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Study Analysis: Shear Strengthening of Reinforced Concrete Beam Using External Stirrup

Arga Saputra[1], Sri Murni Dewi[2], Lilya Susanti[2]
[1, 2, 3]Departement of Civil Engineering, University of Brawijaya, Malang, East Java, Indonesia - 65145
Email Address: [1]arga.civilengineer@gmail.com

Abstract— *Initial design errors, especially installation of stirrup, one of them can cause the beam having shear failure due to installed capacity of stirrup less than the shear capacity that occurs. Shear strengthening in this study used externally stirrup Ø6-75 which were install in the shear area only. The results of calculation analysis, shear capacity can increased up to 137.82%; 133.42% and 137.12%.. When viewed from the deflection that occurred during the first crack, the reinstrengthd beam experienced a relatively smaller deflection of 0.61 mm beam; 0.31 mm and 0.18 mm rather than beams without externally stirrup 1.28 mm; 0.55 mm and 0.32 mm, so that the beam with externally stirrup can be said to be more rigid than the beam without externally stirrup.*

Keywords— *Strengthening, Shear, Stirrup.*

I. Introduction

Increasing the strength of building structures has become an important topic lately. Transfer functions of a building, failure of structures such as beams and columns due to age, environment that affects the decrease in structural strength and even initial design errors that are weak or lacking or due to natural events such as earthquakes. Therefore strengthening structure becomes one of the solutions to strengthen and even increase the strength of structure to meet security and strength requirements.

One study about strengthening of reinstrengthd concrete beams using stirrup is Sesetty (2018) which uses 3 methods using the addition of spiral steel reinstrengthment, diagonal steel reinstrengthment and the last with the addition of externally stirrup. From the study said that strengthening methods using two innovative reinstrengthment methods (spiral reinstrengthment method and diagonal reinstrengthment method) provides better results than strengthening method using externally stirrup, but innovative strengthening is very unlikely to be applied in the project and the use of externally stirrup is considered more economical than the two methods another. In addition to the above research there are many more studies that discuss shear reinstrengthment in reinstrengthd concrete beams.

So in this study an study analysis will be carried out to obtain index data on strength enhancement from the use of externally stirrup as shear strengthening of reinstrengthd concrete beams.

II. Theoritical Basis

A. Shear In Beams

MacGroger (2011) said that nominal shear strength (V_n) in reinstrengthd concrete with stirrup was contributed by several components of the strength as follows:

$$V_n = V_{cy} + V_d + V_{ay} + V_s$$

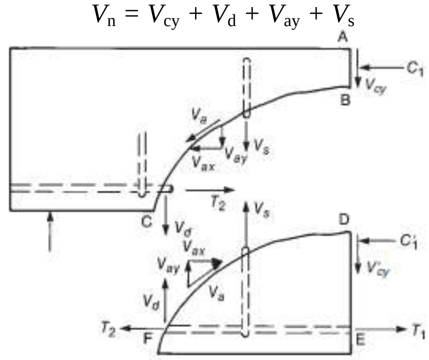

Fig. 1. Internal strengths in a cracked beam with stirrup (MacGroger, 2011))

Based on the formula used as the basis for the calculation of shear reinstrengthment listed in SNI-03-2847-2013, as follows:

1. In article 11.1.1, shear strength design (V_r), nominal shear strength (V_n), the shear strength held by concrete and stirrup (V_u) are formulated as follows:
$$V_r = \emptyset V_n \text{ and } \emptyset V_n \geq V_u$$
$$V_n = V_c + V_s$$
where Ø is the shear reduction factor taket at 0,75 (SNI 03-2847-2013 Pasal 9.3.2.3).
2. In article 11.1.3.1, V_u can be taken at a distance d (became V_{ud}) from coloumn face.
$$V_{ud} = V_{ut} + \frac{x}{y}(V_u - V_{ut})$$

