Modelling of Structural Strengthening Techniques for Existing Building and Structures: Case Study Club House Graha Natura Under Lift Loading Using Carbon Fibre-Reinforced Polymer (CFRP)

Eka Susanti[1,2][a], Heri Istiono[1,2][b], Indra Komara[1,*][c], Dewi Pertiwi[1][d], Jaka Propika[1,2][e], Yanisfa Septiarsilia[1,3][f], Dita Kamarul Fitria[1,3][g] and Alexandria Inka Yayan[1]

[1]*Civil Engineering Department, Institute Technology Adhi Tama Surabaya, Jl. Arif Rahman Hakim 100, Klampis Ngasem, Sukolilo, Surabaya, East Java, Indonesia*

[2]*Civil Engineering Department, Petra Christian Unviersity, Jl. Siwalankerto No.121-131, Siwalankerto, Surabaya, 60236, East Java, Indonesia*

[3]*Civil Engineering Department, Institut Teknologi Sepuluh Nopember, Jl. Teknik Kimia, Keputih, Sukolilo, Surabaya, East Java, Indonesia*

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Abstract: The carbon fibre-reinforced polymer, also known as CFRP, is a relatively new type of reinforcement that is being used in concrete materials. It possesses a number of desirable mechanical and physical properties. In addition to its other mechanical properties, CFRP possesses excellent compressive, flexural, and shear strengths. Furthermore, the use of CFRP has enhanced ductility and makes it suitable for preventing cracks. The research was carried out by contrasting the results of an independent computation of FRP-confined RC section ductility with those of an analysis produced by SAP2000 under case study of Club house graha natura. This comparison included the capacity of beam section added using CFRP. The existing building constructed without consideration of lift loading which is affect the loading distribution. CFRP offer the additional strength to support lift loading without changing the whole structure dimension significantly. The accuracy of the software response that is being examined in this research was significantly improved by defining the properties of the retrofitted material by using a variety of different approaches.

1 INTRODUCTION

Concrete structures that are susceptible to sustaining a variety of forms of damage as a result of the occurrence of natural disasters such as earthquakes, fires, or hurricanes, in addition to other factors such as errors in design, are referred to as "concrete structures at risk." (Gagg, 2014; Jensen, Kovler and Belie, 2016). A member of the concrete structure may only have a small amount of reinforced steel or fibre, meaning that it is unable to withstand any bearing loads (Maalej and Leong, 2005; Khairi *et al.*, 2021). In a similar situation, shock loads from explosions, changes to the construction's function, and increased service loads on construction members that were not accounted in the initial design all prevent the constructions from performing their intended functions. On the other hand, additional strengthening support identify the service category (Arrangement *et al.*, 2013; Yildiz *et al.*, 2019).

Under these circumstances, demolishing and rebuilding concrete members is an inefficient

[a] https://orcid.org/0009-0009-4773-729X
[b] https://orcid.org/0009-0002-7220-3846
[c] https://orcid.org/0000-0001-7260-0855
[d] https://orcid.org/0009-0008-1010-1872
[e] https://orcid.org/0009-0008-5622-9513
[f] https://orcid.org/0009-0008-4486-1810
[g] https://orcid.org/0009-0008-9954-0184

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procedure when accounting for the cost, the effort, and the amount of time involved (Novák, 2012; Sonebi, Ammar and Diederich, 2016). As a result, engineers have decided that the most effective course of action is to reinforce and restore existing construction members (ACI Committee 116, 2000; Thanoon *et al.*, 2005; Alexander, Dehn and Moyo, 2015). The first thought that came to mind was to make the reinforced concrete (RC) components have a larger cross-sectional dimension. However, this approach increases concrete member durability and changes space dimensions, especially in deep beams. Due to these issues, new methods were developed, such as raising threshold supports and concrete member reinforcement ratios (Eide, Hisda and L, 2012). Nevertheless, these techniques resulted in an increase in the structural loads in addition to other issues. Researchers made ongoing efforts to find other substitute methods and alternative materials to overcome the loss caused by the problems that were described earlier. They found that exterior packaging made of polymeric fibres including carbon, aramid, and glass fibre-reinforced polymer (FRP) concrete strengthens and repairs concrete elements due to their good mechanical and physical qualities (An, Saadatmanesh and Ehsani, 1991; Maalej and Leong, 2005).

