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Shear Capacity of RC Beams Retrofitted

A. Amiruddin[1], A. B. Muhidin[1], R. Karamma[1]

[1] Department of Civil Engineering, Faculty of Engineering, Hasanuddin University, Indonesia
Correspondence: A. A. Amiruddin, Department of Civil Engineering, Hasanuddin University, Jalan Poros Malino, Gowa, Indonesia.

Tel: (+62)-0411-587636. E-mail: *a.arwinamiruddin@yahoo.com*

ABSTRACT

The aim of the study was to analyze the effect of retrofit on shear capacity; cracks; and failure modes of beams. Four concrete beams reinforced internally with steel and externally with both wire mesh (Ø4,06mm) and SCC (2.5mm) applied to the specimens were tested under three-point bending. The shear failure is initiated by a major diagonal crack within the beam shear span. This diagonal crack extended horizontally at the level of the wire mesh. Results show that SCC with wire mesh is very effective for shear strengthening. Increases in strength of 71.82% for BWS over the BN as control, un-retrofitted beams were noted.

Keywords: Shear Capacity, Retrofit, RC beams, Wire Mesh, SCC.

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1. INTRODUCTION

Shear failure is one of primary modes of failure in reinforced concrete (RC) beams. Shear failure is brittle in nature and does not allow substantial redistribution of loads; thus, shear failure occurs without any prior warning and is often catastrophic. Poorly designed beams may fail in shear before reaching the flexural strengths. Hence, RC beams must have sufficient shear strength, higher than flexural strength, in order to ensure a ductile failure mode. Shear failure of RC structures may be due to many factors, e.g., insufficient shear reinforcement, reduction of steel area due to corrosion and spalling of concrete caused by aggressive environmental conditions, increased service load due to change in usage of the structure, and any detailing, design, and/or construction error.

Thus, strengthening and rehabilitation of RC structures may be needed to increase the ultimate load carrying capacity of shear-deficient beams. Structures that are deficient in shear can be strengthened or repaired by using various methods, e.g., external prestressing, shortcreting, polymer impregnation, steel plate bonding [1]. Among these retrofit solutions, the use of externally bonded fiber reinforced polymers (FRPs) is becoming more frequently used and widely recognized by modern design codes and guidelines [2, 3]. However, in this paper, a new technique for seismic strengthening of RC beams is presented. Beams in existing structures are externally reinforced by means of high-strength wire mesh. The reinforcement is performed by wrapping wire mesh and self-compacting concrete (SCC) around the beams. This method has numerous advantages compared to other more traditional techniques, e.g., light weight and ease of installation, high strength to weight ratio, high stiffness to weight ratio, and corrosion resistance. However, the accurate prediction of the shear strength of wire mesh-SCC-retrofitted beams is a complex task.

Shear retrofit of RC beams with externally bonded wire mesh-SCC is being widely recognized as an efficient retrofit technique [4]. Nowadays, there are three types of wire mesh, namely stainless steel welded wire mesh, galvanized welded wire mesh, and PVC coated welded wire mesh. Stainless steel welded wire mesh is made of high quality stainless steel wire and welded by advanced computer-controlled machines. Compared with galvanized welded iron wire mesh or PVC coated welded iron wire mesh, these features can compensate for its seemingly higher cost. Galvanized welded wire mesh or hot dipped galvanized can be shaped in the forms of rolls or panels, for construction, fences and other industrial uses. It enjoys the feature of corrosion resistance compared with plain welded wire mesh.

PVC Coated Welded Wire Mesh is made of high quality of welded galvanized iron wire mesh, to be coated with PVC powder by advanced automatic equipment. Indonesia regulation in 1971 about reinforced concrete, requires that the material has a yield stress characteristics of 4,800 kg / cm² classified into the class of U-48. So based on the above information, iron wire mesh having a voltage limit of 5,000 kg / cm² can be classified into the class of U-50 [5]. To increase security, the wire used to wire mesh has a tensile strength of at least 10% higher than the characteristics yield stress as a guarantee a warning against the danger of collapse. To ensure that high standards are maintained continuously, wire factory tested regularly in Jakarta and Surabaya. Added another with advanced testing performed in research centers materials of Bandung. Copies of certificates available and can be checked. Each cross wire welding, to allow for the network in question is well anchored in the concrete. Shear stress is minimal seam welds every 2,500 kg / cm² to ensure that the binding that is linked can be obtained.