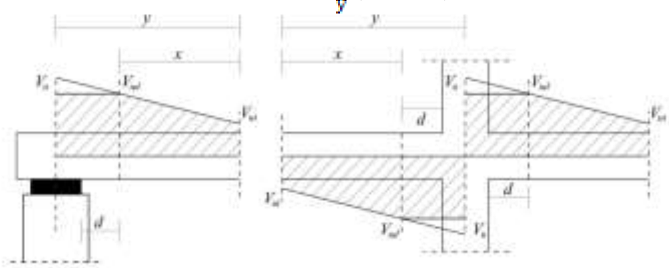

Fig. 2. Maximal Shear Location (V_{ud}) (SNI 03-2847-2002)

3. In article 11.2.1.1, nominal shear strength carried by concrete (V_c) can be calculated using:
$$V_c = \frac{1}{6}\sqrt{f'_c}\, b\, d$$
4. Nominal shear strength provided by shear reinstrengthment (V_s) can be calculated using:
$$V_s = (V_u - \emptyset V_c) / \emptyset$$
5. Article 11.4.5.3,
$$V_s \text{ harus} \leq \frac{2}{3}\sqrt{f'_c}\, b\, d$$

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If $V_s > \frac{2}{3}\sqrt{f_c'}$ b d, then the beam size must be enlarged.

6. In article 11.4.7.2, if the shear reinstrengthment is used perpendicular to the axis of structural component then V_s can be calculated as follows, with A_v is the cross-sectional area of shear reinstrengthment that at space *s*.

$$V_s = \frac{A_v . f y . d}{s}$$

Where:
V_n = nominal shear strength
V_{cy} = components of shear strength in the concrete block stress area
V_d = components of *dowel action* by longitudinal reinstrengthment
V_{ay} = nominal shear strength between cracked surfaces
V_s = nominal shear strength provided by shear reinstrengthment
V_c = nominal shear strength carried by concrete
V_u = factored shear strength a section
$f_{c'}$ = compressive stress in concrete
f_y = specified yield strength of nonprestressed reinstrengthment
b = width of beam
d = effective depth
s = space of shear reinstrengthment

B. *Deflection*

If a beam with a straight longitudinal axis is loaded by lateral strengths, then the axis will deform into an arc, called the beam deflection curve ... Deflection is sometimes calculated to investigate whether the price is still within the tolerance limit (Gere & Timoshenko, 1997 , translation of Suryoatmono, 2000: 116).

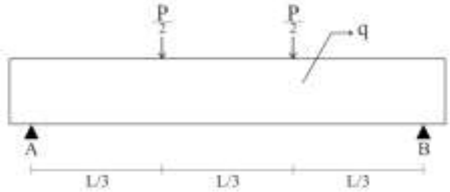

Fig. 3. Two point bending load scheme (ACI 435R-95)

From the scheme that has been planned with two concentrated load (*P*) and span length of beam (*L*) with distance between concentrated load and face of support (*a*), according to ACI 435R-95 Table 3.2 (2002) amount of deflection that occurs due to load acting can be obtained by use the following equation:

$$\Delta = \frac{\frac{P}{2}a}{24 E_c I_g}(3L^2 - 4a^2)$$

where E_c is modulus elasticity of concrete taken at $4700\sqrt{f_c'}$ and I_e is effective moment of inertia. Where the effective moment of inertia according to SNI 03-2847-2002 can be calculated from the following equation:

$$I_e = \left(\frac{M_{cr}}{Ma}\right)^3 I_g + \left[1 - \left(\frac{M_{cr}}{Ma}\right)^3\right] I_{cr}$$

M_{cr} is cracking moment, M_a is maximum moment in member at the stage for which deflections, I_g is moment inertia of gross concrete section and I_{cr} is moment inertia of cracked section transformed to concrete. The value of these parameters can be obtained from the following formula:

$$M_{cr} = \frac{f_r I_{cr}}{h - \bar{y}}$$

whereas f_r is the modulus of rupture of concrete which according to SNI 03-2847-2002 or ACI 435R-95 can be obtained from:

$$f_r = 0{,}7\sqrt{f_c'}$$

To get moment inertia of gross concrete section (I_g) and moment inertia of cracked section transformed to concrete (I_{cr}) can use the following equation:

$$I_g = \frac{1}{12} b h^3$$

$$I_{cr} = I_g + \left[A_g \times \left(\bar{y} - \frac{h}{2}\right)^2\right] + [(n-1) \times A_s \times (d - \bar{y})^2]$$
$$+[(n-1) \times A_s' \times (\bar{y} - d')^2]$$

