STRENGTH ENHANCEMENT IN CONCRETE CONFINED BY SPIRALS

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Abstract: The strength and ductility of the concrete can be enhanced by confinement.It can be achieved in many ways. Using spirals is one of the ways to enhance the strength by confinement. The confinement effect in concrete by spirals can be applicable to enhance the load carrying capacity of columns and shear carrying capacity of beams and flat slabs. This effect prevents structures from catastrophic failures during earthquakes. In this research study, experiments were conducted to determine the anchorage depth of the spiral, the shear enhancement in beams due to confinement by spirals and increment in failure load of flat slab panels a when spiral is used as a shear resistor. The actual shear carrying capacity and theoretical shear carrying capacity of the beams were checked using average integration method and discrete method.The experimental results indicated that the shear carrying capacity of the beam was enhanced by 35.7% for 30mm pitch spiral, 26.8% for 45mm pitch spiral and 16.1% for 60mm pitch spiral. The actual shear carrying capacity based on the experimental results matched closer to the value obtained by the average integration method. The failure load of the flat slab panel was increased by 12.3% when spiral was used as shear resistor.

Keywords: Confinement, Ductility, Pitch, Punching Shear, Spiral, Strength

1. Introduction

The strength and ductility of concrete can be enhanced by confinement effect. It can be achieved by using conventional internal reinforcing steel or external steel or fibre reinforced polymer (FRP) jackets. The spiral reinforcement is also a method to enhance the strength and ductility of concrete by confinement. It can be used to increase the load carrying capacity of columns and shear carrying capacity in beams and flat slabs.

The spiral reinforcement can be used to prevent the punching shear failure in flat slabs. The punching shear failure is the worst failure mechanism due to its catastrophic nature. The damage due to punching shear failure is high compared to other failure mechanisms. The spiral reinforcement can postpone the punching shear failure in flat slabs.The spiral can be easily made by steel wires. The fixing of spiral also not a difficult task, even with unskilled labourers.

The use of spiral as shear reinforcement is a suitable method in Sri Lankan conditions as it is easy to make spirals either large or small amounts for the construction works. The performance of the spiral reinforcement depends on the strength of steel wires used. High tensile steel wires are preferable to make spirals. Currently there are no precise design methods available to find the shear carrying capacity of spirals. Therefore, it is important to find a suitable design method to determine the shear carrying capacity of the spiral reinforcement.

2. Literature Survey

The shear carrying capacity of concrete in beams and flat slabs is enhanced by the confinement of spirals. The shear imposed on the spiral can be high, since the concrete contribution is minimal. Hence the spiral needs to be checked to determine whether it is sufficient to prevent shear failure.

There are two methods available to calculate the shear carrying capacity of spirals, the average integration method and discrete method. Ghee et al. (1989) investigated the shear carrying capacity of spirals and proposed an analytical expression based on an average integration method. The discrete method was proposed by Dancygier (2001) to calculate the shear carrying capacity of spirals.

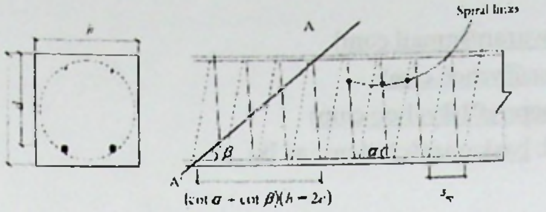

Figure 1

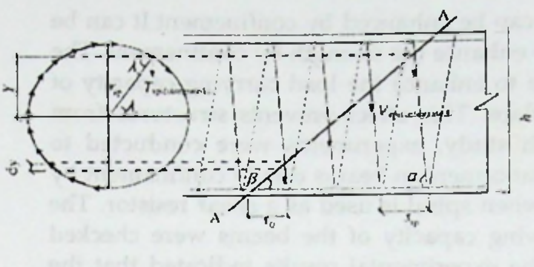

Figure 2

Average Integration Method

The average integration method proposed by Ghee et al. (1989) is on the resultant tension force component in the direction of the shear force, which is developed in the reinforcing hoops.The value ofV_{spi} can be calculated by integrating along the circle and then averaging this integration over the spiral spacing.

$$T_{spi(integrated)} = \frac{\pi}{4} A_{sp} f_{ysp} \tag{1}$$

The force will be taken as an averaged value equal to the value derived in equation (1), at any location along the spiral. This is based onthe assumption that the spiral spacing is small, so that the individual components can be smeared out uniformly, and so all angular positions around the spiral have equal chance of affecting the shear strength.

