced with a provided steel ratio of (ρ 0.866%) for the first sets of beams and (ρ 1.29%) for the second set of the beams. By using a high strength concrete of f_{ck}= 60N/mm^2
In this research, the six under-reinforced high strength RC beams dimensions of 200 mm (width), 300 mm (height) having 2000 mm in length with a clear span of 1700 mm that is divided into three categories control beam, single and double confinement beam having same pitch but different steel provided ratio. From this experiment, it expected that the confined concrete beams will have a higher flexural strength and enhanced the shear strength compare to the controlled beams.

Keywords: Concrete beams, Confinement, Brittle failures, Over-reinforced, Under reinforced

الملخص
توفر الخرسانة عالية المقاومة قوةً أكبر من الخرسانة العادية ولكنها أقل مرونة. ويؤدي الإفراط في تسليح الكمرات الخرسانية إلى انخفاض مرونتها، مما قد يتسبب في انهيار المنشآت فجأةً. ولتجنب هذا النوع من الانهيارات الهشة، لا تسمح المواصفات الأوروبية وغيرها من المعايير للمصممين بالإفراط في تسليح الكمرات الخرسانية. مع ذلك، قد يضطر المصممون أحيانًا إلى الإفراط في التسليح نظرًا لبعض القيود. لذا، يهدف هذا البحث إلى زيادة مرونة الكمرة من خلال استخدام التسليح الحلزوني في منطقة الضغط.
تتناول هذه الدراسة دراسة سلوك الكمرات الخرسانية المسلحة ذات التسليح الحلزوني الأحادي والثنائي في منطقة الضغط. وستركز الدراسة على سلوك الانحناء لهذه الكمرات الخرسانية المسلحة المحصورة، وذلك فيما يتعلق بمقاومة القص

القصوى. تم استخدام تسليح ناقص في عوارض الخرسانة المسلحة بنسبة حديد تسليح (0.866% ρ) للمجموعة الأولى من العوارض و (1.29% ρ) للمجموعة الثانية. استُخدمت خرسانة عالية المقاومة (60 نيوتن/مم^2) .

في هذه الدراسة، تم استخدام ست عوارض خرسانية مسلحة عالية المقاومة ذات تسليح ناقص، بأبعاد 200 مم (عرض) و300 مم (ارتفاع)، وطول إجمالي 2000 مم، وبمسافة صافية 1700 مم. قُسّمت هذه العوارض إلى ثلاث فئات: عوارض مرجعية، وعوارض ذات تسليح أحادي، وعوارض ذات تسليح مزدوج، جميعها لها نفس المسافة بين العوارض ولكن بنسب حديد تسليح مختلفة. أظهرت النتائج أن عوارض الخرسانة ذات التسليح المزدوج ستتمتع بمقاومة انحناء أعلى ومقاومة قص مُحسّنة مقارنةً بالعوارض المرجعية.

الكلمات المفتاحية: الكمرات الخرسانية، التقييد، حالات الفشل الهشة، التعزيز المفرط، التعزيز الناقص.

Introduction

Concrete acquired by mixing cement, sand, and aggregates with water. Fresh concrete shaped into almost any shape, giving it an inherent advantage over other materials. It is very common after the invention of Portland cement in the 19th century [1]. Nevertheless, it is limited tension resistance initially prevented its wide use in building construction. To control poor tensile strength, steel bars implanted in concrete to form a composite material called reinforced concrete (RC) [2]. Reinforced concrete considered to of the most materials that used in recent buildings. It viewed to be one of the most significant materials in the construction field due to its advantages. Reinforced materials implanted in the concrete in such a way that the two materials resist the applied forces together. The compressive strength of concrete and the tensile strength of steel form a strong bond to resist these stresses over a long span [3, 4].

The reinforcements will help to improve mainly the tensile strength and ductility of the structures. Other than that, reinforced concrete needs low maintenance cost, has longer service life, has good resistance to fire, and protects the steel against corrosion.

Introduction of confinements into the reinforced concrete elements especially reinforced concrete beams is made as to reduce the need to increase the size of the section as well as the increase in compressive strength of concrete. Confinement of concrete in reinforced concrete flexural members would have the same effect in reducing the developed strain values, thus enhancing the concrete ductility, which result into higher absorbing energy of the concrete [5]. This allow beams with confined concrete in the compression zone to sustain higher ultimate load. In addition, the beam will have a better warning against failure, especially so for beam reinforced with a percentage of steel higher than the balanced steel ratio stipulated by most of current codes of practice.