With *b* is width of beam, *h* is depth of beam, A_g is gross area of section, *n* is the modular ratio $\left(\frac{E_s}{E_c}\right)$, A_s is area of nonpresstressed tension reinstrengthment, A_s' is area of compression reinstrengthment, *y* is the height of the neutral line cross section beam transformation, *d* is effective depth = distance from extreme-compression fiber to centroid of tension reinstrengthment and *d*' is distance from extreme-compression fiber to centroid of compression reinstrengthment.

III. Specimens

The details of dimensions and specimens that the researcher uses are as follows:

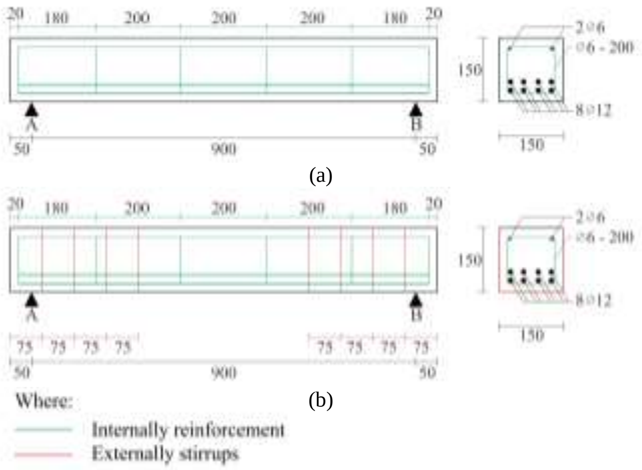

Fig. 4. Specimens detail

The specimens used in this study is a specimens of previous researcher who has been strengthened using external stirrup, so that in this study the researcher only theoritical calculation. The test material also used a mixture of other materials, but in this study the researchers did not discuss the mixture of materials.

The number and code of specimens in this study are summarized in the following table:

Arga Saputra, Sri Murni Dewi, and Lilya Susanti, "Study Analysis: Shear Strengthening of Reinstrengthd Concrete Beams Using External Stirrup," *International Research Journal of Advanced Engineering and Science*, Volume 4, Issue 2, pp. 287-290, 2019.

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TABEL I. Type and code of specimens

No	Type of specimens	Code	Total
1	Beams without external stirrup	B1a	1
		B2a	1
		B3a	1
2	Beams using external stirrup	B1b	1
		B2b	1
		B3b	1

IV. Result and Discussion

TABEL II. Parameters of test results and calculations on cylinders and beams (B1a and B1b)

Parameter		Units		Parameter		Units
b	150	mm		*fr*	3,37	MPa
h	150	mm		*Ec*	22640	MPa
L	900	mm		*fy*	240	MPa
d	106	mm		*fu*	370	MPa
d'	29	mm		*Es*	200000	MPa
As	904,78	mm^2		β_1	0,85	
As'	56,55	mm^2		*n*	8,83	
fc'	23	MPa				

TABEL III. Parameters of test results and calculations on cylinders and beams (B2a and B2b)

Parameter		Units		Parameter		Units
b	150	mm		*fr*	3,55	MPa
h	150	mm		*Ec*	23816	MPa
L	900	mm		*fy*	240	MPa
d	106	mm		*fu*	370	MPa
d'	29	mm		*Es*	200000	MPa
As	904,78	mm^2		β_1	0,85	
As'	56,55	mm^2		*n*	8,40	
fc'	26	MPa				

TABEL IV. Parameters of test results and calculations on cylinders and beams (B3a and B3b)

Parameter		Units		Parameter		Units
b	150	mm		*fr*	3,40	MPa
h	150	mm		*Ec*	22849	MPa
L	900	mm		*fy*	240	MPa
d	106	mm		*fu*	370	MPa
d'	29	mm		*Es*	200000	MPa
As	904,78	mm^2		β_1	0,85	
As'	56,55	mm^2		*n*	8,75	
fc'	24	MPa				