$$V_{sp(integrated)} = \frac{T_{spi}\sin\alpha(\cot\alpha + \cot\beta)(h-2c)}{S_{sp}} \tag{2}$$

Discrete Method

The discrete method was proposed by Dancygier (2001) based on his work,by considering spiral contribution to shear force due to the spiral geometry. The following equations are derived based on the assumption that an inclined beam section along the diagonal tension cracks becomes critical and forms the failure plane. The discrete method takes into account the spiral force contribution as a result of a crack crossing the spiral at different locations.

$$V_{sp(discrete)} = A_{sp} f_{ysp} \sum_{i=1}^{n} \sin\alpha\cos\lambda_i \tag{3}$$

where n is the number of hoops that is crossed by failure surface A-A'shown in Figure 2. It depends on the inclination and position of this line.

$$n = \frac{\cot\beta\,(h-2c)}{S_{sp}} - \frac{S_0}{S_{sp}} \tag{4}$$

According to Dancygier (2001) n should always be rounded up to the nearest integer.

Based on the discrete method analysis shear carrying capacity is given by the following equation,

$$V_{sp(discrete)} = A_{sp} f_{ysp} \sin\alpha \sum_{i=1}^{n} \sqrt{1 - \left(1 - \frac{a_i}{r_{sp}}\right)^2} \tag{5}$$

The discrete method is more accurate compared with average integration method, as it takes into account, the variation in shear force at different locations due to the spiral geometry. Kamal Jaafar (2009) based on his experimental works showed that the spiral shear contribution is highly governed by both the crack inclination angle and the spiral spacing. Therefore those two parameters should be considered when designing for spiral contribution. It can thus be concluded that the spiral shear force variation is more complicated and cannot be simplified by a linear variation or by introducing a reduction factor similar to the $\pi/4$. He also suggested that the average integration method might be a valid method for assessing the spiral shear contribution. But its applications should be limited to cases where spiral spacing is very small.

In this research study, the experimental the valued obtained by tested beams were compared with both methods, to identify the suitable method to calculate the shear carrying capacity of spiral reinforcement.

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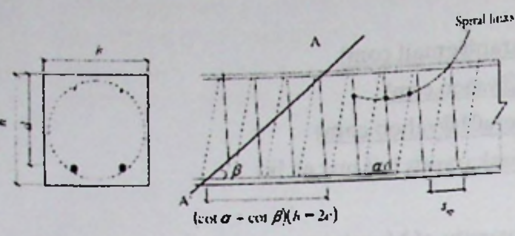

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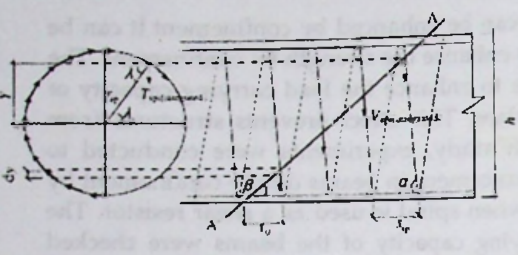

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In this research study, the experimental the valued obtained by tested beams were compared with both methods, to identify the suitable method to calculate the shear carrying capacity of spiral reinforcement.

3. Experimental Program

The experiments were conducted to assess the strength enhancement in concrete due to confinement by spirals. The pullout test was done to identify the anchorage depth of the spiral inside the concrete to avoid pullout failure. The beam test was done to assess the enhancement in shear carrying capacity when spiral is used as shear reinforcement. The slab test was done to identify the increment in failure load when spiral reinforcement is used.

3.1 Experimental Series 1

This experiment was conducted to identify the anchorage depth of the spiral inside the concrete to avoid pullout failure.The spiral was made out of 5.8mm steel having 300N/mm^2 yield strength. The centre to centre diameter of the spiral was 118mm. The samples were made by embedding the spiral with different depths inside the concrete cubes having dimensions of 150mm (width), 150mm (length) and 150mm (height).The Figure 3 shows the arrangement in a test sample.

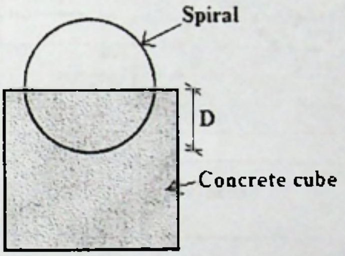


Figure 3: Arrangement in a Tested Sample

The samples were tested under the direct tensile force using universal tensile testing machine as shown in Figure 4.

Figure 4: Testing Arrangement

From the experiments, four failure mechanisms were obtained. Those are pullout, shear, block shear and fracture in steel. The results are tabulated in Table 1.

