INCLINED LINK AS SHEAR REINFORCEMENT IN
REINFORCED CONCRETE BEAM

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Specially dedicated to my parents and beloved wife.

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ABSTRACT

The sudden failure of reinforced concrete beams due to shear made it necessary to explore more effective ways to design these beams. The effects on the shear capacity of reinforced concrete beam were investigated with three different arrangements of shear reinforcement; vertical link, inclined link and inclined link with additional bar. The mode of failure was secured to allow for shear failure. All beams were casted with the same grade of concrete, provided with identical amount of main reinforcement, simply supported and tested under symmetrical two-point loads at shear span. The study shows that the contribution of inclined links to the shear capacity is significant and directly proportional to the amount and spacing of the shear reinforcement. The increase in the shear capacity ranged from 18% to 33% compared with the control beam. Ultimate shear resistance was also compared with the analytical calculation according to Eurocode 2 (EC 2) and American Concrete Institute (ACI). Performance of the beams in resisting shear is in the form of deflection, cracking, strains in the reinforcement, strains in concrete, and ultimate load. It may therefore be suggested that these types of shear reinforcement can be used to ease the congestion of links near the supports, thus, savings in the amount of steel bars.

ABSTRAK

Kegagalan secara tiba-tiba pada rasuk konkrit bertetulang disebabkan oleh ricih telah menimbulkan keperluan untuk menerokai kaedah yang lebih berkesan bagi merekabentuk rasuk-rasuk ini. Kesan keatas keupayaan ricih pada rasuk konkrit bertetulang dikaji dengan tiga jenis tetulang ricih; perangkai pugak, perangkai condong dan perangkai condong dengan bar tambahan. Mod kegagalan telah dikawal bagi membolehkan kegagalan ricih berlaku. Semua rasuk dibina dengan gred konkrit yang sama, dengan bilangan tetulang utama yang sama, disokong mudah, dan diuji di bawah dua titik beban yang simetri di rentangan ricih. Kajian ini menunjukkan bahawa sumbangan perangkai condong kepada keupayaan ricih adalah signifikan serta berkadar terus dengan jumlah dan jarak tetulang ricih. Peningkatan keupayaan ricih bagi rasuk yang diuji adalah antara 18% hingga 33% berbanding dengan rasuk kawalan. Rintangan ricih muktamad turut dibandingkan dengan pengiraan analitikal berdasarkan Eurocode 2 (EC 2) dan American Concrete Institute Code (ACI). Prestasi rasuk dalam menghalang ricih adalah dalam bentuk nilai pesongan, keretakan, keterikan dalam tetulang, keterikan dalam konkrit, dan beban muktamad. Oleh yang demikian, tetulang ricih jenis ini boleh dicadangkan bagi mengurangkan kesesakan perangkai ricih berhampiran penyokong rasuk, lantas menjimatkan bilangan bar keluli.

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A	-	Area of a cross-section
A_s	-	Area of tension reinforcement
A_{sb}	-	Area of steel in bent-up bars
$A_{s,prov}$	-	Area of tension reinforcement provided
$A_{s,req}$	-	Area of tension reinforcement required
A_{sv}	-	Total cross-sectional area of links at the neutral axis
a	-	Shear span
b	-	Width of beam
b_v	-	Breadth of member for shear resistance
c	-	Cover to reinforcement
d	-	Effective depth
f_{cu}	-	Characteristic concrete cube strength at 28 days
f_s	-	Service stress in reinforcement
f_{tt}	-	Design tensile stress in concrete at transfer
f_y	-	Characteristic strength of reinforcement
f_{yb}	-	Characteristic strength of inclined bars
f_{yv}	-	Characteristic strength of link reinforcement
L	-	Effective span of a beam
M	-	Bending moment
M_{max}	-	Maximum bending moment
s_b	-	Spacing of bent-up bars
s_v	-	Spacing of links
V	-	Shear force at ultimate design load
V_b	-	Design ultimate shear resistance of bent-up bars
V_c	-	Design ultimate shear resistance of a concrete section
v	-	Shear stress

v_b	-	Design shear stress resistance of bent-up bars
v_c	-	Design shear stress resistance of a singly reinforced concrete beam
α	-	Angle between a bent-up bar and axis of a beam
β	-	Bond coefficient
θ	-	Angle
ϕ	-	Bar diameter

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CHAPTER 1

INTRODUCTION

1.1 General

One of the main objectives of the design of reinforced concrete beams is to ensure the safety of the occupants. Sudden failure due to low strength shear is not a desirable mode of failure. Reinforced concrete beams are designed primarily for flexural strength and shear strength. Beams are structural members used to carry loads primarily by internal moment and shear. In the design of a reinforced concrete member, flexure is usually considered first, leading to the size of the section and the arrangement of reinforcement to provide the necessary resistance for moments.

