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USE OF U-WRAP TO OVERCOME CONCRETE COVER DELAMINATION IN VARIOUS SIZES OF BEAMS USING STRUT AND TIE MODELLING

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A B S T R A C T

Reinforced concrete beams reinforced with Fiber Reinforced Polymer (FRP) have several failure patterns, one of which is Concrete Cover Delamination. To prevent this failure, in this study, FRP U-Wrap was installed which was calculated using Strut and Tie Modelling (STM). The specimens of reinforced concrete beams with a length of 3300 mm, a width of 300 mm, and variations in height of 500, 600, and 700 mm were loaded with the two-point load method. Data collection and analysis was carried out using Digital Image Correlation, LVDT, strain gauge, and data logger. The bending behaviour reviewed in this study is ductility, crack pattern, type of failure, flexural capacity, and stiffness. In this study, the addition of U-Wrap did not have a significant effect on flexural behaviour when compared to beams without U-Wrap FRP. All beams experienced a failure pattern of FRP Debonding, so that the Concrete Cover Delamination did not occur.

1. INTRODUCTION

In planning the structure of the concept that is considered is how the existing load does not exceed the capacity of the structural elements. However, in practice there is a burden that can be increased at any time due to changes in the function of the building. Thus, to overcome the problem of increasing the load, reinforcement is needed before the occurrence of structural failure. One of the popular reinforcement options today is to use reinforcement from Fiber Reinforced Polymer (FRP) (Dong J.F. et al., 2012; Gao, B. K.,2004; Godat A. et al., 2010).

FRP has a higher tensile capacity than steel reinforcement. So that when the steel reinforcement has reached the yield condition, the beam does not immediately fail because the tensile force on the concrete is also transferred to the FRP. Beam capacity increase with FRP reinforcement (Khalifa, A. T., 1999; Mofidi, A. at al, 2012; Starnes, D. D., 2004).

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One of the weaknesses that often occurs is beam experienced premature failure, namely concrete cover delamination. Concrete cover delamination is the release of the concrete cover due to being pulled together with the FRP, in which the FRP has not yet reached its maximum capacity but has failed (Smith, S. T., 2002; Yao, J. T., 2005). The U-Wrap configuration on beam reinforcement with FRP in preventing premature failure showed that the use of FRP U-Wrap could delay premature failure in beams reinforced with FRP. In this study, using beams with the same cross-section and using Strut-and-Tie Modelling (STM) idealization of beams reinforced with longitudinal FRP and U-Wrap FRP to review the load transfer mechanism. Modelling of beam elements with STM shows that the tie that transmits tensile stress to the FRP is concrete material, which is known to have a low nominal tensile strength (Dhahri, 2018). The provision of FRP U-Wrap by using anchor bolts in its installation is quite effective in reducing the tensile stress on the damaged concrete parts (Dhahir, 2017).

In fact, the behaviour of the beam is also influenced by the cross-sectional size of the beam so that it is possible for different failures to occur. Therefore, this study will review the behaviour of the stiffness ratio of reinforced beams with FRP reinforced with U-Wrap FRP. The behaviour of the stiffness ratio of the beam will be reviewed from the crack pattern, failure, flexural capacity, stiffness, and validation of the concrete cover delamination failure pattern which is calculated using the Strut and Tie method.

Strut-and Tie Modelling (STM) is a frame structure model of a structural element or of a D-Region within the element, which consists of compression members and tension members connected at nodal points, and capable of transmit factored loads to the fulcrum or to the adjacent B-Region. With the STM method, it can be seen that in the concrete cover the parts experiencing the greatest tensile stress. The greatest tensile stress begins at the end of the Longitudinal FRP reinforcement. This section was used because of the failure of the concrete cover delamination.

2. RESEARCH METHODS

2.1 Test Specimen

The test specimens were 16 concrete specimens consisting of 6 beam specimens for flexural strength testing and 10 cylindrical specimens for compressive strength testing. All beams have the same length of 3300 mm. All beam specimens used 4 pieces of flexural reinforcement with a diameter of 19 mm for the lower tensile reinforcement and 2 threaded reinforcements with a diameter of 19 mm for the upper compression reinforcement. The flexural reinforcing steel uses a yield capacity (Fy) of 420 MPa. All beam specimens used stirrups with 10 diameter plain steel reinforcement with a spacing of 100 mm. The stirrups use plain reinforcement with a yield capacity (Fy) of 280 MPa. The concrete blanket around the side of the reinforcement uses a thickness of 20 mm where the thickness of 20 mm is measured using concrete tofu. The dimensions and stiffness of each beam can be seen in Table 1.

