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Effect of U-Shape Thickness on Upgrading Capacity Momen of Precast Beam Column Joint Using CFRPS

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Abstract: ***Research to investigate the possibility of CFRPS to be a connecting material of beam column joint had been presented [1]. This paper present the effect of U-shape thickness to upgrade the capacity momen of joint. Three specimens were prepared and tested so far. One of them was monolith connection that used as a control specimen (MN). The others were C1S1, joint with one layer of U-shape using one belt and C2S1, joint with two layer of U-shape using one belt. Performance of the three specimens are present in this paper. Results indicated that upgrading twice of CFRPs thickness had increased 2.1 times the momen capacity of joint. The C1S1 reached 15 kN, just 62.5% of capacity momen respectively to the control specimen, but the C2S1 was 31.5 kN, 131.3%..***

Keywords: Beam-column joint, U-shape, U-shape thickness, belt, CFRPs, capacity momen

1. Introduction

Development of people needs infrastructures such as road, bridge, flyover, building and others, so needs good material to support the aims. Other case, old structures needs repairing and strengthening. Time of construction, cost, environment and structure‟s life time and service ability, were the variable. The company and researcher run in competition to create high quality materials, low cost and smart environment.

Right now, concrete is still a majority material in civil construction. Even, concrete was product in fabrication as a part of structure, calls precast elements such as column, beam and plate. As known that precast method was applied in several modern buildings. In precast method, member of structure product separately and assembling each other to be a monolith structure as show as figure 1.

Figure 1: Assembling of precast members

All the members assembled must work as a monolith structure each other, especially in seismic condition, as show as figure 2. But it was still difficult to create the members worked together as a monolith structure caused by the joint. The problem still around the joint of the members.

Figure 2: Members in a monolith system

2. FRP Strengthening and Connection on RC Beam-Column Joints

Application and research of FRP on structure have been done before in several ways. FRPs on strengthening column-tie beam using CFRPs and E-GFRPs indicated the upgrading of strength, stiffness, displacement and ductility of joint. Upgrading of strength were 152% of CFRPs and 154% of E-GFRPs, respectively to the monolith specimen. Displacement upgraded 20% of CFRPs and 35% of E-GFRPs. Ductility was increase 35% compare to the monolith specimen, respectively [6]. Evaluation on performance of retrofitted reinforced concrete beam column joints indicated increasing of maximum loads 42.45%. [2]. Strengthening beam-column joint using FRP combine with steel plate under seismic loads (cyclic loads) resulted upgrading in strength 63% and ductility 100% respectively to the monolith [5]. GFRP Wrapping on beam column joint subjected to static load upgraded 13% on load capacity and 14% on energy absorption. Wrapping CFRP 36% on loads capacity and 26% of absorption energy. GFRP using in stirrups spacing gave upgrading 12% of load capacity and 13% of absorbs energy [9].

Application in field of FRP had been practiced on Malelleng‟s bridge in Maros-South Sulawesi. It was success to repair and retrofit the bridge‟s beam, transversal and longitudinal. CFRP used to cover the crack as long as the beam span and GFRP used to upgrade the shear strength, as show in Figure 3.

Figure 3: Application of CFRPs and GFRPs on Malelleng‟s Bridge

Assembling of precast structure members could be done as wet connection and dry connection, even using mechanical joint. FRP as a connection material to assembling precast beam and column, had been investigated. Joint connection using CFRP without belt (C1S0) reached 90.6% the capacity momen of monolith joint [8]. The capacity and behavior could be upgrade by increasing the thickness of U-shape and belts to strengthening the U-shape‟s bonding.

3. Experimental Program

The experimental program included of two specimens of precast RC beams and columns connected by CFRPs U-shape and monolith one as control specimen. The specimens were same in connection pattern but different in thick of U-shape. All specimens tested by lateral load (monotonic) on the beam span. The column placed horizontal, fixed to the floor and the beam on vertical way, free as shown in figure 9. So far, three tests had been performed, the results presented and discussed herein. The next sections report a detailed description about design of precast beam and column, connection pattern of members, test setup and instrumentation. Figure 4 shows the section of precast column and Figure 5 for the beam section. Pattern of two CFRPs and monolith specimen, shown in figure 6, 7 and 8.

