FLEXURAL CAPACITY OF THE PRECAST RC BEAM-COLUMN
CONNECTION USING CFRP SHEET

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ABSTRACT: Precast concrete have advantages in quality and shorter construction time. The connection of a precast concrete structures is important for the successful construction. This paper presents an experimental investigation of the flexural capacity of the portal system beam-column connection of precast concrete using CFRP sheet. The study was conducted to develop a connection system using CFRP sheet on a precast concrete frame of a highway bridges. A series of specimens with parameter of CFRP sheet patterns was prepared. A shear key on the column was prepared to support the beams connected to the column. Therefore the CFRP sheet was patched to sustain only the flexural forces occurred on the connection. The CFRP sheet patterns applied were combined with CFRP belt to increase the bonding capacity of the main CFRP sheet. A monolith specimen was also prepared as control specimens. Initially the columns and beams were casted separately to produce a precast concrete. The shear key on the column was strengthened using anchored steel plate. Results indicated that the specimens using CFRP sheet as connection has flexural capacity of approximately 85% of the monolith specimens..

INTRODUCTION

The growing of the population may cause the increasing of the necessity of social infrastructures. Especially on the big city, the development of highway bridges is increasing to fulfill the mobility problems of people. In order to speed up the construction time as well as to increase the quality of the structures, the using of precast technology is one of the best alternatives. The advantages of the precast construction involves reduction in construction time, energy, in site labors as well as more favorable cost-benefit relation, less environmental impact, and greater control and final quality of the structures (L.F.Maya et.al, 2012), (Rohit B, et.al. (2014). Figure 1 shows the application of the precast technology in constructions. The precast technology has been developed for building constructions, drainage constructions,
and bridges constructions including highway bridges constructions. Figure 2 shows an illustration of the structures of a highway bridges using portal frame systems. In most cases, the join between column and beam on the precast concrete in portal system is still casted in place. The low quality control of the cast in place may decrease the quality of the structures system. This will reduce the quality advantage of the precast concrete technology in structures system. The connection is critical factor and one of the most important parts that determine the general structural behavior (Brooke, N., et al., 2006). Some alternatives has been developed to avoid the casting in place of column-beam join by using tendon connection system or tension bolt connection systems, etc. (G. Metelli et al. (2008)), (R. Vidjeapriya et al. (2012)), (Sergio M.A. et al. (2000)). The secure joint of column-beam is critical point especially in application for structures which design for seismic loads, such as high rise building or constructions on the place with high risk of earthquake. In the case of the elevated road, especially construction on the place with low risk of earthquake, then the column-beam joint may not have to be designed to sustain the earthquake loads. Therefore, the moment on beam around joint will be negative moment and the moment at span center will be positive moment, respectively.

In the other hand, the development of the advance materials such as carbon fiber, glass fiber and aramid fiber in the form of fiber reinforced plastics (FRP) that has been applied in some fields in civil engineering structures or building constructions. Carbon fiber sheet and glass fiber sheet has been used widely especially for strengthening of the concrete structures. Many research has been done regarding the application of those FRP materials (Ali R.K. et al., 2003), (L.F.Maya et al., 2012). This study was conducted to investigate the application of FRP sheet as the connection for column and beam in the portal system with anchored steel shear key. This research has the aim to develop an alternative dry connection system of column-beam join for pre-cast concrete structures of portal frame.

**EXPERIMENTAL PROGRAM**

In order to achieve the aim of this study, two type of specimens with FRP sheet connection and one monolith specimen as comparison were prepared. A total 3 specimens were prepared in this experimental program. The steel reinforcement of the specimens was designed based on Indonesian national standard (SNI-2002).
Detail of Specimens
Two types of specimens were prepared to investigate the flexural capacity of the beam-column joint of a portal system. Type 1 is non-precast specimens (monolith beam column join) and Type 2 is precast specimens. Figure 3 shows the detail of non-precast and precast specimens, respectively. Both types of specimens were design using same reinforcement ratio. The column was reinforced using 6 D13 rebar with stirrup of D8. The beam was reinforced by tensile reinforcement of 2D13 with compression steel of 2D13. The concrete was a normal concrete with compressive strength of 20 MPa. Table 1 presents the material properties of steel reinforcement and concrete. The precast specimens were divided into Specimen PL and Specimen PLB, respectively.

Table 1. Material Properties of Concrete and Steel Reinforcement

<table>
<thead>
<tr>
<th>No</th>
<th>Type of material</th>
<th>Compressive Strength (MPa)</th>
<th>Tensile Strength (MPa)*</th>
<th>Young Modulus (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Concrete</td>
<td>20.4</td>
<td>2.75</td>
<td>21.5</td>
</tr>
<tr>
<td>2</td>
<td>Steel</td>
<td>-</td>
<td>390</td>
<td>200</td>
</tr>
</tbody>
</table>

*) Yield strength for steel

(a) Monolith Specimens
(b) Precast Specimens

FIG. 3. Detail of specimens

(a) Specimen PL
(b) Specimen PLB

FIG. 4 Type Precast Specimens
Specimen PL was the specimen with only longitudinal carbon fiber sheet for jointing, whereas Specimen PLB was the specimen with longitudinal and transversal (belt) carbon fiber sheet for jointing. The jointing formation of carbon fiber sheet is shown in Figure 4. Noted here that the ACI 440.2R-08 was used as reference in application of the CFRP sheet in this study (ACI Committee (2008)).

