SHEAR REINFORCEMENT SYSTEMS IN RECTANGULAR REINFORCED CONCRETE BEAMS

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DEDICATION

This effort is devoted to our esteemed and loving parents, who assisted me overall hard times in my life and sacrificed all the comforts of their lives for my bright future. This is also a tribute to my honourable teachers who guided me to face the challenges of life with patience and courage, and who made me what I am today.

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ABSTRACT

Shear failure in beams is characterised by diagonal cracks in the shear span or near support. Consequently, any form of well anchored bar placed to cross these cracks will be able to carry shear to some extent. This project report presents the results of a study in which the development and application of various types of shear reinforcement for the design of reinforced concrete beams were reviewed and discussed. The structural concept of these reinforcement and the behaviour of beams containing them were investigated and compared. The results indicate that the conventional vertical links is still the sole type of shear reinforcement preferred and applied by designers is almost all construction works. Although the bent-up bars had been used before, it has not been adopted since the last fifty years or so. This perhaps due to the unavailability of sufficient number of mid-span reinforcement to be extended and bent-up near the support. Alternative systems of shear reinforcement have also been tested namely the independent bent-up bars which configuration has later been improved and renamed the welded inclined bars, inclined links, independent horizontal bars and the swimmer bars. Of these the welded inclined bars proved to have relatively good shear resistance. Furthermore, since it is in the form of vertical longitudinal sheets tied to the top and bottom reinforcement, installation in beams is more practical.

ABSTRAK

Kegagalan ricih dalam rasuk bercirikan keretekan pepenjuru didalam rentang ricih atau berdekatan dengan penyokong. Dengan itu sebarang bentuk bar dengan tambatan yang mencukupi yang disusun untuk merentasi keretakan tersebut akan berupaya menanggung ricih ke tahap tertentu. Laporan projek ini memaparkan keputusan satu kajian dalam mana perkembangan dan penggunaan berbagai jenis tetulang ricih dalam rekabentuk rasuk konkrit tetulang dikaji dan dibincangkan. Konsep struktur tetulang ini dan gayalaku rasuk rasuk terbabit dikaji dan dibandingkan. Keputusan menunjukkan bahawa perangkai pugak konvensional masih menjadi pilihan unggul sebagai tetulang ricih oleh perekabentuk dalam hamper semua kerja pembinaan. Walau pun bar condong digunakan dengan meluas sebelum ini, ia tidak lagi dipilih sejak sekitar lima puluh tahun yang lalu. Ini barangkali berpunca dari kesukaran mendapatkan bilangan bar yang mencukupi untuk dipanjangkan dan dibengkokkan dekat penyokong. Sistem tetulang ricih alternative telah juga diuji sepeti bar condong bebas yang mana konfigarasinya kemudian di perkemaskan dan dinamakan semula sebagai bar condong berkimpal, perangkai condong, bar ufuk tambahan dan bar perenang. Daripada semua ini ar condong berkimpal terbukti mempunyai rintangan ricih yang baik. Disamping itu, oleh kerana ia merupakan kepingan memanjang pugak yang diikat pada tetulang atas dan bawah, pemasangan dalam rasuk adalah lebih praktikal.

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LIST OF ABBREVIATIONS

UTM	-	Universiti Teknologi Malaysia
WIB	-	Welded Inclined Bars
FRP	-	Fiber Reinforced Polymer
CFRP	-	Carbon Fiber Reinforced Polymer
GFRP	-	Glass Fiber Reinforced Polymer
AFRP	-	Aramid Fiber Reinforced Polymer
CSA	-	Canadian Standards Association
ACI	-	American Concrete Institute
WFRP	-	Wound Fiber Reinforced Polymer
EC-2	-	Eurocode 2

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Beams made up of plain concrete are incompetent as flexural member since the concrete is weak in tension and exhibits very small percentage of its compressive strength due which such type of beams are capable of carrying low loads in tension region and fails before the fully utilization of concrete strength in compression region. Steel bars are incorporated into tension side of beam for this reason and the stresses induced by bending moments is primarily resisted by streel reinforcement where in the compression zone concrete alone is usually able to withstand.

The shear forces induced by the loads are usually be larger in beams towards the support regions. Cyclic loading on a beam is a continuous and repetitive load that lead to instable stresses, forces, strains, and tensions. These repeated cyclic loads generate through different mechanisms and expose the member to shear mode of failure. For structural members, brittle type of shear failure is considered to be high risk type of failure which can lead to collapse of structure. To avoid this kind of failure the design of beams should be adequate such that they will behave ductile in flexural failure rather than shear (Toniolo G, 2017) .