Therefore, with confinement, steel ratio less than the balance can be used which can also be cost effective. With this regard, more techniques for concrete confinement need to provide and more research required investigating other critical and practical aspects of shear and flexural failures in reinforced confined concrete beams [6, 7].

Literature Review

The improvement of high strength concrete has an important effect on the structure which it increases the capacity and stiffness. In addition, HSC also raises the compressive strength that decreases the volume and produce smaller designs and increasing available space. However, the problem occurs that the brittle nature of high strength concrete is a major obstacle in its widespread use and it may lead to sudden failure effect. Therefore, helical reinforcement suggested overcoming the problem by setting it in the compression zone to increase the strength and ductility [8, 9].

In general, it known that confined concrete increases the strength and ductility of concrete, however it was doubtful the impact of confinement on high strength concrete [10]. Designed concrete structure is the key term of confinement with seismic taken under consideration. Confined concrete is able to produce a greater deformation phase even exceeding the elastic phase with considerable loss of strength [11].

Confined reinforcement can be stirrups or spiral reinforcement and normally prepared by providing a zero-shear area and performed on the pure bending condition. It considered as the way to increase the ductility and as a main to decrease the ratio of tensile reinforcement. It can transform the reinforced concrete from brittle to ductile [12]. Using helical reinforcement gives reasonable solution to improve the strength of flexural members. Beams with helical reinforcement have higher plastic phase compared to beams without helical reinforcement that will present brittle behavior [13].

Based on previous research conducted on reinforced concrete beams with different reinforcement ratio where the ratio of ρ = 1.9% and ρ = 2.5% have been tested with monotonic loading [14]. The results have proved that an increase up to 300 % in concrete strain for beams with confinement on the compression zone than beams without confinement. The increase also occurred in the load capacity and the curvature of beams with confinement, while the moment capacity did not show significant improvement [15, 16].

Confinement efficiency affected by helical pitch – helix yield as well as the helix bar diameter, thus there is no influence of confinement until a certain lateral stress due to Poisson's effect reached. In addition, when 60% of the maximum cylinder strength reached, the confinement influence on ductility and strength properties of concrete takes place [17, 18].

Ductility is one of the main factors to confirm the large deformation occurred under overloaded conditions and excessive ductility allows the concrete section or a joint to withstand plastic deformations without any decrease in stress. The compressive strength, strain at highest stress and ductility of high concrete strength proven by rectilinear steel ties and all are increased when the amount of confinement degree increased [19]. Ductility is an important structural property for designing reinforced concrete structures. It ensures that the structures can sustain large inelastic flexural deformation without substantial reduction in strength. In a statically determinate structure, ductility gives early warning of the imminence failure. While in an indeterminate structure; ductility allows the structure to accommodate large imposed deformations and enables a redistribution of internal forces to occur at overload [20].

In theory, confined high strength concrete shows the ductility behavior and described section can be prepared from theoretical moment-curvature curves. Furthermore, it known that the helical reinforcement has more efficiency than the usual rectangular ties as it increases the strength and ductility in the confined concrete and withstanding the lateral expansion [21]. Additionally, which has viewed that the 25mm helix pitch registered high ductility compare to 50, 75 and 100mm pitch, otherwise, helical pitch of 160mm has exhibited to be very weak or brittle in the failure whereby those results verified that the tinier pitch diameter provided higher ductility [22].

Ductility explained as the amount of additional deformations withstood by a structure after the yield load approached. In addition, described that the ductility of reinforced concrete beams depends on several factors such as concrete strength, quantity of reinforcement, concrete confinement, spalling of concrete cover and section geometry [23, 24]. Furthermore, stated that for the presence of four-point bending test of RC beams; the moment at the top fiber in the strain diagram showed an increase in ductility with decreasing uniform moment zone length. At the level of 60% of the peak moment in the post peak range, a reduction of 57% in the uniform moment zone length result in the post peak strain to be doubled [25, 26].