Table 1: Results of Experimental Series 1

Embedded depth of spiral (mm)	Failure load (kN)	Mode of failure
26	7.32	Pullout
33	11.12	Shear
43	13.35	Shear
48	16.46	Block shear
53	18.91	Fracture of steel

The anchorage depth required to avoid pullout failure was identified as 33mm for the concrete having strength of 37.5N/mm^2, from this experimental series.

3.2 Experimental Series 2

This experimental series was conducted to assess the shear strength enhancement in beams due to the spiral.Four beams with 770mm length and 150mm×150mm cross section were casted and tested in this experiment. The beams were named as A, B, C andD. Beam A was provided with 2T10 bars at the bottom.All the beams were provided with spiral reinforcement with different pitches in addition to 2 T16 bars. The spiral was made out of 5.8mm steel having 300N/mm^2 yield strength. The centre to centre diameter of the spiral was 118mm. The details of reinforcement in beams are given in Table 2.

Table 2: Details of Reinforcement in Beams

Beam Identification	Description
A	2T16 at bottom
B	2T16 at bottom and spiral with 30mm pitch
C	2T16 at bottom and spiral with 45mm pitch
D	2T16 at bottom and spiral with 60mm pitch

The strain gauges were fixed on the spiral reinforcement to check whether spiral yields under the applied load. They were fixed at two locations closer to the supports at the place where crack was expected to cross the spiral. The average compressive strength of the concrete used was 43.5 N/mm^2 from cube testing. The testing arrangement is shown in Figures 5 and 6.

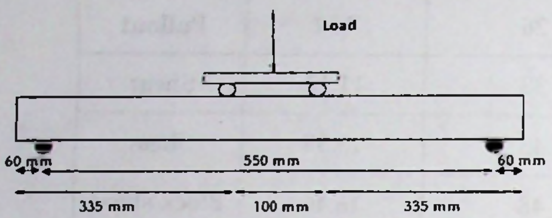


Figure 5: Testing Arrangement

A 60mm distance was kept from the supports to avoid the anchorage failure. The dial gauge was fixed at the midpoint of the beam to measure the deflection.

Figure 6: Testing Arrangement

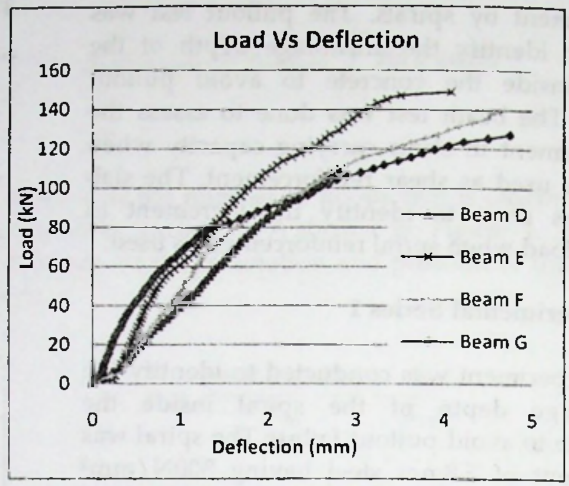
The experimental results are tabulated in Table 3.

Table 3: Failure Loads

Beam Identification	Failure Load (kN)
A	109.9
B	149.1
C	139.3
D	127.5

All the beams failed under shear. The load versus defection curve and the strain variation in spiral with load for Beam B are shown in Figures 7 and 8 respectively.

Figure 7: Load vs Deflection



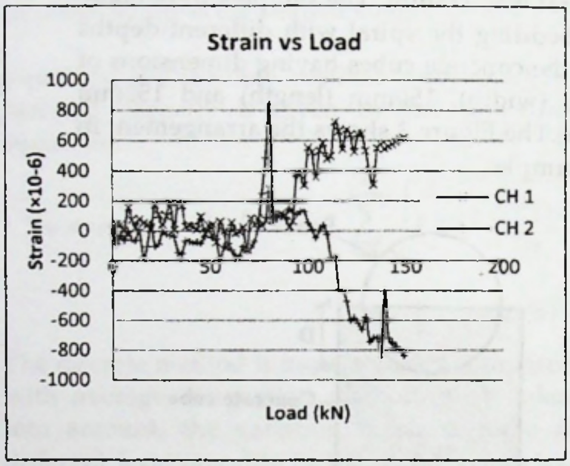


Figure 8: Strain vs Load

3.4 Experimental Series 3

This experiment was carried out to assess the increment in failure load of flat slab panel when spiral reinforcement is used as shear resistors. The spiral was made out of 3.2mm high tensile steel wire having 700N/mm^2 yield strength. The centre to centre diameter of the spiral was 108mm and the pitch was 30mm. The dimensions of the tested slab panels were 1200mm (width), 1200mm (length) and 150mm (thickness).Both panels were provided with 200mm×200mm×200mm column head at the middle. Panel A was provided with reinforcement at bottom and top using T10 bars andPanel B was provided with the same amount of reinforcement and spiral reinforcement as shear resistors. The strain gauges were fixed on the spiral to measure the variation of strain with the applied load. The arrangement of spiral reinforcement in Panel B is shown in Figure 9.