Table 1. Specimens of Test Objects

Code Specimen	Size (mm)		fc' (MPa)	EI Beam (Nmm^2)	EI FRP (Nmm^2)	EI Rasio (EI Beam/ EI FRP)
	b	h				
BF 500	300	500	25	8.85E+13	2376000	3.09E+07
BU 500	300	500	25	8.85E+13		
BF 600	300	600	25	1.50E+14		5.34E+07
BU 600	300	600	25	1.50E+14		
BF 700	300	700	25	2.34E+14		8.48E+07
BU 700	300	700	25	2.34E+14		

The BF code indicates that the beam is only reinforced with Longitudinal FRP, while the BU code means that the beam is reinforced with Longitudinal FRP and additional U-Wrap. Codes 500, 600, 700 indicate the height of the beam. Dimensions of longitudinal FRP reinforcement and U-Wrap on each beam can be seen in Table 2.

Table 2. Dimensions of FRP Reinforcement in Each Beam

Specimen Code	Number of Specimen (unit)	Reinforcement Dimensions with Longitudinal FRP (mm)			Reinforcement Dimensions with FRP *U-Wrap* (mm)			
		Width (b_f)	Thickness (t_f)	Length (l_f)	Width (b_{fw})	Thick (t_{fw})	Height (h_{fw})	Multiple Laver
BF 500	1	100	1.2	2400	-	-	-	-
BU 500	1	100	1.2	2400	300	0.166	120	1
BF 600	1	100	1.2	2400	-	-	-	-
BU 600	1	100	1.2	2400	300	0.166	120	2
BF 700	1	100	1.2	2400	-	-	-	-
BU 700	1	100	1.2	2400	430	0.166	120	2

Details of each cross section of the beam can be seen in Figures 1 to 3. The FRP U-Wrap in this study was only designed to hold a 20 mm thick concrete blanket. Dimensions of FRP U-Wrap are obtained by calculating based on the Strut and Tie method on each beam. Longitudinal FRP on each beam has the same dimensions.