Table 1: Results Obtained from Flexural Test (for Beams) and Compression Test (for Concrete Specimens [27]

Beam	**Calculated Ultimate Flexural Load**	**Calculated Ultimate Shear Load $V_{Rd,s}$ $\theta=22^0$(kN)**	**Calculated Ultimate Shear Load $V_{Rd,s}$ $\theta=45^0$(kN)**	**Calculated $A_{s\,bal}$(mm^2)**	**$A_{s\,prov}$ (mm^2)**	**Bal0anced Steel Ratio Pb(%)**	**Failure Load (kN)**	**Ratio of (Failure Load :$V_{Rd,s}$ $\theta=22^0$)**	**Ratio of (Failure Load : Ultimate Flexural Load)**
B1C	292	296.62	332.90	1152	1658	1.42	293	0.98	1.00
B2S50	292	296.62	332.90	1152	1658	1.42	318	1.07	1.08
B3S100	292	296.62	332.90	1152	1658	1.42	364	1.23	1.25
B4C	327	296.62	328.35	1152	1885	1.64	370	1.25	1.13
B5S50	327	296.62	328.35	1152	1885	1.64	351	1.18	1.07
B6S100	327	296.62	328.35	1152	1885	1.64	350	1.18	1.07

According to the result as shown in Table 1, even though the beams have failed in shear before flexural failure, the beams are able to withstand the shear loads, which are greater their calculated shear failure load. Because, the shear reinforcements provided are insufficient to prevent from shear failure due to the strut angle of 22°. However, for the over reinforced confined concrete beams, it shown that they fail at the shear load, which is lesser than the controlled over reinforced concrete beam. This may due to some errors or mistakes that are unexpected such as incorrect amount of constituents of concrete mixture, inconsistent pitch of the helical confinements, and so on. Hence, the improvements that done are to strengthen the shear reinforcements, accurate calculations on the concrete mix design, proper construction method of helically confined reinforced concrete beam, and the others.

Research Hypothesis

1. Applying single and double helical restraint in the compression zone of high-strength concrete beams with insufficient reinforcement will result in a significant increase in the ultimate flexural and shear strength compared to unrestrained beams.
2. More effective, lateral compression achieved with double helical restraint than with single helical restraint, thus improving the ductility of the restrained concrete and its ability to deform after peak loading.
3. Restrained beams will exhibit a ductile bending failure pattern with sufficient warning signs (cracking and deflection), unlike the expected brittle failure of unrestrained high-strength beams.
4. The observed failure loads will exceed the theoretical design values calculated according to Euro 2, due to the additional restraint effect, which effect not fully accounted for in the standard's provisions.
5. The shear failure observed in some restrained beams attributed to inadequate shear joint detailing rather than the restraint itself. Simultaneously, helical reinforcement primarily affects the behavior of the compression zone.

Research Methodology

Specimen Details

Six full-scaled 200mm (width)×300mm (height)×2000mm (length) simply supported RC beams with a clear span of 1700mm will be prepared and tested under a four-point static loading test. Two longitudinal tensile steel reinforcement ratios (ρ) used. The first three beams are reinforced with ρ = 0.866 % and the other three beams ρ = 1.29 %. These beams correspond to the ratio of 2.6 ρb and 2.63 ρb, where ρb is the balanced steel ratio.

For first set of beams the balanced area of tensile bars are $A_{st\ bal}$ =1351 mm^2, the provided rebar area is $A_{st\ prov}$ = 452 mm^2 for B1-C, B2-S-40 & B3-D-40. While second set of beams the balanced area of tensile bars are $A_{st\ bal}$ =1375 mm^2, the provided rebar area is $A_{st\ prov}$ = 566 mm^2 for B4-C, B5-S-40 & B6- D-40. Concrete confinements made of mild steel in the form of spirals with T8-40 mm pitches. All the beams reinforced with T8-50 mm shear links at the shear span.

