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Effect of Stirrup Ratio and Stirrup Distance Variation on Column Retrofitting of Cyclic Lateral Load

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Abstract— *Column is the most important element because it is the cause of building collapse due to damage to its structural components. So special attention is needed if the column is damaged. Especially if the column has a poor planning classification, especially if after being hit by an earthquake and or from the implementation side it does not match the technical requirements. One method that can be used in retrofit columns is by concrete jacketing. Retrofit columns are reinforced and stirrups with bamboo material. This is because bamboo has a development that is more like the tropics in Indonesia than the strong pull of its own bamboo. In this study the effectiveness of the installation of bamboo stirrups in the retrofit column will be observed with variations in the ratio of stirrups and different stirrup distances. The test method in this study was carried out based on the Cyclic Lateral Loading Test method on existing specimens and retrofit where axial loading was given in cost and lateral load based on displacement control patterns as a form of simplification of earthquake loads. The results of the study show that reinforcement with concrete jacketing from the initial dimensions of 15x15x90 cm to 21x21x90 cm shows an increase in lateral capacity, ductility, and stiffness.*

Keywords— *Retrofit Column, ratio of stirrup, stirrup distances, Cyclic Lateral Load.*

I. INTRODUCTION

Columns are vertical structural elements which transmit the weight of the structure above to other structural elements below and also resist lateral loads. Column is the most important element because it is the cause of building collapse due to damage to its structural components. Research conducted by Ottani, 1999; Wibowo. Et al., 2009 which showed that the main cause of failure of a building structure system during an earthquake was more than the loss of lateral load restraint. Especially if the column has a poor planning classification, and after being hit by an earthquake and or from the implementation side it does not match the technical requirements. Therefore, this column structure can be resolved by increasing the performance of the building which is sure to provide sufficient inelastic deformation capacity, so that it can withstand large lateral loads without significant failure.

Retrofitting RC elements has been carried out in recent years and many methods have been developed and tested. Jacketing RC has been considered as one of the important methods and is used to correct design errors, less concrete production and implementation processes, repair of damage after an earthquake, accident or in cases where it is necessary to continue with changes in structural functions. Therefore, it is very important that the researcher investigates behavior and retrofit in the column with concrete jacketing method.

In retrofit columns other than the main reinforcement, stirrup also has a very important role because it is the main reinforcement component in the column. Installation of stirrups is very influential on the level of strength of the column, because the more tight the distance between the bars, the column will be stronger and increase the effectiveness of restraints that occur in the column (Park & Paulay, 1975). In this study the retrofit column will be installed with the main reinforcement and stirrups with bamboo material. Bamboo was chosen as an alternative for replacing steel material because bamboo is a material that is quite cheap and abundant to meet the broad needs for economical housing (Nayak et al, 2013). Bamboo has low stiffness and strength compared to steel, but bamboo can still be used as a reinforcement but in a limited number of floors. And bamboo must be treated before being used as reinforcement in concrete (Abhijitsinh et al, 2016).

The test in this study was carried out based on the cyclic lateral loading test method on existing specimens and retrofit where axial loading was given in cost and lateral loads based on displacement control patterns as a form of simplification of earthquake loads. This study will obtain maximum lateral capacity, stiffness, ductility and collapse patterns in the retrofit column so that the effectiveness of the retrofit column can be known with varying ratios and different stirring distances. So, in this study, we will conduct an experiment on the effect of stirrup ratio and stirrup distance on the capacity of RC jacketing columns using bamboo material in receiving axial and lateral loads.

II. LITERATURE REVIEW

A. Column RC

Reinforced concrete, which is structural concrete that is repeated with no less than the minimum prestressed steel or minimum non-prestressed reinforcement specified in SNI 2847-2013 Articles 1 to 21. The value of compressive strength of concrete is relatively high compared to its tensile strength, and concrete is a brittle material.

B. Ductility

Ductility is the ability of a structure not to experience sudden collapse, but it is still able to deform large enough during maximum loads before the structure experiences collapse (Park R. & T. Paulay, 1975). Whereas according to

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(Paulay and Priestlay, 1992) ductility shows the ability of structures to resist the effects of deformation due to excessive loading conditions.

$$\mu = \frac{\Delta_u}{\Delta_y}$$

Ductility can be formulated as a comparison between deformations when the ultimate divided deformed when the first yield occur. Several alternatives suggested to determining the yield point. One of that is from (Park R. & T. Paulay, 1975) given suggest to determine yield point. Several researchers have used option D from that or determination of yield points based on the equivalence of yield points at elasto-plastic.