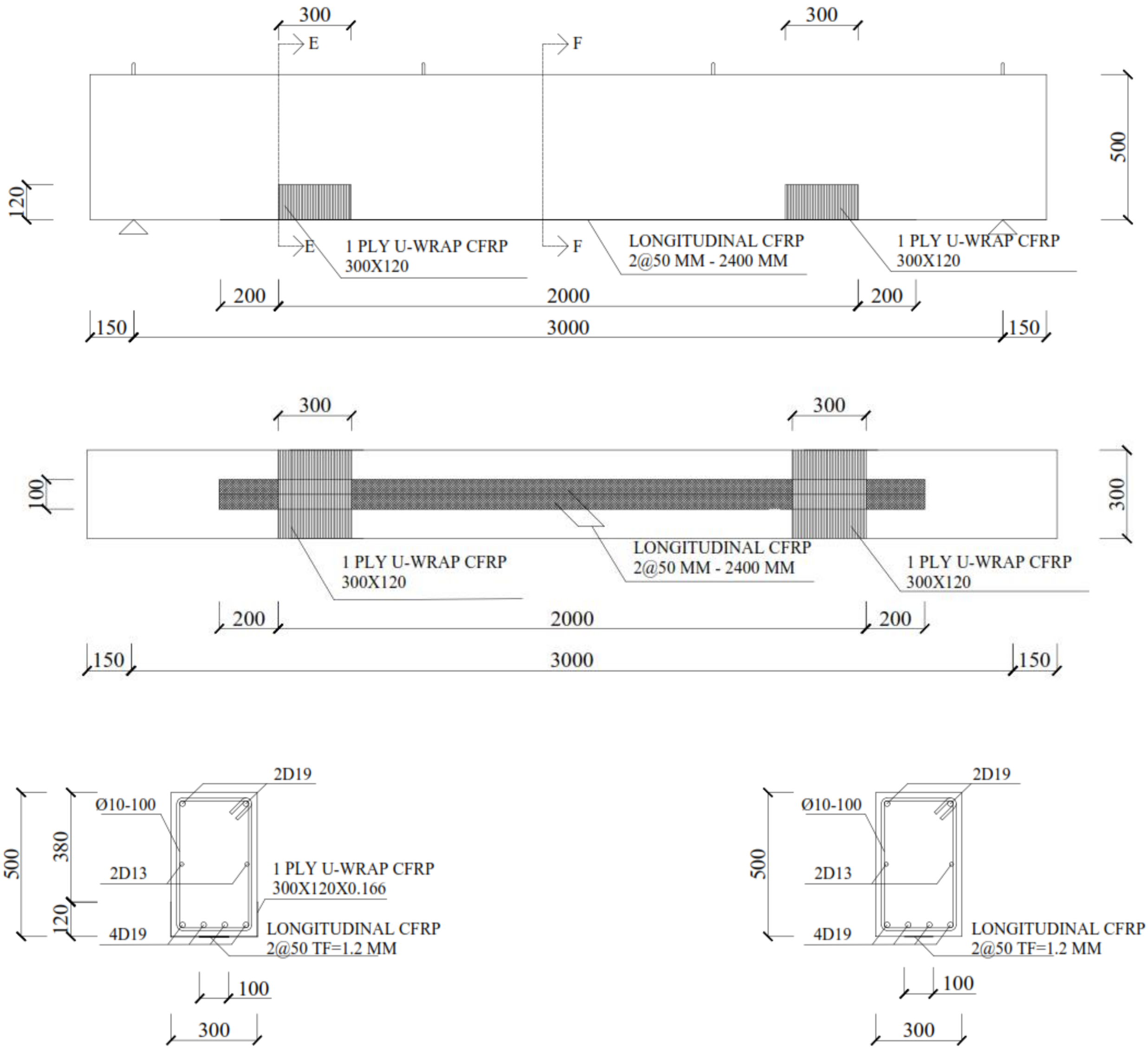

Figure 1. Cross section of BU-500 beam; (a) Details of Installation Placement of *Longitudinal* FRP and FRP *U-Wrap* (b) Detail of Cross-section with FRP *Longitudinal* and FRP *U-Wrap*