Table 2: Beam Reinforcing Steel Details [27]

Beam	Sample	Provide reinforcement ratio p (%)	$A_{st\ prov}$	Number and diameter of bars	Balanced steel ratio pb (%)	$A_{st\ bal}$	Spirals at constant moment zone	Shear span links
1	B1-C	0.866	452	4H12	2.6	1351	None	T8-50
2	B2-S-40	0.866	452	4H12	2.6	1351	T8-40	T8-50
3	B3-D-40	0.866	452	4H12	2.6	1351	T8-40	T8-50
4	B4-C	1.29	566	5H12	2.63	1375	None	T8-50
5	B5-S-40	1.29	566	5H12	2.63	1375	T8-40	T8-50
6	B6-D-40	1.29	566	5H12	2.63	1375	T8-40	T8-50

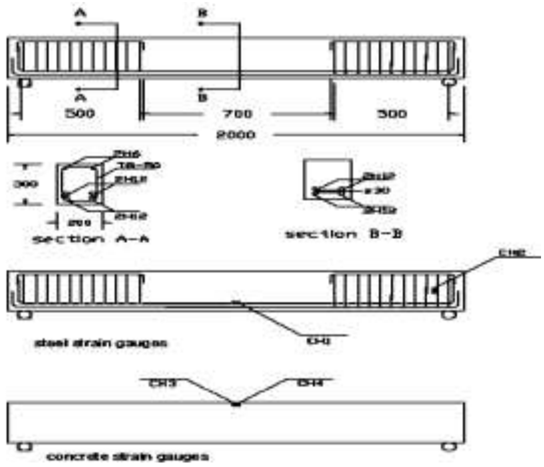

Figure 1: Specification of Beam B1-C (ρ 0.866 %)

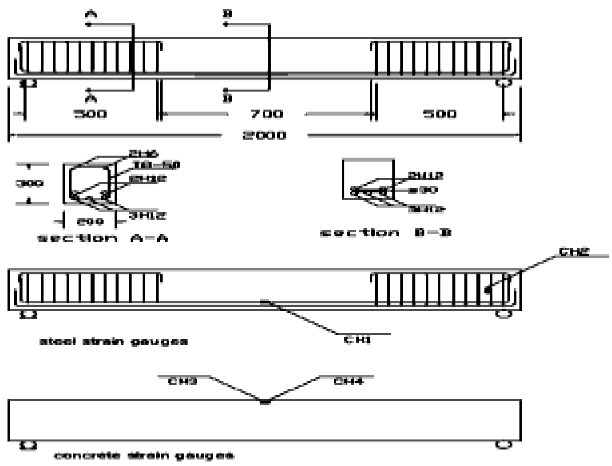

Figure 2: Specification of Beam B4-C (ρ 1.29 %)

Materials

Concrete
HSC, high strength concrete of grade 60 MPa used in this research.

Confinement
This paper focuses on the effects of using single and double helical confinement installed in the compression zone of the beam. The helical confinement provided as 8 mm bar that is spiral shaped as shown in figure3. Moreover, the confinement provided with 40 mm pitches of steel for both types of helical confinement.

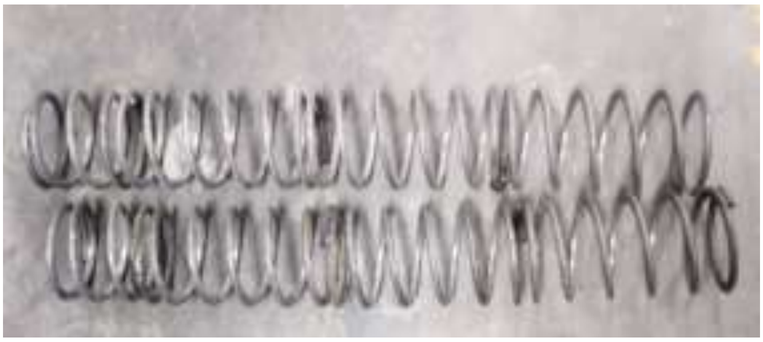

Figure 3: Helical confinement

Steel reinforcement
Steel reinforcement is also known as rebar which is steel bar used usually in tension zone in reinforced concrete to strengthen and hold the concrete from tension failure.

The steel bars improve the strength of the concrete where it weakens, which means as stated previously that the concrete by itself is strong in compression state but weak when it subjected to tensile forces. In addition, it is inevitable where in concrete beams, compression and tensile forces go in concurrence with each other, where compression forces occur at the top of the concrete specimens and the tensile forces occur at the bottom of the specimen. The steel bars need to purchase from suppliers as the following:

- Mild Steel (275 N/mm^2) for shear and helical reinforcement (6 mm and 8 mm bars).
- High Yield Steel (500 N/mm^2) for tension reinforcement(12 mm)

Tests

A series of tests conducted to determine the workability of the mix using a slump test. A compressive strength test performed on the samples, and a tensile test conducted to determine the yield strength of the steel used in this study. Additionally, a four-point bending test performed to determine the shear effect of confinement.