Some of the main reasons of shear failure in beam are inadequate shear reinforcement on the support, change in loading mechanism on the structure, inadequate provision of end anchorage and poor construction. To some extent, any form of reinforcement designed to cross these cracks will be able to withstand the shear stress. The styles of shear reinforcing that have been identified are vertical links, bent-up bars and horizontal bars are also capable of resisting shear. While the bent-up bars are effective at reducing the width of the crack and able to carry larger shear forces, the links help the longitudinal tension steel sustain dowel action and support the concrete in compression containment.

The combination of vertical links and bent-up bars could lead to an economic solution from overall considerations. However, for the past four decades or so, the developers have not favoured bent-up bars. Shear forces are only resisted by vertical links in almost all design and construction situations, resulting in the use of very closely spaced links. Nonetheless, possible diagonal cracking of all but very lightly loaded or minimal beams may need reinforcement.

Various researches have been carried out to study the parameters that effect shear strength of beam such as size of beam, strength of concrete, shear span to depth ratio, effective beam length and transverse reinforcement (Mansour, Dicleli, Lee, & Zhang, 2004). Swimmer bars have been investigated for effectiveness and were found effective. (Al-Nasra, 2013), (H. A. Mohamed, 2017). Welded inclined bars are another form of shear reinforcement which have been investigated several times and reported as more effective as compared to vertical links (Galip, Noor Mohamed, & Abdullah, 2018).

The previous study shows that researchers are more interested in exploring the study of new methods and techniques that are effective to shear capacity of beam. In our study we will study the shear reinforcement techniques which are most effective to shear forces in beams.

1.2 Problem Statement

Bottom reinforcement of beam was also used to resist shear forces by bending them within the shear span known as bent up bars. Use of bent bars in reinforced concrete beams becomes limited in the case when there is less amount of tension reinforcement is required and complexities in the installing of multiple bent up bars with the high cost of laboring does not make this method economical.

So far stirrups are the most common method used in beams against shear forces. Construction industry prefers use of stirrups because these are easy to manufacture and fix which makes them economical also.

However, in the case of high magnitude of shear forces the use of close spaced stirrups make congestion in shear span of beam due to the high amount of shear reinforcement. This situation makes the difficulties in installation and increase the amount of cost (H. A. Mohamed, 2017).

1.3 Objectives of the study

In general, this study was carried out to explore the shear behavior of rectangular reinforced concrete beams with different modified systems being used in researches in the shear span. More specific in term the objectives of the study are:

a) To summarize the modified systems used in beams as shear reinforcement.

b) To identify the most effective method among modified systems.

c) To evaluate effect of amount in the shear reinforcement.

1.4 Scope of the study

This project is entirely focused on the theoretical investigation in the following scope:

a) The review of shear reinforcement system was based on their shear capacity, deflection and failure mode.

b) Comparison of modified shear reinforcement systems was based on their practical applicability in construction industry considering the factors cost, time, difficulties in manufacturing and fixing onsite.

c) The recent developments in shear reinforcements was assessed based on their effectiveness.

1.5 Significance of the study

Shear failure is considered to be very critical due to its unpredictable nature in failure when loads exceeds the maximum capacity of beams. Use of stirrups is the conventional method as shear reinforcement in beams but in case of higher shear force the quantity of reinforcement becomes larger.

The provision of shear reinforcement in large amount creates congestion on the other hand increasing the labor cost, quantity and time. Researchers are looking in to resolve this problem investigating experimentally by using different methods as shear reinforcement.

This review study will enable us to give insight on different shear reinforcement systems being used in research to identify the possibility of implementing alternative method against conventional method of stirrups.