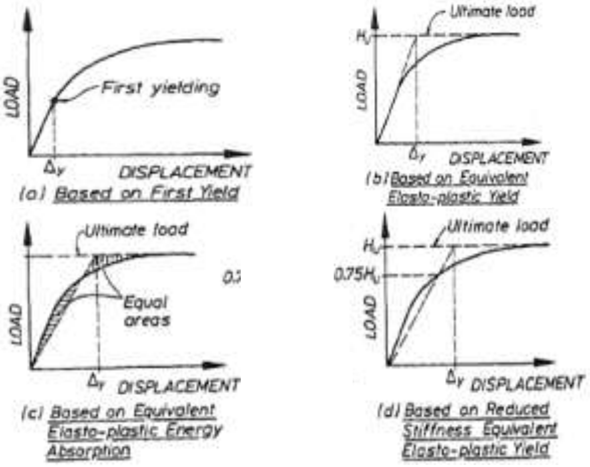

Fig. 1. Alternative for determining yield points (Park R. & T. Paulay, 1975)

C. Stiffness

One concept that is often used in determining the stiffness of an element is the secant stiffness method. In several studies many conducted studies related to these methods, one of them by (Sullivan, Calvi, & Priestley, 2004) states that the character of structural stiffness in the building of dynamic response with DBD (displacement based design) is more effective if using the secant stiffness method.

$$K = \frac{P1 + P2}{\Delta 1 + \Delta 2}$$

D. Stress-Strain Relationship and Effectiveness of confinement

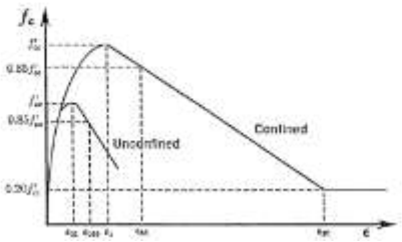

Fig. 2. Proposed stress-strain relationship (Saatcioglu & Razvi, 1999)

In concrete that is eroded after the peak load has a more gentle decrease in stress, confined concrete has a greater density compared to unconfined concrete. stirrup mounted on the column can be used as a restraint to increase the development of reinforcement in concrete.

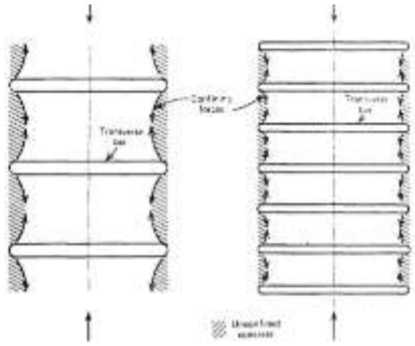

Fig. 3. Stirrups distance affects the effectiveness of confinement (Park R. & T. Paulay, 1975)

Installation of stirrups can affect the effectiveness of the column structure. The installation of tight stirrups on the column structure is more effective compared to the stretched columns that are stretched. This depends on the column installed by the stirrups of the meeting value and the greater ductility of the column mounted by the stretch bark. Because on a tightly knit column, the volume of concrete that is not confined is getting smaller.

The ratio of transverse reinforcement is defined as the total cross-sectional area of the cross section divided by the cross-sectional area of the column perpendicular to the direction of the load.

$$\rho_{area} = \frac{n\,A_v}{b_c\,s}$$

The ratio of transverse reinforcement volume is obtained by dividing the transverse reinforcement volume with the volume of the concrete core along the distance between the transverse reinforcement. Volume from outside of stirrups (Park R. & T. Paulay, 1975).

$$\rho_{volume} = \frac{A_v\,(2b_x + 2h_x)}{b_h\,h_h\,s}$$

E. Strengthening Columns with the Jacketing Concrete Method

The concrete jackting system is a method of repairing or reinforcing a concrete structure by providing additional concrete blankets and reinforcement to original concrete structures. The advantage of this system is that this method can increase and increase the limit of the strength and ductility of concrete. The second advantage is that the jacket protects from damage to repaired fragments and structures having the ability to accept loads, because jackets can reduce direct shear failure, but can also increase the capacity of the structure itself.

