Jurnal Teknik Sipil & Perencanaan 21 (1) (2019) 9 – 19

JURNAL TEKNIK SIPIL & PERENCANAAN

10.15294/jtsp.v21i1.19364

# Analysis of Strengths of Reinforced Concrete Beam Structures with CFRP Sheet Using Abaqus Software 6.14

Ahmad Yasir [1, a)], Mahmud Kori Effendi [1], Arie Taveriyanto [1], Henry Apriyatno[1]

[1] *Civil Engineering Department, Faculty of Engineering, Universitas Negeri Semarang*

[a)] Corresponding author: ahmadyasir400@gmail.com

**Abstract**. Concrete beams are parts of a structure that serves as a channeling moment to the column structure. The structure of the beam which has undergone yielding reinforcement must be repaired. One of the beam repairs that can be done is by providing reinforcement using Carbon Fiber Reinforced Polymer (CFRP) sheets. The reinforcement structure modeling and analysis were carried out using the Abaqus software. There are two types of modeling, those were laboratory test beam modeled with Abaqus (BPA) and reinforced beam using CFRP (BPC). The beam structure analysis using Abaqus software showed that BPA beam experiences a first crack when the load is 5311.96 lbs with a 0.08 inch displacement, while the BPC-2 beam is first cracked at a load of 5019.93 lbs with a 0.10 inch displacement. The BPA beam experiences an ultimate when the load was 12620.84 lbs with a 0.64-inch displacement, while the BPC-2 beam experiences ultimate when the load was 12403.48 lbs with a displacement of 0.60 inch. The type of crack pattern in both beam models is the type of bending crack.

Keywords: Beam Structure, CFRP, Cracks, Abaqus, Displacement

## INTRODUCTION

Reinforced concrete is composed of concrete and steel reinforcement. A composite material has different properties in both types of material. Concrete has high compressive strength but low tensile strength. In addition, steel reinforcement has the opposite properties such as low compressive strength but high tensile strength. Therefore, the combination of the properties of both materials is good as a composite material that is widely used in various construction buildings. For example in beams, steel reinforcement is placed in the pull area [1].

The development of reinforcement techniques is very fast in terms of both capacity building techniques and structural improvement techniques. This demand has encouraged the development of technology and science related to strengthening techniques. Several reinforcement techniques have been developed such as reinforcement with reinforced concrete blanket methods, methods of wrapping with steel plates, reinforcement methods with polymer cement. It has also been studied to reinforce columns using a wire and steel plate system [2].

Buckhouse has studied methods for strengthening concrete beams for the use of flexible external structural steel channels. This study includes testing experimental control beams that can be used to calibrate finite element models. The width and height of the beams tested are 10 in. and 18 in [3]. Then Wolanski conducted a Buckhouse test block study using the Ansys and David R. Dearth Software conducted research on Buckhouse test beams using MSC / Mars software. With reference to previous research, this current research was conducted using the Abaqus CAE 6.14 software to analyze the flexural strength of reinforced concrete beams.

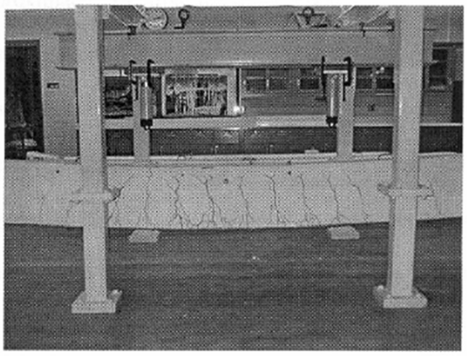

**FIGURE 1**.Typical Cracking of Control Beam at Failure [3]

Structural reinforcement is performed by providing additional strength to a building structure in the form of columns, beams or plates related to the structure of a building by adding materials such as Carbon Fiber Reinforced Polymer (CFRP), Carbon Fiber Wraps (CFW) or Carbon Wrapping.

## Relationship Between Load and Deflection

The relationship between load and deflection of reinforced concrete beams is illustrated on Figure 2. The relationship between load and deflection consists of three areas before the collapse [4] as follows:

- Area I : Pre-cast level, in which the structural stems are free of cracks. The precast segment of the load curve - deflection is a straight line that shows full elastic behavior.
- Area II : Post-load load level, in which structural rods have controlled cracks that are still acceptable, both in distribution and width.
- Area III : The degree of post-serviceability crack, in which the stress on the tensile reinforcement has reached its yielding stress.