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APPENDICES

Appendix A

Test Results for Welded Inclined Bars

Reference	Beam Sample	Nominal Links	Shear Reinforcement		Ultimate Load (kN)	Shear Failure load (kN)	Deflection (mm)	Failure Mode
			Vertical Links	Welded Inclined Bars (WIB)				
(Saleh Baras, 2013)	B1	R6 – 150	R6 - 50	-	220	110	14.77	Shear
	B4		-	H10 - 150 @ 45˚	230	115	21.71	Flexure
	B5		R6 - 50	H10 - 150	240	120	9.9	Flexure
	B6		-	H10 - 150 @ 30˚	240	120	10.22	Shear
(Mian, 2016)	B 1	R6 – 150	R6 - 65	-	208	104	14.32	Shear
	B 2		-	H16 - 200 @ 60˚	260	130	14.92	Flexure
	B 3		-	H16 - 200 @ 45˚	245	122.5	15.34	Flexure
	B 4		-	H10 - 150 @ 45˚	245	122.5	14.48	Flexure
	B 5		R6 - 150	H16 - 200 @ 45˚	300	150	11.56	Flexure
	B 6		-	H16 -200 @ 45˚	240	120	9.46	Shear
(Gimbiya, 2017)	BM 1	R6 – 100	R6 - 50	-	221	120	14.34	Shear
	BM 2		-	H16 - 200 @ 45˚	272	190	16.67	Flexure
	BM 3		-	H16 - 200 @ 60˚	290	185	17.24	Flexure
	BM 4		-	H16 - 125 @ 45˚	270	190	17.29	Flexure
	BM 5		-	H16 - 125 @ 60˚	271	190	21.39	Flexure
(Galip et al., 2018)	B 1	R6 - 150	-	-	105.50	52.75	4.80	Shear
	B 2		2R6 - 70	-	313.10	156.55	22.98	Flexure
	B 3		-	R8 - 150 @ 60˚	260.60	130.33	12.78	Shear
	B 4		-	R8 - 100 @ 60˚	303.60	151.33	16.84	Shear
	B 5		-	H8 - 120 @ 60˚	321.10	160.55	19.41	Flexure

Test Results for Swimmer Bars

Reference	Beam Sample	Nominal Links	Shear Reinforcement		Shear Failure load (kN)	Deflection (mm)	Failure Mode
			Vertical Links	Swimmer Bars			
(Moayyad M. Al-Nasra, 2013)	BC	ϕ8 - 600	ϕ8 - 600	-	180	11	Shear
	BW		-	Two swimmers welded ϕ10 - 275	220	14.2	Shear
	BB		-	Two swimmers Bolted ϕ10 - 275	215	13.8	Shear
	BU		-	Two simmers U-Link ϕ10 - 275	210	13	Shear
(Al-Nasra, 2013)	B1	-	ϕ8 - 550	-	260	11.8	Shear
	B2		-	Single swimmer ϕ14 - 137.5	310	12.3	Shear
	B3		-	Single swimmer ϕ12 - 137.5	305	12	Shear
	B4		-	Single swimmer ϕ10 - 137.5	285	14.9	Shear
	B5		-	Two swimmers with cross ϕ8 - 175	240	9.7	Shear
	B6		-	Two swimmer ϕ8 - 275	220	9.8	Shear
(Sreejith, 2017)	BNS-8-300	-	ϕ8 - 300	-	148	7.92	Shear
	BNS-8-250		ϕ8 - 250	-	201	8.91	Shear
	BNS-8-200		ϕ8 - 200	-	204	8.89	Shear
	BSW-8-300			Single swimmer ϕ8 - 300	246	10.32	Shear
	BSW-8-250			Single swimmer ϕ8 - 250	272	9.53	Shear
	BSW-8-200			Single swimmer ϕ8 - 200	283	10.71	Shear

Note:

BNS – Beam with normal stirrups

BSW – Beam with single swimmer bar

Test results for shear capacity

Shear Reinforcement Method	Shear Capacity	Country	Reference
1. Welded swimmer bars 2. Bolted swimmers bars 3. U-link bolted swimmer bars	All exhibits similar results	West Virginia	(Moayyad M. Al-Nasra, 2013)
1. Continuous rectangular spiral reinforcement 2. Advanced spirals and shear-favourably inclined vertical links	1. less effective 2. Improved capacity	Greece	(Karayannis & Chalioris, 2013)
1. Single swimmer bar 2. Rectangular swimmer bar 3. Rectangular swimmer bar with cross bracing	1. Increased 2. Not effective 3. Not effective	West Virginia	(Al-Nasra, 2013)
1. basic lattice type (90˚ angle) 2. Parallelogram (45˚ angle)	Each shape exhibits similar results (4 to 12%)	ACI structural journal	(D. J. Kim et al., 2014)
1. AFRP 2. GFRP 3. CFRP	Shear reinforcement was same so only CFRP showed larger strength		
1. Inclined link 2. Inclined link with additional bar	1. Significant increase (18 to 33%)	Malaysia	(Suhaimi, 2015)
GFRP basic lattice type (90˚ angle)	Improved	Republic of Korea	(H. Kim et al., 2015)
1. Swimmer bar as shape 1 2. Swimmer bar as shape 2	1. Increased capacity about 58.1%	Egypt	(H. A. Mohamed, 2017)
Spiral reinforcement	Improved	Jordan	(Shatarat et al., 2016)
Single Swimmer bars	Capacity increase by 35.81%	India	(Sreejith, 2017)
1. Wound FRP stirrups with 3 layers 2. Wound FRP stirrups with 3 layers	1. increased by 208%	U. K	(Spadea et al., 2017)
Welded Inclined Bars (60˚)	Found effective	Malaysia	(Galip et al., 2018)
Inclined links (45˚)	20% increased shear capacity	Malaysia	(Fazlin & Mohamed, 2018)
1. Inclined Stirrups (45˚) 2. Truss type stirrups 3. Bracing type stirrups	All methods were found effective	India	(Deepthi et al., 2019)
CFRP Strips	Large improvement	Jordan	(Amaireh et al., 2020)