Self-compacting concrete (SCC) is a flowing concrete mixture that is able to consolidate under its own weight. The highly fluid nature of SCC makes it suitable for placing in difficult conditions and in sections with congested reinforcement [6]. Use of SCC can also help minimize hearing-related damages on the worksite that are induced by vibration of concrete. Another advantage of SCC is that the time required to place large sections is considerably reduced. Mixture proportions for SCC differ from those of ordinary concrete, in that the former has more powder content and less coarse aggregate. Moreover, SCC incorporates high range water reducers (HRWR, super plasticisers) in larger amounts and frequently a viscosity modifying agent (VMA) in small doses. The questions that dominate the selection of materials for SCC are: (i) limits on the amount of marginally unsuitable aggregates, that is, those deviating from ideal shapes and sizes, (ii) choice of HRWR, (iii) choice of VMA, and (iv) interaction and compatibility between cement, HRWR, and VMA. These are discussed below. Aggregates constitute the bulk of a concrete mixture, and give dimensional stability to concrete.

Among the various properties of aggregate, the important ones for SCC are the shape and gradation. In the case of SCC, rounded aggregates would provide a better flow ability and less blocking potential for a given water-to-powder ratio, compared to angular and semi-rounded aggregates. Moreover, the presence of flaky and elongated particles may give rise to blocking problems in confined areas, and also increase the minimum yield stress (rheology terms are discussed in the next section). Incorporation of aggregate shape in the mixture design would enable the selection of appropriate paste content required to overcome these difficulties. It is possible that the highly flow able nature of SCC could allow a higher proportion of flaky aggregates compared to normal concrete. However, this aspect needs to be checked. The major difference between self-compacting and conventionally-vibrated concrete is the higher flow ability of SCC, and consequently a higher proportion of fine materials.

For this purpose need experimental studies of a retrofit method using wire mesh and SCC to evaluate shear capacities of reinforced concrete beams as efforts to develop new innovations in the construction of the concrete.

2. The Research Method

Research to be conducted is a purely experimental research in the form of laboratory studies. Research conducted in the laboratory of Earthquake Engineering Research Laboratory of Civil Engineering, Faculty of Engineering, Hasanuddin University, Makassar. The materials to be used in this study include:

a. Aggregate coarse, derived from rocks Ex. Bili-Bili Gowa. the breakdown of the stone (stone crusher) PT Cipta Pratama Garungga South Sulawesi).
b. Fine aggregate using river sand Jeneberang Gowa in South Sulawesi.
c. Portland Cement type 1 (PC) which is used as a binder is produced from PT. Tonasa Portland Cement from Pangkep in Southeast Sulawesi.
d. For the wire mesh used that produced from PT Union Metal.
e. The super plasticisers obtained from the building material store in the city of Makassar.

The test specimens consisted of four RC beams classified into two types according to wire mesh strengthening system is shown in Figure 1.

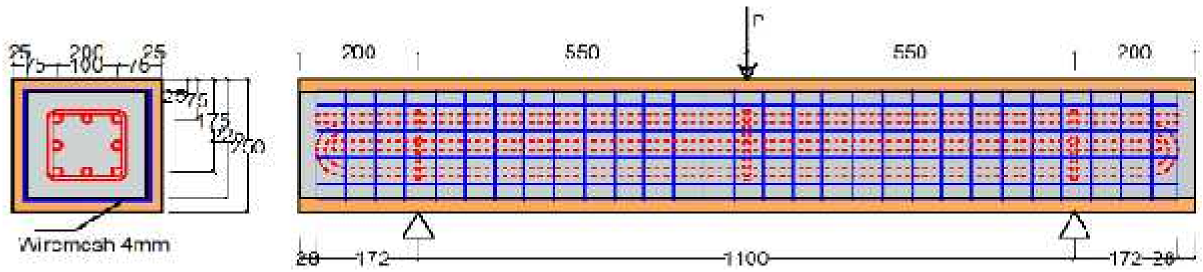


Figure 1. Wire Mesh Strengthening System.

Two beams were tested without strengthening (BN) and served as a control specimen for comparison purposes to evaluate the improvement in shear strength provided by externally bonded wire mesh reinforcements and SCC with thickness of 25mm.

Two beams (BWS) were strengthened with wire mesh systems using wire mesh (Ø4.06 mm) as shown in Table 1. In design, compressive strength of concrete f'c of 30 MPa. The test specimens as much as four reinforced concrete beams with dimensions of 200mm x 200m x 1500mm.

