Pre-Test Analysis on Reinforced Concrete Beams with Shear Strengthening using GFRP by Finite Element Method

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Abstract. Research on the developments of new materials as well as the methods and techniques of retrofitting structures showed that the Fiber Reinforced Polymer (FRP) is a promising material for use in strengthening reinforced concrete structures. This research aims to model reinforced concrete beams with shear strengthening using GFRP based finite element method. By using computer program Finite Element Analysis (FEA) the modelling was carried out by 2-dimension models on 3 testing material variations namely: the test normal concrete beams without the shear retrofitting (BGN), beams with shear retro fitting using GFRP are continuous on the shear span (BGPF), beams with retrofitting using 3 strips (BGP3S). The research result indicated that generally, the program used can show the behavior closed to the theoretical design result. The ultimate load of results normal concrete beams without the shear retrofitting (BGN) is 76,393 kN, beams with shear retrofitting using GFRP are continuous on the shear span (BGPF) is 77,798 kN, and beams with retrofitting using 3 strips (BGP3S). The results showed that the percentage increase of normal ultimate load of beam with shear reinforcement using GFRP was 1.4%, 11.01%, for reinforced using 3 strips (BGP3S). This indicated that the material behavior response produced from simulation study can well be described by the program.

Key words: Shear Beams, GFRP, Retrofiting, 2-dimensional modeling

1. Introduction

The fail of shear on concrete beams without reinforcement, generally damage occurs in areas along approximately three times the effective height of the beam and is called the span of the shear. Cracking due to diagonal drag is one way of shear damage. In shorter shear spans, the damage arises from a combination of shifting, crushing and splitting, while for sliding shear beams with longer shear spans, cracks due to flexural tensile stress will occur first before cracking due to the diagonal pull (Kusnadi, 2011).

The occurrence of flexural tensile cracking on the beam without shear reinforcement is an early warning of shear damage. A sloping skew due to sliding in the body of a reinforced beam may occur without the crack due to bending in the vicinity, or it may also be a continuation of the precipitate crack that has preceded it (Asroni, 2010).

Fiber Reinforced Polymer (FRP) is a very promising material for use in reinforcing reinforced structures. The use of GFRP in reinforced concrete beams can contribute to increasing load capacity when compared to reinforced concrete beam without GFRP reinforcement. As shear reinforcement on
reinforced concrete beams, GFRP can be glued to the side of the beam. The increase in capacity varies with the addition of the number of layers (Khalifa et al., 1998).

The nominal shear strength of the reinforced concrete beam is the number of strong shear concrete and strong shear reinforcement. In the case of a beam reinforced with a nominal shear strength FRP can be calculated by adding a shear strength of FRP (Nawy, 1998).

Alam et al. (2010), examined the effect of GFRP mounting variations on increasing shear strength of reinforced concrete slabs and concrete beam cracking behavior without GFRP reinforcement (beam normal) with reinforced concrete beams using GFRP retrofitting. The maximum load increase that occurs when compared to unreinforced beams is 14.46% for reinforced shear reinforcement shears with 3-stripped GFRP and 20.13% for reinforced retrofitted reinforced concrete slabs 5 strips in the area near the pedestal. The addition of GFRP on both sides of the beam along the span of the shear affects the pattern of the crack that occurs.

Kader (2012), examined the performance of reinforced concrete beams with bending strengths of Carbon Fiber Reinforced Polymer (CFRP) sheets that varied with the quality of concrete and the number of CFRP pieces. The quality of concrete is 23 MPa by using 3 layers of CFRP gives an increase of beam capacity when compared to concrete beam with the same quality without reinforcement is 30.15% and affect the collapse pattern that occurs in the beam. Deskarta (2009), examines the effect of the addition of GFRP plate with the fiber direction of 0° / 90°, ±45° and 0° to increased shear capacity of reinforced concrete cross-section. The cross section of the beam is 100 x 150 cm long and 950 cm long. The GFRP plate is added to both sides of the beam surface by coating the surface with epoxy resin and adding glass fiber in woven roving in the required direction and finally closed back with epoxy. The beams are simply supported and loaded at four points. The data collected is a load-deflection at each load load until collapse and the collapse pattern of the beam. The results showed that the beam without GFRP experienced a shear collapse pattern whereas the beam with GFRP experienced a bending collapse pattern. Furthermore, the addition of GFRP on beam boost beam load capacity of the average about 12.48%.