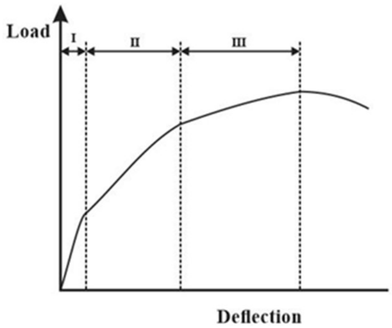


**FIGURE 2**. Relationship between load-deflection in beams [4]

## Crack Patterns

Cracks are the types of damage that most often occur in concrete structures, which visually look like lines. Cracks occur when the concrete starts to harden (concrete has not been able to withstand service load) and are caused by several factors such as, freezing cold air (in areas with winter), shrinkage (shrinkage), and decline (settlement). The cracks that occurs when the concrete hardens is structural cracking. This crack occurs because of loading which results in the emergence of bending stresses, shear stresses and tensile stresses [5]. Basically there are three types of cracks in beams [6]:

1. Flexural Crack
2. Shear Crack
3. Flexural Shear Crack

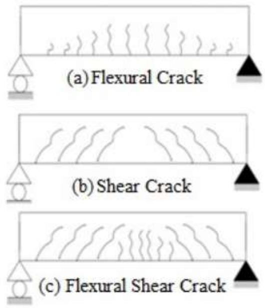


**FIGURE 3**. Cracks on reinforced concrete beams [6]

## Fiber Reinforced Polymer (FRP)

The development of Fiber Reinforced Polymer (FRP) composite materials has opened up new opportunities for the need to repair and strengthen reinforced concrete structures. There are three types of FRP that are distinguished by their constituent fibers: Carbon Fiber Reinforced Polymer (carbon fiber), Glass Fiber Reinforced Polymer (glass fiber), and Aramid Fiber Reinforced Polymer (aramid fiber). In this study, Carbon Fiber Reinforced Polymer (carbon fiber) was used.

1. Carbon Fiber Reinforced Polymer (CFRP)

   Carbon Fiber Reinforced Polymer (CFRP) is one type of FRP. CRFP polymer fibers are made of plastic matrices are reinforced by fine fibers from carbon. Carbon Fiber Reinforced Polymer is used in the construction of existing building structures. The use of CFRP on a construction is usually caused by several things, namely:

   The application of CFRP material as a function of repairing and strengthening existing concrete structures has developed rapidly in several countries. This reinforcement technique is very efficient, does not cause rust like an external steel plate. The reinforcement function with CFRP composite systems is to increase strength or provide increased flexural, shear, axial and ductility capacity, or various combinations of them. High CFRP durability is more economical to use in corrosive environments where steel will easily rust.

   CFRP can be used to increase the flexural and shear capacity of reinforced concrete beams, plate bending, pressure, shear and bending. CFRP in the form of sheets, plates or bars can be mounted on the surface of the beam or plate which is stretched as flexible reinforcement. As beam shear reinforcement, CFRP sheets can be glued to the side of the beam. When it is used on columns, CFRP sheets or coatings can be placed on the outside of the column to increase ductility and strength.

2. The moment of bending of the beam is reinforced by CFRP

   Planning guidelines for CFRP can refer to the ACI (American Concrete Institute) standard, namely "ACI 440.2R-08 Guide for Design and Construction of External Bonded FRP Systems for Strengthening Concrete Structures" [7].

   For flexible reinforcement with CFRP, design calculations refer to the ACI committee 440.2R-08. In designing beams with CFRP reinforcement, strain values below the CFRP breaking strain are used. It can be seen in Figure 4.

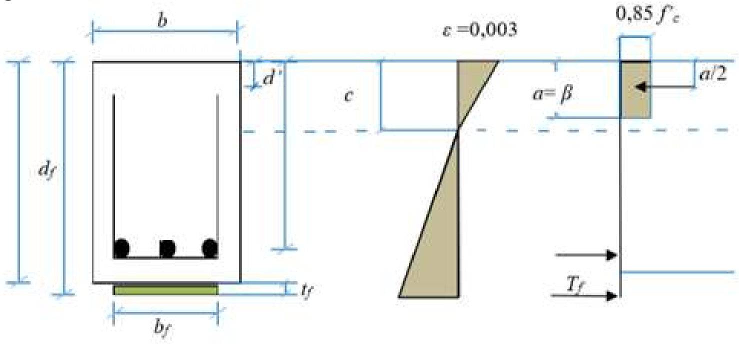


**FIGURE 4**. Strain for the ACI method 440-2R-08

The nominal moment capacity of flexural reinforcement using CFRP can be calculated by the following equation. For flexural strength, the ACI committee 440 recommends a reduction factor value for CFRP ($\psi$f) of 0.85 [6].

$$M_n = A_s f_s \left( d - \frac{\beta_1 c}{2} \right) + \psi_f A_f f_{fe} \left( h - \frac{\beta_1 c}{2} \right)$$

## Abaqus

Abaqus is a finite element-based computer program used to analyse various kinds of nonlinear problems including reinforced concrete. This program is able to accurately mesh with various choices of element models. Therefore, it can be closer to the actual conditions and able to perform dynamic analysis and cyclic loading. Abaqus provides solutions to various constitutive equations to solve nonlinear problems so that it is easier for users to choose the right solution for the model to be analysed [8].

