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Evaluation of Model Strengthening on Dry Joint in Precast Beam and Column Using CFRP Material (Carbon Fiber Reinforced Polymer)

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Abstract— *Along with the massive number of earthquake disasters that occurred and have an impact on the collapse and damage of a building structure, making repairs and strengthening of a structure become a common thing in the field especially in precast joint structure components which often experience a decrease in strength or even malfunction so that they are no longer able to withstand the load of a building. Along with the development of strengthening methods used in structural reconstruction work, there is a need for an evaluation model that can provide results to help develop models in structural strengthening. This study aims to evaluate the model of strengthening on dry joint in precast column and beam using CFRP materials by analyzing the maximum capacity values and behavior of structural strengthening such as ductility and stiffness with the loading method quasi-cyclic. The strengthening model used in this discussion is divided into 2 strengthening model variants including (a). steel plate + CFRP sheet and (b). CFRP plate + CFRP sheet which is attached to the concrete surface with the aid of glue (epoxy). The results of the testing of strengthening with the model steel plate + CFRP sheet show the results of maximum capacity values, ductility and stiffness higher than the models with material CFRP plate + CFRP sheet.*

Keywords— *Dry Joint, steel plate, CFRP plate, CFRP sheet.*

I. INTRODUCTION

Along with the massive number of earthquake disasters that occurred and have an impact on the collapse and damage of a building structure, making repairs and strengthening are often found in the field especially in precast joint structure components which often experience a decrease in strength or malfunction after a disaster occurs so that they are no longer able to withstand the load of a building. For this reason, strengthening a structure is one of the solutions for comfort and safety for its residents.

The beam-column joint is a component that has a very important and critical role in building structures, especially for structures specifically designed for earthquake-resistant building designs. This is because the beam-column joint has a role that functions as a distributor of the force received by the building to the whole structural element. The beam-column concrete joints can be categorized into 2 types, namely dry joints and wet joints. [1] Dry joint is a joint that is usually applied to precast concrete which usually connected using steel plates, welds and bolts while the wet joint is a joint that is connected by using strengthening from inside the concrete which is casted directly.

The number of strengthening methods used in structural reconstruction work requires the evaluation of models that can provide results conclusions to help develop a model in structural strengthening. This study aims to evaluate the precast column dry beam strengthening model using CFRP material by analyzing the value of the maximum capacity of the column beam dry joint precast reinforced using CFRP, joint behavior which includes ductility and stiffness using the loading method *quasi*-cyclic by displaying the results inform of the hysterical curve.

II. LITERATURE STUDY

A. Column and Beam Joints

Joints are areas that are used for connecting two or more structural components [2]. The column and beam joint are an area that needs to be considered for its quality in a concrete frame structure, which requires a special design to accept earthquake forces. This occurs due to the magnitude of the moment received by column and beam joints when an earthquake suddenly occurs. Those moments are considered as the cause of the high risk of building collapse. The type of joint can be divided into several groups. For column and beam joints that are often encountered in the field, it can be divided into three types of joints, which are: interior joints, exterior joints and angular joints [3].

B. CFRP (Carbon Fiber Reinforced Polymer)

The use of CFRP (*Carbon Fiber Reinforced Polymer*) in the process of structural strengthening has been widely used starting from strengthening beams, columns, plates, walls and also concrete joints. CFRP is a type of FRP model made from composite material-material arrangements and consists of a polymer matrix reinforced with fine fibers made of carbon. The advantages of ttrengthening using CFRP are corrosion resistance, a relatively high tensile strength, high ductility, very light density so it does not require heavy equipment for workmanship and easy installation. The
following is an example of a picture of the CFRP *plate* and CFRP *Sheet:*

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a. CFRP *Sheet* b. CFRP *Plate*

Figure 1. Example of a CFRP model

C. Ductility

Ductility is the ability of a material or structural element to experience deformation without experiencing destruction in the inelastic period. The nature of ductility can limit the magnitude of the force generated by the earthquake. The greater the ductility that the structure has, the greater the level of energy dissipation possessed by the structure. Ductility (μ) can also be defined as the ratio between the maximum total displacement or deformation ratio (Δ_u) with the beginning of the melting time (B_y), [4].

$$\mu = \frac{\Delta u}{\Delta y} \quad (1)$$

D. Stiffness

Stiffness in a structure is one of the elements that really needs to be considered in designing a building, especially for earthquake resistant buildings. This is one of the basic requirements that must be owned by buildings in resisting lateral forces and complete vertical. The stiffness for the loading method *quasi-cyclic* can be defined as *peak to peak stiffness* or called *secant stiffness* where the slope of the line connecting the positive peak point and the negative point. The type of stiffness above is usually called the secant stiffness [5]

$$K = \frac{P_1 + P_2}{\Delta_1 + \Delta_2} \quad (2)$$

E. Previous Literature

Research on strengthening using CFRP material are already conducted with different installation methods and models. The following is a summary of the previous research that discussed the strengthening of column and beam structures with CFRP material:

Al-Salloum Y.A. [6] conducted a study on the seismic behavior of exterior beam joints reinforced with FRP. The subject matter is the failure of the shear beam exterior joint shear that was identified as the main cause of the collapse of the skeletal structure which held the moment during the earthquake. In this study, the specimen was divided into 3 types of specimens, which are: EC) Test specimens, ER) Specimens reinforced with CFRP, and ES) Grouted specimens.