F. Cyclic Lateral Load

Cyclic load is a load that is given repeatedly or alternating on a structure. Failure in a structure is not only caused by static loads, but also cyclic loads also have a considerable influence on the performance of the structure. A structure that is exposed to a cyclic load continuously will experience fatigue at the meeting point between the foundation and

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column. Cyclic load is added gradually by displacement control. The loading series consists of two cycles for each increase in lateral displacement.

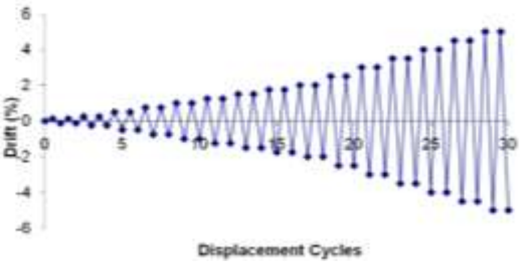


Fig. 4. *Quasi-Static Lateral Loading History* (Wibowo, 2012)

III. RESEARCH CONCEPT FRAMEWORK

A. *Research Conceptual Framework*

Based on the problems, so an algorithm was made to facilitate problem solving. The following is an overview of the conceptual framework in this research:

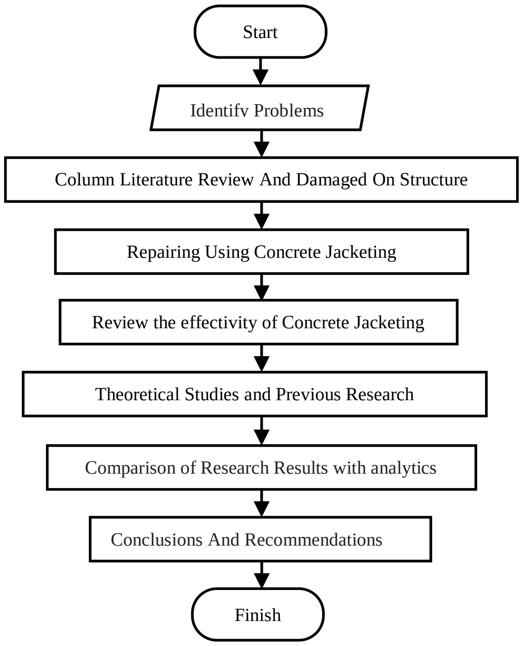


Fig. 5. Alghoritm conseptual framework of research

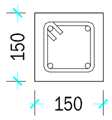
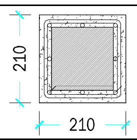
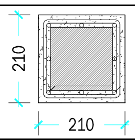
B. *Research Hypotesis*

- Increasing the ratio of transverse reinforcement and transverse reinforcement distance can increase ultimate drift capacity, ductility and increase stiffness in the retrofit column.
- Bamboo material can be used as a retrofit with concrete jacketing in RC.

IV. RESEARCH METHOD

A. *Detail of Specimens*

TABLE I. Detail of specimens column

Specimen	Existing	Damaged On Structure Column	Undamaged On Structure Column
Dimension	150 x 150	210 x 210	210 x 210
Cross-Section			
Amount of Specimen	4	2	2
Label of Specimen	• Pre B-4-75 • Pre C-4-75	• B-8-75 • C-8-100	• E-8-75 • F-8-100
Longitudinal rebar	• 4Ø12 • Deform steel rebar • Rebar ratio, ρ = 2,01%	• 8⊠10 • Bamboo rebar • Rebar ratio, ρ = 2,45%	• 8⊠10 • Bamboo rebar • Rebar ratio, ρ = 2,45%
Transversal Ties	• Ø8–75 mm • Plain steel rebar	• Ø8–75 mm • Bamboo rebar • Volume ratio of 0,86% • Area ratio 0,42 %	• Ø8–100 mm • Bamboo rebar • Volume ratio of 0,65% • Area ratio 0,31%

B. *Material Testing*

TABLE II. Data properties material

No	Properties material	Value
1	f'c , concrete existing	20,05 MPa
2	f'c , concrete retrofitting	25,84 MPa
3	fy, steel reinforcement	411,65 MPa
4	fu, steel reinforcement	658,64 MPa
5	fu, bamboo reinforcement	256,05 MPa
6	fs, bamboo reinforcement	74,03 MPa