# RESEARCH METHODOLOGY

## Data Material

The data materials in the analysis study are used based on [9].

$f_c^{'} = 4800\,\text{psi}$
$f_y = 60900\,\text{psi}$

$E_c = 394000\,\text{psi}$

$E_s = 29000000\,\text{psi}$

The data used in the CFRP beam analysis study include the assumptions as follows:

- $f_c^{'}$ and $f_y$ are assumed by 50% reduction during the condition of the installment of CFRP ( $f_c^{'} = 2400\,\text{psi}$ $f_y = 30450\text{psi}$ ) based on the crack section inertia reduction factor ranges from 0.4-0.8
- CFRP used attaches well to the beam structure.
- $E_{cfrp} = 23931226.7\,\text{psi}$

In modeling a beam test object, using Abaqus there are six parts or parts as in Table1.

**TABLE 1.** Data part or beam element section [10]

| No. | Name Part | TypePart |
|---|---|---|
| 1 | Beam | Solid |
| 2 | Reinforcement | Wire |
| 3 | Stirrups | Wire |
| 4 | Plate Load | Solid |
| 5 | Suport Plate | Solid |
| 6 | CFRP | Shell |

In this study, the concrete material used is Concrete Damaged Plasticity. Other data used in this study are elastic material, constitutive concrete material in pressure and tensile conditions, and plasticity parameters. The parameters included in this research model are listed in Table 2, Table 3 and Table 4.

**TABLE 2**. Data parameters for plasticity concrete [10]

| Dilatation angle ($\psi$) | Eccentricity | $F_{b0}/f_{c0}$ | K | Viscosity |
|---|---|---|---|---|
| 36 | 0,1 | 1,667 | 0,667 | 0.0 |

**TABLE 3**. Constitutive data on compressive concrete [10]

| $\varepsilon_c$ | $\sigma_c$ (psi) | $d_m$ |
|---|---|---|
| 0 | 1663,75465 | 0 |
| 0,00039 | 2562,2718 | 0 |
| 0,00061 | 3046,8763 | 0 |
| 0,00109 | 3777,42255 | 0 |
| 0,00159 | 4129,1418 | 0 |
| 0,00179 | 4159,3859 | 0 |
| 0,00209 | 4093,32245 | 0,02 |
| 0,00259 | 3702,9085 | 0,11 |
| 0,00354 | 2079,69295 | 0,5 |
| 0,00459 | 877,7749 | 0,79 |
| 0,00559 | 506,11815 | 0,88 |
| 0,00595 | 136,03175 | 0,97 |

**TABLE 4**. Constitutive data on tensile concrete [10]

| $\varepsilon_c$ | $\sigma_c$ (psi) | $d_m$ |
|---|---|---|
| 0 | 275,1259 | 0 |
| 0,00008 | 305,69625 | 0 |
| 0,00013 | 289,82165 | 0,05 |
| 0,00015 | 281,88435 | 0,08 |
| 0,0002 | 264,20885 | 0,14 |
| 0,00039 | 194,5784 | 0,36 |
| 0,00052 | 146,95605 | 0,52 |
| 0,00061 | 115,2083 | 0,62 |
| 0,00093 | 0 | 0,99 |

In this study, the data used are elastic modulus and constitutive steel material as in Table 5 and Table 6.

**TABLE 5**. Parameter of elasticity of steel reinforcement [10]

| Modulus Elasticity (psi) | Poison Ratio ($v$) |
|---|---|
| 29000000 | 0,3 |

**TABLE 6.** Parameters of Plasticity of steel reinforcement [10]

| Yield Stress (psi) | Strain |
|---|---|
| 60900 | 0 |
| 60900 | 0.018 |
| 72500 | 0.028 |
| 72500 | 0.198 |

The CFRP material data used is the modulus of elasticity and the plasticity parameters of CFRP in Table 7 and Table 8.