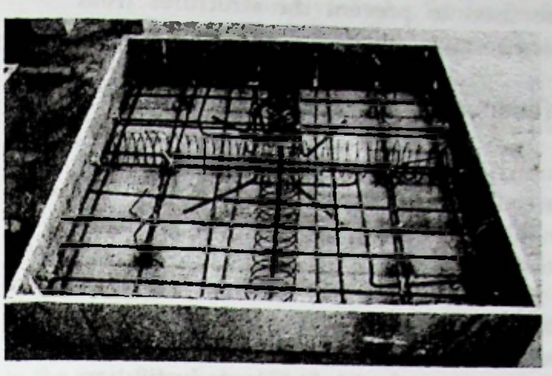


Figure 9: Arrangement of spiral reinforcement

The slab panels were simply supported along the edges on top of stacked concrete cubes. The load was applied to the column head using a hydraulic jack and the deflection was measured using dial gauges closer to the column head. The testing arrangement is shown in Figure 10.

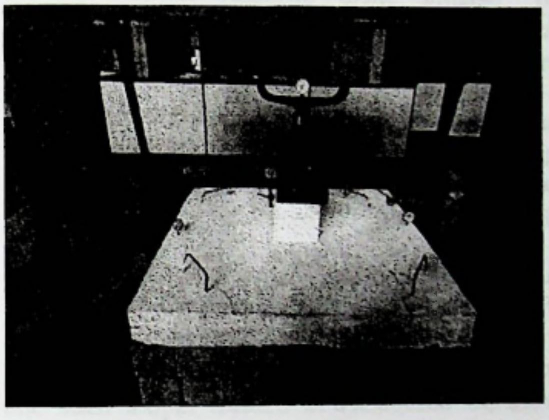


Figure 10: Testing Arrangement

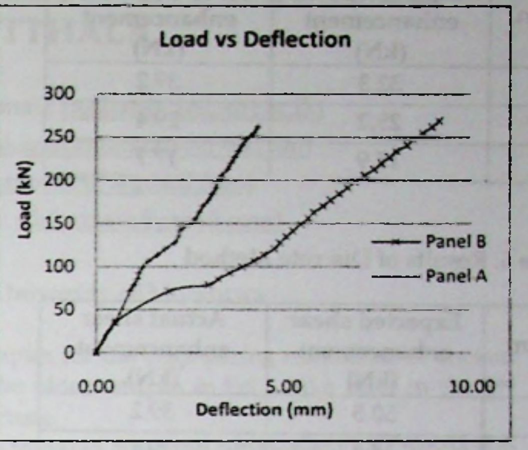
The compressive strengths of the concrete used for Panel A and Panel B were28.53N/mm^2 and 28.76N/mm^2 respectively.The failure loads of slab panels are given in Table 4.

Table 4: Failure Loads

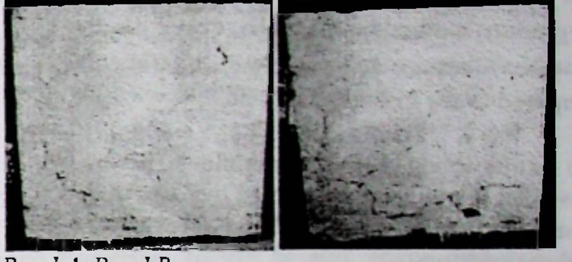
Slab panel	Failure load (kN)
A	262.1
B	299.0

The load versus deflection curve is shown in Figure 11.

Figure 11: Load vs Deflection



The crack patterns of slab panels after failure are shown in Figure 12.



Panel A Panel B

Figure 12: Crack Patterns

4 Interpretations of Results

The anchorage depth required to avoid pullout failure was found as 33mm from the Experimental Series 1.

The theoretical shear carrying capacity of the tested beams was calculated using average integration method and discrete method. The arrangement of spiral reinforcement and failure surface of Beam B is shown in Figure 13.

