Shear strength of annealed wire fiber reinforced concrete coupling beam under cyclic loads

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IOP Conference Series: Earth and Environmental Science

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To cite this article: C Kandou *et al* 2020 *IOP Conf. Ser.: Earth Environ. Sci.* **473** 012147

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Abstract. The design and construction of the coupling beams remain challenging due to the presence of large reversed-cyclic nonlinear rotation demands combined with large shear forces. One way to increase the shear strength of a coupling beam is to use fiber. The purpose of this research is to determine the shear strength for coupling beam using annealed wire fiber. Two coupling beam test specimens measuring 20 cm x 40 cm with a length of 115 cm with a ratio of L_n / h is 2.875 with the details of 1 coupling beam without fiber (CB-1) and 1 coupling beam with fiber (CBF-1). Annealed wire fiber used in research with diameter (D) 0.8 mm with fiber length (L) 48 mm (L / D ratio is 60) with fiber composition 0.75% of volume. The results show the Shear strength of coupling beam using fiber increases by 58% from normal concrete shear strength. Also, the shear strength of the coupling beam in SNI 2847:2013 is 0.67 and 0.42 of the experimental shear strength of normal CB and annealed wire fiber CB so that the design of the coupling beam based on SNI 2847:2013 can be used as a reference in planning earthquake resistant building structures.

Introduction

Reinforced concrete (RC) coupled shear wall structures are commonly used for primary lateral load resistance in medium and high-rise buildings. The typical coupled wall system consists of two or more vertical shear wall piers connected by relatively short, deep beams called coupling or link beams at the floor and roof levels. Properly designed RC coupled shear wall structures can provide large strength, stiffness, and energy dissipation under lateral loads; however, the design and construction of the coupling beams remain challenging due to the presence of large reversed-cyclic nonlinear rotation demands combined with large shear forces [1].

The design of coupling beams, with span-to-depth ratios that often range between 1.5 and 3.5, requires special attention because of the large inelastic rotations and shear stresses coupling beams can be subjected to during a strong earthquake [2]. John Wallace [3] Conduct experimental tests to show cases of unsatisfactory shear walls and coupling beams. The results obtained explain several factors that cause the collapse or failure of the coupling beam, among others due to large shear forces, ductility, reinforcement problems that cause energy dissipation is not good.

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One way to increase shear strength, ductility and energy dissipation in a coupling beam is to use fiber. In principle, the addition of this fiber to increase the tensile stress of concrete. There are a number of researchers conducting research on coupling beam that uses fiber, especially steel fibers [4, 5]. The result is increased shear strength, improve the tensile strength of concrete when cracked, reduce reinforcement, and improve cracking. Annealed wire fiber is one of the local fibers as an alternative to steel fibers. There are a number of studies on concrete materials using annealed wire fiber related to material characteristics, namely compressive strength, tensile strength, shear and flexure [6-8] which show an increase or improvement in material characteristics.

The purpose of this study is to determine the value of shear forces for coupling beam using annealed wire fiber.

1.1. Mechanical properties of annealed wire fiber concrete

The effective value of aspect ratio (ratio between length and diameter of annealed wire fiber) is between 50 - 00. By using an aspect ratio of 60 and 1mm annealed wire diameter, the obtained fiber length is 60 mm [6]. The shape of the annealed wire fiber is shown in figure 1.

Figure 1. Annealed Wire Fiber

Research conducted by Suhendro on compressive strength and tensile strength testing of concrete cylinders using annealed wire fiber with a volume of 0.7% and an aspect ratio of 60 has proven that concrete annealed fiber is able to increase the compressive strength of concrete by 12%, while the strength the tensile strength increased by 52% compared to the normal tensile strength of concrete [6].

Research conducted by Wahjono to prove experimentally that the shear strength of a reinforced concrete beam increases when added to the annealed wire fiber in a concrete beam mix. 6 reinforced concrete beams made in size 120 mm x 240 mm x 1600 mm with details of three blocks made of ordinary concrete with vertical stirrups and three blocks made of fiber concrete with vertical stirrups. Fiber weight per cubic meter of concrete is 46.76 kg or equal to vf = 0.7% of the mixed volume. From the test results it can be concluded that the shear strength limit of reinforced concrete beams with annealed wire fiber increased by 20% compared to the ultimate shear strength of reinforced concrete beams without fiber [8].