**TABLE 7.** Parameter elasticity CFRP

| Modulus Elasticity (psi) | Poison Ratio ($v$) |
|---|---|
| 23931226,7 | 0,32 |

**TABLE 8**. Parameter plasticity CFRP

| Yield Stress (psi) | Strain |
|---|---|
| 152289,6 | 0 |

## Test Specimen

Detailed specimen of laboratory test beams (BPA) and Abaqus model (BPC) beams can be seen in Figure 6 and Figure 7 [8]. Dimension data and BPA beam reinforcement data can be seen in Table 9 and BPC beam dimension data can be seen in Table 10. The CPRP beam is installed in the mid span beam, 60 inch, 80 inch, 120 inch and 180 inch (BPC-1, BPC-2, BPC-3 and BPC-4), respectively from center of the beam.

**TABLE 9**. BPA beam dimension data [9]

| Beam Dimension (inch) | Main Reinforcement (inch) | Reinforcing stirrups (inch) | |
|---|---|---|---|
| | | field | support |
| 180 x 10 x 18 | 0,628 D 3 | Ø0.374 – 12 | Ø0.374 – 7,5 |

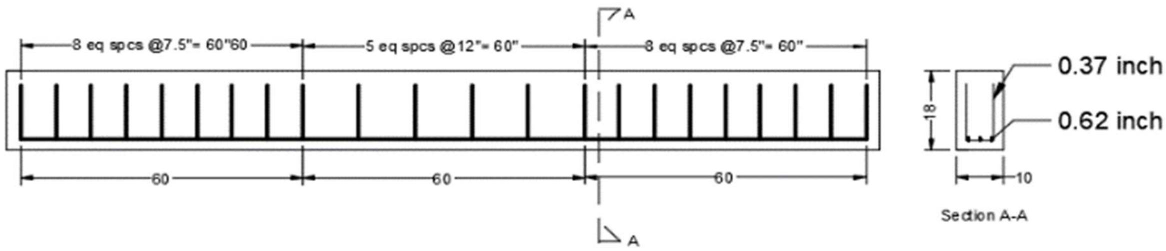


**FIGURE 6**. BPA beam details [9]

**TABLE 10**. BPC beam dimension data [9]

| Dimension (inch) | | Main Reinforcement (inch) | Reinforcing stirrups (inch) | |
|---|---|---|---|---|
| Beam | CFRP | | field | support |
| 180 x 10 x 18 | 80 x 10x 0.01181 | 0,628 D 3 | Ø0.374 – 12 | Ø0.374 – 7,5 |

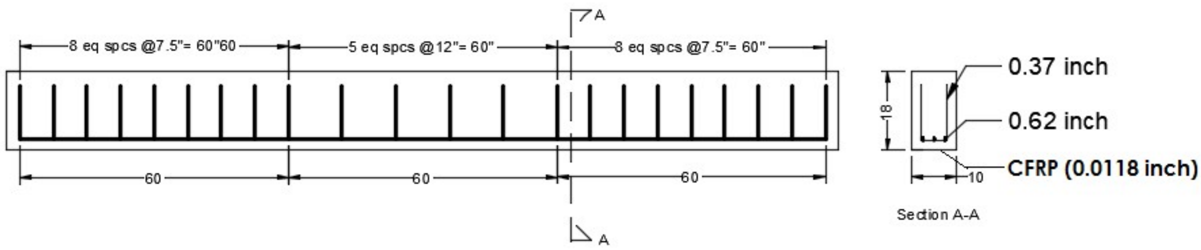


**FIGURE 7**. BPC beam details [9]

## RESULT AND DISCUSSION

After modeling reinforced beams using Abaqus, a graph of the relationship between load and displacement is obtained. Can be seen in Figure 8 and Figure 9.