A. *Shear Capacity and Shear Load*

Calculation of shear capacity is intended to determine the shear capacity that is able to be received by the beam and the installed sengkang. The beam specimens in this study used a 6 mm diameter stirrup with a spacing between 200 mm stirrup as seen in Fig. 4. To find V_n, it is necessary to calculate V_c and V_s. The examples of calculations are as follows:

Example:

1. Nominal shear strength carried by concrete (V_c)

$$V_c = \frac{1}{6}\sqrt{f_c'}\ bd$$
$$= \frac{1}{6} \mathrm{x} \sqrt{23} \text{ x } 150 \text{ x } 106$$
$$= 12765 \text{ N}$$
$$= 1{,}28 \text{ Ton}$$

2. Shear strength provided by internal stirrup ($V_{s\ int}$)

$$V_{s\ int} = \frac{Av \cdot fy \cdot d}{s\ int}$$

The installed internal stirrup is Ø6-200

$$V_{s\ int} = \frac{(0{,}25 \times \pi \times 6 \times 6) \times 240 \times 106}{200}$$
$$= 7193 \text{ N}$$
$$= 0{,}72 \text{ Ton}$$

3. Nominal shear strength provided by internal stirrup ($V_{n\ int}$)

$$V_{n\ int} = V_c + V_{s\ int}$$
$$= 1{,}28 + 0{,}72$$
$$= 2{,}00 \text{ Ton}$$

From the above calculation, the nominal shear strength is obtained without external stirrup $V_{n\ int}$ = 2.00 Ton. Then the shear load is calculated by using from load scheme in Fig. 3:

$$V = \frac{P}{2} + \frac{qL}{2}$$

P in the equation then assumed to be maximum shear load that occurs in the beam without the external stirrup which is then called $P_{g\ int}$.

$$P_{g\ int} = \left(V_{n\ int} - \frac{qL}{2}\right)2$$
$$= \left(2{,}00 - \frac{61{,}10.900}{2}\right)2$$
$$= 3937 \text{ Kg}$$
$$= 3{,}94 \text{ Ton}$$

While the nominal shear capacity that occurs with the addition of external stirrup ($V_{s\ ext}$) can be obtained by the following calculation:

4. Shear strength provided by external stirrup ($V_{s\ ext}$)

$$V_{s\ ext} = \frac{Av \cdot fy \cdot d}{s\ eks}$$

The installed external stirrup is Ø6-75

$$V_{s\ ext} = \frac{(0{,}25 \times \pi \times 6 \times 6) \times 240 \times 150}{75}$$
$$= 27143 \text{ N}$$
$$= 2{,}71 \text{ Ton}$$

5. Nominal shear strength provided by internal stirrup (V_{nint})

$$V_{n\ ext} = V_c + V_{s\ int} + V_{s\ ext}$$
$$= 1{,}28 + 0{,}72 + 2{,}71$$
$$= 4{,}71 \text{ Ton}$$

From the above calculation, the nominal beam shear capacity with external stirrup $V_{n\ ext}$ = 4.71 Ton is obtained. Then it is calculated based on the loading scheme in Fig. 3. The maximum shear load that occurs in the beam with external stirrup is referred to as $P_{g\ ext}$.

$$P_{g\ ext} = \left(V_{n\ eks} - \frac{qL}{2}\right)2$$
$$= \left(4{,}71 - \frac{61{,}10.900}{2}\right)2$$
$$= 9365 \text{ Kg}$$
$$= 9{,}37 \text{ Ton}$$

For the results of nominal shear calculations and shear loads in brief can be seen in the following table:

TABEL V. Shear load calculation results and index

Specimens	Vn Ton	P g Ton	*i*
B1a	2,00	3,94	137,82%
B1b	4,71	9,37	
B2a	2,06	4,07	133,42%
B2b	4,78	9,50	
B3a	3,96	3,96	137,12%
B3b	4,72	9,39	

Where *i* is increase in shear strength index. From the calculation it can be said that beam with the addition of external stirrup has a considerable increase in strength.