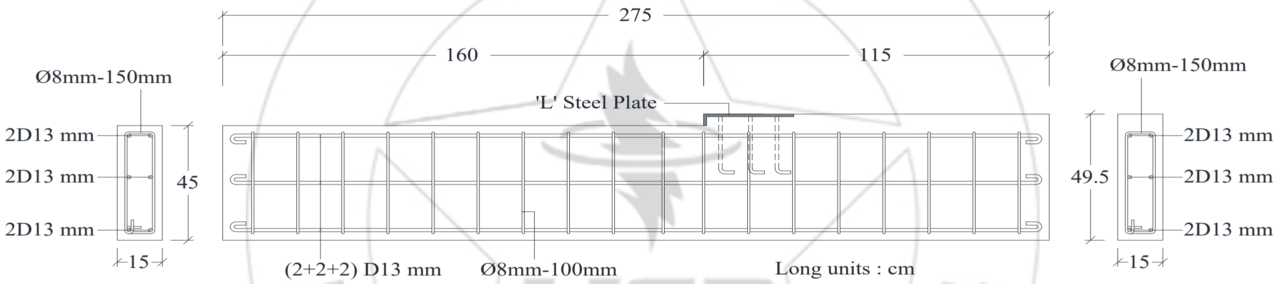

Figure 4: Cross section and reinforcement of precast column

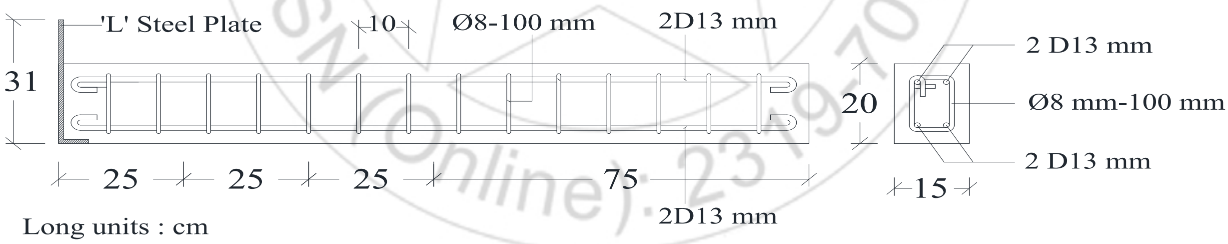

Figure 5: Cross section and reinforcement of precast beam

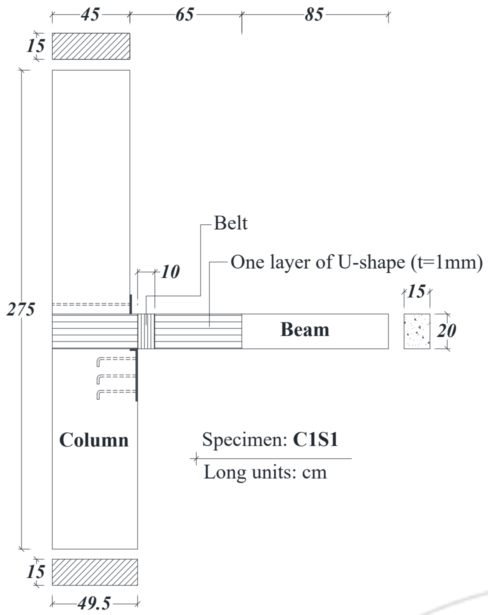

Figure 6: Specimen C1S1

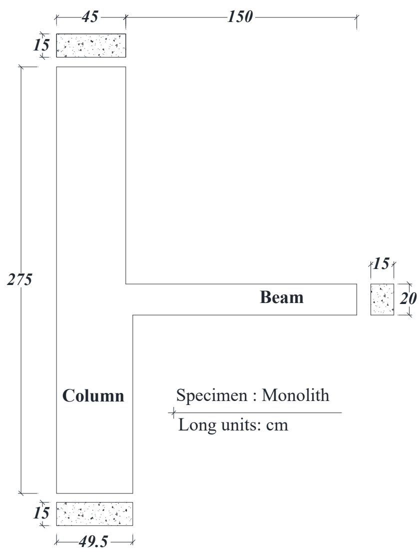

Figure 8: Specimen monolith (MN)