Data collection

For this study, strain gauge is the tool for data collection. The position of the strain gauges shown in figure 4, which installed on top of the concrete cover and the rebar cage. This tool facilitates the method used to gain the right information regarding the confined under-reinforced concrete beams. Strain gauges were installed in various locations throughout the beams where used to record the strain values of the confinement, tension steel and compression concrete, with the aid of a data logger provided by SEGi university.

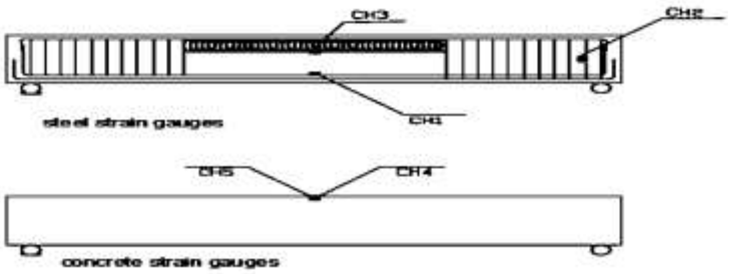

Figure 4: Location of installed Strain gauges

Figure 5 shows the LVDT, it known as the Linear Variable Differential Transformer. Which is an electronic device that aid in taking measurement of the linear displacement that takes its place below the beam at the mid span.

Figure 5: LVDT

Experimental Results and Discussion

A. Slump Test

Slump test carried out for ready mix concrete to check its workability. Table 3 shows the observed slump testing Segi Laboratory, which was compatible with the value recorded in concrete plant.

Table 3: Slump Test Results

Grade of Concrete, fck (N / mm^2 or MPa)	Required Slump (mm)	Observed Slump (mm)
60	210-230	230

B. Compression Test

The table below shows the results of the compressive test of the concrete cubes, the cubes divided into two groups, first group tested at 7 days after casting, and second group tested at 14 days after the casting. From table 4 it can see that our concrete reached it is design strength, and that is because the mix is a ready concrete mix and it is self-compacting properties. The cubes were able to reach 51.1 and 59 N/mm^2 for 7 days and 14 days respectively.

Table 4: Compressive Test Results

Test Days	Maximum Load Applied (kN)			Average Load (kN)	Compressive Strength (N /mm^2)
	Cub1	Cub2	Cub3		
7	1090	1210		1150	51.1
14	1360	1420	1310	1363.3	59

C. Tensile Test

Tensile test results show that the steel specimen bars have almost yielded the same strength as the theoretical value of EC3. 6 and 8-mm bar diameters were made of mild steel. They able to reach a yield strength of 275 MPa. While the high tensile strength steel reached 500 MPa. Table 5 and table 6 show the results of the tested specimen.

Table 5: Steel Bars Theoretical Values

Bar Size (mm)	Type of Steel Bar	Area (mm^2)	Yield Strength (MPa)
6	Mild Steel	28.28	275
8		50.27	
12	High Tensile Strength	113.1	500

Table 6: Tensile Test Result

Bar Size (mm)	Type of Steel Bar	Area (mm^2)	Yield Strength (MPa)	Ultimate Tensile Strength (MPa)
6	Mild Steel	28.28	-	-
8		50.27	275	280
12	High Tensile Strength	113.1	500	680

D. Flexural Test Result

In this section, the results of four - point flexural test for all the under-reinforced concrete beams are described based on the data obtained from the data logger, loads, displacement and strain values were recorded.
Only 4 beams were tested (two beams weren't tested due to an unfortunate accident occurs while testing the fourth beam when it failed that cause major damages to the load machine wires and the displacement instrument. Hence, the testing process have stopped due to incorrect informational recording from the data logger.
The table 7 shows a summary of the loads that the beams were able to withstand before flexure failure occurred.