Table 1. Summary of Specimen Types

Beam Types	Wire Mesh	SCC
BN (control)	-	-
BWS	Ø4,06mm	25mm

The stages in this study was initiated to make normal reinforced concrete beams (as control beam). The longitudinal bars using 8D16-50mm and transversal bars 3D8-550mm. Furthermore, the control beam is wrapped with wire mesh 4M on the entire surface of the beam and finally wrapped with SCC as thick as 25mm.

Table 2. Material properties of concrete and SCC

Beam Types	Materials	Design values		Experimental values	
		f'_c (N/mm²)	E_c (N/mm²)	f'_c (N/mm²)	E_c (N/mm²)
BN	Concrete	30	25,743	32.66	23,412
BWS	SCC			35.68	25,187

A design and experiment of material properties values of the concrete and SCC are given in Table 2. The results were found that a good agreement between design and experiment values. The evaluation of the concrete characteristics obtained by sampling are carried out in accordance with casting of beam test. The Samples were tested in the form of concrete cylinder 100mm x 200mm and beams with dimensions of 100mm x 100mm x 400mm made at the time of casting reinforced concrete beam as a control sample. In casting the beams, the number of cylindrical samples were made as much as 9 cylinders for testing compressive strength, tensile strength and modulus of elasticity sides each with 3 pieces of each test, and 3 samples by using 100mm x 100mm x 400mm for flexure testing. Material test of concrete beam using the Tokyo Testing Machine (TTM). The test of concrete material conducted after the specimen reaches the age of 28 days. Moreover, in Table 3 shows kinds of steel bars and wire mesh were used in the experiment.

Table 3. Material properties of steel bars and wire mesh

Diameter (mm)	Directions	f_y (N/mm²)	f_u (N/mm²)	E_s (N/mm²)	ε_s (N/mm²)
ø 8	Transversal	320.862	465.200	159,423	2013.5
ø 16	Longitudinal	438.835	649.827	217,852	2014.5
Wiremesh M4 ø 4	Transversal and longitudinal	240.835	524.156	120,275	2002.4

All beams were loaded in three-point bending that the subjected to static load is shown in Figure 2. The beams were instrumented with a displacement meter at the mid-span and both of loading point to monitor displacement, as well as strain gauges bonded on concrete, SCC, and wire mesh surface to measure the strain values.

A 500kN load cell was used to measure the applied load.

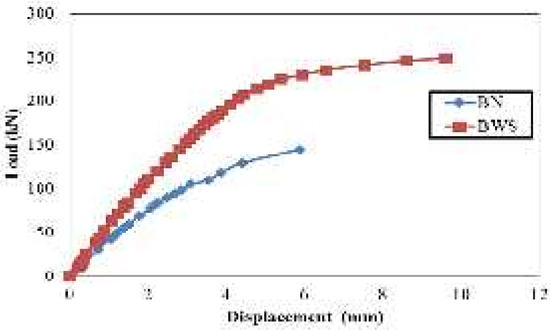


Figure 2. Specimen under testing and loading system.

3. TEST RESULT

A. Load – displacement relationship

The load displacement as showed in Figure 3 plot for beam BWS along with that of the shear control beam, BN. The control beam failed in shear and also for BWS type. BWS type had shear strength more than BN type and increases in shear strength of 71.82% for BWS over the BN, un-retrofitted beams.

Figure 3. Load displacement relationship.

B. Load – strain relationship

Figure 4 shows relationship of load with compressive strain of concrete/SCC and tensile strain of steel bars/wire mesh.

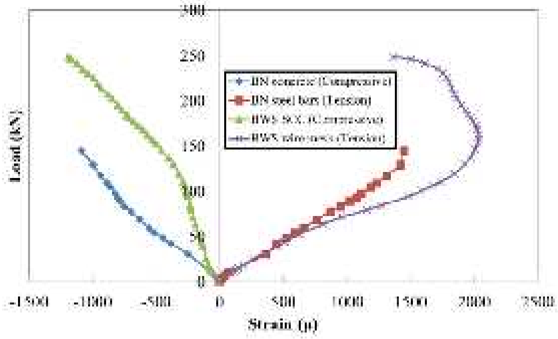
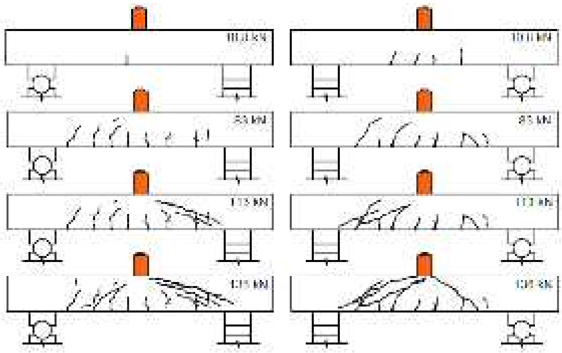
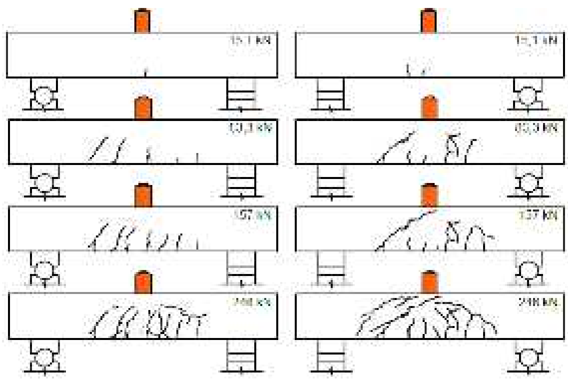