Test results for deflection

Shear Reinforcement Method	Deflection	Country	Reference
1. Welded swimmer bars 2. Bolted swimmers bars 3. U-link bolted swimmer bars	No major difference between new systems	West Virginia	(Moayyad M. Al-Nasra, 2013)
1. Continuous rectangular spiral reinforcement 2. advanced spirals and shear-favourably inclined vertical links	2. Improved post-peak deformation	Greece	(Karayannis & Chalioris, 2013)
1. Single swimmer bar 2. Rectangular swimmer bar 3. Rectangular swimmer bar with cross bracing	1. Improved	West Virginia	(Al-Nasra, 2013)
1. basic lattice type (90˚ angle) 2. Parallelogram (45˚ angle) 1. AFRP 2. GFRP 3. CFRP	Not studied however recorded but not discussed	ACI structural journal	(D. J. Kim et al., 2014)
1. Inclined link 2. Inclined link with additional bar	-	Malaysia	(Suhaimi, 2015)
GFRP basic lattice type (90˚ angle)	Improved	Republic of Korea	(H. Kim et al., 2015)
1. Swimmer bar as shape 1 2. Swimmer bar as shape 2	decreased by 38.4% as compared to shape 2	Egypt	(H. A. Mohamed, 2017)
Spiral reinforcement	Improved	Jordan	(Shatarat et al., 2016)
Single Swimmer bars	Improved	India	(Sreejith, 2017)
1. Wound FRP stirrups with 3 layers 2. Wound FRP stirrups with 3 layers	Improved	U. K	(Spadea et al., 2017)
Welded Inclined Bars (60˚)	Offered less deflection	Malaysia	(Galip et al., 2018)
Inclined links (45˚)	less deflection compared to control beam	Malaysia	(Fazlin & Mohamed, 2018)
1. Inclined Stirrups (45˚) 2. Truss type stirrups 3. Bracing type stirrups	All types offered less deflection to conventional method	India	(Deepthi et al., 2019)
CFRP Strips	Increased ultimate deflection	Jordan	(Amaireh et al., 2020)

Test results for failure mode

Shear Reinforcement Method	Failure mode	Country	Reference
1. Welded swimmer bars 2. Bolted swimmers bars 3. U-link bolted swimmer bars	Shear	West Virginia	(Moayyad M. Al-Nasra, 2013)
1. Continuous rectangular spiral reinforcement 2. Advanced spirals and shear-favourably inclined vertical links	Shear	Greece	(Karayannis & Chalioris, 2013)
1. Single swimmer bar 2. Rectangular swimmer bar 3. Rectangular swimmer bar with cross bracing	Shear	West Virginia	(Al-Nasra, 2013)
1. basic lattice type (90˚ angle) 2. Parallelogram (45˚ angle) 1. AFRP 2. GFRP 3. CFRP	Shear compression	ACI structural journal	(D. J. Kim et al., 2014)
1. Inclined link 2. Inclined link with additional bar	Shear	Malaysia	(Suhaimi, 2015)
1. GFRP basic lattice type (90˚ angle)	Shear	Republic of Korea	(H. Kim et al., 2015)
1. Swimmer bar as shape 1 2. Swimmer bar as shape 2	Some failed in shear and some in flexural	Egypt	(H. A. Mohamed, 2017)
Spiral reinforcement	shear	Jordan	(Shatarat et al., 2016)
Single Swimmer bars	shear	India	(Sreejith, 2017)
1. Wound FRP stirrups with 3 layers 2. Wound FRP stirrups with 3 layers	1. Shear tension 2. Flexural	U. K	(Spadea et al., 2017)
Welded Inclined Bars (60˚)	All failed in shear only 2 failed in flexure	Malaysia	(Galip et al., 2018)
Inclined links (45˚)	Shear compression	Malaysia	(Fazlin & Mohamed, 2018)
1. Inclined Stirrups (45˚) 2. Truss type stirrups 3. Bracing type stirrups	Shear	India	(Deepthi et al., 2019)
CFRP Strips	Shear	Jordan	(Amaireh et al., 2020)