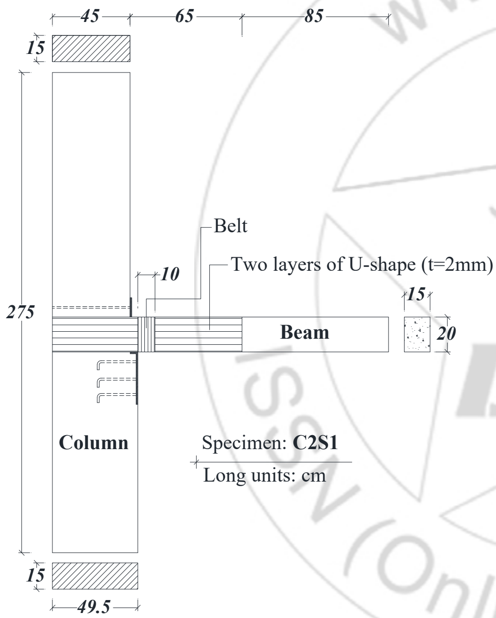

Figure 7: Specimen C2S1

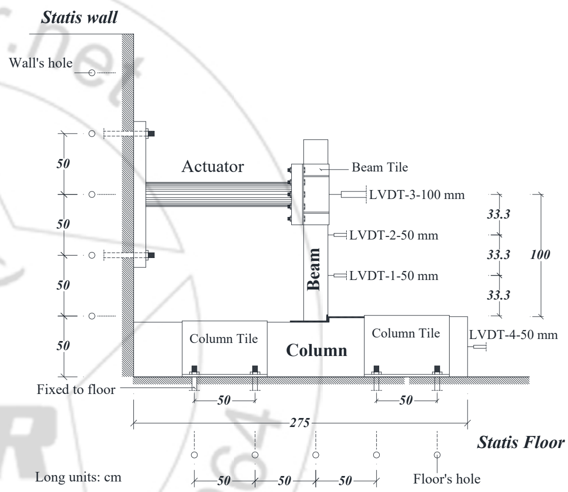

Figure 9: Experimental Setup

4. Test Result and Discussion

1) Capacity Momen

The three specimens have been tested so far and the capacity momen as shown as table 1.

Table 1: Capacity momen of joints

Specimen	Capacity Momen (kN)	Percentage (%)
MN	24.00	
C1S1	15.00	62.5%
C2S1	31.50	131.3%

Notes:
MN Monolith Joint
C1S1 Joint using one layer of U-shape and one belt
C2S1 Joint using two layers of U-shape and one belt

Function of belt was to upgrade the boundary of U-shape to the precast members. On C1S1 and C2S1, belt was placed at the front of joint exactly 0 cm from the edge of joint. The other hand, the belt would reduce debonding velocity. The maximum of C1S1 was 15 kN of loads and 27.1 mm of displacement. Those values were lower than monolith capacity, at least just 62.5 % respectively.

Low capacity momen shown by the C1S1, caused by the risen of premature rupture by the effect of edge stress that cutting the U-shape. Using belt have reduced the capacity momen. Action of the belt stress was perpendicular and pressure to the way of U-shape stress, so it caused U-shape was cutting by the belt. The need of failure mode is initially by the belt and follow by debonding of U-shape, not caused by the broken of u-shape as shown in Figure 10. It shows that boundary of belt is more power full than U-shape‟s strength ($\sigma_{belt} > \sigma_{U\text{-}shape}$).

Figure 10: U-shape cut by the belt‟s edge stress of C1S1

The other effect of using belt is the running of rupture into the column side by un-protection (Figure 2) U-shape. This effect lead the rupture into the way of column only, so the column will break but the beam is still fresh. The rule of strong column weak beam is breaking. The other hand, the belt was needed to protect and reduce the velocity of debonding. It‟s mean that the belt is needed, but the way and position of the belt and the strength of U-shape must be managed. So, if the intercept of stress was happened, the rupture was initially by the belt and followed by U-shape.

Due to the bad behavior of C1S1, so the next specimen C2S1 is prepare to repair the bad of C1S1. The specimen C2S1, was made by using two layer of U-shape CFRPs and strengthening by one piece of belt. Using of two layer U-shape would increase the strength of U-shape bigger than the belt, so even the intercept was happened, U-shape wasn‟t broken anymore by the belt.

Figure 3, shows that the rupture of C2S1 is initially by the broken of the belt at 31.5 kN and suddenly followed by debonding of U-shape. Failure mode of C2S1 is different with C1S1, where U-shape was not broken (cutting) anymore by the edge stress but the belt was. Using two layers of U-shape has success to upgrade the strength of U-shape over the belt strength ($\sigma_{U\text{-}shape} > \sigma_{belt}$). The capacity momen of C2S1 was depended to the strength of belt boundary, so when the belt boundary was broken, suddenly followed by debonding of U-shape as shown in Figure 14. The steps of failure happened on C2S1 was the right failure that needed.

