The Effects of Inclined Shear Reinforcement in Reinforced Concrete Beam

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Abstract. This research provided experimental data on the effects of inclined shear reinforcement in reinforced concrete (RC) beam. The behaviour of RC beams in shear is complex. Shear failure in reinforced concrete beam is one of the mode of failures to be avoided due to its rapid progression. This sudden type of failure made it necessary to explore the efficient ways to design these beams for shear. Therefore, this research studied the effectiveness of inclined links as shear reinforcement in RC beam. Two types of shear reinforcements are investigated, conventional stirrups as the control specimen and inclined shear reinforcement. In addition, to support the use of inclined shear reinforcement in RC beam, the comparison of shear resistance between vertical links and incline links is made. Then, the result from the experiment is compared with the result of calculation in accordance to EC2. This study is carried out in laboratory by preparing two specimens of RC beams with different type of shear reinforcement. All beams were tested under four point load test. From the results, it was observed that the ultimate load for RC beam with vertical links and RC beam with inclined links is 207 kN and 250 kN, respectively and both RC beams were failed in shear compression. In nutshell, the inclined shear reinforcement work efficiently in resisting the shear capacity compared with vertical links.

Introduction

Safety is one of the crucial part in the construction industry. Sudden failure due to low strength in shear is something need to be avoided in this industry. In reinforced concrete (RC) design, beam are designed primarily to resist moments and shears. However, in the RC design, the flexure is one of the main aspect to be consideration first, leading to the size of the section and the arrangement of reinforcement to provide necessary resistance for moments. For the safety purposes, limits are placed on the amounts of flexural reinforcement in order to achieve ductility failure. However, the perfect design for bending does not guarantee the safe phenomenon of shear.

The shear behaviour of reinforced concrete beam is complex, this due to its non-homogeneity, presence of cracks and reinforcement and the nonlinearity in its material response. In a homogeneous elastic beam, shear stresses and diagonal tensile and compressive stresses of the same magnitude is developed due to the vertical shear forces. Near the support, the principal stresses become incline due to its greater shearing forces. Therefore, shear reinforcement is provided to avoid diagonal cracking of the concrete near to the support.

Reinforced concrete beams must have an adequate safety margin against bending and shear forces, hence it will perform effectively during its service life. At the ultimate limit state, the combined effects of bending and shear may exceed the resistance capacity of the beam and it will lead to tensile cracks. The shear failure is difficult to predict accurately.

Therefore, during the design stage, the shear reinforcement must be provided when the value of actual shear stress exceeds the permissible shear stress of the concrete. The shear reinforcement is crucial in order to prevent shear failure by increasing the ductility of the beam and minimizes the risk for the sudden failure. Vertical link are the conventional shear reinforcement that which has been used widely in the construction industry due to the simplicity in the fabrication and installation. It is also due to the fact that the vertical links seems to be more practical and faster to install as compared with others type of shear reinforcement.

Problem Statement

The use of inclined shear reinforcement has not been so popular in the industry due to the difficulty of fabrication. However, due to diagonal cracking pattern of shear failure in RC beams, it seems that inclined position is more effective in resisting the shear crack compared with the use of vertical position. Therefore, the use of inclined links provided in the high shear region was recommended in this experiment to prove the efficiency of use the inclined links compared with the use of vertical links in RC beams. It is also recommended by EC2, the actual shear reinforcement configuration was in inclined position.

Objectives

The objectives of this research are the following:

1. To study the effectiveness of inclined links as shear reinforcement in RC beam.
2. To compare the shear resistance between vertical links and inclined links.
3. To compare the shear capacity between experimental value and theoretical value.

Scope of Study

This research is to investigate the effects of inclined shear reinforcement in RC beam. Several limitations have been made to achieve the objectives. All testing methods and procedures are specified according to British and Eurocode standard. Following are the scope of study:

- The test were carried out on two specimens of reinforced concrete beams of identical size 150mm width, 250mm height and 2200mm length.
- All specimens of RC beams is identical in amount of longitudinal steel, 2T16 as tension reinforcement and 2T10 as compression reinforcement.
- The concrete compressive strength of the beams is designed to achieve 30N/mm2 at 28 days.
- The RC Beams were tested under four point load test with a shear span to effective depth (a/d) ratio is 1.5.
- The variable of this experiment is the orientation of shear reinforcement which are vertical links and inclined links.