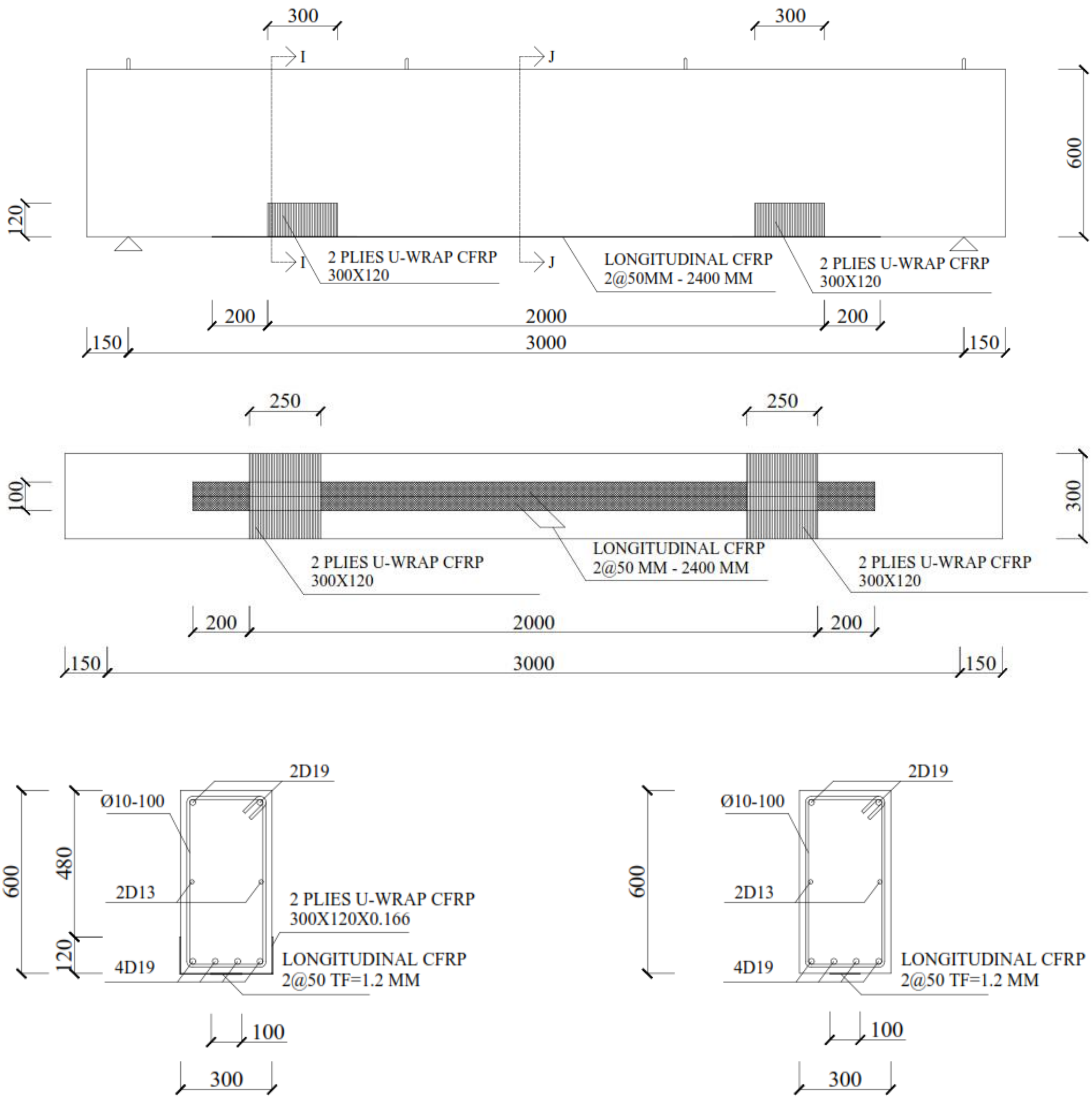

Figure 2. Cross-section of the BU-600 beam; (a) Details of Installation Placement of *Longitudinal* FRP and FRP *U-Wrap*, (b) Detail of Cross-section with FRP *Longitudinal* and FRP *U-Wrap*