## Relationship between Load and Displacement

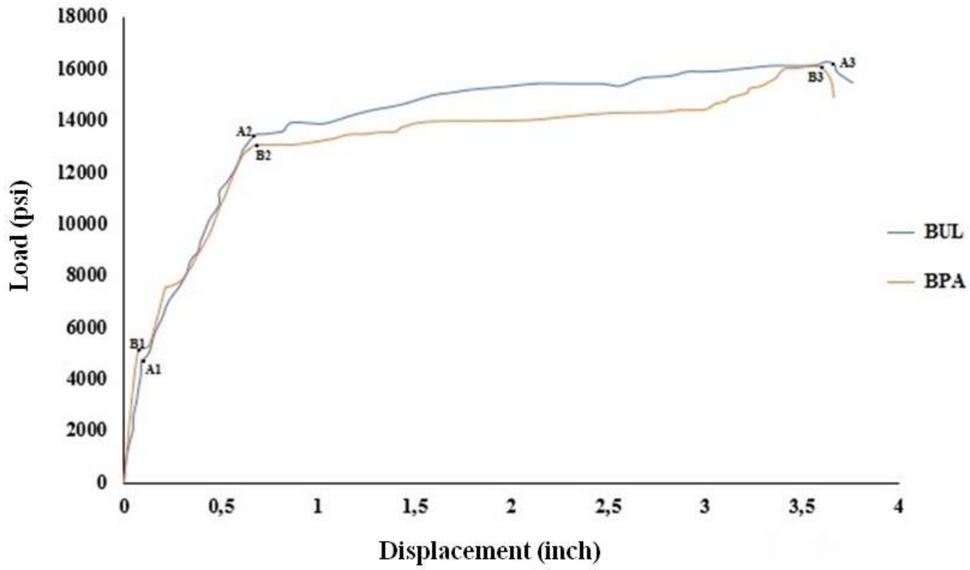


**FIGURE 8.** Graph of BUL and BPA load and displacement relations

From Figure 8, it can be seen the load relationship and displacement of the experimental beam (BUL) [3] and Abaqus (BPA) beam. The first crack on the BUL beam occurs at a load of 5078 lbs with a displacement of 0.05 inch (point A1) and the BPA beam experiences a first crack at a load of 5311.96 psi with a displacement of 0.08 inch (point B1). While the ultimate BUL beam occurs at a load of 13779 psi with a 0.57 inch displacement (point A2). The ultimate BPA beam occurs when the load is 12620.84 psi on a 0.64 inch displacement (point B2). Then the BUL beam collapses when the load is 16118.4 psi at a 3.63 inch displacement (point A3). The BPA beam collapsed when the load was 15934.6 psi with a 3.58 inch displacement (point B3). From this data, the difference between BUL beams and BPA beams has a difference of only 4%.

