Flexural strength using Steel Plate, Carbon Fiber Reinforced Polymer (CFRP) and Glass Fiber Reinforced Polymer (GFRP) on reinforced concrete beam in building technology

Johannes Tarigan, Fadel Muhammad Patra and Torang Sitorus
Department of Civil Engineering, Faculty of Engineering, 5 Jalan Perpustakaan, Universitas Sumatera Utara, Medan, North Sumatera, 20155, Indonesia
E-mail: johannes.tarigan@usu.ac.id, patrafadel@gmail.com and torangs02@gmail.com

Abstract. Reinforced concrete structures are very commonly used in buildings because they are cheaper than the steel structures. But in reality, many concrete structures are damaged, so there are several ways to overcome this problem, by providing reinforcement with Fiber Reinforced Polymer (FRP) and reinforcement with steel plates. Each type of reinforcements has its advantages and disadvantages. In this study, researchers discuss the comparison between flexural strength of reinforced concrete beam using steel plates and Fiber Reinforced Polymer (FRP). In this case, the researchers use Carbon Fiber Reinforced Polymer (CFRP) and Glass Fiber Reinforced Polymer (GFRP) as external reinforcements. The dimension of the beams is 15 x 25 cm with the length of 320 cm. Based on the analytical results, the strength of the beam with CFRP is 1.991 times its initial, GFRP is 1.877 times while with the steel plate is 1.646 times. Based on test results, the strength of the beam with CFRP is 1.444 times its initial, GFRP is 1.333 times while the steel plate is 1.167 times. Based on these test results, the authors conclude that beam with CFRP is the best choice for external reinforcement in building technology than the others.

1. Introduction
Many of today's buildings use concrete as building technology, rather than the steel or wood, as construction materials because concrete has several advantages. The price is relatively low because it uses materials from local materials such as aggregate and cement. Concrete is wear-resistant and fire resistant materials so that the cost of maintenance is low. Concrete is composed of high-pressure material and has resistance to decay by environmental conditions. Also concrete is very sturdy against earthquakes, vibrations, and wind loads. Besides that, fresh concrete can be easily lifted or cast in any form and any size depending on the desire so that the casting time is short.

With many advantages of concrete, it is not surprising that the current building construction uses concrete as material. But now many buildings of old concrete so much damage that occurred. By rebuilding or redesigning already damaged buildings, it is not economically feasible. Under these circumstances, it is now widely used retrofitting or repairing concrete using reinforcement. The concrete constructions can apply it to increase the strength in high rise buildings and also for reinforcement due to the earthquake.
Strengthening concrete construction has developed for years. Some commonly used retrofitting methods include giving sheath to concrete construction or called jacketing using Fiber Reinforced Polymer material (FRP) and installing the steel plate in the concrete beam section.

Nowadays many reinforced concrete structures are beginning to break down indicated by cracks, excessive deflections, and corrosion in reinforcing bars. The error in mix design and human error when casting in the field are several factors that cause damage to buildings. We can retrofit it so that the existing structure can accept the load according to the initial design as well as the new one for the functional changing structure. There are several ways to do it such as adding a layer of concrete, reinforcing steel plate, or using Fiber Reinforced Polymer (FRP).

Fiber Reinforced Polymer has many types among others, are CFRP (Carbon Fiber Reinforced Polymer) and GFRP (Glass Fiber Reinforced Polymer) whose function is almost the same as the use of thin steel plate as reinforced concrete beam reinforcement, which strengthens the tensile part of the reinforced concrete beam.[4]

Fiber Reinforced Polymer has greater tensile strength than steel plate and high stiffness, Fiber Reinforced Polymer (FRP) is simple in installing and lighter than the steel plate. Fiber Reinforced Polymer (FRP) is also resistant to corrosion. Despite its relatively high price, FRP provides the most economical solution to retrofitting because it can dramatically reduce labor costs.