Previous Study

The purpose of shear reinforcement is to avoid failure in shear, to increase beam ductility and to prevent the sudden failure from occur. Technically, the inclined shear crack start at the middle height of the beam near support at approximately 45° and extend toward the compression zone. Hence, any form of effectively anchored reinforcement that intersects these diagonal cracks will be able to resist the shear forces to any value. Practically, shear reinforcement is provided in three forms: stirrups, inclined bent up bars and combination of both. However, in the industry, vertical stirrups are most commonly used because of their simplicity in fabrication and installation [1].

Many researchers has conducted the study of the alternative type of shear reinforcement to replace the conventional type that uses widely in the industry.[2] carried out study about the use of horizontal and inclined bars as shear reinforcement. The study had presented several results of the experiment on six reinforced concrete beam. The purpose of the study were studying the effectiveness of adding horizontal bars on shear strength n rectangular beams, the effectiveness of shear reinforcement and lastly, to determine the optimum amount of both types of shear reinforcement to achieve a shear capacity similar to the conventional stirrups. The result of the experiment was found the use of independent horizontal and bent up bars as shear reinforcement were stronger that the use the conventional system.

Another researcher study the effectiveness of independent bent up bars with sufficient anchorage and inclined links as shear reinforcement. The test also conducted on six specimens with identical size. The study prove the inclined links are effectively replaced vertical shear links in restrained the shear stresses formation in RC beam and the anchorage length of independent bent up bars can be reduced up to 150mm. However, the study concluded that the independent bent up bars are better alternative to replace the convention shear reinforcement [3].

Mode of Failures

The behaviour of reinforced concrete (RC) beams without transverse reinforcement is solely depends on the value of the shear span to depth (a_v/d) ratio. Beams is expected to fail in shear before attain the flexure capacity for the values of a_v/d from1 to 6. The beams should achieved its flexural capacity for any other values. Technically, the causes of shear failure is associated with the stress condition in the region of the path along which the compressive force is transmitted to the support after the occurrence of diagonal cracking [4].

Other studies also proved that the important factors affect the failure modes of reinforced concrete (RC) beams are the shear span to depth ratio (this parameter takes in account the ratio between bending moment M and shear force V occurring simultaneously in the same cross section M/ (Vd), and for three and four point test it calculated as av/d, where av is a distance between the applied force and the support and d is the effective depth of cross section) and effective length to depth ratio. In this study, shear span to depth ratio av/d is the primary parameter that significantly affects the shear strength in concrete member reinforced longitudinally and without shear reinforcement. However, in this study also proved that the size of the member exerted the influence on shear strength and mode failure of the beams. This is because the decrease of ultimate shear capacity along with increase of beam's depth [5].

There are too many factors that affecting the shear failure and it would be a 'monumental task' to deal with all of it. This include the proportion and shape of the beam, the structural restraints and the interaction of the beam with other components in the system, compressive and transverse reinforcement, the load distribution and loading history, the placement of concrete and curing and the surrounding environment [6].

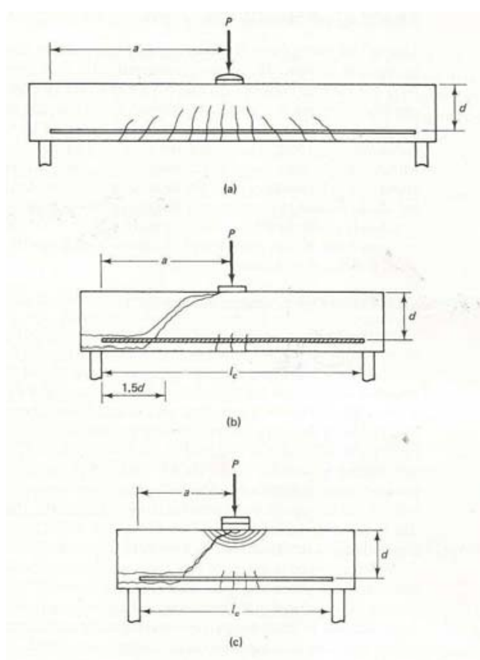

Figure 1: Failure pattern (a) Flexural failure, (b) Diagonal tension failure and (c) Shear compression failure [7].