Table 7: Summary of Beam Loads and Co+ncrete Strength

Specimen	Calculated ultimate Shear Load (V x 2) (KN)	Design shear Load (KN)	Observed Failure Load (KN)
B1-C	109	54.5	290
B2-S	109	54.5	298.1
B3-D	109	54.5	383.5
B5-S	239	115	292.4

E. Comparison load vs compressive strain of beams

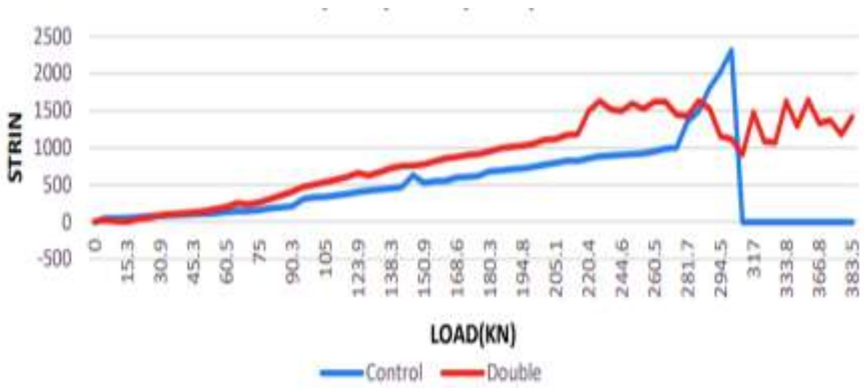

Figure 6: Load versus Maximum Strain Comparison

The graphs show the performance of the beams against the applied loads in terms of strain factor. The control beam strain was gradually increasing by the load applied at the first three-quarters of the chart. However, the last quarter of the graph especially at load of 275 KN have experienced abnormal conduct while reaching the yield point where it has increased suddenly from 0.001 until it reached the maximum strain which was 0.2313 after that sudden rapture have occurred to the concrete due to the ultimate limit of resistance have been reached.

Moreover, the confinement beam has explained a satisfactory performance at all stages of the experiment. The first three-quarters of the chart experienced a gradually increasing in terms of strain factor. However, the last quarter of the chart has shown the quality of reaching the yield point at 220 KN smoothly at strain of 0.0012, while the peak point attained at 366.8KN with strain of 0.0016. Moreover, flexural cracks occurred at the middle span of the beam a clear sign and gave better warning than the control beam against the failures. Furthermore, the failure occurs at two stages.

The chart also explained the difference in the ultimate limit state for each beam in terms of load resistance, which was massive. The ultimate load control beam reached to 290 KN while the confined beam has reached 383.5 KN approximately (132.24%) increment of the control beam which was for the reason of adding the confinement. Overall, can say the experiment was successful in terms of resisting more loads.

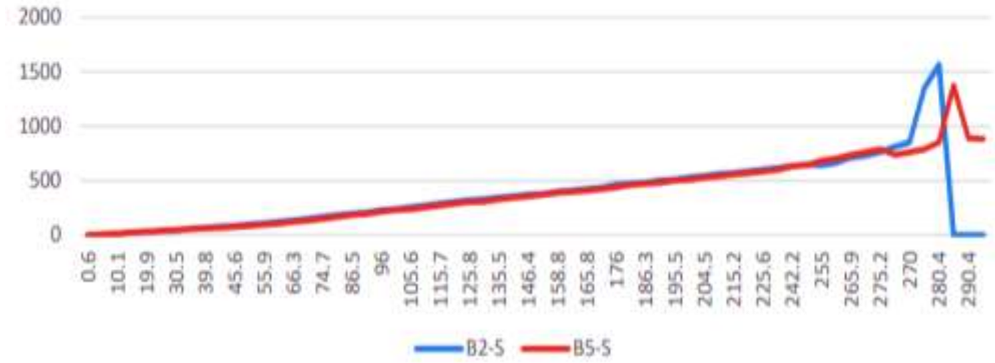

Figure 7: Load versus Maximum Strain Comparison

Shear failure have occurred in these two beams. However, this graph shows the performance of the beams against the applied loads in terms of strain factor until it reaches the maximum ultimate loads. Both beams have almost the same strain profile results along with the applied load. Moreover, both specimens have suddenly reached the peak points at the same manner. The first beam failed at maximum loading of 285.1 KN while the second beam has failed at 292.4 KN.

Since both beams have failed in shear, yet, there was a clear indication of the failure that expressed by shear cracks at both edges of the beam, which was a better warning than the control beam against the failures.