Balasubramanian, K. [7] This study discusses the performance evaluation of the strengthening concrete beam-column joints with the design for cyclic loading using four models of installation, which are: (1) CFRP lamination, (2) CFRP lamination and covered with CFRP sheets, (3) Strengthening with 50 mm steel plates, and (4) iron-embedded strengthening method with the addition of external CFRP sheets as cover . The research idea used in this study is almost similar to this method.

Faella, Ciro. [8] Discusses column and beam joints reinforced with 2 strengthening types, which are: a). FRP and b) steel plate. The aim of research to analyze the performance of RC column beam seismic design reinforced with FRP and steel systems with the aim of increasing joint seismic design behavior.

III. RESEARCH METHODS

A. Detail of Specimens

Specimens on this study are existing test specimens obtained from previous studies that discussed the precast column and beam joint analysis with the dry joint method that inspect the loading behavior *quasi*-cyclic until it reaches a 20% decrease after reaching the peak value. The dimensions of the existing specimens are planned with a width of 150 mm and a height of 200 mm for beams. As for columns, the width are 200 mm and the height are 200 mm with the same quality of 25 mpa. The existing specimen variant model are divided into 2 joint variant models, which are by distinguishing the number of anchors that function as a connecting device between columns and beams. Variants for the number of anchors include 2 and 4 anchors, the following for detailed pictures of existing test pieces are as follows:

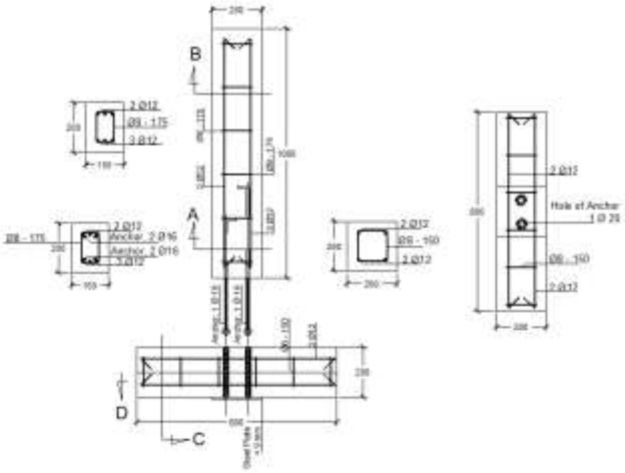

Figure 2. Existing specimen design

After achieving the control value which had been set by the previous researcher, the existing test specimen that has been damaged needs to be carried out by the concrete treatment process by separating the concrete cracks from the specimen which is still in solid state, then the existing specimen is reinforced using FRP (*Fiber Reinforced Polymer*). In this study, the type of FRP used was CFRP (*carbon fiber reinforced* polymer) divided into two models of additional materials in the joint strengthening method, namely (a). *steel plate* + CFRP *sheet* and (b). CFRP *plate*, + CFRP *sheet* which is attached to the concrete surface with the aid of glue*(epoxy).* The next is the detail of the strengthening variant of the specimen and for the installation model.

TABLE I. Code and number of test

ID	Items	Amount of Anchor	Number of Test Items	Strength Type
Retrofit-A	RA4	4	1	Steel Plate + CFRP Sheet
	RA2	2	1	Steel Plate + CFRP Sheet
Retrofit-B	RB4	4	1	CFRP Plate + CRFP Sheet
	RB2	2	1	CFRP Plate + CRFP Sheet

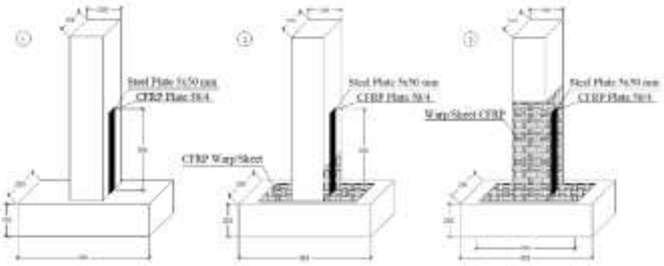

Figure 3. Strengthening grooves of specimens

B. *Testing Method*

In a laboratory scale, there are several types of methods of loading on specimens, but the most familiar and widely used are monotonic static load and cyclic load. The loading method used in this study is *quasi*-cyclic loading method Q*uasi*-cyclic is a method of loading that almost resembles a cyclic load which is charged back and forth and repeatedly until it reaches the specified control value. This method is conducted to know behavior of components of a building when receiving earthquake loads. The application of the *quasi*-cyclic loading method has been exemplified previously in [9]. by giving a load laterally and gradually according to the loading pattern depicted in the following pattern:

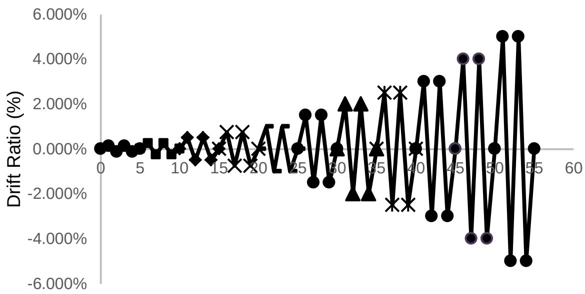

Figure 4. Pattern of loading

For the setting of the equipment carried out for testing with *quasi*-cyclic, several tools are needed. Due to the lack of adequate equipment used in the cyclic loading method, a tool that is capable of resembling a load is *Hydraulic Jack*, which is laterally installed. For detailed planning, the installation of tools used to resemble cyclic loads is described as follows:

Figure 5. Setting of loading *quasi*-cyclic devices

III. Results and Discussion

The result of the research for strengthening of precast column and beam joints with CFRP material carried out in the UB Engineering Department's Construction Materials Laboratory. The data obtained from the study using *quasi*-cyclic loading method plotted in the *backbone* curves of the negative load which functions to analyze the results, between values maximum capacity, ductility value and stiffness value using CFRP materials. The following is a display of the test results in the backbone curve:

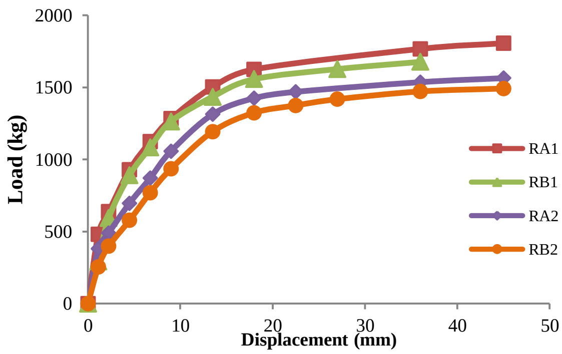

Figure 6. *backbone*

A. *Maximum Capacity*

TABLE II. Maximum capacity value of

ID	Pmax (kg)	Δu (mm)	Value Average (kg)
RA4	1806.00	45.00	1685
RA2	1564.00	45.00	
RB4	1677.00	36.00	1584.5
RB2	1492.00	45.00	

Table above is the results of the maximum capacity value from all specimens testing, where specimens are strengthened with models steel plate + CFRP sheet with 4 anchor and 2 anchor joints having a value of 1806 kg and 1564 kg higher than strengthened using material CFRP plate + CFRP sheet with a value for 4 anchors of 1564 kg and for 2 anchors of

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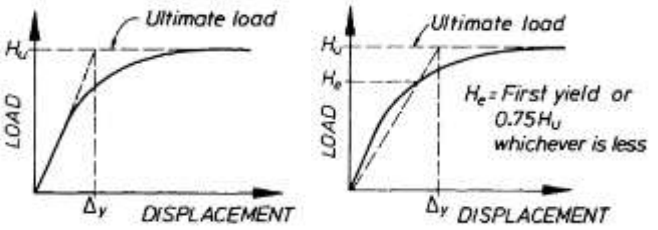
1492 kg. From these results, it is concluded that strengthening by adding steel plate has a higher maximum capacity value when compared to CFRP plate.

B. Ductility

Due to the process, researchers did not place or use a *strain gauge* to control the melting value of strengthening and anchor. In order to obtain the melting point used to determine the ductility value of the specimen, a method has been described previously by [10], where the method used in this test is the Tangential Method and Secant Method when the load value is at the peak. Here is a picture of the method to determine the melting value described as shown below:



a. Tangential method b. Secant method
Figure 7. Method for determining the yield point when Pmax

TABLE III. Ductility Tangential

ID	Pmax (kg)	Py (kg)	Δu (mm)	Δy (mm)	Ductility (μ)	Average (μ)
RA4	1806,00	481,00	45,00	4,30	10,47	**10,72**
RA2	1564,00	380,00	45,00	4,10	10,98	
RB4	1677,00	594,00	36,00	6,10	5,90	**5,91**
RB2	1492,00	398,00	45,00	7,60	5,92	

The results of the ductility test obtained by the tangential method are enclosed in the table above. From the results, the value found for reinforcement using the steel plate + CFRP sheet has a half value higher than strengthening value the CFRP plate + CFRP sheet.