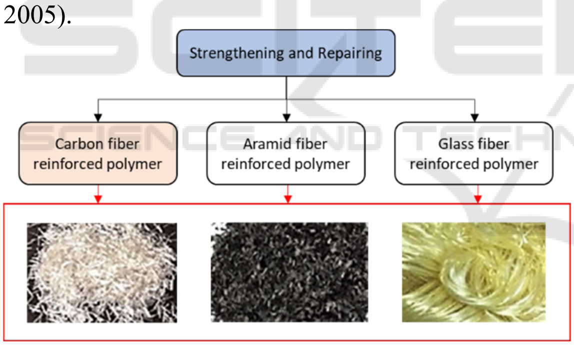

Figure 1: CFRP materials for strengthening and repair purposes (Wu and Li, 2017).

CFRP can also be used to repair or strengthen existing concrete. Previous CFRP research has yielded promising results. Many research initiatives have examined how CFRP affects normal concrete's mechanical properties. However, CFRP modeling for reinforcing and repairing concrete is limited and lacks applications. Thus, to apply CFRP to NC, all essential data must be collected. Based on the literature evaluation, future research should highlight an additional research gap and inadequate data (Asaei, Lau and Bunnori, 2013; Hassan, Sherif and Zamarawy, 2017).

Although steel-reinforced concrete members provide superior strength, strengthening concrete members is hampered by a number of factors, the most significant of which are the weight of the concrete members and the corrosion that occurs over time, especially when exposed to significant exposure. Additionally, restoring damage with steel reinforcement in concrete is impossible (Wu and Li, 2017). Carbon, aramid, and glass fiber reinforced polymers (FRP) are better for reinforcing and rebuilding concrete sections due to their benefits (see Figure 2).

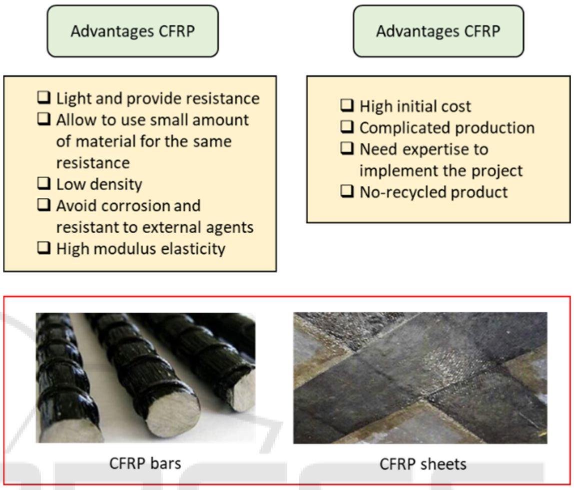

Figure 2: Advantages and disadvantages of CFRP and illustration of CFRP product (Mustafaraj and Yardim, 2018).