Aswin examined the crosssection capacity of beams based on flexural and ductility testing which was calculated based on deflection for beams without fibers and with annealed wire fibers due to the use of bent steel reinforcement. There are five types of beams in this study: 3 beams without fiber each without bending, bending 90 and 180 while 2 beams use annealed wire fibers each bend 90 and 180 with the addition of fiber of 2% of the volume of the mixture. The results showed the addition of fiber by 2% gave a 22% increase in bending for beams with 90 curves and 29% for beams with 180 curves [7].

1.2. Shear strength of reinforced concrete coupling beam

The strength of diagonally reinforced (DR) coupling beams shown is determined based on Section 21.9.7 of ACI 318 – 11 [9]. It is assumed that both the flexural and shear strengths of a DR coupling beam depend only on the contribution of diagonal reinforcement. In other words, the contribution of horizontal reinforcement is not included in the flexural strength. The nominal flexural strength of a DR coupling beam is calculated by:

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$$M_n = A_s f_y \cos\alpha\,(h - 2d') \quad (1)$$

Also, the effects of concrete and transverse reinforcement on the shear strength of DR coupling beams are not considered in ACI 318 – 11 [9]. The nominal shear strength of a DR coupling beam is expressed as follows:

$$V_n = 2A_s f_y \sin\alpha \quad (2)$$

Here, is the total area of diagonal reinforcement in one direction, and is the yield stress of diagonal reinforcement. Also, is the depth of the beam, and is the distance from the top (or bottom) of the beam to the centroid of diagonal reinforcement. Is the inclination angle between the diagonal bars and the longitudinal axis of the beam [10].

There are 2 types of coupling beam with diagonal bars [9, 11]

- Diagonal reinforcement with individual diagonal restraints (figure 2)

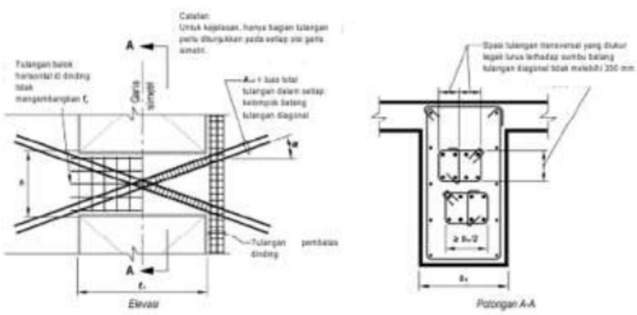

Figure 2. Reinforcement with Individual Diagonal Restraints

- Diagonal reinforcement with full restraints cross section of diagonal reinforced concrete blocks (*Behavior of fibrous concrete*).

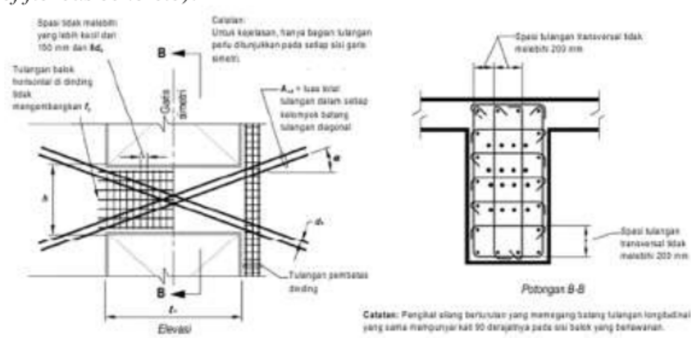

Figure 3. Diagonal reinforcement with full restraints cross section of diagonal reinforced concrete blocks

2. Research methodology

2.1. Material

Annealed wire fiber used in research with diameter (D) 0.8 mm with fiber length (L) 48 mm (L / D ratio is 60) with fiber composition 0.75% of volume (66 kg / m^3).
For concrete material fc' is planned at 25 MPa while fy steel is 240 MPa for 8 mm and 10 mm plain reinforcement while for 13 mm and 10 mm diameter deformed with fy 400 MPa. For workability, Viscocrete 3115N superplasticizer is used at 0.5% by weight of cement. For concrete mix design compositions with fc' 25 MPa are presented in table 1.
For concrete materials in the top block and bottom block, ready mix concrete with an fc 'of 30 MPa is planned.

Table 1. Mix design

Material	Weight (kg)
Water	187,72
Cement	405,4
Sand	643,78
Gravel	1065,85
Fiber	66
Superplasticizer	0,5% of cement weight

2.2. Specimen design

Coupling beam test specimens measuring 20 cm x 40 cm with a length of 115 cm with a ratio of Ln / h is 2.875 which is categorized with a slender type coupling beam ie the ratio of Ln / h is between 2 and 4. For the specimen coupling beam as much as 2 pieces with the details of 1 coupling beam without fiber (CB-1) and 1 coupling beam with fiber (CBF-1). For reinforcement in the coupling beam is a diagonal reinforcement, namely the diagonal reinforcement group (CB-1 and CBF-1) in table 2 and figure 4.