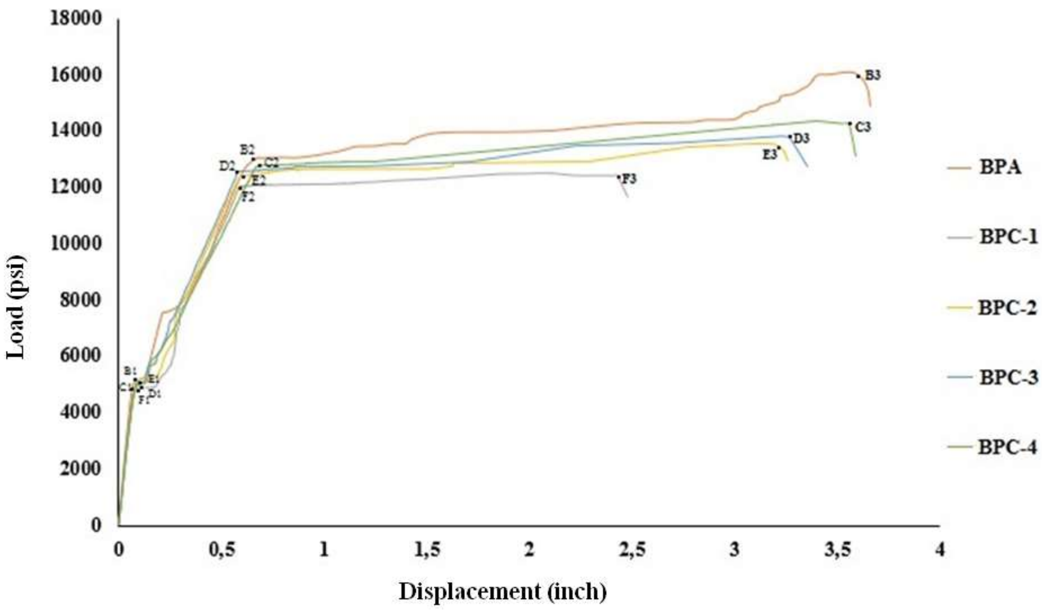


**FIGURE 9**. Graph of BPA and BPC load and displacement relations

From Figure 9, it can be seen that the BPA beam experiences first crack at a 0.08 inch displacement when holding a load of 5078 lbs (point B1), ultimate BPA occurs when the load is 12620.84 psi at a 0.64 inch displacement (B2 point), and collapses at the displacement 3.58 inch while holding a load of 16085.34 lbs (B3 point) while for BPC-1 beams, experiencing a first crack on the displacement at 0.09 inch when holding a load of 4894.74 lbs (F1 point), ultimate when load 11986.47 lbs (point F2), and collapses at a 2.42 inch displacement when holding a load of 12433.01 lbs (point F3). For the BPC-2 beam, it experiences a first crack at a 0.10 inch displacement when holding a load of 5019.93 lbs (point E1), ultimate when the load is 12403.48 lbs (E2 point), and collapses at a 3.22 inch displacement when holding loads 13528, 56 lbs (point E3). While the BPC-3 beam experienced a first crack at a 0.10 inch displacement when holding a load of 5021.08 lbs (point D1), ultimate when the load is 12561.87 lbs (point D2), and collapses at a 3.24 inch displacement when holding 13780 loads, 79 lbs (point D3). And the BPC-4 beam has a first crack at 0.11 inch displacement when holding a load of 5058.64 lbs (point C1), ultimate when it loads 12674.64 lbs (point C2), and collapses at a 3.47 inch displacement when holding loads 14337.92 lbs (point C3).

Based on the graph Figure 8, it can be seen that the BPC-2 beam is the most effective, it can be seen from the distance between the yielding time at 0.10 inch displacement and when the concrete collapses at a 3.22 inch displacement. For the BPC-1 beam, the distance of collapses is too short, which is on the 2.42 inch displacement. And for the BPC-3 beam, it is considered to be less efficient because it has a significant collapse distance compared to the BPC-2 beam, which is at a 3.24 inch displacement even though it has a 40 inch CFRP length difference. Whereas the BPC-4 beam is also inefficient compared to the BPC-2 beam because with the CFRP 100 inch long difference only able to resist collapsing on the 3.47 inch displacement.From Figure 8, we can see the load at first crack and the ultimate load when in Table 11.

**TABLE 11**.The load of first crack and the ultimate BPC beam

| Beam Code | $P_{cr}$ | $P_u$ |
|---|---|---|
| BPC-1 | 4894,74 lbs | 11986,47 lbs |
| BPC-2 | 5019,93 lbs | 12403,48 lbs |
| BPC-3 | 5021,08 lbs | 12561,87 lbs |
| BPC-4 | 5058,64 lbs | 12674,64 lbs |

Based on Table 11, it can be seen that the most effective use of CFRP on beams is the 80-inch CFRP (BPC-2). Because it is able to withstand the load when first crack is 5019.93 lbs, the current load is equal to 12403.48 lbs and collapses when it reaches a load of 13528.56 lbs with a 3.22 inch displacement. First crack and ultimate load and displacement recap on BUL beam, BPA beam, and BPC-2 beam can be seen in Table 12.

**TABLE 12.** First crack and ultimate load

| Beam Code | *First Crack* | | *Ultimate* | |
|---|---|---|---|---|
| | Load (lbs) | *Displacement (inch)* | Load (lbs) | *Displacement (inch)* |
| BUL | 5078 | 0,05 | 13779 | 0,57 |
| BPA | 5311,96 | 0,08 | 12620,84 | 0,64 |
| BPC-2 | 5019,93 | 0,10 | 12403,48 | 0,60 |

## Crack Pattern

The crack pattern that occurs in BPA beams is a type of flexural crack. The direction of the crack occurs almost perpendicular to the beam axis. The crack pattern of BPA beams when first crack and ultimate can be seen in Figure 10 and Figure 11.