V. RESULTS AND DISCUSSION

A. *Lateral Load Capacity*

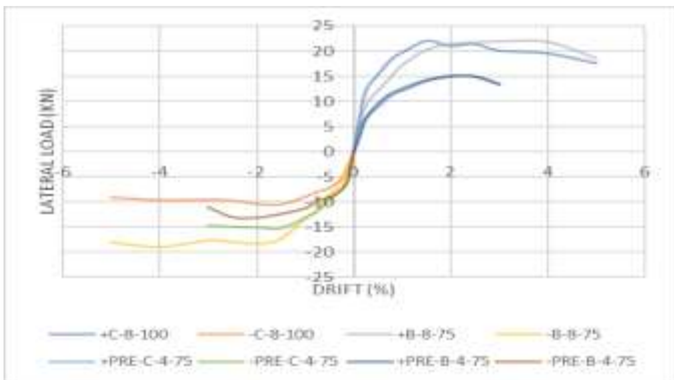


Fig. 2. Envelope curve of specimen lateral load capacity

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If seen in the picture about the effect of column specimen restraints with different ratios and stirrups distances, it can be seen that columns with tight stirrups distances and larger ratios produce better smaller lateral comparisons. So in retrofitting columns other than the longitudinal rebar, stirrups also has a very important role because of the main reinforcement component in the column. Installation of stirrups is very decisive on the level of strength of the column, because the higher the meeting between the stirrups, the column will be stronger and the increasing restraints that occur in the column (Park R. & T. Paulay, 1975).

TABLE II. Recapitulation of Experimental and Theoretical Results

Specimen	Condition	Experimental		Theoretical	
		Load	Load	Load	Load
		P (kN)	δ (%)	P (kN)	δ (%)
Pre-B-4-75	*Crack*	9,60	0,50	9,40	0,54
	Yield	13,07	1,13	13,02	0,91
	Ultimate	15,05	2,50	14,53	2,67
	Rapture	13,51	3,00	13,17	3,19
Pre-C-4-75	*Crack*	8,76	0,50	9,40	0,54
	Yield	11,50	0,80	13,02	0,91
	Ultimate	15,21	2,00	14,53	2,67
	Rapture	13,39	3,00	13,17	3,19
B-8-75	*Crack*	14,70	0,75	16,58	0,75
	Yield	16,49	0,93	24,55	0,93
	Ultimate	21,99	3,00	29,45	3,70
	Rapture	18,63	5,00	14,07	4,46
C-8-100	*Crack*	15,40	0,50	16,58	0,75
	Yield	17,00	0,60	24,55	0,93
	Ultimate	22,06	1,50	29,45	3,70
	Rapture	17,65	5,00	14,07	4,46
E-8-75	*Crack*	14,91	0,50	16,58	0,75
	Yield	17,50	0,73	24,55	0,93
	Ultimate	23,44	2,00	29,45	3,70
	Rapture	18,24	5,00	14,07	4,46
F-8-100	*Crack*	13,68	0,50	16,58	0,75
	Yield	16,80	0,68	24,55	0,93
	Ultimate	22,19	2,00	29,45	3,70
	Rapture	20,40	5,00	14,07	4,46

In this study, the results of the experimental tests are then validated with the results of the analysis based on theoretical. Theoretical analysis using moment curvature analysis and showing results that are close enough to the experimental results.

B. *Ductility*

TABLE IV. Ductility specimen

Specimen		Drift Yield	Drift to Peak Maximum	Improved Daktilitas	
		δy	δu		
		(mm)	(mm)	(mm/mm)	(%)
µ1	Pre-B-4-75	1,13	2,50	2,21	*(Control)*
µ2	Pre-C-4-75	0,80	2,00	2,50	*(Control)*
µ3	B-8-75	0,93	3,00	3,21	45,71
µ4	C-8-100	0,60	1,50	2,50	0,00
µ5	B-8-75	0,73	2,00	2,73	23,64
µ6	C-8-100	0,68	2,00	2,94	17,65

The confinement capacity provided by transverse reinforcement can be increased by reducing the distance between the transverse reinforcement (closed-spaced transverse reinforcement). This parameter can be expressed in the transverse reinforcement ratio, which compares the transverse reinforcement available with the concrete core that must be restrained. With the addition of additional restraints given transversal reinforcement, higher compression stresses and strains can be achieved by the column before failure (Park & Paulay, 1975). In the configuration of this study it was shown that the density of the tight joint with 75 mm greater ductility than the 100 mm crossing distance. The confinement ratio of a large concrete core can increase ductility by ∅8–75 mm with a volume ratio of 0.86% and an area ratio of 0.42% more with a percentage increase in ductility on average 34.68%, whereas with ∅8–100 mm with a volume ratio of 0.65% and an area ratio of 0.31% more with a percentage decrease in ductility averaging 8.82%.