Hence, the type of failure according to shear span ration seems more convenient. Fundamentally, there are three types of mode failure which are (1) Flexural failure, (2), Diagonal tension failure and lastly (3) Shear compression failure as shown in Figure 1 [7]. First type is flexural failure usually occurs in beams with a shear span to depth ratio more than 6. In this case, cracks are mainly vertical in the middle third of the beam span and perpendicular to the line of principal stress. These crack occur due to a small shear stress and dominant flexural stress. At the beginning, a few very fine vertical cracks start to develop in the mid span area at about 50% of the failure load in flexure. If the external load continue to increase, additional cracks develop in the central region and the initial cracks widen and deeper towards the neutral axis.

The shear span to depth ratio between 2.5 to 6 will cause the beam to fail in diagonal tension failure. Cracks initiates with few vertical flexural cracks at mid span, then followed by the destruction of the bond between the reinforcing steel and the concrete at support. Later, several diagonal cracks will develop about 1.5d to 2d distance from the face of the support. When the cracks it stabilize, one of these cracks widen into a principal diagonal tension crack and extends to the top compression fibres of the beam.

Lastly, shear compression failure always occurs in the beam with shear span to depth ratio between 1 and 2.5. Cracks initiates with few vertical flexural cracks at mid span and stop propagating as destruction of the bond occurs between longitudinal bars and the concrete at support region. Next, an inclined crack steeper than in the diagonal tension case will develops and proceeds to propagate towards neutral axis. The rate of its propagation is slower with crushing of concrete in the top of compression fibres .when the principal inclined crack joins the crushed concrete zone, it will cause the failure to occur without warning.

Shear Reinforcement of a Beam with Vertical Links

A cracked beam acts as a truss, the tension reinforcement acts as bottom chord, the stirrups act as the vertical members and the cracked concrete acts as diagonal compression member and lastly the un cracked concrete at the top of the beam acting as the top chord as shown in Figure 2.

The distance between the top and bottom chords is assumed approximately equal to d and that the cracks form at an angle of 45 ° to the neutral axis, then the horizontal length of the crack also approximately to d. as shown in Figure 3. If the links are spaced at a distance, s_v apart, thus the number of links in a horizontal distance d is equal to d/s.

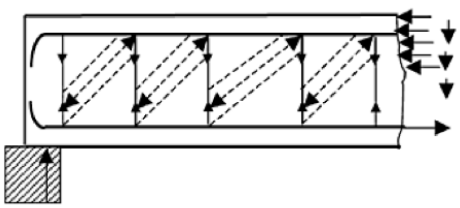

Figure 2: Analogous truss [8].

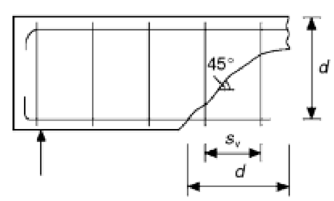

Figure 3: Shear resistance of link [9].

By assuming the stress in the links is equal to its yield stress, the shear force, $V_{Rd,s}$ resisted by the links is equal to:

$$V_{Rd,s} = \frac{A_{sw}}{s_v} z f_{ywd} cot\theta \quad (1)$$

where A_{sw} is the cross sectional area of the shear reinforcement, θ is the angle between shear reinforcement and the beam axis perpendicular to the shear force, and f_{ywd} is the design yield strength of the shear reinforcement. Applied shear force V is resisted by a combination of concrete and steel links.

$$V = V_{Rd,c} + V_{Rd,s} \quad (2)$$

$$V_{Rd,c} = \frac{0.36 f_{ck} b_w d (1 - \frac{f_{ck}}{250})}{(\cot\theta + \tan\theta)} \quad (3)$$

At every potential cracks, at least it should be crossed by one link. Although in deriving the formula, it was assumed that all the links crossing the crack inclined at an angle of 45° are effective, on other hand, the test proved that all the links which intercept the crack near the top are relatively ineffective. Thus, the code limit the spacing to 0.75d in the direction of the span.

The spacing of links at right angle to the span is to be such that no tension bar is more than 150mm or d, or either one is smaller from a vertical leg. This is because to ensure that the longitudinal bars are well supported in order to maintain their dowel shear capacity.