Limits are placed on the amounts of flexural reinforcement to ensure that the beam has sufficient ductility behaviour at failure for safety reasons. This is then followed by shear reinforcement design. Since shear failure is sudden with little or no early warning, the design for shear must ensure that the shear strength for every member in the structure exceeds the flexural strength. The shear failure mechanism varies depending on the cross-sectional dimension, geometry, types of loading, and the properties of the member.

During the design stage, whenever the value of actual shear stress exceeds the permissible shear stress of the concrete, the shear reinforcement must be provided. The purpose of shear reinforcement is to prevent shear failure by increasing the ductility of the beam and considerably reduces the likelihood of a sudden failure.

Inclined shear crack normally started at the middle height of the beam near the support at approximately 45° and extended towards the compression zone. Any forms of effective anchored reinforcement that intersects these diagonal cracks will be able to resist the shear forces to a certain extent. In practice, shear reinforcement is provided whether in the form of vertical links, inclined links, inclined bent-up bars and also a combination of vertical and horizontal bars.

Vertical links are most commonly used as shear reinforcement in building construction, for their simplicity in fabrication and installation. Normally, spacing between links is reduced to resist high shear stress. Congestion near the support of the beams due to the presence of the closely spaced links is sometimes unavoidable. Apart from that, the fixing of shear reinforcement which is closely spaced is time consuming and increases the cost of materials.

It is generally accepted that the inclined reinforcement improves the ductility and increases the energy dissipation capacity of a reinforced concrete member. Experimental and analytical research [1],[2] have confirmed that if the steel grid in a shear reinforced concrete element is set parallel to the direction of the applied principal stresses, the cyclic response of the shear element is maximized to a limit that the shear-dominant element behaves similar to flexural-dominant element.

In this study, three reinforced concrete beams with the same grade of concrete and size were tested using the vertical links system and the inclined links system. Two types of inclined links systems were used to study the effect of inclined links configuration on the shear load carrying capacity of the beams. The first beam, AS-C, is used as a control beam with vertical links as shear reinforcement. Meanwhile, the other two beams were reinforced with inclined links. Beam AS-T1 is reinforced with inclined links tied to the longitudinal top and bottom bars, while beam AS-T2 is designed with additional bar, which was added to the rectangular shaped inclined links and tied to the longitudinal top and bottom bars.

All the tested beams were designed so that it will fail solely in shear. Therefore, adequate amount of tension reinforcement were provided to give sufficient bending moment strength and the test results were compared.

1.2 Importance of Study

Providing experimental data of the effect of inclined links on the shear capacity of a reinforced concrete beam. The test data will be of great benefit especially for guidance in structural assessment.

1.3 Objectives

The main objectives of this study are as follow:

a) To investigate the shear capacity of beams with inclined links.

b) To compare the results between inclined links and vertical links calculated according to Eurocode 2 (EC 2) [3] and American Concrete Institute Code (ACI) [4].

c) To study the effectiveness of inclined links as shear reinforcement.

1.4 Scope of Study

This study is based fully on the experimental investigation to be carried out with the scope given below.

a) The study was based on experimental investigation on three reinforced concrete beams.

b) All specimens were of the same size, 200 mm width × 250 mm height × 2000 mm length and reinforced with identical amount of longitudinal steel, 3T16 as tension reinforcement and 2T12 as compression reinforcement.

c) The beams were tested to failure under two point loads near the support to give a shear span-to-effective depth ratio (*a*/*d*) of less than 2.0.

d) The concrete compressive strength of the beam specimens is designed to achieve 35 N/mm^2 at 28 days.

e) The variables in the specimens were the shear reinforcement systems, which are vertical links, inclined links and inclined links with an additional bar. The inclination of the inclined links was 45° from the longitudinal axis.