In general, the study of the behavior of reinforced concrete structural elements with shear strengthening using GFRP is obtained through experimental results in the laboratory. Possible failure or destruction of GFRP donated shear reinforcement to reinforced concrete, ie failure due to fracture or fracture of GFRP and failure due to loss of GFRP reconnection with reinforced concrete beam. So it is important to conduct an experimental test to get an idea of the response of reinforced concrete structural elements with shear reinforcement using GFRP in receiving real loads. But in addition to complex and complicated execution, to obtain good experimental results required a large quantity of test specimens. Obviously this resulted in the large cost required and also takes a long time. In addition there are those that cannot be viewed experimentally such as voltage patterns and patterns of reinforced concrete beam blocks with GFRP. To try to overcome this, before the experimental test, it is important to perform pre-test analysis based on Finite Element Method (FEM) first.

The numerical approach is very useful and useful in calculating cases relating to material strength, thermal analysis, structural strength even to fluid mechanics. One approach often used in numerical studies is the finite element method, in which the continuum structure is viewed as a series of finite small elements connected to each other through the nodal points found on the edges of the elements. Each element has several nodes that have a degree of freedom (degree of freedom) (Wahjoe in 2011).

There are three steps in finite element analysis: pre-processing, finite element solver and result processing. System in LUSAS finite element program there are 2 parts of finite element analysis
implementation that is: (1) LUSAS modeller, for graphical modelling before and after process. (2) LUSAS solver, for finite element analysis (Lusas, 2004).

Kader (2011), analyzing the T-beam (without and with reinforcement FRP), which is modelled using FEM-based software is software LUSAS. The cross section used is a cross section of BinaMarga on a scale of 1:4. From the validation of the T-beam testing (beam without and with FRP reinforcement) generally shows a fairly good proximity of behavior between laboratory test results and FEA LUSAS test results.

This study aims to simulate reinforced concrete beams with shear reinforcement using GFRP-based finite element method.

2. Materials and Methods
The draft refers to a study conducted on the model of the beam reinforced concrete with shear strengthening to be performed in the laboratory in the form of material characteristics. For example, the compressive strength of concrete, $f'_c$ is the compressive strength of the cylindrical concrete at 28 days (SNI, 2002). If described in a flow chart then the method as follows:

![Flow chart of materials and methods](image)

2.1. Structural Modeling
Variation of reinforced concrete beam test objects in FEA LUSAS simulation follows the model which will be tested in laboratory which consists of 5 variations of the model i.e, normal reinforced concrete beams without using GFRP (BGN), concrete beams with GFRP retrofit continuously mounted on a shear beam span (BGPF) and concrete beams with GFRP mounted 3 strips on the edge of the beam (BGP3S). Where with a total length of 3300 mm, a net length of 3000 mm, and a cross-sectional dimension 150 mm, height 3 50 mm. For more details, the proposed geometry model can be seen in Figure 1 and variations of FEA beams of LUSAS can be seen in Table 1 and Table 2.
2.2. Numerical Analysis Design
Numerical analysis in this study done using software Finite Element Analysis (FEA) LUSAS. The FEA LUSAS pre-test analysis is performed using a 2-dimensional field model element material. Concrete, sheets and epoxy GFRP modeled as plane stress quadric lateral (QPM8), while for steel reinforcing it is modeled as a line element (BAR3). To model contacts between GFRP and concrete elements in use namely the element of joint no rotational stiffness (JNT). The QPM8 model is for normal beam (BGN), GFRP continuous shear beam (BGPF) reinforcement, GFRP 3 strip (BGP3S) retaining beam. For material properties used to model reinforced concrete blocks using isotropic materials for concrete, reinforcement, GFRP and epoxy. More details for the material properties can be seen in Table 3.
Table 1. Cross Section Geometry of FEA LUSAS

| No | Code | Profile of beam |
|----|------|-----------------|
| 1  | BGN  | ![BGN Profile](image1) |
| 2  | BGPF | ![BGPF Profile](image2) |
| 3  | BGP3S| ![BGP3S Profile](image3) |

Table 2. Cross Section Geometry of FEA LUSAS

| No | Code | Profile Beams |
|----|------|---------------|
| 1  | BGN  | ![BGN Profile](image4) Normal reinforced concrete beams without using GFRP |
| 2  | BGPF | ![BGPF Profile](image5) Concrete beams without using GFRP, a is a shear beam span in mm units |
| 3  | BGP3S| ![BGP3S Profile](image6) |