Shear Reinforcement of a Beam with Inclined Links

Shear reinforcement is designed based on a modified truss analogy. Based on the analogy, it is assumes that the total shear is carried by shear reinforcement. On other hands, research on both non pre stressed and pre stressed members has indicated that shear reinforcement need to be designed to carry only the shear exceeding the shear that cause inclined cracking. It is assumed to provide the diagonal members which is inclined at 45°.

In EC2, the design of members with the shear reinforcement is based on a truss model as shown in Figure 4.

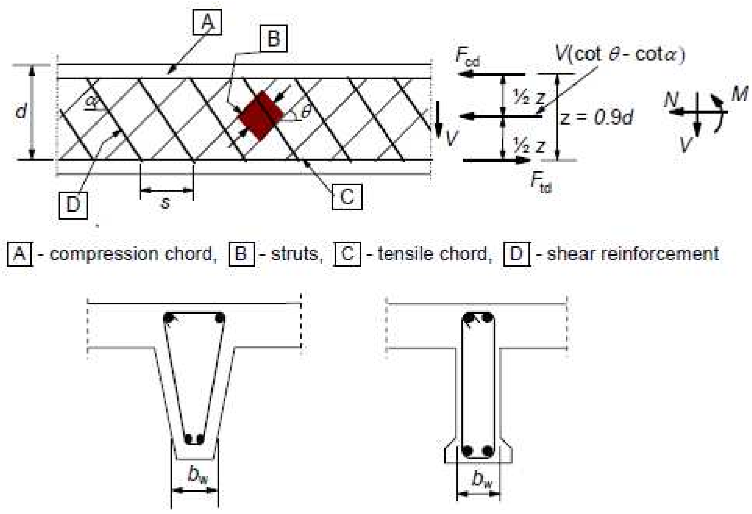

Figure 4: Truss model and notation for shear reinforcement members [10].

The values of cot θ for use in a country has its limits and it may be found in its National Annex. The value is recommended:

$$1 \leq \cot\theta \leq 2.5 \tag{4}$$

The shear resistance for the members with inclined shear reinforcement is the smaller value of

$$V_{Rd,s} = \frac{A_{sw}}{s} z f_{ywd}(\cot\theta + \cot\alpha) sin\alpha \tag{5}$$

$$V_{Rd,max} = \alpha_{cw} b_w z v_1 f_{cd}(cot\theta + cot\alpha)/(1 + cot^2\theta) \tag{6}$$

Applied shear force V is resisted by a combination of concrete and steel links.

$$V = V_{Rd,c} + V_{Rd,s} \tag{7}$$

$$V_{Rd,c} = \frac{0.36 f_{ck} b_w d(1 - \frac{f_{ck}}{250})}{(\cot\theta + \tan\theta)} \tag{8}$$

Methodology

Mix Concrete

The concrete mix used for all the specimens was designed to achieve 30 N/mm^2 compressive strength at 28 days. Quantities of materials specified in the concrete mix as shown in Table 3.1. The concrete was mixed using concrete mixer at Structural Laboratory of Faculty of Civil Engineering. Admixture (superplasticizers) was added at rate of 1% by cement weight to increase the workability of the concrete. The concrete had a measured on site slump of 60mm and it was designed according to the British Research Estabklishment [11].

Table 1: Quantities of materials used in the concrete mix

Quantities	Ordinary Portland Cement (kg)	Water (Litre)	Fine Aggregate (kg)	Coarse Aggregate (kg)
Per kg/m^3	379.63	205	849.9	920.6

The concrete mix was placed in the formwork and vibrated with poker vibrator for compaction purposes. The slump test was carried out to detect the change in workability. This was done according to BS1881: Part 102: 1983. The slump test gave a result of 60 mm.

Concrete cube moulds of 100mm x 100mm x 100mm, cylinder moulds of diameter 150mm and height of 300mm, and prism moulds of 100mm x 100mm x 500mm were also prepared during casting and cured at room temperature for 28 days .The cubes, cylinders and prisms were used for compression, splitting and flexure test respectively for 7 and 28 days.