The purpose of this research is to perform experiments on the use of steel plates, Carbon Fiber Reinforced Polymer (CFRP) and Glass Fiber Reinforced Polymer (GFRP) on the strength of concrete bending and analyze which type of reinforcement beam is best. While the dimensions and treatment of test specimens are made equal, the specimens can be compared properly. As for the output of this study is expected to be used as a reference of the best external reinforcement in building technology.

2. Literature Review

2.1. Related theory from previous studies

Previous studies related to external reinforcements in building technology have been widely used. Pangestuti and Handayani examine the use of Carbon Fiber Reinforced Plate (CFRP) as an external reinforcement in the structure of reinforced concrete beams. In this experiment, the beam’s measurement is 150 \times 250 \text{ mm} and 2 \text{ m long} with two treatments. The first beam is given a single reinforcement which is used as a control beam and a second beam without reinforcement and is given a layer of CFRP. From this research is found that placement of CFRP as external reinforcement in tension side of beam can inhibit the emergence of first crack and load beam ability until the initial crack increase by 50%.[12]

Ireneus Petrico discusses the comparison of flexural strength of Reinforced Concrete Beam using Carbon Fiber Reinforced Polymer and Glass Fiber Reinforced Polymer. The results of the study and analysis using CFRP and GFRP showed significant increases in flexural strength of the beam. CFRP can increase the flexural strength of the beam to 65.934\%, while the GFRP is only at 43.956\%. As for the comparison of these two materials, CFRP is superior to GFRP in terms of adding flexural strength.[4]

Alnadher Ali in his study discusses the comparison of reinforced concrete beams without CFRP and with CFRP using experimental methods as many as 16 reinforced concrete samples are casted with SCC (Self Consolidating Concrete) concrete design. The result of the research is that there is an increase of bending strength in the reinforced concrete beam of 7.4\% of the reinforced concrete bending strength without CFRP.[11]

Manna Haloho and Johannes Tarigan in their studies discuss reinforced concrete reinforcement using steel plate. Based on the analytical result there is an increase in the strength of the beam is 3.79 times the initial strength while the test obtained an increase in beam strength of 2.44 times the initial strength. Based on the results of this test, it can be concluded that the use of steel plate in the tensile area can increase the
strength and minimize deflection and the use of anchor to paste the steel plate with concrete can overcome
the problem of loose plate from the concrete beam.[3]

Ivandy Yoman and Johannes Tarigan discuss the strength comparison of reinforced concrete beam
using steel plate and Fiber Reinforced Polymer (FRP). The researchers use Carbon Fiber Reinforced
Polymer (CFRP) while steel plate data taken from Manna Haloho’s previous research. Based on the
analytical result there is an increase of beam strength with FRP is 1.991 times the initial strength, while
with steel plate that is 1.646 times the initial strength. From the test obtained an increase in beam strength
with FRP of 1.444 times the initial strength, while with steel plate of 1.167 times the initial strength.
Based on the results of this test, it can be concluded that the use of FRP in the tensile side of beam is able
to withstand bigger strength than steel plate and also able to inhibit the initial crack.[2]

2.2. Compressive strength of concrete
Concrete is a good material in compressive strength, and very weak with tensile resistance. When the
concrete is accepting the compressive stress the concrete will shorten, altering the length of the alias there
is a strain which is linear. The stress on the concrete reaches its peak at the stress ($f'c$) around the 0.002
strain, then drops slightly to crack at 0.003 strain. This is typical of concrete stress at its age.[6]

![Figure 1. The graph of the strain-stress on concrete.](image)

For compressive strength calculation of the cylindrical sample can be used the following formula:

$$f'c = \frac{P}{A}$$

Information:
- $f'c$ = Compressive Strength on Concrete (MPa)
- $P$ = Pressure Load (N)
- $A$ = The cross-sectional area of sample (mm$^2$)