The CFRP is not only lightweight but also sturdy, as it possesses a high tensile strength, stiffness, resistance to chemicals and corrosion, and minimal thermal expansion (Osman *et al.*, 2016). Despite the fact that CFRPs are more expensive than other construction materials, they are frequently used in situations that call for a high strength-to-weight relation (Bukhari *et al.*, 2010; Khairi *et al.*, 2021). In the construction industry, CFRPs are frequently used to reinforce concrete, steel, and masonry structures. This can be accomplished either by retrofitting already-existing structures to increase their strength or by using CFRPs as an alternative reinforcing material to steel (Wu and Li, 2017). The primary application of CFRP involves on retrofitting structure to enhance load capacity and lower the damage. The illustration properties of CFRF under various type vs. steel presented in Figure 3. Not only that, to support utilities, opening somehow necessary to be placed on the structure (Komara *et al.*, 2021; Pertiwi, Komara and Fristian, 2021), FRP offer strengthening without changing the conditions. FRP also popular to increase durability performance especially when the it is attract the significant environmental compared to high strength concrete (Komara *et al.*, 2020; Casita, Suswanto and Komara, 2022), concrete with supplementary materials (Mooy *et al.*, 2020) or engineered cementitious concrete (Komara *et al.*, no date; Oktaviani *et al.*, 2020).

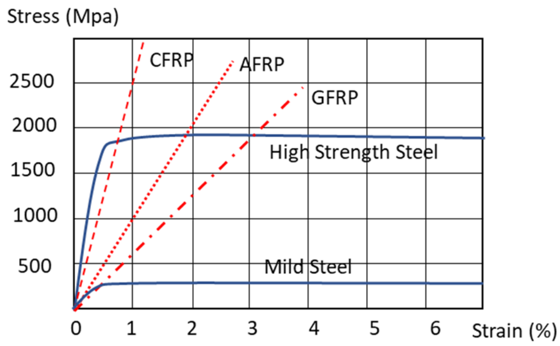

Figure 3: CFRP strength properties vs steel (Hassan, Sherif and Zamarawy, 2017).

2 STRENGTHENING RC MEMBERS USING CFRP

FRP is increasingly used as reinforcement in RC members due of its ultra-high strength and flexibility. FRPs are durable, corrosive-resistant, and low-maintenance (Thanoon *et al.*, 2005). Recently, FRP bars and sheets have proven to have endless promise as a steel plate substitute for reinforcing or repairing concrete structures (Maalej and Leong, 2005; Osman *et al.*, 2016).

In addition, FRP has established itself as a viable option for the strengthening of RC members in applications where the use of conventional strengthening procedures might be difficult and fraught with complications (Gu, Pan and He, 2019). A method for increasing the strength of RC members that involves externally epoxy-bonding steel plates is comparable to the FRP approach. This method is very prevalent and widely used. This method is straightforward, useful, and economical all at the same time. Nevertheless, this method is plagued by a number of drawbacks and challenges, including the following: the challenge of installing the heavyweight steel plates at the construction site; the weakening of the bond between the steel and the concrete as a result of the corrosion of the steel; and the restricted delivery lengths of steel plates (for the purpose of reinforcing the long construction members) (Asaei, Lau and Bunnori, 2013).

In circumstances such as these, FRP laminates, sheets, and bars are evaluated as potential replacements for steel plates in the context of the strengthening of RC elements. Therefore, fiber reinforced plastic (FRP) could be used in place of steel for the purpose of reinforcing and repairing RC members due to the fact that it is simple to install, has a wide range of availability (in terms of length and type), is simple to transport, requires minimal maintenance, has a reduced influence from corrosion, and possesses a number of other desirable characteristics.

The effect of CFRP fortification on the general behavior and failure modes of RC members has been the subject of a great deal of research, and it has been evaluated in a number of different ways. Nevertheless, each of these studies recommended a unique method of putting CFRP materials in place. The carbon fiber reinforced plastic (CFRP) components that are used in construction are typically accessible in the form of sheets and bars (strips). Additionally, these CFRP sheets and segments can be installed in RC members according to the specific requirements of the construction application. It is possible to bind CFRP composite strips to the external tension zones of beams and slabs, which will result in an increase in the flexural strength of the RC members. On the other hand, CFRP sheets can be wrapped around RC columns to increase containment and axial strength (Gao and Cai, 2015; Triantafillou, 2016). This is illustrated in the figure. Furthermore, CFRP enhances ductility and shear strengthening in columns and beams, in addition to increasing flexural, shear, and torsion strengths (Inge, Nugroho and Njo, 2018; Muthukumaraswamy kamalakannan *et al.*, 2021).