The details of RC Beams

Two reinforced concrete beams were designed to achieve 30N/mm^2 at 28 days. The beams were tested under four point loading arrangement. The loading was positioned in length of 309mm from support, with the ratio of shear span to effective depth (*a_v/d*) is 1.5. The dimension of both beams is 150mm width, 250mm height and 2200mm long. The steel used in this experiment was high tensile strength steel with grade of 460 N/mm^2 (denoted by T) for reinforcement steel and low tensile strength steel with grade of 250 N/mm^2(denoted by R) for shear links. In details, the bar size for links, tension and compression reinforcement used were 6mm, 16mm and 10mm respectively. The RC beam with vertical links was represents as control specimen as shown in Figure 5 and the other one was RC beam with the inclined links of 45 degree as shown in Figure 6.

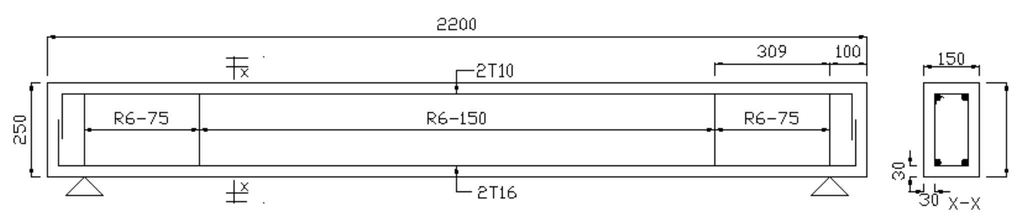

Figure 5: The RC beam with vertical links

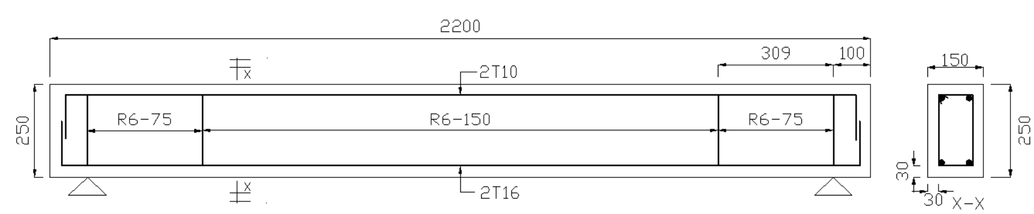

Figure 6: The RC beam with inclined links

The shear reinforcement was instrumented with TML type FLK-6-11 strain gauges (Tokyo Sokki Kenkyujo Co. Ltd. of Japan), which have a gauge length of 6 mm. Each beams were instrumented with two strain gauges. Strain gauges were attached at 309mm from the left end at the right end from support of the beam.

The surface of the concrete also was instrumented with TML type PL-60-11 strain gauges (Tokyo Sokki Kenkyujo Co. Ltd. of Japan), which have a gauge length of 60 mm. Each beams was instrumented with two strain gauges at the same place with steel strain gauges.

The Test Procedure

For the preparation of testing, the surface of the specimens were painted using white emulsion paint to aid the process in detecting the cracking development during the test. At 28 days, when the concrete mixture reached the required strength as designed, the beams were prepared for testing. The location of the loading point, support and the mid span of the beams was clearly marked using permanent marker pen in order to facilitate the installation process later.

The main testing apparatus used were Magnus Frame, Data Logger and hydraulic jack. Load was applied using a 1000kN capacity hydraulic jack in compression. The jack was equipped with a calibrated 200kN load cell to measure the load during the increment process. The arrangement of testing apparatus as shown in Figure 7.

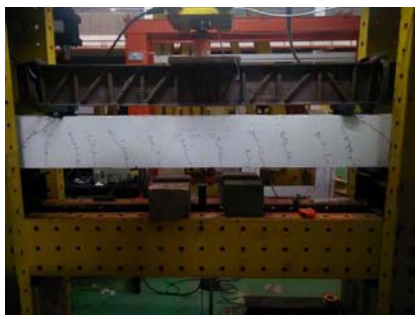

Figure 7: The arrangement of testing apparatus

The beams was supported by solid circular steel with effective length of 2000mm. The spreader was located above the beam and it also supported with the solid circular and plate steel. Above the spreader, the load was distributed into two point load symmetrically. The shear span of the beam, av, from point load to the support is 309mm and it is sufficient for the beam to fail in shear. Halts were made at every 10kN interval to observe and mark the cracks that formed on the surface of the concrete.