2.3. Tensile strength of steel
Steel is a strong material withstanding tensile, and weak in holding pressure. In steel occurs two types of
def ormation, namely elastic and plastic. The elastic deformation is the deformation that occurs in the steel
when it is applied, and will be lost when the stress is eliminated. This means that when the stress is
eliminated, the steel will return to its original shape and size. Plastic deformation is the deformation that
occurs in steel permanently, even though it is not given a stress. The yield stress ($f_y$) is the steel stress at
which the rising stress is not accompanied by an increase in the strain.[8]
2.4. **Reinforced concrete beam**
To withstand large tensile forces on the lower edge of the beam fibers, it is necessary to have reinforcing steel, so-called reinforced concrete beams. In this reinforced concrete beam section, the steel reinforcement is planted in the concrete in such a way that the tensile force required to withstand the moment at the cracked cross section can be retained by the reinforcing steel.\(^7\)

2.5. **Load-deflection theory on reinforced concrete beam**
As a result of the increase of loading on the beam causes strength and the stiffness of the beam in accepting the load becomes reduced. From this it can be seen that the bigger load accepted, the deflection is bigger too. So that the beam stiffness value becomes reduced.\(^8\)
2.6. Addition of fiber reinforced polymer on reinforced concrete beam

Fiber Reinforced Polymer (FRP) is a type of thin plate in which there are carbon, glass, aramid fibers. Three principles of FRP use in structural reinforcement are increasing the capacity of the bending moment, shear and axial load on the beam.[2]

Specifically, the fiber material applied to the reinforced concrete beam can be glass fiber, carbon, and aramid. Each has a resemblance between one and the other. The choice of fiber types for retrofitting or repairing a structure depends on several factors, such as structure type, available cost, planned load, environmental conditions, etc.

The stress–strain condition of the concrete sections having flexure can be seen in figure 5. $C_c$ is the compressive force of the concrete, $T_s$ is the tensile force of the steel bar and $j_d$ is the distance from $C_c$ to $T_s$.[12]

![Figure 5. The Distribution of Stress-Strain on Reinforced Concrete Beam.](image)

- a) the beam cross section.
- b) the strain diagram.
- c) the actual stress diagram.
- d) the square stress diagram.

Information:

- $b$ = the width of the beam (mm)
- $h$ = the height of the beam (mm)
- $a$ = the height of the square stress diagram (mm)
- $c$ = the distance from neutral line to the outermost of stress fiber (mm)
- $d$ = the distance from the outermost of stress fiber to the steel bar (mm)
- $C_c$ = the compressive force of the concrete (N)
- $T_s$ = the tensile force of steel bar (N)
- $j_d$ = the distance from $C_c$ to $T_s$ (mm)
- $f_c'$ = the compressive strength of concrete (MPa)
- $f_y$ = the yield stress of steel (MPa)
- $A_s$ = the cross-sectional area of steel bar (mm$^2$)

From figure 5 then:

\[ C_c = 0.85 f'c \cdot a \cdot b \]  \hspace{1cm} (2)
\[ T_s = A_s f_y \]  \hspace{1cm} (3)
\[ \sum F_x = 0 \quad \text{then} \quad T_s = C_c \]  \hspace{1cm} (4)
\[ A_s f_y = 0.85 f'c \cdot a \cdot b \]  \hspace{1cm} (5)
\[ a = \frac{A_s f_y}{0.85 f'c \cdot b} \]  \hspace{1cm} (6)

Based on the equations above, the nominal moment of plain reinforced concrete beam is given by equation (7).
\[
\sum M = 0 \quad \text{then} \quad Ts \cdot jd = Mn
\] (7)

Because \( Ts = Cc \), so \( Mn \) can be translated into equation (8).

\[
Mn = As \cdot fy \cdot jd
\] (8)

If the FRP is installed to the RC Beam then the flexural strength of the beam occurs as in figure 6. \( Tf \) is the tensile force of FRP and \( jdF \) is the distance from \( Cc \) to \( Tf \).\(^{(12)}\)

**Figure 6.** The Distribution of Stress-Strain on Reinforced Concrete Beam with FRP.

a) the beam cross section.

b) the strain diagram.

c) the actual stress diagram.

d) the square stress diagram.