Table 2. Coupling beam and reinforcement

Specimen	Dimension (cm)	Length (cm)	Diagonal Reinforcement		Horizontal Reinforcement		Information
			Longitudinal	Ties	Longitudinal	Ties	
CB-1	20/40	115	8D13	Ø10-75	D10-80	Ø10-100	Normal
CBF-1	20/40	115	8D13	Ø10-75	D10-80	Ø10-100	Fiber

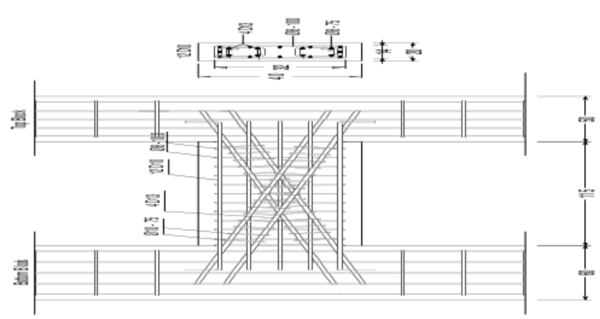

Figure 4. Coupling Beam Reinforcement

2.3. Test setup, instrumentation and loading protocol

The cyclic test was carried out at the Structure and Material Laboratory of the Universitas Hasanuddin Faculty of Engineering with a load capacity of 1500 kN with the cyclic testing model shown in figure 5.

Figure 5. Cyclic Testing Setup

For cyclic testing procedures using SNI 7834:2013 [12] testing standards with displacement control systems (Figure 6). For Ln taken at 115 cm.

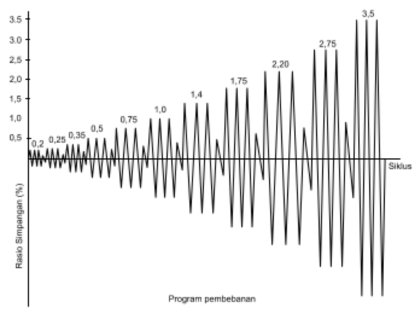

Figure 6. Cyclic Testing Procedure

3. Results and discussion

3.1. Experimental shear strength

Figure 7 shows the load-displacement hysteretic curve for the CB-1 coupling beam specimen. First crack occurred at a displacement value of 2.85 mm with a load of 12.26 kN. The first yield occurs at a load value of 71.58 kN and a displacement of 5.57 mm while the ultimate condition is achieved at a load of 131.73 kN with a displacement value of 18.95 mm.

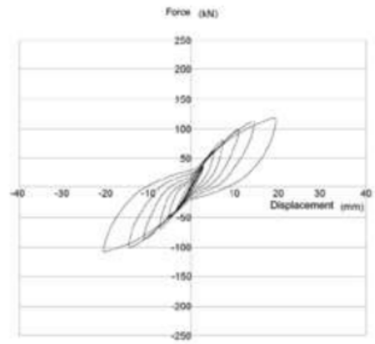

Figure 7. Load-displacement Hysteretic Curve of CB-1 test specimens

Figure 8 shows the load-displacement relationship on CBF-1 specimens due to cyclic loads. For first crack, first yield and ultimate occur at the displacement of 3.32 mm, 8.14 mm and 30.09 mm with a load that occurs is 28.46 kN, 110.73 kN and 208.19 kN.

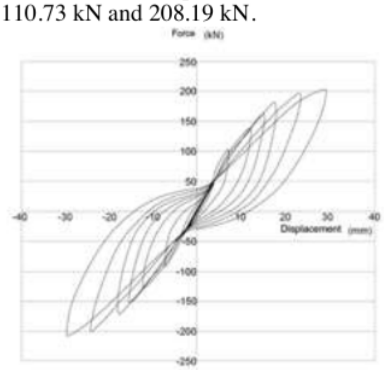

Figure 8. Load-displacement Hysteretic Curve of CBF-1 specimens

The shear strength for the CB-1 specimens was 131.73 kN while the shear strength of the CBF-1 specimens was 208.19 kN. If the shear strength is stated in the function of concrete quality and cross-sectional area, the shear strength of the CB-1 test specimen can be written 0.33√fc'bwh while the shear strength of the CBF-1 specimen can be written 0.52√fc'bwh.
The addition of fiber to the concrete increases the shear strength of the coupling beam by 58% from the shear strength of the coupling beam without fiber.