Result and Discussion

Concrete Properties

The results of compressive strength, splitting tensile strength and flexural strength of the mix concrete is larger than the expected values at early of the experiment. The average values of compressive strength of concrete at 7 and 28 days are 36.81 N/mm^2 and 46.58 N/mm^2 respectively. While, splitting tensile strength of the concrete at 7 and 28 days are 8.94 N/mm^2 and 10.72 N/mm^2 respectively. Lastly, the flexural strength of concrete at 7 and 28 days are 2.47 N/mm^2 and 2.87 N/mm^2.

The maturity of the concrete may be the factors that influencing the properties of concrete. The hydration of cement is affected by the time and the temperature of hydration, thus, strength gain is controlled by these two factors. The maturity concept is a function of the product of curing time and temperature. There is assumption where the different mixes of concrete, curing times and curing temperatures will have about the same level of maturity. In general, it can concluded that the maturity increases compressive strength increases, especially at low maturity value.

The RC Beam with Vertical Links

RC beam with vertical links is the control specimen in this investigation. It was casted with nominal links in the moment region and vertical links in the shear region. The first flexural crack in this beam occurred at an applied load of 40 kN. The cracks initiated from the tension face of the beam immediately propagated to the mid depth of the beam.

As the increment in loading, more of flexural cracks visible along the length of the moment region. Shear crack started to become visible at an applied load of 90 kN and continued to propagate toward the leading point as shown in Figure 8(a), Figure 8(b) and Figure 8(c). The concrete crushes at applied load of 207 kN .The RC beam with vertical links was failed in shear. The recorded deflection at the ultimate load is 18.33 mm, 370με for steel strain and 4600με for the concrete strain.

(a) (b) (c)

Figure 8: The (a) mid span, (b) left side, and (c) right side of the RC beam

The RC Beam with Inclined links

This RC beam was reinforced with inclined links for moment and shear region. The inclination of the inclined links were approximately 45° with respect to the longitudinal axis of the beam, forming rectangular shaped inclined shear reinforcement. The testing procedure was similar with the control specimen.

The first flexural crack in this beam occurred with an applied load of 50kN. The cracks initiated from the tension face of the beam immediately propagated to the mid depth of the beam. As the increment in loading, more of flexural cracks visible along the length of the moment region. Shear crack started to become visible at an applied load of 135 kN and continued to propagate toward the leading point as shown in Figure 9(a), Figure 9(b) and Figure 9(c). However, this experiment has to be stop at the middle of the experiment due to the lack of equipment and safety purposes. Thus, the ultimate for this RC beam with inclined link could not be obtained and it is be estimated to be more than 250 kN and expected to fail in shear. The recorded deflection at applied load of 250 kN is 4.52 mm, 1130$\mu\varepsilon$ for steel strain and 1966$\mu\varepsilon$ for the concrete strain.

(a) (b) (c)

Figure 9: The (a) mid span, (b) left side, and (c) right side of the RC beam

The Comparison of RC Beam with Vertical Links and RC Beam with Inclined Links

In general, the comparison have been made in term of the shear capacity of each beam as shown in Table 2. The RC beam with vertical links acts as a control specimen in this study. The increase of shear capacity about 20.8% when compared with the control specimen. It is proved that the use of inclined shear reinforcement is an effective technique to enhance the shear capacity of the reinforced concrete beams despite of the difficulty in installation of the shear reinforcement. Both beam was failed in shear compression failure.

Furthermore, the comparison between RC beam with vertical links and the RC beam with inclined links are discussed in terms of relationship between load-deflection and load- strain value.

Table 2: The general comparison of the RC beam with vertical and inclined links

Beam	Experiment Result (kN)	The percentage of test results compared with control specimen (%)	Type of failure
RC Beam with vertical links	207	-	Shear compression
RC Beam with inclined linkc	250	20.77	Shear compression

Load-Deflection. Figure 4.3 below shown the comparison between RC beam with vertical links and RC beam with inclined links in term of load deflection relationship. From Figure 10 below, at applied load of 200 kN, the deflection of RC beam with vertical links and RC beam with inclined links are 14.78 mm and 3.72 mm respectively. The different is about 74.8%

The huge different in deflection values for both beams may due to the stiffness of beam. Stiffness is a slope of load- deflection curve. In this case, with the same of applied load, RC beam with vertical links experienced larger deflection compared with the RC beam with inclined links