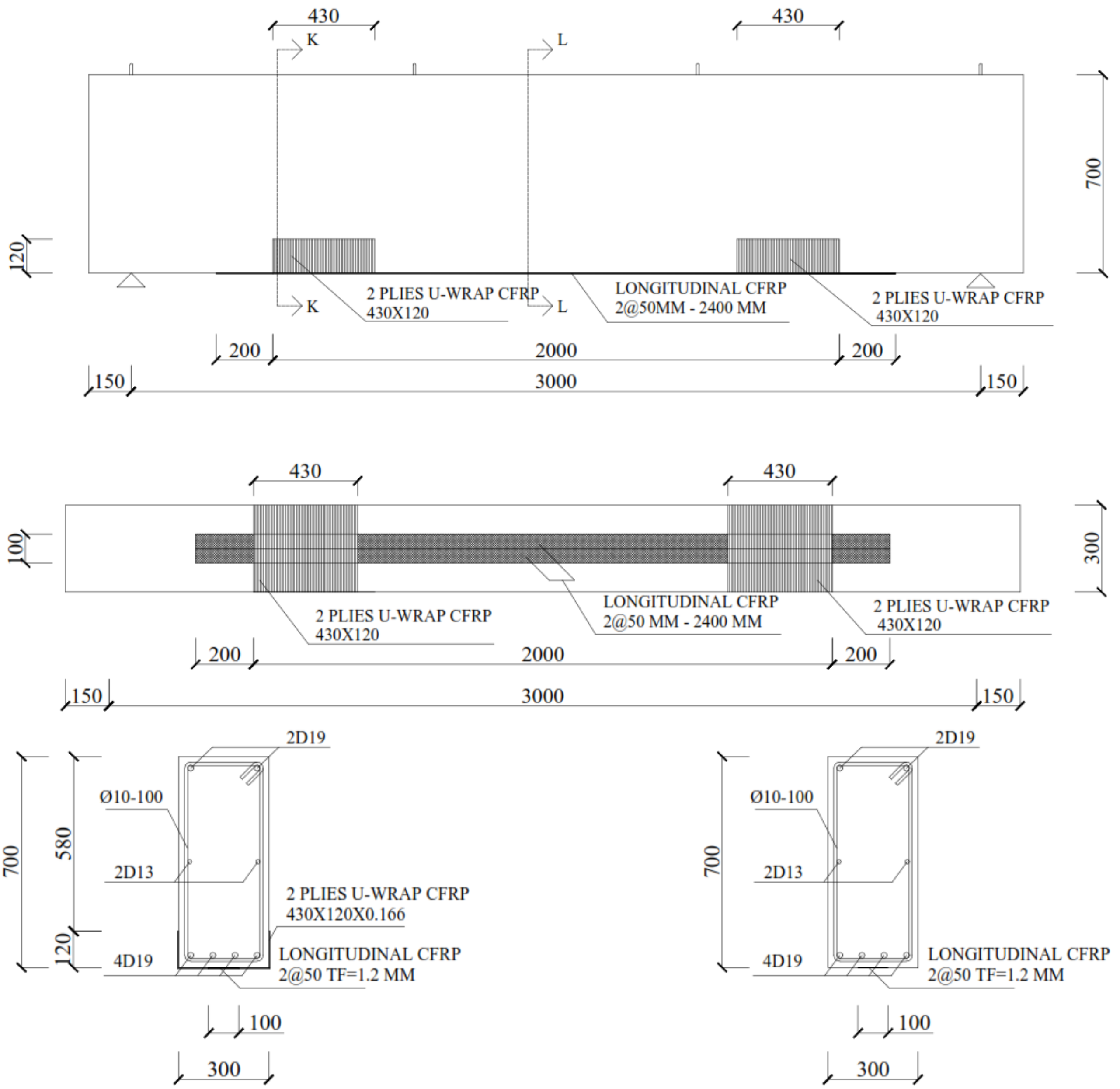

Figure 3. Cross section of BU-700 beam; (a) Details of Installation Placement of *Longitudinal* FRP and FRP *U-Wrap*, (b) Detail of Cross-section with FRP *Longitudinal* and FRP *U-Wrap*

2.2 Test Setup and Instrumentation

The manufacture of all specimens was completed in one casting using a ready mix mixer with a capacity of 6m^3. The concrete is casted using a concrete pump and the concrete is compacted using a vibrator. As soon as the casting on each block is completed, the surface of the concrete block will be levelled. After the beams are 4 days old, the formwork is opened, and curing is done by spraying water on each beam.

After the blocks are 28 days old, the blocks will be painted white and will be tested. The beam to be tested is placed in the loading frame by lifting it by a crane using the 2-point lifting method. The beams were tested using the two-point load method and supported on two rollers with a span of 3000 mm. Loads are placed symmetrically with a distance of 300 mm to the left and right of the beam, which is measured from the centre of the beam span. At each loading point, a steel plate with dimensions of 300x300x60 (thickness) is placed under the loading point. This is done to prevent premature failure due to local crushing during testing.

The setup for the placement of the beam test can be seen in Figure 4. The load is measured by the load cell, the strain on the beam is measured by a strain gauge placed 1 piece on the concrete compression fiber, 2 pieces on the concrete tensile reinforcement and 1 piece on the longitudinal FRP, displacement is measured by 1-piece LVDT. The strain gauge and LVDT are placed in the middle of the beam span. These tools are connected to a data logger that is connected to a computer (Harle, S. J. 2017; Santhosh, K. V., and Roy B. K. 2012; Warren, K. A. at al., 2010). After all the testing tools are installed correctly, black dots are given on the sides of the beam to be reviewed with Digital Imaging Correlation (DIC). During the test, additional LED lights were given, and the beam test was recorded with a camera to carry out DIC measurements. The results of the research using the DIC method using the help of the MATLAB R2017b program which is equipped with Ncorr version 1.2.2.

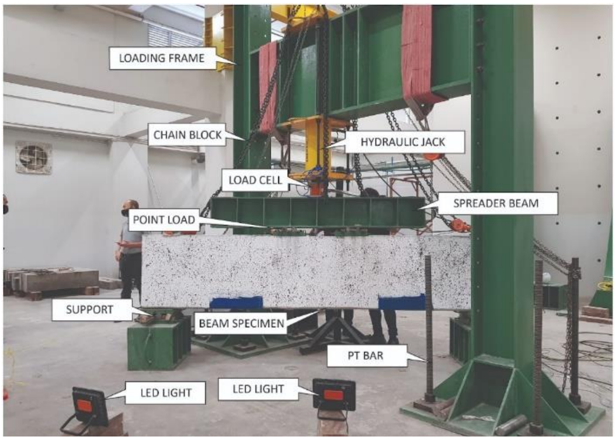

Figure 4. Beam Test Placement Setup

3. RESULTS AND DISCUSSION

Analysis of the effect of the ratio of stiffness of beams reinforced with FRP U-Wrap with reinforced concrete beams reinforced with longitudinal FRP on crack patterns:

a. DIC is good enough to scan or read the results of the crack pattern that occurs. This is evidenced by the comparison of the readings between the DIC and the manual method (Gustafson, H. et al., 2016; Hoult, N. A. at al., 2013; Suryanto, B. 2017; Tahreer M. and Fayyad, J. M., 2014).

b. All types of beams in this study resulted in cracks starting from the middle of the beam span, then the cracks would increase towards the support.

c. The higher the cross section of the beam with the same span, the less crack patterns that occur.

d. Crack patterns in beams reinforced with FRP Longitudinal and FRP U-Wrap have crack patterns that are relatively the same when compared to beams reinforced with FRP Longitudinal only for each beam size.

Analysis of the effect of the stiffness ratio of beams reinforced with FRP U-Wrap with reinforced concrete beams reinforced with longitudinal FRP on failures that occur:

a. All beams experienced the same failure, namely the failure of FRP debonding.

b. Beams reinforced with FRP Longitudinal and FRP U-Wrap are subjected to longitudinal FRP being pulled on one side. This suggests that there is an imperfect installation of the epoxy on the detached side, so it can be concluded that there is a possibility of uneven or consistent epoxy application.

c. All the longitudinal FRP in the two variable beams reinforced with FRP Longitudinal and FRP U-Wrap and the beams reinforced with FRP Longitudinal alone were detached with only a few parts covered by concrete. This shows that not all the longitudinal FRP spans are attached to the concrete blanket properly, so that only the well-fitted parts can pull the concrete off with the FRP.

d. After undergoing FRP debonding, all beams are continuously loaded until the collapse stage. The failure that occurs in all beams studied at this stage is flexural failure.

Analysis of the effect of the ratio of stiffness of beams reinforced with FRP U-Wrap with reinforced concrete beams reinforced with longitudinal FRP on flexural capacity:

a. At the ultimate stage, beams reinforced with FRP Longitudinal and FRP U-Wrap, and beams reinforced with FRP Longitudinal alone can carry a higher load than the results of the analysis.

b. Before reaching the ultimate stage, there has been slippage between the longitudinal FRP and the tensile fibers of the concrete. This is supported by the results of the strain gauge readings on steel reinforcement which have a value greater than the value in longitudinal FRP and the presence of cracks in the epoxy FRP.

c. Overall, this type of FRP U-Wrap reinforcement does not have a significant impact on increasing the load. This is also supported by the strain that occurs in the longitudinal FRP, where the beam reinforced with FRP Longitudinal and FRP U-Wrap does not show any significant difference compared to the strain in the longitudinal FRP on the beam reinforced with FRP Longitudinal only.

Analysis of the effect of the beam stiffness ratio before the first crack reinforced with FRP U-Wrap with reinforced concrete beams reinforced with longitudinal FRP:

a. In the comparison of the calculation of analytical stiffness with experimental, it was found that the difference is not consistent, with some cases where the experimental has a higher stiffness number, and in some other cases the opposite is true. This can be caused by errors that occur in the work in the field, ranging from reinforcement and casting, to testing.

b. For all beam sizes, the addition of U-Wrap FRP reduces stiffness at the stage before the first crack when compared to beams reinforced with Longitudinal FRP alone.

4. CONCLUSION

From the research that has been done, it can be concluded several things:

a. Evaluation of Experimental Beam Failure Based on Strut and Tie Modelling: the failure of the experimental beam was FRP debonding. This is different from the failure obtained using strut and tie modelling, namely concrete cover delamination. This is because there is an epoxy that is not perfectly attached, both to the Longitudinal FRP and to the concrete surface.

b. The addition of U-Wrap did not have a significant effect on flexural behaviour when compared to beams without U-Wrap FRP. All beams experienced a failure pattern of FRP Debonding, so that the Concrete Cover Delamination did not occur.

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