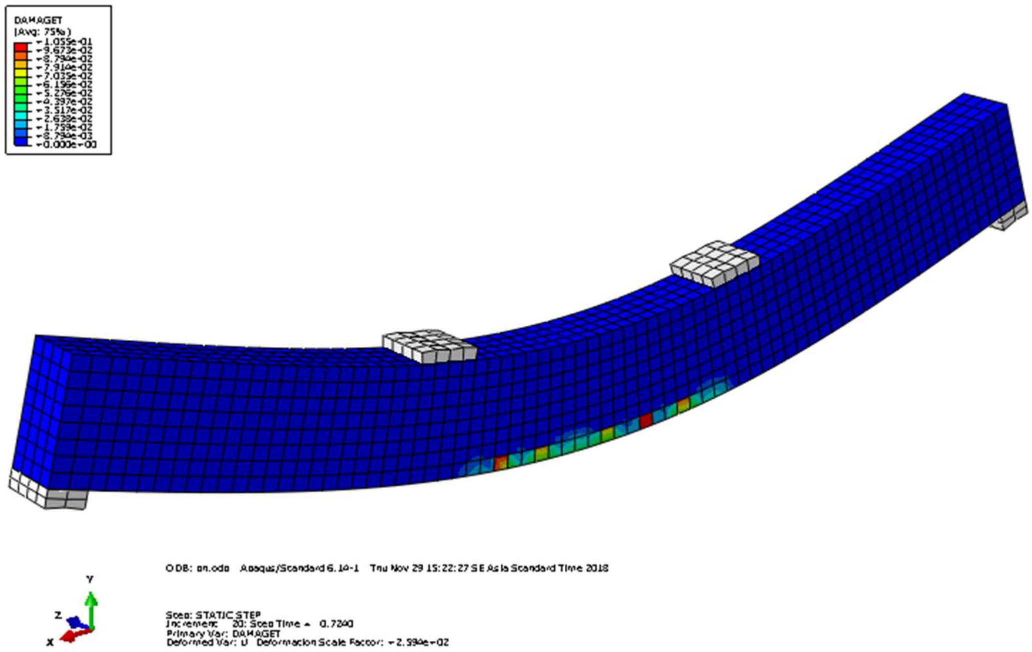


**FIGURE 10**. BPA beam crack pattern when first crack

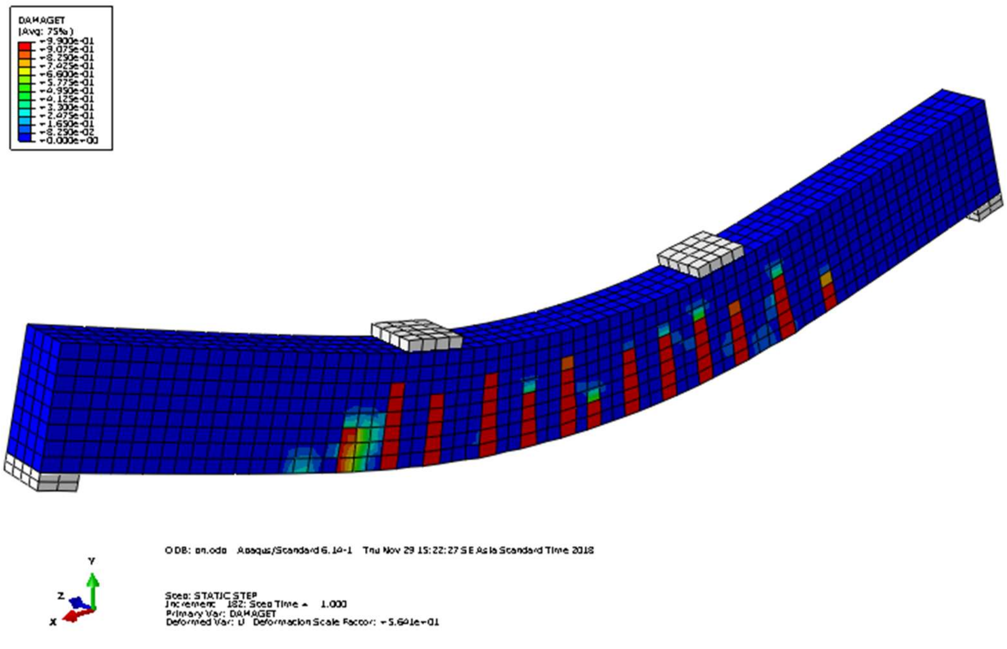


**FIGURE 11.** The ultimate BPA beam crack pattern

In the BPC-2 beam, flexural crack is identified similar to BPA beam. The crack pattern of BPC-2 beam when first crack and ultimate can be seen in Figure 12 and Figure 13.