Table 3. Material Properties of FEA LUSAS

| MATERIAL | Isotropic |
|----------|-----------|
| Concrete | Steel     | Epoxy | GFRP |
| 1 Elastic| Young’s Modulus (MPa) | 23500 | 200000 | 70000 |
|          | Poisson Ratio | 0.2   | 0.3   | 0.2   |
| 2 Plastic| Model (94) | Concrete Stress Potensial | Stress Potensial |
### MATERIAL Isotropic

|                      | Concrete | Steel              | Epoxy                        | GFRP              |
|----------------------|----------|--------------------|------------------------------|-------------------|
| Stress potentials type| Von Mises| ElastoPlasto uniform tension and compression | Von Mises          |
| **Hardening**        |          | 20000              |                              | 279               |
| Hardening Gradient   |          | 0.002              |                              | 0.022             |
| **Uniaxial**         |          |                    |                              |                   |
| **Compressive**      |          |                    |                              |                   |
| **Strength (MPa)**   |          | 25                 |                              |                   |
| **Initial Uniaxial yield stress** |          | 400                |                              | 279               |
| Strain at peak uniaxial Compression |          | 0.00185           |                              |                   |
| Tensile Strength (MPa) |          | 2.5                |                              |                   |
| Strain at End Softening Curve |          | 0.003              |                              |                   |

3. Research Result

3.1. Load and Deflection Connection

FEA LUSAS simulation results are compared with theoretical design results. The pre-test result of FEA LUSAS analysis shows that the percentage of maximum sliding load difference of normal beam between the modelling result and the theoretical design is 7.8%, and the difference of maximum shear load for normal beam of modelling result with 4 different meshing is 8.5%. This shows the material behavior response generated from the simulation study can be well illustrated by the program.

For normal concrete beam without GFRP reinforcement (BGN), based on FEA LUSAS simulation results obtained initial load crack 13.99 kN and ultimate load 17.393 kN. Concrete beams with GFRP retrofit continuously mounted on a shear beam span (BGPF) obtained an initial crack load of 14.39 kN, and an ultimate load of 77.798 kN. For beams with GFRP 3 strip (BGP3S) reinforcement the initial crack loads were 14.389 kN and the ultimate load was 87.407 kN. Deflection for normal reinforced concrete beams without GFRP (BGN) For FEA simulation the LUSAS was obtained by an initial deflection of 0.552 mm crack and ultimate deflection of 6.101 mm. For shear reinforcement rods using continuous shear GFRP (BGPF), the FEA LUSAS simulation was detected by an initial deflection of 0.564 mm crack and ultimate deflection of 8.635 mm. For beams with GFRP reinforcement 3 strips (BGP3S), of the FEA simulation results obtained LUSAS initial deflection crack 0.56 6 mm and 10.04 mm ultimate deflection. For more details see Table 4.

| Beams Code | Load | Displacement |
|------------|------|--------------|
|            | P_{Crack} (kN) | P_{Ultimit} (kN) | Displacement\(^1\) (mm) | Displacement\(^2\) (mm) |
| BGN        | 13,999 | 76,393 | 0.552 | 6,101 |
| BGPF       | 14,390 | 77,798 | 0.564 | 8,635 |
Beams Code & Load & Displacement & Strain of Steel
\hline
 & P_{\text{Crack}} (\text{kN}) & P_{\text{Ultimit}} (\text{kN}) & \text{Displacement}^1 (\text{mm}) & \text{Displacement}^2 (\text{mm}) \\
BGP3S & 14,389 & 87,407 & 0,566 & 10,040 \\
\hline

3.2. Strain
The value of the described strain is the value of the regression n at the initial condition of the crack and under ultimate loading conditions. The obtained concrete strand is a press strain in the middle of the span. For normal concrete beam without GFRP reinforcement (BGN), based on simulation result FEA LUSAS obtained preliminary cracking press crack 0.00006 and at ultimit load 0.00096 . For shear with shear reinforcement using continuous shear GFRP (BGPF), based on simulation results FEA LUSAS obtained preliminary crack strap pressure of 0.00007 and ultimit load 0.0014. For beam with GFRP 3 strip (BGP3S) reinforcement, based on FEA LUSAS simulation results obtained preliminary crack press stress of 0.00007 crack and at ultimit load 0.0018. For more details see Table 5.

3.3. The Crack Model of the Beam
For normal concrete beam without GFRP reinforcement (BGN), the crack model that occurs is shear failure. GFRP continuous shear reinforcement (BGPF) beam, GFRP 3 strip (BGP3S) retaining beam, it shows different models of collapse i.e. collapse due to bending failure. See in figure 2 till figure 3.