TABLE IV. Ductility Secant

ID Test	Pmax (kg)	Py (kg)	Δu (mm)	Δy (mm)	Ductility (μ)	Average (μ)
RA4	1806.0	1354.5	45.0	12.6	3.55	**3, 46**
RA2	1564.0	1173.0	45.0	13.3	3.38	
RB4	1677.0	1257.7	36.0	11.9	3.01	**2.84**
RB2	1492.0	1119.0	45.0	16.8	2,67	

In contrast to the results of the ductility test using the secant method, the difference in the values of the two specimen variants is smaller when compared with the results of the ductility test using the tangential method. However, both methods show the same results, where for specimens reinforced with steel plates + CFRP sheets have a higher ductility value compared to reinforcers using CFR Plate + CFRP sheets.

However, the ductility value in this test cannot be used as a final assessment because the capacity of the testing equipment is not enough to achieve testing control capacity. So, the data retrieval is stopped and the Pmax value in the ductility test is taken from the load value when the test is terminated.

C. Stiffness

In addition to strength and ductility, stiffness is also one of the very important aspects in designing building structures that must complement each other to get a sturdy and strong building. As explained earlier, the results of the stiffness analysis of the specimen can be calculated using the secant stiffness methods. Evidently, it is not much different from the calculation of the other values. Stiffness calculations are also taken from the data plotted in the backbone curve. The results of calculations that have been analyzed using the secant stiffness methods can be seen in the following curve image plot:

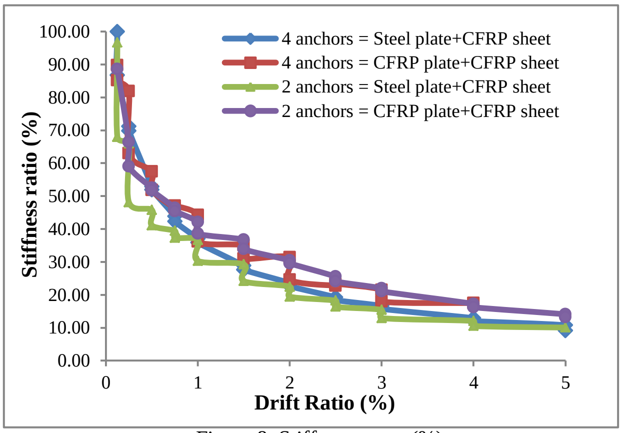


Figure 8. Stiffness curve (%)

The results of the curve above shows that the RA4 test specimen (4 anchors: Steel plate + CFRP Sheet) have the highest stiffness value with a value of 372.89 kg/mm and strengthening steel plate RA2 (2 anchors: Steel plate + CFRP Sheet) has a stiffness that is almost close to the RA4 which its exact value is 321.78 kg/mm with the drift ratio of 0.125%. Furthermore, specimens strengthening with CFRP plate have almost no significant difference even though they have different number of anchors, where RB4 stiffness values (4 anchors: CFRP Plate + CFRP Sheet) and RB 2 (2 anchors: CFRP Plate + CFRP Sheet) with stiffness values are 225.33 kg/mm and 211, 56 kg/mm and the ratio position is at the value of 0.125%.

IV. Conclusion

Based on the results of a study that discusses the evaluate of model strengthening on dry joint in precast column and beam using CFRP material, some conclusions can be drawn as follows:

1. The maximum capacity value of strengthening with model *retrofit A* has an average value of 1685 kg, greater than *retrofit B* with value an average of 1584 kg.
2. The ductility value with the tangential method has a greater value compared to the value of the secant method.
3. The ductility value in this test cannot be used as a final assessment because the capacity of the testing instrument is insufficient to achieve testing control capacity.
4. The stiffness value for test specimens *retrofit A* has a higher stiffness value than *retrofit B.*

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5. Over all, specimens *retrofit A* have maximum capacity values, ductility and stiffness higher when compared to specimens *retrofit* B.

V. SUGGESTIONS

Based on the research that has been done, there are suggestions that are expected to refine the results of this research and also can be used for further development. The suggestions are:

1. It is necessary to try using another strengthening model to be used as a reference for the development of the strengthening system.
2. Further researcher required to add control specimens with monolithic joints in order to obtain validation of ductility and stiffness values.
3. For further research, it is suggested to control the material such as installation of *strain gauge* in order to determine the capacity of the specimen before strengthening occurs.

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