Non-precast concrete was designed regularly where the steel reinforcement of beam was anchored into the column based the necessary development length to secure the monolith connection between beam and column. The specimen was design to fail on the beam due to steel yielding followed by crushing of concrete.

On the precast specimens, due the natural matter of the fiber sheet that only available to sustain tensile load, the joint mechanism was develop only for sustaining of moment. The shear force occurs on the joint was sustained by a shear key on the column as shown in Figure 5. A steel plate was attached on the shear key to distribute the shear force working on the joint. Additionally, a steel plate was also put on the one-end of the beams, as shown in Figure 5. The purpose of this plate is to transfer the shear force to the shear key on the column. This plate is also used for temporary securing of beam during the application of carbon fiber sheet.

All specimens were casted in once using ordinary ready mixed concrete. The casted specimens were then cured for 28 days using wet sack.

Assembling Process of Beam-Column Joint
The assembling process of the beam-column joint was done by placing the precast column in the horizontal position as shown in Figure 6. The sequences of the assembling process is describe as follows:

1. Sanding of the concrete surface where the carbon fiber sheet would be patched
2. Putting the precast beam on the precast column in the manner the steel plate of the beam-end met to the shear key on the column (Figure 5b)
3. Secure the beam to the column using temporary bolt (Figure 5b)
4. A steel wire was used to tie the beam to the column to ensure the beam-end touching the column surface perfectly (Figure 5c)
5. Application of the carbon fiber sheet was conducted as specified by the manufacturer (Figure 5d). Material properties of CFRP sheet used in this study is presented in Table 2.
6. Curing of epoxy of carbon fiber sheet for 4 days.
FIG. 6 Assembling Process of Precast Beam-Column Joint

Table 2. Material Properties of CFRP Sheet

<table>
<thead>
<tr>
<th>Properties CFRP sheet</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultimate tensile strength in primary fiber direction (Composite)</td>
<td>986 N/mm²</td>
</tr>
<tr>
<td>Tensile Modulus based on cross section area of primary fiber</td>
<td>95.8 kN/mm²</td>
</tr>
<tr>
<td>Shear bond strength of composite fiber (patch on concrete)</td>
<td>2.4 N/mm²</td>
</tr>
</tbody>
</table>

Setup of Specimen and Loading procedure
The specimen setup is shown in Figure 7. The column was placed on the floor slab longitudinally with the result that the beam in the standing position. The column part was sustained by steel plate support anchored on the concrete slab floor of the laboratory. Some strain gauges were patched on the concrete and on the CFRP sheet surface to measure the strain occurred during loading. The deformation of the specimens were measured using LVDTs attached on the some point of the specimens as shown in Figure 7. The load was applied gradually with rate of 0.2 kN per second to create a negative moment on the beam-column joint. All the measured data was recorded by a data logger for further analysis.

FIG. 7 Setup of Specimen
RESULTS AND DISCUSSIONS

Load-Deflection Relationship
Figure 8 shows the load-deflection relationship of both monolith (MN) and, the precast specimens with only longitudinal CFRP sheet (PL) and precast specimens with longitudinal and belt CFRP sheet (PLB), respectively. Generally, increasing of load caused a deformation on the beam which was indicated by the increasing of the deflection $\Delta$. At initial stage, the curve of monolith specimen shows a non linear relationship that may be caused by the setup system. Results indicated that the monolith specimen (MN) showed a higher stiffness than the precast specimen PL and PLB after applied load more than 5 kN. Average $P/\Delta$ stiffness of MN, PL and PLB specimens are 1.85 kN/mm, 0.84 kN/mm, and 0.76 kN/mm, respectively.

On the precast specimens, both specimens showed a higher stiffness at initial stage (applied load lower than 5 kN) and it gradually decreased by increasing the load. This phenomenon was understood as the cause of the higher modulus of the CFRP sheet compared to the concrete at elastic stage. Increasing of load, the outermost fiber on CFRP sheet started to fail or delaminate simultaneously that caused the gradually decreasing of the stiffness. This phenomenon occurred until the maximum capacity of the beam-column joint was achieved. Observation on Figure 8 indicated that the monolith specimen had better ductility than the precast specimens. Compared to the monolith specimen maximum deformation, the precast specimens deformation at maximum load were 75% for PL and 69% for PLB, respectively.