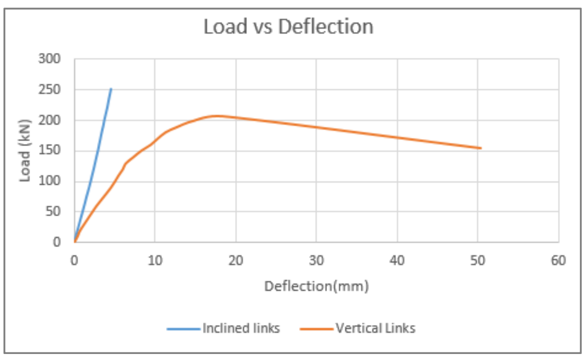

Figure 10: The comparison of RC Beam with vertical link and RC Beam with inclined links in terms of load-deflection relationship.

*Load-Strain (Steel).*The comparison of RC beam with vertical links and RC beam with inclined links in term of load- steel strain relation as shown in Figure 11. For instance, at applied load of 200 kN, the steel strain value of RC beam with vertical links is around 352 $\mu\varepsilon$ is lower than the steel strain value of RC beam with inclined links, which is around 740$\mu\varepsilon$.

In this case, the inclined steel in RC Beam with inclined links works perfectly compared with RC beam with vertical links. Even though, the ultimate load of RC Beam with vertical links is 207 kN, and the beam was failed directly after that. It seems the vertical steel does not work properly to resist the shear. While, the inclined steel in RC beam with inclined links showed high value even though the beam itself does not shows too much sign of failure

*Load-Strain (Concrete).*The comparison of RC beam with vertical links and RC beam with inclined links in term of load – strain (concrete) relation as shown in Figure 12. For example, at applied load of 200 kN, the steel strain value of RC Beam with vertical links is more than 3000$\mu\varepsilon$. Likewise, the steel strain value of RC Beam with inclined links is only near to 2000 $\mu\varepsilon$.

For this case, the concrete of RC Beam with vertical links was failed in compression before steel yield. The steel strain value $\varepsilon_{st} < 2000$ με while the concrete strain, $\varepsilon_{cc} = 3000$με. The failure of this beam is sudden without any sign of warning. For RC beam with vertical links, it is concluded that the concrete was working to resist load. The vertical links in RC Beam with vertical links does not work properly as the inclined links in the RC Beam with Inclined links. Thus, the concrete itself need to work in resisting the load.

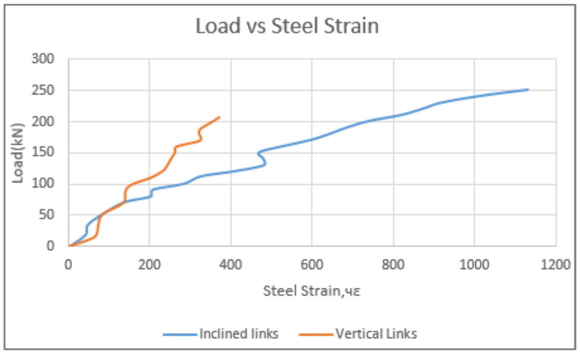

Figure 11: The comparison of RC Beam with vertical link and RC Beam with inclined links in terms of load-strain (steel) relationship.

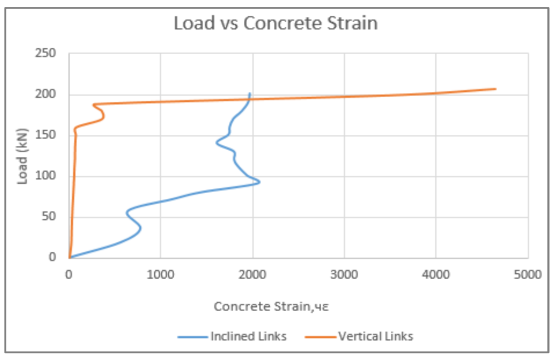

Figure 12: The comparison of RC Beam with vertical link and RC Beam with inclined links in terms of load-strain (concrete) relationship.

The Comparison of Calculation and Experimental Value

In order to calculate the shear resistance of the beams used in the experiment work, Eurocode 2 was referred in this study. Table 3 shown the component of shear capacity calculation and Table 4 shown the comparison of shear capacity between theoretical value and experimental value.