Table 5. Load and Strain Steel of Beams BGN, BGPF, and BGP3S

| Beams Code | Load | Strain of Steel |
|------------|------|----------------|
|            | P_{\text{Crack}} (\text{kN}) | P_{\text{Ultimit}} (\text{kN}) | Strain$^1$ (\text{mm}) | Strain$^2$ (\text{mm}) |
| BGN        | 13,999 | 76,393 | 0,00006 | 0,0096 |
| BGPF       | 14,390 | 77,798 | 0,00007 | 0,0014 |
| BGP3S      | 14,389 | 87,407 | 0,00007 | 0,0018 |

Figure 2. Crack Model in Normal Beam (BGN) when load $P_{\text{Crack}} = 14,390 \text{kN}$

Figure 3. Crack Model in Normal Beam (BGN) when ultimate load $P_{\text{Ultimit}} = 76,963 \text{kN}$
Figure 4. Crack Model in concrete beams with GFRP retrofit continuously mounted on a shear beam span (BGPF) when load $P_{\text{crack}} = 14,390$ kN

Figure 5. Crack Model in concrete beams with GFRP retrofit continuously mounted on a shear beam span (BGPF) when ultimate load $P_{\text{ultimit}} = 97,787$ kN

Figure 6. Crack Model in concrete beams with GFRP mounted 3 strips on the edge of the beam (BGP3S) when load $P_{\text{crack}} = 14,390$ kN

Figure 7. Crack Model in concrete beams with GFRP mounted 3 strips on the edge of the beam (BGP3S) when ultimate load $P_{\text{ultimit}} = 96,577$ kN

3.4. Load and Strain Relation

The load and strain relationships that occur in the shear reinforcement of each beam variation can be seen in Figure 8 to Figure 10. Figure 8 to Figure 10 shows the relationship between the load capacity and the shear steel strain for each shear reinforcement as reference is taken from the tip beam to the centre of beam span.
Figure 8. Chart of Loads and Strain Relation in Normal Beam (BGN)

Figure 9. Chart of Loads and Strain Relation in concrete beams with GFRP retrofit continuously mounted on a shear beam span (BGPF)

Figure 10. Chart of Loads and Strain Relation in concrete beams with GFRP mounted 3 strips on the edge of the beam (BGP3S)

The load relation curve and the shear reinforcement strain on the normal beam without GFRP (BGN) reinforcement are generally more upright. In a sense with relatively large load increments, the increment of strain is relatively small. This is caused before the tensile reinforcement steel, the tensile force at the cross section is accommodated by the tensile reinforcement at the bottom of the cross
section of the beam at elastic time. The $S_{33}$ shear reinforcement curves for each beam variation of either the reinforced beam (BGN) or with the reinforcement (BGPF and BGP3S) show similar behavior. When the load reaches ultimate the $S_{33}$ shear strain reinforcement curve tends to be more gentle than the other shear strain curves. This is because the $S_{33}$ slope reinforcement position is just below the point load so the strain increase is relatively larger as the load increases.

3.5. Discussion

From the result of the research the load and deflection relationship for normal beam shows load capacity which is not much different between FEA LUSAS simulation with the result of theoretical design. For reinforced concrete beams with shear reinforcement using GFRP both continuously (BGPF), using 3 strips (BGP3S), indicates higher load capacity compared to normal reinforced concrete beam (BGN), this proves that GFRP gives contribution style in accepting load. It can be seen that from the 2 models of GFRP installation variation FEA LUSAS simulation results show that the model that gives the largest shear capacity is beams with shear reinforcement using GFRP both continuously (BGPF). This proves that there is a good interaction or cooperation between GFRP and concrete in accepting the load.

The collapse model that occurs on a GFRP unstandardized beam is a shear failure model. The sliding fracture which is a continuation of the bending crack starts to occur in the span of shear or span that carries latitude and flexural force simultaneously. Based on FEA LUSAS simulation results, the more likely diagonal crack lines indicate that the shear crack occurs. Unlike the case with GFRP reinforced beam. Then, the simulation results show that the crack line that occurs in 2 variations of beam with GFRP reinforcement tend to be perpendicular. And it proves that GFRP prevents the occurrence of shear failure, so the collapse model occurring on beams with 2 variations of GFRP reinforcement is the collapse due to bending failure.

4. Conclusions and Recommendations

The research result indicated that generally, the program used can show the behavior closed to the theoretical design result. The ultimate load of results normal concrete beam without the shear retrofitting (BGN) is 76,963 kN, beams with shear retrofitting using GFRP are continuous on the shear span (BGPF) is 97,787 kN, and 96,577 kN beams with retrofitting using 3 strips (BGP3S). The results showed that the percentage increase of normal ultimate load of beam with shear retrofitting using GFRP was 1.4%, 11.01%, for reinforced using 3 strips (BGP3S). Based on the results of this study, it is suggested that further research should be done simulation using 3-D element analysis so that visually can be seen the behavior of each beam component at each stage of loading of the beam until at the time of reaching the load causing the collapse.

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