U-shape‟s thickness upgrading the capacity momen directly. When the thickness of U-shape was two times than before, so the inertia would be increase two times too. Using mechanical analysis we find the upgrading of inertia. Figure 12 shows the illustration of upgrading U-shape thickness.

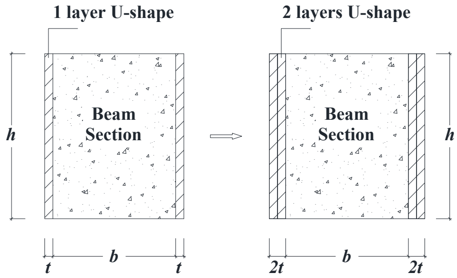

Figure 12: Illustration of upgrading U-shape thickness

Figure 4 shown the illustration of upgrading U-shape thickness where „t‟ was the initial thick and „h‟ was the high of U-shape (similar to the beam high). The thickness increased from „t‟ became „2t‟, so the inertia was found using eq. 1.

$$I_1 = \frac{1}{12}\, t.\, h^3 \text{ .... eq. (1)}$$

By the the increasing of thickness, „t‟ became „2t‟, so inertia became:

$$I_2 = \frac{1}{12}\, 2t.\, h^3 = \frac{1}{6}\, t.\, h^3 \text{ .... eq. (2)}$$

While loading, sections of the U-shape would be in tensile stress, so the stress diagram would be in form of triangle as shown in Figure 13. Momen would be calculated by eq. 3.

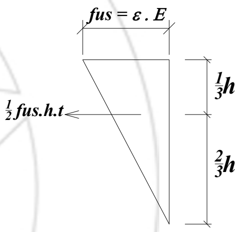

Figure 13: Stress diagram of U-shape

$$M = (\frac{1}{2}\, f_{us}\, .\, h.\, t\,)(\frac{2}{3}\, h) = \frac{1}{3}\, f_{us}.\, h^2.\, t \text{ ...... eq. (3)}$$

If joint using two layers of U-shape (2t), so :

$$M = \frac{1}{3}\, f_{us}.\, h^2.\, 2t = \frac{2}{3}\, f_{us}.\, h^2.\, t$$

Substitute: $f_{us} = \varepsilon\, E$

$$M = \frac{2}{3}\, \varepsilon\, E\, h^2\, t \text{ .... eq. (4)}$$

Where:
f_{us} = U-shape‟s Ultimate tensile strength
= 986 N/mm^2 (Tyfo Carbon SCH41)
ε = U-shape‟s strain
E = U-shape‟s Elasticity Modulus
t = *U-shape's thickness*
h = U-shape‟s high, similar to beam high

Tabel 2, the tested result compare to the value from calculation by eq. 3 or 4.

Table 2: Momen by the Test Result and Calculation:

Specimens	t	h	fus	Capacity Momen	
				Calculation: M = (1/3) th^2	Test Results
	mm	mm	N/mm^2	N.mm	N.mm
C1S1	1	200	986	13,333	15,000
C2S1	2	200	986	26,667	31,500
Momen's Upgrading				200%	210%

Table 2, shown the upgrading of capacity momen by increased the thickness of U-shape, where increasing by the calculation was 200% and by the test result was 210%. Both were different 10% respectively, so the test result nearly similar with the calculation. Increasing two layers of U-shape have been success to upgrading capacity momen of joint into 210% compare to one layer of U-shape and 131% compare to monolith joint.

2) Displacement

Effect of U-shape thickness to joint displacement is not as big as capacity momen. Test results due to the loads and displacement shown in Table 3.

Table 3: Result Test Due To Loads And Displacements

Specimen	Loads		Displacement	
	(kN)	(%)	(mm)	(%)
MN	24	-	44.7	-
C1S1	15	62.5	27.1	60.6
C2S1	31.5	131.3	28.6	64.1

Displacement upgrading due to the U-shape thickness increasing was 1.5 mm, a little increasing only. Comparing to MN, load capacity of C2S1 reach 31.5 kN or 131.3%. It‟s 7.5 kN higher than MN load capacity respectively. But the displacement was 28.66 mm, lower than monolit joint or just 64.1%.

Having bigger load capacity but lower displacement shown that joint C2S1 was brittle than MN and also indicate that CFRP was the majority in handling loads than concrete. As known that CFRP was the high strength material, so it would be brittle.