Information:

- \( Tf \) = the tensile force of FRP (N)
- \( jdF \) = the distance from \( Cc \) to \( Tf \) (mm)
- \( fyf \) = the tensile strength of FRP (MPa)
- \( Asf \) = the cross-sectional area of FRP (mm\(^2\))

From figure 6, we can find that:

\[
Tf = Asf \cdot fyf
\] (9)

\[
Cc = Ts + Tf
\] (10)

\[
0,85 \cdot f'c \cdot a \cdot b = As \cdot fy + Asf \cdot fyf
\] (11)

\[
a = \frac{As \cdot fy + Asf \cdot fyf}{0,85 \cdot f'c \cdot b}
\] (12)

\[
Mn = As \cdot fy \cdot jd + Asf \cdot fyf \cdot jdF
\] (13)

For flexural strength with FRP, design calculations refer to ACI Committee 440\(^{(11)}\). The calculations are summarized in the equations above. Based on equations (8) and (13), there is an increase to the flexural strength of RC beam due to the addition of \((Asf, fyf \text{ and } jdF)\). This proves that the addition of FRP can improve the ability of beam in flexure much better than normal condition (without reinforcement). This research will validate the theory above by doing analysis and experiments on RC Beams.

### 3. Research Methodology

The method in this research is an experimental performed at the Concrete Laboratory of FT USU and the FT USU’s Structural Laboratory. The test specimens consisted of three cylindrical of 15 cm in diameter.
and 30 cm in height for concrete compressive strength test, and two reinforced concrete beam with 15 × 25 × 320 cm measurement for flexure test with \((f’c)\) 20 MPa. The test specimens consist of one RC Beam without reinforcement (BK) and one RC beam by using GFRP reinforcement (BG). The beams are tested at 28 days of concrete age.

The RC Beam with steel plate\(^{[3]}\) and CFRP\(^{[2]}\) data are taken from previous research to compare with the results of this research. Data analysis in this research refers to ACI Committee 440\(^{[1]}\) which has been explained in the previous section.

![Flowchart of research methodology](image)

**Figure 7.** The flowchart of research methodology.

The beam is placed above the static loading frame with the joints of the roll-joint and the distance between the 3000 mm placement. The loading is done with a centralized load system with a distance between 1000
mm load to obtain pure bending. The beams are marked with grids of 5 × 5 cm to make it easier to draw a crack pattern. At the bottom of the beam is installed 3 pieces of dial gauge to read deflection at point ¼ L from the left, the middle and ¼ L from the right.

Data Collecting is performed by recording the result of load and deflection on RC beam until collapsed and putting it in the table. The loading is stopped after cracking and the dial gauge’s reading does not increase again.

The casting of the specimens is performed at Concrete Laboratory of FT USU. The Flexure test of concrete beam referred to ASTM C-78[5] is performed at Structural Laboratory of FT USU. The GFRP used in this study is MapeWrap G Uni-Ax type E-Glass, which is the most widely used type. The advantage is having high mechanical properties.

![Figure 8. The model of reinforced concrete beam.](image)

![Figure 9. The casting of specimens.](image)  
![Figure 10. The curing of specimens.](image)
4. Findings
After analyzing the reinforced concrete beam according to ACI Committee 440\cite{1}, the theoretical analysis of the beams can be summarized in Table 1.

| Sample                        | Ultimate Load (kg) | Maximum Deflection (mm) |
|-------------------------------|--------------------|-------------------------|
| Plain RC Beam (BK)            | 2946.7             | 17.4712                 |
| Steel Plate RC Beam (BB)      | 7705               | 14.8878                 |
| CFRP RC Beam (BC)             | 8731.5             | 22.6785                 |
| GFRP RC Beam (BG)             | 8478.96            | 29.2967                 |