B. *Deflection*

In this study, deflection (Δ) was calculated by analysis when the beam is still elastic, ie when the beam before cracking and deflection calculation will use a load which

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results in the cracking beam (P_{crack}). The examples of deflection calculations are as follows:

1. Total cross-sectional area of all transverse (A_{tr})

$$A_{tr} = A_g + [(n-1)A_s] + [(n-1)A_s']$$
$$= (150 \times 150) + [(8{,}83-1)940{,}78] + [(8{,}83-1)56{,}55]$$
$$= 30031 \text{ mm}^2$$

2. Calculate a neutral line across a transformation ($\bar{y}$)

$$\bar{y} = \frac{\left[A_g \times \frac{h}{2}\right] + [(n-1)A_s d] + [(n-1)A_s' d']}{A_{tr}}$$
$$= \frac{\left[150 \times 150 \times \frac{150}{2}\right] + [(8{,}83-1)904{,}78 \times 106] + [(8{,}83-1)56{,}55 \times 29]}{30031}$$
$$= 81{,}64 \text{ mm}$$

3. Moment inertia of cracked section transformed to concrete (I_{cr})

$$I_{cr} = I_g + \left[A_g \times \left(\bar{y} - \frac{h}{2}\right)^2\right] + [(n-1) \times A_s \times (d - \bar{y})^2] + [(n-1) \times A_s' \times (\bar{y} - d')^2]$$
$$= \left(\frac{1}{12} \times 150 \times 150^3\right) + \left[(150 \times 150) \times \left(81{,}64 - \frac{150}{2}\right)^2\right] + [(8{,}83-1) \times 904{,}78 \times (106 - 81{,}64)^2] + [(8{,}83-1) \times 56{,}55 \times (81{,}64 - 29)^2]$$
$$= 48613105 \text{ mm}^4$$

4. Cracking moment (M_{crack})

$$M_{crack} = \frac{I_{cr} \times f_r}{h - \bar{y}}$$
$$= \frac{48613105 \times 2{,}99}{150 - 81{,}64}$$
$$= 2397821 \text{ Nmm}$$

5. Cracking load (P_{crack})

$$P_{crack} = \frac{M_{crack} - \frac{qL^2}{8}}{\frac{L}{6}}$$
$$= \frac{\left(\frac{2123784}{10000}\right) - \frac{61{,}10 \times 0{,}9^2}{8}}{\frac{0{,}9}{6}}$$
$$= 1298 \text{ Kg}$$
$$= 1{,}30 \text{ Ton}$$

6. Effective moment of inertia (I_e)

$$I_e = \left(\frac{M_{crack}}{M_{crack}}\right)^3 I_g + \left[1 - \left(\frac{M_{crack}}{M_{crack}}\right)^3\right] I_{cr}$$
$$= \left(\frac{2397821}{2397821}\right)^3 \left(\frac{1}{12} \times 150 \times 150^3\right) + \left[1 - \left(\frac{2397821}{2397821}\right)^3\right] 48613105$$
$$= 42187500 \text{ mm}^4$$

7. Deflection

$$\Delta = \frac{\frac{P}{2} a}{24 E_c I_e} (3L^2 - 4a^2)$$
$$= \frac{\frac{1298}{2} \times 300}{24 \times (22640 \times 0{,}1) 42187500 \times} [(3 \times 900^2) - (4 \times 300^2)]$$
$$= 0{,}21 \text{ mm}$$

For the calculation results of deflection between beams without external stirrup and with external stirrup, external stirrup make no difference because in the formula used to calculate deflection is not affected by the installed. The calculation results of deflection for each beam can be seen in the following table:

TABEL VI. Deflection calculation on middle span

Specimen	Δ
	mm
B1a	0,21
B1b	0,21
B2a	0,21
B2b	0,21
B3a	0,21
B3b	0,21

V. CONCLUSION

The results of the calculation of the analysis show that if the beam using external stirrup, the beam experiences a large increase in shear load capacity of 137.82%; 133.42% and 137.12%. For deflection that occurs according to the calculation of analysis for beams without reinforcement outside the beam or beam with reinforcement outside the crossing of 0.21 mm, for deflection values have the same value because for the calculation of deflection using cross-section parameters only without using the stirrup parameters.

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