3.2. Shear strength according to SNI 2847:2013 and experimental

The shear strength of the coupling beam calculated based on SNI 2847:2013 [11] is 89 kN or $0.22\sqrt{fc'}b_wh$ while the shear strength for the CB-1 and CBF-1 specimens is 131.73 kN, 208.19 kN stated in the concrete quality function and the cross-sectional area is $0.33\sqrt{fc'}b_wh$, $0.52\sqrt{fc'}b_wh$.

If the shear strength according to SNI 2847:2013 [11] is compared with the shear strength of the coupling for normal concrete (CB-1), it can be seen that the shear strength value of the coupling beam according to SNI 2847:2013 [11] is 67% of the CB-1 shear strength and 42% of the CBF-1 shear strength. Thus it can be concluded that the calculation of the coupling beam shear strength according to SNI 2847:2013 [11] is quite conservative and safe to be used as an analytical approach in the design of the coupling beam as a structural element in the shear wall.

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To determine shear or flexural behavior or a combination of coupling beam, only use the criteria of the ratio of span length to cross section height ie for l_n / h smaller than 2 are categorized as shear behavior and the reinforcement model must be a diagonal reinforcement group. For l_n / h more than 4, the coupling beam behaves flexibly, while ln / h between 2 and 4 is categorized as sliding and flexural behavior with the reinforcement model diagonal in groups or singly [11, 10].

Additional parameters for the coupling beam behavior category that is based on intervals of shear stress demand values of 3 in psi units (or 0.25 in MPa units) and stress demand values of 6 in psi units (or 0.5 in units MPa) [13]. For stress demand values less than 0.25, they are used as a reference for the coupling beam flexural behavior category and for shear stress demand values more than 0.5 shear coupling beams. Whereas values between 0.25 and 0.5 are categorized as shear-flexure. From the cyclic test the coupling beam with l_n / h is 2.875 (values are between 2 and 4), for CB-1 specimens with shear stress ratio is 0.33 at shear stress intervals of 0.25 and 0.5 while for CBF- 1 shear stress value of 0.52 is slightly higher than the upper limit set.

In this regard, then in the coupling beam design calculated additional shear stress criteria can be used to determine the behavior of the coupling beam that is sliding, bending or a combination of shear and flexure [11]. Specifically for diagonal reinforcement in coupling beam, requires the value of shear strength not to exceed the maximum shear strength of 0.83√fc'bwh. For CB-1 and CBF-1 coupling beam specimens, the shear strength value is smaller than the maximum shear strength required so that the specimen meets the required shear criteria [11].

3.3. Crack pattern

In figures 9 and figure 10 the crack pattern for the CB-1, CBF-1 specimens is presented in the ultimate condition. In the CB-1 specimen, the first crack occurred at the bottom of the coupling beam due to the thrust load. Furthermore, it can be seen that the crack occurs starting from the bottom of the test specimen and along with an increase in load the crack begins to increase to the top. At the top of the coupling beam during the ultimate condition, not all of them have cracked because the concrete has experienced the ultimate condition at the bottom. The crack pattern that occurs is a combination of shear and flexure cracks.

Specimen CB-1	Crack Pattern
	

Figure 9. Crack pattern of Specimen CB-1

On the CBF-1 specimen, which is a coupling beam that uses fiber, the crack also starts from the bottom and then as the load increases, the crack also spreads towards the top. Compared to CB-1 specimens, cracks occur more and more evenly up to the top of the coupling beam specimen. This is due to the addition of fibers causing the ultimate concrete strain when destroyed also increases. For the crack pattern that occurs is a combination of shear and flexure cracks.

Specimen of CBF-1	Crack Pattern
	

Figure 10. Crack pattern of Specimen CBF-1

4. Conclusion

- The shear strength of the coupling beam in SNI 2847:2013 is 0.67 of the experimental shear strength so that the design of the coupling beam based on SNI 2847:2013 can be used as a reference in planning earthquake resistant building structures.
- Shear strength of coupling beam using fiber increases by 58% from normal concrete shear strength and reinforcement on coupling beam is reduced with the aim to simplify reinforcement causing the fiber to work more effectively especially for its attachment.
- Adding fiber to the coupling beam improves the crack pattern, i.e cracks that occur more and more evenly up to the top of the coupling beam.

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