After testing on the reinforced concrete beam according to ASTM C-78 \cite{5} then the beam test results can be summarized in Table 2.

| Sample                        | Ultimate Load (kg) | Maximum Deflection (mm) |
|-------------------------------|--------------------|-------------------------|
| Plain RC Beam (BK)            | 9000               | 22.45                   |
| Steel Plate RC Beam (BB)      | 19500              | 26.80                   |
| CFRP RC Beam (BC)             | 22000              | 28.98                   |
| GFRP RC Beam (BG)             | 21000              | 29.69                   |

5. Discussion and Analysis
5.1. Compressive strength of concrete
Concrete compressive strength testing is performed at FT USU's Concrete Laboratory. The test specimens consisted of three cylindrical of 15 cm in diameter and 30 cm. The concrete strength of the concrete plan \(f'_c\) is 20 MPa and from the result of the compressive strength test according to SNI 1974: 2011 procedure \cite{10} obtained the result 29.348 Mpa. While from Slump Test according to SNI 1972: 2008 \cite{9} got slump value of 11 cm.

5.2. Tensile strength of steel
Tensile strength testing of bar and steel plate is performed at “Balai Riset dan Standarisasi Industri Medan”. The tensile strength plan of steel bar \(f_y\) is 240 MPa. From result of tensile strength test of Ø6 is got yield stress of 428.3 MPa and ultimate stress of 606.3 MPa. For reinforcement Ø12 obtained a yield
stressed at 289.1 MPa and an ultimate stress of 428.4 MPa. For steel plate obtained yield stress of 333.5 MPa and ultimate stress of 460.1 MPa.\[3\]

5.3. **Theoretical analysis of reinforced concrete beam**

From table 1, shows that the beam with GFRP reinforcement is more elastic. While on beam reinforcement with steel plate the elasticity of the beam decreased compared to beam with GFRP and CFRP. This is due to an increase in thickness in the reinforcement area thus increasing the stiffness of the beam. And it has been proven that steel plate (5 mm thick) can increase the stiffness of the beam higher than CFRP (1.2 mm thick) and GFRP (0.35 mm thick). Thus, theoretically GFRP’s beam is able to withstand the most significant deflection compared to others and beam with CFRP is able to withstand maximum load best than others. The results of this study have relevance to the load-deflection theory that the bigger the loading given, the bigger the deflection that occurs too. This proves that the addition of FRP and steel plate can improve the ability of beam in flexure much better than normal condition (without reinforcement).

![Figure 13. The comparison of the load-deflection on each beam sample based on theoretical analysis.](image)

5.4. **The results of reinforced concrete beam testing**

From table 2, shows that the beam with GFRP reinforcement is more elastic. This is due to an increase in thickness in the reinforcement area thus increasing the stiffness of the beam. And it has been proven that steel plate (5 mm thick) can increase the stiffness of the beam higher than CFRP (1.2 mm thick) and GFRP (0.35 mm thick). Thus, experimentally beam with GFRP is able to withstand the most significant deflection compared to others and beam with CFRP is able to withstand maximum load best compared to others. The results of this study have relevance to the load-deflection theory that the bigger the loading given, the bigger the deflection that occurs too. This proves that the addition of FRP and steel plate can improve the ability of beam in flexure much better than normal condition (without reinforcement).
5.5. Comparison of testing and analytical results

5.5.1. Ultimate load. Based on the analytical results, on the beam without reinforcement, the ultimate load is 2.946 tons, the beam with 7.705 tons of steel plate, the beam with the CFRP of 8.731 tons, and the beam with GFRP of 8.478 tons. Based on it, strength of the beam with CFRP is 1.991 times its initial strength, GFRP is 1.877 times while with the steel plate is 1.646 times.

![Figure 14](Figure 14. The comparison of load-deflection on each beam sample based on test results.)