Table 3: The calculation of shear capacity

Beam Type	**$V_{Rd,s}$ (kN)**	**$V_{Rd,c}$ (kN)**	**V (kN)**
RC Beam with Vertical links	37.47	171.41	208.8
RC Beam with Inclined links	49.5	170.10	219.6

Table 4: The comparison of shear capacity between theoretical value and experimental value

Beam Type	**V_{exp} (kN)**	**V_{calc} (kN)**	**$\frac{V_{calc}-V_{exp}}{V_{calc}}$ (%)**
RC Beam with Vertical links	207	208.8	0.7
RC Beam with Inclined links	250	219.6	12.2

As explained before in the relationship of load- steel strain, inclined shear reinforcement works perfectly compared with vertical shear reinforcement. The graph of relationship as shown in Figure

11 had approved the calculation of shear resistance of steel, VRd,s,. According to the manual calculation using EC2, the value of VRd,s for inclined shear reinforcement (49.5kN) is higher than the value of VRd,s for vertical shear reinforcement (37.47kN). The strength of inclined shear reinforcement is higher about 30% than the control specimen.

The calculation of concrete shear resistance, VRd,c does not show much different. The graph of relationship of load-concrete strain as shown in Figure 12 had supported the calculation of VRd,c As according to the calculation, the concrete in RC beam with vertical links works more that the vertical links in resisting the applied load. That is one of the reason the RC beam was failed immediately after reach the ultimate load.

In addition, the comparison of shear capacity between theoretical and experimental are shown in Table 4.3. In the case of RC beam with vertical links, the experimental value is lower 0.7% only than the calculation value. This beam was expected to fail at an applied load of 208.8 kN and the beam was failed slightly lower than the expectation. This is because the problem in equipment used in testing the beam.

On other hand, the comparison of the theoretical value and experimental value of the RC beam with inclined links, the different is about 12.2% only as the experiment was terminated due to the lack of equipment. However, according to the observation, this beam may have the bigger shear capacity that the calculation.

Conclusion and Recommendations

Conclusion

From the experimental study, the following conclusion can be drawn:

1. Referring to the first objective of study, the inclined link significantly enhances the ductility of beams. The increase in the shear capacity is about 20% compared with to the control beam. Therefore, the use of inclined links is an effective technique to enhance the shear capacity of reinforced concrete beam.
2. Inclined shear reinforcement works better than the vertical shear reinforcement in resisting the shearing forces. This is because the fact itself the orientation of inclined links are almost perpendicular to the diagonal shear cracks initiated in shear zones.
3. Concrete in RC beam with vertical links works more than the vertical links in resisting the load. The concrete of RC Beam with vertical links was failed in compression before steel yield. The steel strain value ε_{st} < 2000 $\mu\varepsilon$ while the concrete strain,ε_{cc} = 3000$\mu\varepsilon$. The failure of this beam is sudden without any sign of warning.
4. According to the last objective, the EC2 design codes was used to predict the shear strength of reinforced concrete beams with vertical links and inclined links. Beam with inclined links achieved the highest value of shear resistance (219.6 kN) while vertical links did not show much different with the calculation of shear capacity at 208.8 kN.
5. The percentage different between the experiment reading of RC beam with vertical links shear capacity and the calculation value is less than 1%. While, the experiment reading of RC beam with inclined links only shows the different about 12.2% as the experiment was terminated due to the lack of equipment.

Recommendations

Shear is a complex problem and it had not any close general formulation without any calibrated factor to have the close prediction to the problem. From the previous research works did not shown any similar nature between those reports. In this work, it could be simplified the result by the uses of inclined links in RC Beam, the inclined link significantly enhances the ductility of beams and the shear capacity. There are recommendations suggested to do in future:

1. It is recommended to test the effect on shear capacity and the failure behaviour when using different shear span ratio in range to get the accurate pattern of diagonal cracks. As in this

case, some of the cracks did not went through the strain gauge, thus the reading could not be taken.

2. It is recommended to instrument all the reinforcements, shear links and the main reinforcement to get the full variation of steel strain. The complete set of strain information will allow to get the closely accurate estimation of steel and shear strength capacity.
3. Try different angle of inclined shear reinforcement to get the best inclined angle and it must be easy to fabricate also.
4. Lastly, further the scope of this research by increase the number of specimens to get the average of the results.

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