C. *Stiffness*

TABLE V. Stiffness specimen

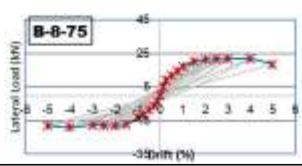
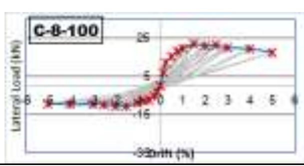
Specimen	P1	P2	Δ1	Δ2	Stiffness	Improved Stiffness
	(kN)	(kN)	(mm)	(mm)	(kN/mm)	(%)
Pre B-4-75	13,14	15,05	1,50	2,00	8,06	*(Control)*
Pre C-4-75	15,30	15,21	2,50	4,00	4,69	*(Control)*
B-8-75	18,91	21,99	4,00	3,00	5,84	-27,47
C-8-100	10,46	22,06	1,50	2,00	9,29	97,95
E-8-75	15,11	23,44	1,50	1,50	12,85	59,50
F-8-100	19,48	22,19	3,00	2,00	8,33	77,50

In principle, the theory that stiffness (k) of material, elements and structure is directly proportional to the max load (P) which is held back and inversely proportional to the deformation that occurs (Δ).

If we look at the effect of different ratio configurations and stirrup spacings in this study, it can be seen that the configuration of 75 mm stirrup distance, which is closer to the transverse reinforcement distance than the 100 mm stirrup distance configuration, produces better stiffness with an increase of 16.01 % and 87.72%. This is seen from the configuration of reinforcement on the specimen that has been loaded at the beginning (Pre-loading) until it is damaged and the specimen that does not experience loading at the beginning. Of course the effect of variations in restraints due to differences in crossing distance and stirrup ratio in this study is less influential. This is certainly in accordance with the factors that influence based restraints (Park R. & T. Paulay, 1975).

D. *Collapse Mechanism For All Retrofit Columns*

TABLE VI. Collapse mechanism retrofit columns

Specimen Retrofit	Crack Pattern	Hysteristic curve
B-8-75		
C-8-100		

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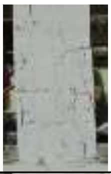
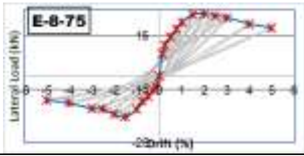
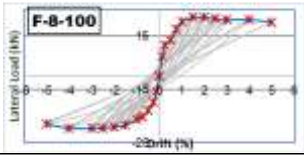
E-8-75		
F-8-100		

VI. CONCLUSION

From the research result and analysis that has been done, the conclusion are as follows:

1. Concrete jacketing can increase the lateral capacity of the damaged column. while the increase that can be obtained is around 45%.
2. Ductility is important to the structure in the inelastic period. Ductility in existing damaged columns can be increased by concrete jacketing repair and strengthening. The ductility that can be increased is 8,82% - 34,68%.
3. If viewed in terms of stiffness of the test object, it can be seen that in the configuration of reinforcement points variation A gives more stiffness. On a retrofit of a damaged column the stiffness capacity rises to of 16.01 % and 87.72%.
4. The collapse mechanism for all existing columns is flexible, while the collapse in the retrofit column is the flexure collapse in the initial phase and ends the flexible melting penetration at high ductility.

VII. SUGGESTION

From the research result and analysis that has been done, the conclusion are as follows:

1. It is necessary to carefully control column retrofit material as a parameter determining the suitability of experimental results with analytical.
2. It is necessary to review the stirrup variations related to the effectiveness of the stirrup distance and the ratio of stirrups to the thickness of the concrete blanket.
3. It is necessary to review related surface treatments between old concrete and new concrete such as shear connectors, anchors, etc., to old concrete.
4. Need a review in numerical simulation analysis on software such as ABAQUS, ANSYS, etc.

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