Based on the test results, on the beam without reinforcement obtained ultimate load of 9 tons, on the beam with steel plate obtained ultimate load of 19.5 tons, on the beam with CFRP obtained ultimate load of 22 Ton, and on the beam with GFRP of 21 tons. Based on it, obtained strength of the beam with CFRP is 1.444 times its initial strength, GFRP is 1.333 times while the steel plate is 1.167 times.

![Figure 15](Figure 15. The ultimate load on each beam sample based on theoretical analysis.)
5.5.2. Deflection. From the result of the theoretical analysis and testing it is found that the beam deflection increases when reinforced by steel plate, CFRP and GFRP. The biggest deflection occurs in the beam with GFRP. While beam with CFRP bears the biggest load than others. The results of this study have relevance to the load-deflection theory that the bigger the loading given, the bigger the deflection that occurs too.

5.5.3. Crack Pattern. The crack pattern found in the test of these two beams is the flexural crack (under-reinforced). Flexural cracking is a crack that usually occurs because the load exceeds the ability of the beam. In this test the first crack occurred at the load of 6 tons on the plain beam (BK) and 11 tons on the beam with GFRP reinforcement (BG), followed by the next crack reaching the ultimate load of 9 tons for plain beam (BK) and 21 tons for beam with GFRP reinforcement (BG) and finally collapsed.

6. Conclusions and Recommendations
The paper presents the effect of the use of Steel Plate, Carbon Fiber Reinforced Polymer, and Glass Fiber Reinforced Polymer on the behavior of external reinforced RC beam flexure measured in terms of bearing load capacity and beam specimen ductility. The results from this research can be summarized in the following paragraphs:

From the findings, purpose and the issues reviewed in this research can be concluded that the addition of external reinforcements both FRP (Carbon Fiber Reinforced Polymer, and Glass Fiber Reinforced Polymer) and steel plate can improve the ability of beams in flexure much better than normal conditions (without reinforcement). The conclusions of this research are in accordance with FRP theory, the analysis and test results.

Based on the analytical results, on the beam without reinforcement, the ultimate load is 2.946 tons, the beam with 7.705 tons of steel plate, the beam with the CFRP of 8.731 tons, and the beam with GFRP of
8.478 tons. Based on it, strength of the beam with CFRP is 1.991 times its initial strength, GFRP is 1.877 times while with the steel plate is 1.646 times.

Based on the test results, on the beam without reinforcement obtained ultimate load of 9 tons, on the beam with steel plate obtained ultimate load of 19.5 tons, on the beam with CFRP obtained ultimate load of 22 Tons, and on the beam with GFRP of 21 tons. Based on it, obtained strength of the beam with CFRP is 1.444 times its initial strength, GFRP is 1.333 times while the steel plate is 1.167 times.

Based on the test results, the beam with CFRP has the highest efficiency of 59.091 % followed by the beam with GFRP of 57.143 % and the beam with the steel plate of 53.846 %.

According to Pangestuti is concluded that the installation of FRP plates on beams is able to inhibit the initial crack propagation and crack growth as evidenced in the above experiments where the initial crack on the reinforced beam occurs at a load of 6 tons, while on the beam with GFRP reinforcement occurs at 11 tons load.

The research of Ireneus Petrico is concluded that CFRP can increase the flexural strength of the beam to 65.934%, while the GFRP is only 43.956%. As for the comparison of these two materials, CFRP is superior to GFRP in terms of adding flexural strength. The results of this study have the same conclusions with the results of research performed by the author.

The research of Alnadher Ali is concluded that there is an increase in the flexural strength of the reinforced concrete beam by 7.4% of the reinforced concrete without CFRP. This proves that the installation of external reinforcement on the beam with CFRP can increase the flexural strength of the non-reinforcing conditions. This is also in accordance with the results of analysis and experiments performed by the author.

After testing and analyzing the three types of reinforcements, the author can conclude that CFRP reinforcement is the best solution to improve the ability of concrete beams in building technology, followed by GFRP and steel plate.

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