3 CASE STUDY

3.1 Design Parameter of CFRP

The calculation of the bearing capacity of the flexural members should meet the basic assumptions of the Specifications for Design of Concrete Structures. In addition to these basic assumptions, the calculation of the bearing capacity when using carbon fiber to strengthen the beam and slab members should also meet the following requirements:

a. When the member achieves the ultimate state of flexural load-bearing capacity, the tensile strain of the carbon fiber is determined according to the assumption that the section strain remains flat.

This tensile strain, however, should not exceed the allowable tensile strain of the carbon fiber;

b. When the influence of the secondary force is taken into consideration, the initial strain of the concrete at the edge of the tension zone before reinforcement should be calculated based on the load condition during reinforcement and the supposition that the section strain continues to be flat;
c. The tensile tension of carbon fiber ought to be equal to the product of the carbon fiber's elastic modulus and its tensile strain;
d. The bond between the carbon fiber and the concrete does not fail to peel apart until after the ultimate condition of flexural bearing capacity has been reached.

Simple fitting of CFRP for the effective tension. Assuming that the function of carbon fiber fabric is comparable to that of a stirrup, the following equation must be used in order to describe shear theory:

$$V_f = \frac{f_{fe} A_f h_f}{s_f} \tag{1}$$

$$\varepsilon_{fe} = 0.00001 f_c^{3/2} (\rho_f E_f)^{-1.1299} \tag{2}$$

Where V_f is the shear capacity, respectively, $f_{fe} A_f h_f$, the effective tensile strength, the area of the carbon and the height of the carbon fibre cloth. In addition, s_f is spacing and ε_{fe} is effective strain. From Eq. (1) and (2), CFRP strain in proportion to the concrete strength.

3.2 Structural Modelling – SAP 2000

In this evaluation, case study on building Club House Graha Natura was used. To determine the current situation which consider lift loading. In the beginning the structure was not designed to have such load parameters, then after some identification, lift then decide to be constructed on the current structure. CFRP is the alternative on the design implementation. For the information, the building has a function as a sport centre with 17.5 m height in total. It has 5-story, each story having 3.5 m height. The building is located in Surabaya using reinforced concrete (RC). The inputted materials are Informed in Table 1 as follows.

Table 1: Concrete and reinforcement quality.

Item	
Concrete strength (*f'c*)	
- Column	25 MPa
- Beam	25 MPa
- Plate	25 MPa
Steel reinforcement (*fy*)	
- Plain bar	240 MPa
- Deformed bar	490 MPa

The combination of loading is designed according to the SNI 1727-2013 (Badan Standardisasi Nasional, 2013) , where the life load for all story assigned as 2.5 kN/m^2. The response spectrum design parameter is designed in accordance with the SNI 1726-2019 (Badan Standardisasi Nasional, 2019) with the repetition period 50 years. The condition of the soils characterized as soft soil (SE) with level of risk category is III. The model is illustrated in Figure 4. Where moment curvature representing hinge properties informed in Figure 5. This condition of material property illustrates the real behaviour of RC and CFRP.

The percentage of difference that exists between the two different sets of outcomes can be calculated using equation (3). The new stress strain of the concrete material is calculated based on relevant studies in order to arrive at the result of ultimate moment and curvature for CFRP-confined concrete (Elarbi, 2011; Asaei, Lau and Bunnori, 2013) and then it is applied to the material definition of SAP2000 analyser. This allows one to obtain the result of ultimate moment and curvature for CFRP-confined concrete. The findings of the difference percentage have demonstrated that it is almost the same, but there was a deviation from the permissible range of difference. According to the manual definition of SAP2000, the acceptable range of difference for comparing the outcomes of independent calculations and analyses using SAP2000 is specified to be 5%. Although the difference between an independent calculation and the SAP2000 analysis outcome based on Yuan et al. (Triantafillou, 2016) was 10.7% for ultimate moment, the percentage difference for ultimate curvature was only 1.7%. In spite of the fact that the difference was very close to the acceptable range of variation when using the method of calculation of moment and curvature. It was discovered that the difference between moment and curvature could be found with a smaller amount of deviation when using the basic calculation of ultimate moment and curvature.