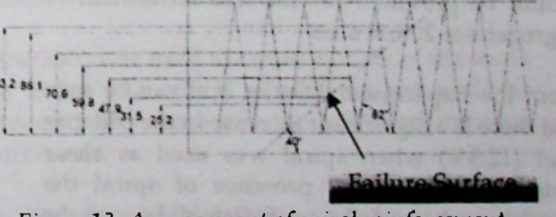


Figure 13: Arrangement of spiral reinforcement

The expected shear enhancement using average integration method and discrete method are given in Tables 5 and 6 respectively.

Table 5: Results of Average Integration Method

Beam	Expected shear enhancement (kN)	Actual shear enhancement (kN)
B	32.3	39.2
C	25.2	29.4
D	15.9	17.7

Table 6: Results of Discrete Method

Beam	Expected shear enhancement (kN)	Actual shear enhancement (kN)
B	50.5	39.2
C	38.6	29.4
D	24.5	17.7

This results show that the values from average integration methods are much closer to the actual values obtained by experiments, compared to the discrete method.

The results obtained from Experimental Series 3 show that there was a significant increase in the failure load (36.9kN) when the spiral was used as shear resistors.

In Experimental Series 3, the spirals were not crossed by cracks in Panel B. Due to of this reason the shear carrying capacity of these spirals cannot be calculated using theoretical equations.

5 Conclusions

There was a significant enhancement in shear carrying capacity of beams when spiral reinforcement was used. It can be seen that the shear carrying capacity decreases when the pitch of the spiral increases.The optimum pitch was 30mm. The pitch cannot be reduced below 30mm, as a minimum clear spacing of 25mm should be provided for the free movement of aggregatesof 20mm size.

From the Experimental Series 3, it can be seen that there is a significant increase in the collapse load (12.3%) when spiral was used as shear resistors. Due to the presence of spiral the punching shear failure of flat slabs can be prevented or postponed. The punching shear failure is a catastrophic failure which leads to severe damages.

From this research study it can be concluded that the strength of the concrete can be enhanced by using spiral reinforcement.Since making and fixing of spirals is not difficult, it is an effective method to enhance the strength of the concrete by confinement. This technology can be used to prevent the structures from seismic effects.

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ASSESSING THE CRACKS DEVELOPED IN DEMATAMAL VIHARAYA, BUTTHALA

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Abstract: Stupas of Sri Lanka stand as proud examples for the engineering excellence of ancient Sri Lanka. Dematamal Viharaya at Butthala is one of the oldest stupas in Sri Lanka built in the 2nd Century BC which is a, 19m tall non-plastered brick structure.
This stupa has developed cracks since 1998. Cracks have initiated from the pesawalalu and propagate to the top of the dome. The research covered in this report is aimed at the identification of the causes. A comprehensive study was carried out to identify the possible causes for the cracks which may be due to self weight and shape of the stupa, expansive nature of soil, arch action induced due to separation of old and modern masonry. Experiments were done to assess the expansive nature of the soil and a Finite element analysis was carried out using the Finite element software SAP2000.
The results revealed that the possible cause may be the arch action induced due to separation of old and modern masonry.

Keywords: Cracks, Arch Action, Expansive Soil

1. Introduction

The creation of stupas has been one of the greatest achievements of ancient Sri Lankans unmatched by anyone else in the world. Large and small stupas scattered all over the island have stood the test of time and conserving them for the future generation should be a non debatable priority of all Sri Lankans.

Dematamal Viharaya, in the Ruhuna region is one such stupa, located at Helagama on the Buttala-Okkampitiya road. It is one of the oldest stupas in the island. This 19m high non-plastered brick structure was built by King Mahanaga of Ruhuna.

This small stupa has unfortunately come under the threat of nature, and has developed some cracks in the recent past. This research is a study on these cracks, which suggests some possible reasons and analyses the reasons. This research would be helpful in the Sri Lankan context for future attempts at restoration of stupas and would give an idea of what should and should not be done. The cracks started to appear in 1998 and have been propagating since. They can be seen at the *pesawalalu*and the dome, the maximum width being 3mm.

The expansive nature of soil, shape and self weight of the structure and the discontinuity between the old and new parts of the stupa are few of the suspected reasons for the cracks.

2. Methodology

Expansive nature of soil in the area was analysed by collecting samples at the site and testing them for relevant soil parameters. They were compared with standard values to measure the expansive nature of the soil.

Drawings of the stupa were obtained from the Department of Archeology. Brick samples were collected at the site and tested for material properties. Properties of the ancient bricks were taken from associated literature.

SAP2000 was used to create models of the stupa to check the effects of self weight and the discontinuity between the old and modern structures.

3. Results and Discussion

The above mentioned three reasons for the development of the cracks have been analysed and the results are discussed below.