Figure 4. Load strain relationship.

Tensile strain of steel bars of BN was achieved up to about 1497.14 μ but less than 2014.5 μ at the maximum of shear load. On the other hand, tensile strain of BWS type was achieved up to 2048,57 μ more than 2002.4 μ as a design value for tensile strain of wire mesh. Therefore, all of beams the specimens had shear failure modes. Figure 5 shows the crack pattern and failure mode of the beam under test.



(a) BN



(b) BWS

Figure 5. Crack Pattern and Failure Mode of Beam Under Test.

C. Comparison of analysis and experiment values of Ps

The design of load is divided into four parts, load at first crack (Pcr), first yield at steel reinforcement in tension area (Py0) so that steel bars was separated with concrete, ultimate strength (Pu), and shear strength (Ps). In particular for Ps, the analysis was carried out based on Japan Road Association (JRA) Bridge Part V method [7].

In design, the shear failure was proposed on Py0 / Ps > 1.5. In experiment result, it was obtained that for all of specimen types had propagation of cracks showed shear failure behavior. Especially for BWS type, slip between wire mesh and SCC was occurred so that obtained wire mesh was not broken but separate with SCC and experiment value become more than design value. The comparison of analysis and experiment value is given in Table 4 and Figure 6, respectively.

Table 4. Comparison of analysis and experimental values

Beam Types	Analysis					Experiment					Ratio (Py/Ps)
	Pcr (kN)	Py (kN)	Pu (kN)	Ps (kN)	Py/Ps	Pcr (kN)	Py (kN)	Pu (kN)	Ps (kN)	Py/Ps	(P_{anls}/ P_{expri})
BN-1	10.74	96.03	139.92	69.96	1.37	10.66	81.97	153.11	76.56	1.07	1.28
BN-2	10.74	96.03	139.92	69.96	1.37	10.83	84.63	136.78	68.39	1.24	1.11
BN-Average	10.74	96.03	139.92	69.96	1.37	10.75	83.30	144.95	72.47	1.15	1.20
BWS-1	10.74	130.50	238.72	119.36	1.09	15.33	121.62	251.57	125.79	0.97	1.13
BWS-2	10.74	130.50	238.72	119.36	1.09	15.16	118.12	246.5	123.25	0.96	1.14
BWS-Average	10.74	130.50	238.72	119.36	1.09	15.25	119.87	249.04	124.52	0.96	1.14

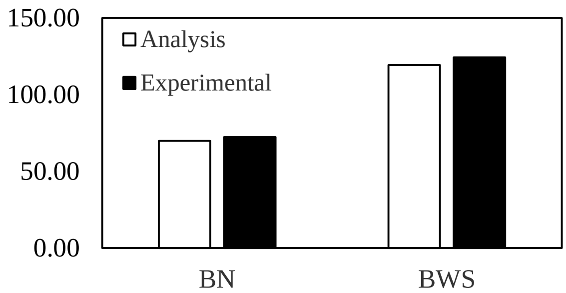


Figure 6. Comparison of analysis and experimantal values.

4. CONSLUSION

In three-point bending test results, BN type as control beam or un-retrofit type failed by shear. However, the retrofit specimens (BWS) also were failed at shear and these conditions parallel with design concept. BWS type was failed by separation with wire mesh from SCC. BWS had not enough adhesive strength to prevent relative slip to SCC. Based on experiment results, the retrofit of RC beams (BWS) have revealed that shear strength increase 71.82% as significantly to control beam.

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