REFERENCES

1. Mansour MY, Lee J-Y, Hindi R. *Analytical prediction of the pinching mechanism of RC elements under cyclic shear using rotation-angle softened truss model*. Eng Struct 2005;27:1138-50.

2. Lee J-Y, Kim J-H. *Behavior of reinforced concrete members having different steel arrangements*. J Korea Concr Inst 2006;19(6):685-92 (in Korea).

3. EN 1992-1-1:2004: *Eurocode 2: Design of Concrete Structures – Part 1-1: General rules and rules for building (2004)*

4. ACI 318-11, 2011. *Building Code Requirements for Structural Concrete Commentary.*

5. The Joint ASCE-ACI Task Committee 426 on Shear and Diagonal Tension on Masonry and Reinforced Concrete of the Structural Division, *'The Shear Strength of Reinforced Concrete Beams'*, Journal of the Structural Division, Proceedings of ASCE, Vol.99, No.6, June 1973 pp 1091-1187

6. Report of ACI-ASCE Committee 326, *'Shear and Diagonal Tension'*, Part 1 and 2, ACI Journal, Proceedings Vol.59, No.l, Jan 1962 pp 1-30, and No.2, Feb 1962 pp 277-334

7. Bresler, B., MacGregor, J.G., *'Review of Concrete Beam Failing in Shear'*, Journal of the Structural Division, Proceedings of ASCE, Vol.93, ST1, February 1967, pp 343-372.

8. Regan, P.E., *'Research on Shear: A Benefit to Humanity or A Waste of Time?',* The Structural Engineer, Vol.71, No. 19, 5 October 1993, pp 337-347.

9. Taylor, R., *'Some shear tests on reinforced concrete beams without shear reinforcement'*, Magazine of Concrete Research, Vol. 12, No. 36, November 1960, pp 145-154.

10. Ziara, M. M. (1993). *The influence of confining the compression zone in the design of structural concrete beams*. Heriot-Watt University.

11. Wahid Omar (1998), *The Shear Assessment of Concrete Beams With a Honeycomb Zone Present in The High Shear Region*. University of Birmingham: Ph.D Thesis.

12. Pendyala RS, Mendis P. *Experimental study on shear strength of high-strength concrete beams.* ACI Struct J 2000;97(4):564–71.

13. Ritter W. Die Bauweise Hennebique. Schweiz Bauzeitung 1899;33(7):41–3. 49–52, 59–61.

14. Mörsch E. Der Eisenbetonbau. Seine Theorie und Anwendung, 5th ed., V1 (Part 1 and Part 2). Stuttgart: Wittwer; 1922.

15. Russo G, Puleri G. *Stirrup effectiveness in reinforced concrete beams under flexure and shear*. ACI Struct J 1997;94(3):451–76.

16. Pendyala RS, Mendis P. *Experimental study on shear strength of high-strength concrete beams.* ACI Struct J 2000;97(4):564–71.

17. Fenwick RC, Paulay Sr T. *Mechanism of shear resistance of concrete beams*. J Struct Eng ASCE 1968;94(10):2325–50.

18. UNI EN 1992-1-1:2005. *Eurocode 2. Design of concrete structures – Part 1-1: general rules and rules for buildings*. European Committee for Standardization (CEN), Brussels; 2005.

19. Noor Azlina (2005), *The Use of Horizontal and Inclined Bars as Shear Reinforcement*. Universiti Teknologi Malaysia: Master Thesis.

20. Ang Ting Guan (2008), *The Influence of The Anchorage of Independent Bent-Up Bar on Its Shear Capacity*. Universiti Teknologi Malaysia: Master Thesis.

21. Moayyad M. Al-Nasra, Naem M. Asha, and AbdulQader S. Jami (2013) *Investigating the Use of Swimmer Bars as Shear Reinforcement in Reinforced Concrete Beams*.

22. *EN 206-1: Concrete – Part I: Specification, performance, production and conformity* (2000)

23. BS 8110 Structural Use of Concrete: *Code of Practice for Design and Construction*, London, British Standard Institution 1985.