The confined concrete resisted more shear loads then it expected compared with the theoretical calculations by a massive difference due to the confinement action. For beam (B2-S) the maximum calculated shear force was almost 97 KN while the failure load was at 285.1 KN approximately (293.9%) increase which shows the confinement effects on the concrete beams. However, beam (B5-S) has maximum calculated shear force of almost 120 KN while the ultimate load reached to 292.4 KN around (243.7%) also because the confinement affects upon the concrete.

F. Ultimate load and ultimate shear force

The calculated ultimate shear forces and ultimate flexural loads based on nominal strength of materials compared with the observed failure loads Table 8. The calculate ultimate flexural loads including partial safety factors for loads were carried out in accordance with (Eurocode 2). It noted that the failure loads for all beam specimens were greater than the calculated flexural load. It observed that the failure load for all beams were slightly greater than the calculated flexural load.

Table 8: Calculated and Observed Failure Load

Beam	Calculated Ultimate Flexural Loads (kN)	Calculated Ultimate Shear Loads (kN)	Failure Type	Failure Load (kN)
B1-C	109	295	Flexural Failure	290
B2-S-40	109	295	Shear Failure	289.1
B3-D-40	109	295	Flexural Failure	383.5
B4-C	239	247	-	-
B5-S-40	239	247	Shear Failure	292.4
B6-D-40	239	247	-	-

The calculated flexural load of the samples control beams B1 - C and B4 - C are 109 kN and 539 kN respectively. From Table 8, it noted that greater failure load achieved for all beam specimens with confinements.

The calculated ultimate shear capacity for the control beams was obtained based on the diagonal compressive strut angle θ = 22° and including partial safety factors for load. The shear capacity, $V_{Rd,S}$ based on θ = 22° is 295 kN for beam B1- C and beam B4 – C ,$V_{Rd,S}$ based on θ = 22° is 247 kN. The shear capacity for the beam specimens with confinement were also designed, $V_{Rd,S}$ based on θ=22° is 295 kN for beam of single and double confinement with provided steel ration ρ = 0.866 % and as well as for second set specimens provided steel ration ρ = 1.29 %, VRd,S based on θ = 22° is 247 kN. With the use of under reinforced concrete beams.

For this study, strain gauge is the tool for data collection. The position of the strain gauges shown in figure 4, which installed on top of the concrete cover and the rebar cage. This tool facilitates the method used to gain the right information regarding the confined under-reinforced concrete beams. Strain gauges were installed in various locations throughout the beams where used to record the strain values of the confinement, tension steel and compression concrete, with the aid of a data logger provided by SEGi university.

Conclusion

The failure of the control and beam (B3-D-40) was in bending and these two particular beams have shown high withstand against the applied load upon them and gave a clear indication of the failure before it happened as a major flexural crack appeared at the middle span of the beams. Meanwhile, beams (B2-S 40) and (B5-S-40) have experienced a shear failure. However, both beams have shown an exceptional behavior against the applied load compared to the theoretical ultimate load. Moreover, both beams expressed a huge symptom before it failed as a clear shear crack at both ends of the beams.

By using of single and double spiral confinement on the compression zone of the under-reinforced concrete beams enhanced the shear capacity of the beam. The confinement has improved the overall features of the beams and the use of confinement has benefits the under-reinforced concrete beams in terms of strength and deformation. It observed that the failure loads for all beams were higher than the calculated flexural load. Due to the confinement effects, the compressive strength at the compressive zone enhanced. Hence, it proven that the provision of single and double confinement and as well as shear links could reduce the flexural and shear cracks. Maximum shear cracks width found to be 0.25 mm, which is less than the Eurocode 2 allowable limit 0.3 mm.

Recommendation

Giving some guidance to future researchers in order to get a proper result with avoiding some problems faced, some recommendation listed below:

1. For better results, strain gauges may handle carefully; otherwise, it will provide irrelevant readings.
2. Provide better data logging equipment, it gave some unreasonable data throughout the tests.
3. Different type of confinement considered, regarding to the shape and diameters.

Conflict of Interest Statement

1. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this study.
2. The experimental work conducted independently at SEGi University laboratory, and no funding received from any commercial or private entity that could bias the results or interpretations.
3. All co-authors have approved the final version of the manuscript agree to its submission to the journal.

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