$$Percent\ difference = 100\left(\frac{SAP2000\ result}{Independent\ result}\right) - 1 \qquad (3)$$

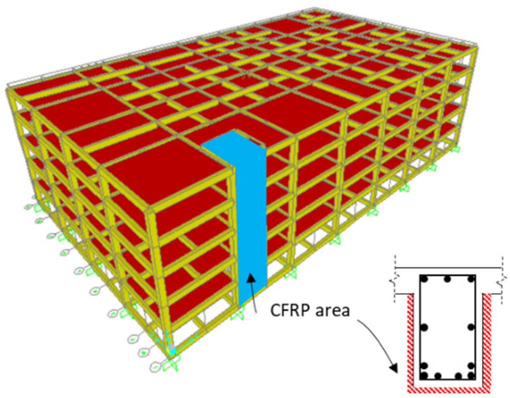

Figure 4: Structural model using SAP2000.

Table 2: Distribution of CFRP sheets.

Beam 1 - 5		
Moment ultimate [kN]	Moment nominal [kN]	Strengthening CFRP (sheet number)
89	122	-
89	122	-
178	122	-
82	122	3
132	122	1
142	122	1
83	122	1
115	122	1
98	122	1
71	122	1
15	122	-

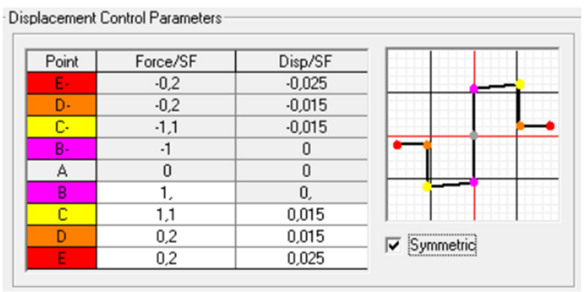

Figure 5: Hinges property under distribution of displacement control parameter on the SAP2000 modelling.

The CFRP material that is using in this analysis used SIKA Wrap 231C with specified tensile strength 4800 MPa and yield strain 1.8%. Modulus elasticity informed with 2.34×10^5 MPa. Reduction factor according to the ACI 440, *CE* = 0.95. With the result, design ultimate strength of CFRP = 4560 MPa and ε_{fe} = 0.004. From the evaluation, the placed CFRP on the beam are needed 10 sheets in total which placed in every stories. Detailed distribution of the strengthening on beam element due to the lift loading is illustrated in Table 2.

4 CONCLUSIONS

This research is focused on verifying the model of FRP-confined columns in SAP2000, which states that the calculation of the material properties of wrapped RC columns. The modelling process and the process of designating specialties are both discussed in context, and the results of the analysis have been compared to previous research in order to determine the reliability of the analysis's findings. For FRP confined RC columns, the SAP2000 permissible range of difference is controlled both with and without consideration to the ACI 440 rules for rectangular and circular section. This is done in accordance with the recommendation that was given.

Research was conducted to determine the performance of FRP-confined columns. The outcomes of this study revealed that the performance of these columns is comparable to that of conventional RC columns in terms of yield; nevertheless, it is distinct from the performance of these columns in terms of flexibility and post-yield. In the meantime, it has been found out that an adequate stress-strain model for FRP restricted concrete material in the compression zone should also be considered in order to generate an accurate analysis and response of software in the pushover analysis domain. This discovery came about as a result of research that was conducted. Calculation formula simplifies the numerical modelling calculation process, and it can quickly evaluate the actual project in certain circumstances.

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