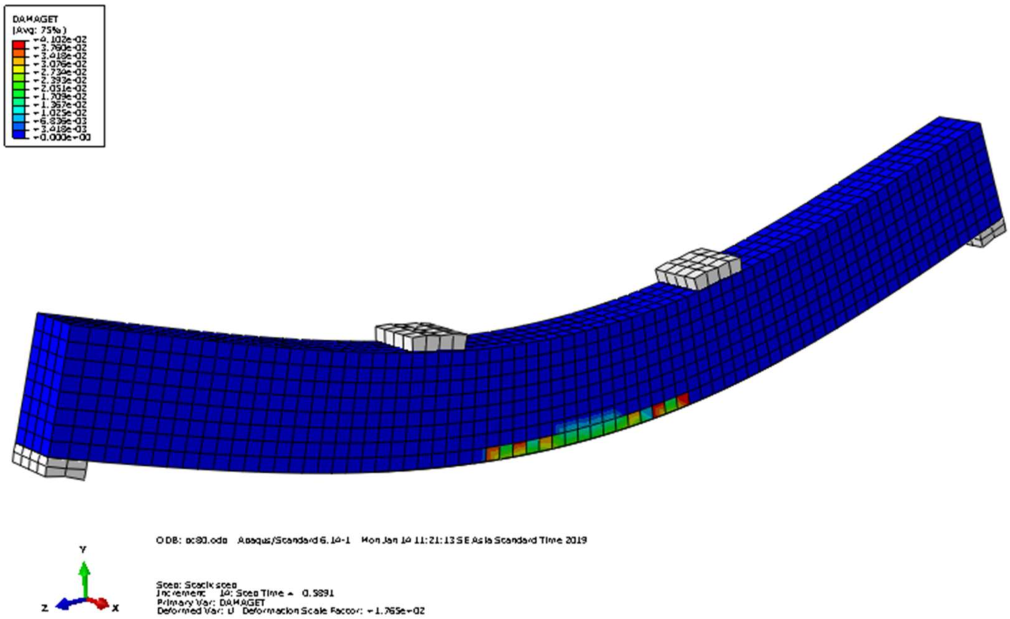


**FIGURE 12.** BPC-2 beam crack pattern when first crack

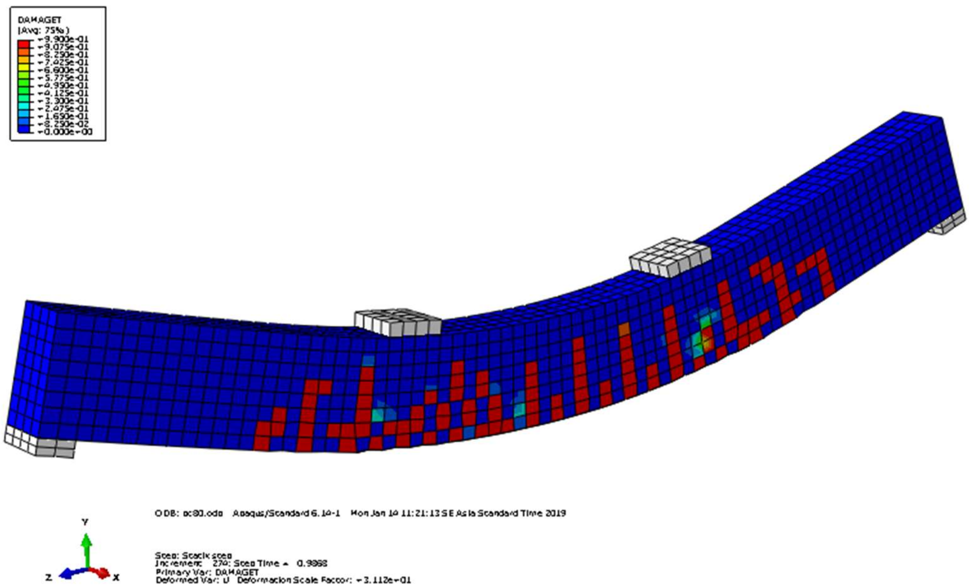


**FIGURE 13.** The ultimate BPC-2 beam crack pattern

## CONCLUSION

The results of reinforcement of fc' and fy which were reduced by 50% were strengthened using CFRP sheets, namely the BPC-2 beam collapses when it reaches a load of 13528.56 lbs with a 3.22 inch displacement. These results almost approached the situation when the beam was still in normal condition (BPA ) which was collapsing when the load is 16085.34 lbs with a 3.58 inch displacement. The type of crack pattern that occurs in the BPA beam model and BPC-2 beam is a flexural crack because the crack propagation moves intensively from the pull side to the beam press side.

## REFERENCE


[1] C.-K. Wang, B. Hariandja, and C. G. Salmon, *Desain beton bertulang*. Erlangga, Jakarta, 1987.

[2] J.-I. Sim and K.-H. Yang, "Flexural behavior of reinforced concrete columns strengthened with wire rope and T-Plate units.," *ACI Struct. J.*, vol. 106, no. 5, 2009.

[3] E. R. Buckhouse, "External flexural reinforcement of existing reinforced concrete beams using bolted steel channels," 1997.

[4] E. Nawy, *Reinforced concrete: A fundamental approach*. 2000.

[5] A. AZIZ, "Perilaku Sambungan Balok Kolom Eksterior tipe 'L' tanpa dan dengan Bekisting Bataton." Universitas Gadjah Mada, 2015.

[6] R. I. Gilbert and N. C. Mickleborough, *Design of prestressed concrete*. CRC Press, 1990.

[7] A. C. I. C. 440, "ACI 440.2 R-02: Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures," 2003.