Due to the mechanics analysis, displacement of a cantilever beam is calculating by equation 5.

$$\Delta = \frac{PL^3}{3EI} \quad \text{........eq.(5)}$$

Where is:
P loads
L span
E Elasticity Modulus
I Inertia

Increasing U-shape thickness would upgrading the Inertia, so it would reduce the displacement. Increasing twice of U-shape thickness, so Inertia would upgrading twice also. When the load was increasing 2.1 times (table 1), so it would cause the displacement upgrading to 1.05 times ($\Delta_{C2S1} = 1.05\ \Delta_{C1S1}$). So, the displacement of double thickness of U-shape could calculated by eq. 6.

$\Delta_{C2S1} = 1.05\ \Delta_{C1S1}$ ....eq. (6)
$= 1.05 \cdot 27.1 = 28.5$ mm
Where is: $\Delta_{C1S1} = 27.1$ mm (table 3)

The value from equation 6 was 28.5 mm and the result test was 28.6 mm. According to both of them, just a little different of calculation and measuring displacement, 0.1 mm or 0.7% respectively.

3) Ductility

Ductility was the ratio of ultimate displacement to the yield displacement. The characteristic indicate the ability of joint to be ductile when handling the periodic loads or cyclic loads. According to the test result, ductility of monolith joint was 4.3 and categories in to medium ductility. The others are display in table 4.

Table 4: Joint‟s Ductility

Specimen	Δu (mm)	Δy (mm)	$\mu = \frac{\Delta u}{\Delta y}$	Category
MN	44.7	10.5	4.3	Medium ductility
C1S1	27.1	8.8	3.1	Medium ductility
C2S1	28.7	1.8	16.4	high ductility

Due to the test result in Table 4, the lowest ductility was shown by C1S1, as known as effect of edge stress, and the highest was C2S1 over the monolith, categories in to high ductility. Comparing to MN, both of ultimate and yield displacements of C2S1 were lower than monolith. It caused by the highly elasticity modulus of CFRPs but the ductility was high because the reduction of ultimate displacement was lower than reduction of yield displacement.

4) Dissipation Energy

Dissipation energy is one of the majority parameter of structure planned on cyclic loading, such as earthquake. It‟s the specific energy dissipated through the load cycles related to the correspondent perfect elastic-plastic cycle [4]. It was gave the information of joint‟s ability on change and distribute the energy into deformation while loading by seismic loads.

Joint with high dissipation energy had elastic behaviour in long duration and high load capacity. It depended on yield and ultimate condition, as far as their condition, it would gave the high dissipation energy. On structure with lateral loads, energy given by the region of area beyond the hysteresis loop of a loading period. Dissipation energy of the three specimens tested were display in table 5.

Table 4: Joint‟s Dissipation Energy

Specimen	Dissipation energy	Category
MN	0.02	Non dissipative
C1S1	0.42	Medium dissipation
C2S1	0.02	Non dissipative

Note:
Non dissipative : dissipation energy < 0,10
Low dissipation : dissipation energy 0.1 – 0.3
Medium dissipation : dissipation energy 0.3-0.5
High dissipation : dissipation energy > 0.5

Table 5 shown that the highest dissipation energy was C1S1, categories as medium dissipation joint, but C1S1 was low in strength. The lowest dissipation energy was C2S1, similar with MN and categories into non dissipative joint. C2S1 low in dissipation energy but high in strength. Increasing thickness of U-shape CFRPs reduce the dissipation energy but upgraded the strength.

5) Failure Mode

Failure mechanism that needed was initially by defeated of belt and followed by debonding of U-shape. In this case, failure mechanism that needed was the right step of loads over taking to guaranty the strong column weak beam principal and no suddenly rupture. Monolith specimen shown the failure initially by the smooth cracking of concrete. The crack increased in size and quantity by adding loads. The end of process was signed by defeated of concrete at the compressive side of the beam. For C1S1, failure mechanism was initially by cut off of the U-shape by belt‟s edge stress. This mechanism was not good, even caused the premature failure and made the connection was low in strength. C2S1 prepared to cover the mistake behavior of C1S1 based on fact that the strength of U-shape was weakly than belt. Result shown that two layers of U-shape was unbitten by the belt‟s edge stress, so no cut off of the U-shape anymore ($\sigma_{U\text{-shape}} > \sigma_{belt}$). The failure mode of C2S1 was ride on right mechanism that needed, initially by defeated of belt and followed by debonding of U-shape as shown in Figure 14.

Figure 14: Failure mode of C2S1

5. Closing Remarks

Using two layers of U-shape success to repair the bad behavior of one layer U-shape and upgraded the capacity momen and ductility of joint. The current scenario also risen the right failure mode, initially by defeated of belt and followed by U-shape debonding.

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