Flexural Capacity of the Joint
Table 3 shows the ultimate capacity of the specimens based on the experimental results. The ultimate moment of the monolith specimens was achieved based on reinforced concrete (RC) flexural mechanism (James K. Wight (2011), C.K.Wang et.al (1985)). The internal moment of RC beam is developed by the internal couple
moment between Tension (T) forces and Compression (C) forces, as illustrated in the Figure 9(a). Comparing to estimated ultimate flexural capacity of monolith specimens calculated using Eq.(2) shows that the experimental results has higher value. It was noted that the steel has yielded in achieving of its ultimate capacity.

\[
a = \frac{(A_s - A_s')f_y}{0.85f_{cb}} \quad \text{............................... (1)}
\]

\[
Mu = (A_s - A_s')f_y \left(d - \frac{a}{2}\right) + A_s'f_y(d - d') \quad \text{................. (2)}
\]

### Table 3. Ultimate Flexural Capacity

<table>
<thead>
<tr>
<th>Specimen Name</th>
<th>Experimental Value</th>
<th>Estimated Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pu (kN) Mu (kN.m)</td>
<td>Pu (kN) Mu (kN.m)</td>
</tr>
<tr>
<td>Monolith MN</td>
<td>24.0</td>
<td>24.0</td>
</tr>
<tr>
<td>Precast PL</td>
<td>20.4</td>
<td>20.4</td>
</tr>
<tr>
<td>Precast PLB</td>
<td>15.0</td>
<td>15.0</td>
</tr>
</tbody>
</table>

(a) Strain – Stress Diagram of Monolith Beam-Column Joint

(b) Strain – Stress Diagram of Precast Beam-Column Joint using CFRP sheet

**FIG.9 Strain-Stress Diagram of Monolith and Precast CFRP Joint**

On the precast specimens jointed using CFRP sheet, the moment capacity was developed by the hinge action on the edge point of the shear key where the beam sitting, as illustrated in Figure 9(b). The compression force worked on the hinge while the tension forces (T) was sustained by the CFRP sheet. The hinge action method was
developed because of the natural matter of the CFRP sheet that not effective in sustaining a compression load. As shown in Figure 9(b), the critical stress is on the outermost fiber of CFRP sheet (in this case is on the top). The strain and stress then linearly decrease up to zero on the hinge point. By assuming that the fibers achieve its rupture strength, the estimated ultimate flexural capacity \( M_u \) of the joint system may be calculated by Eq.(4).

\[
T_{cf} = \left( f_{ct} t_{f} H \right) \quad \text{............... (3)}
\]

\[
M_u = \frac{2}{3} T_{cf} H \quad \text{............... (4)}
\]

Comparing to the experimental results of specimen PL, the estimated value seems to be over estimate. This may be due to that the fact, the failure of specimen PL was due to the debonding/delaminating of the CFRP sheet. The specimen PLB (specimens strengthened with CFRP belt) indicated much lower than its estimated value. Observation during the experiment, indicated that the outermost fibers of CFRP sheet on specimen PLB failed prematurely due to the edge-cutting effect of its belt, as illustrated in Figure 10. This caused the flexural capacity of specimen PLB decreased lower than the specimen PL. The longitudinal CFRP could not develop more effective action in sustaining tension load of flexural moment. Comparing to the monolith specimen, the precast specimen of PL and PLB has flexural capacity of 85% and 63%, respectively.

**FIG.10 Illustration of Cutting-Edge Action on Specimen PLB**

**Failure Mode**

Figure 11 shows the failure photograph of the specimens. The specimen PL failed due to the delaminating of the CFRP sheet. Prior to the final delaminating, some sounds indicated the propagation of micro delaminating was identified. Final failure due to delaminating caused the decreasing of load. The laminating of specimen PL is shown in Figure 11(a). In different failure mode occurred on the specimen PLB. The purpose of installing the CFRP belt was to increase the bonding capacity of the longitudinal CFRP sheet. However, the existence of the belt caused a premature cut-off of the outermost fibers on the longitudinal CFRP sheet. Therefore, the specimen PLB did not fail under delaminating/debonding, but it failed due to the rupture of
longitudinal CFRP sheet as shown in Figure 11(b). The longitudinal CFRP sheet was cut off small-by-small from the outermost fibers. The final failure was determined when the significant width (in this case about 1/3 of width) of CFRP sheet has failed.

![Debonding of CFRP sheet](image1.png) ![Cut-off due to edge-cutting action of CFRP Belt](image2.png)

(a) Failure of Specimen PL (b) Failure of Specimen PLB

FIG.11 Failure Mode of Precast Specimens

CONCLUSIONS

Experimental study on the specimens of the beam-column joint using CFRP sheet provided the following conclusions:

(1) The joint system using CFRP sheet with shear key may become an alternative in jointing system, especially for portal frame system that mainly sustain vertical load.

(2) The developed precast join system still has lower ductility compared to the monolith specimen. Compared to the monolith specimen maximum deformation, the precast specimen deformation at maximum load were approximately 75%.

(3) Flexural capacity of the developed model was approximately 85% of the monolith specimen flexural capacity.

(4) The belt on the longitudinal CFRP sheet may cause a premature cut-off of the outermost fiber causing the decreasing of the flexural capacity.

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