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FATIGUE RESISTANCE OF REINFORCED CONCRETE BEAMS WITH GFRP SHEET REINFORCEMENT AGAINST LONG-TERM EFFECTS OF SEAWATER IMMERSION

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ABSTRACT

This study aims to analyze the flexural behavior of reinforced concrete beams with GFRP-S reinforcement immersed in seawater against fatigue loads. Through this method, beam flexibility is tested on two simple supports and is fatigue tested with a frequency of 1.5 Hz until the beam collapses. Sinusoidal type fatigue loading. The test object is 10 blocks of reinforced concrete measuring 15 cm x 20 cm x 330 cm. 5 beams were tested statically as a comparison, 5 beams were tested fatigue. 4 non-immersed beams, 2 normal beams, 2 GFRP-S beams as control. The blocks were soaked for 1 month, 3 months and 6 months. The test results show that the use of GFRP-S can increase the fatigue life of the beam. The variation of sea water immersion for 1 month, 3 months and 6 months can increase the value of beam stiffness with GFRP-S reinforcement when compared to GFRP-S beams without seawater immersion due to fatigue loads, namely 5.046%; 5,149%; 3,604%. Meanwhile, the stiffness value decreased when compared to the static load, namely 3.142%; 3,818%; 5,941%; 7,451%. The ductility value of GFRP-S blocks immersed in seawater for 1 month and 6 months due to fatigue load decreased by 7.61%. The attachment capacity of GFRP-S to the fatigue load that was immersed in sea water for 1 month and 6 months decreased by 9.306%.

Keyword: durability, GFRP-S, fatigue load, static load, ductility, sea water immersion.

1. INTRODUCTION

Civil building construction, especially concrete construction, is currently experiencing a very rapid development. The construction of concrete structures around or near the coast even in sea water is something that is not impossible to do. The construction of concrete structures in this direction has been done a lot, for example, bridges, pier construction, break water structures, bridge piles, coastal building foundations and maritime buildings of all kinds. All the work is done using concrete material as the basic structure.

But the development of concrete technology is also faced with structural failure problems, the failure of these structures is caused by internal factors such as corrosion of steel, as well as external factors such as earthquakes. If the damaged building structure is wanted to continue to be used without demolition, then one way to solve it is by strengthening the structure of the building.

The application of FRP material as a function of repair and reinforcement of existing concrete structures has grown rapidly in several countries such as North America (Grace & Sayed, 2003) [4], Europe (Meier *et al.,* 1992; Steiner, 1996; Nanni, 1997) [8][9][12] and in Japan. (Katsumata *et al.*, 2001; Masukawa *et al.*, 1997) [6][7]. Strengthening techniques like this can be made efficient, not causing rust like external steel plates. The reinforcement function with the FRP composite system is to increase strength or provide increased flexural capacity, shear, axial and ductility, or various combinations thereof. The high durability of FRP is more economical to use in corrosive environments where steel will rust easily. The use of FRP is more popular considering the many advantages that can be obtained such as small unit weight, easy to apply and handle, low installation and maintenance costs. The most important disadvantage of using FRP as a reinforcement system is the relatively higher price of the material.

The use of GFRP is usually used for the reinforcement of beams, columns and other building structures. In addition to retrofitting, GFRP can also be used for interior and exterior spaces, because GFRP is a material that is resistant to all types of weather, resistant to water containing salt such as sea water, and others (Jenova, 2013) [5].

In offshore structures, environmental influences are mainly cyclic wave loads and can also occur due to repeated movements of the structure itself. Therefore, it is necessary to analyze the structural fatigue problem due to repetitive or cyclic loads on a structure.

Fatigue analysis of reinforced concrete beams with FRP reinforcement has been widely studied such as (Meier, 1992; Barnes & Mays 1999; Papakonstantinou, 2000; Shahawy & Beitelmen, 1999) [8] [10][3] [11], the results of all studies indicate that failure of reinforced concrete beams is a bending failure. Due to steel fracture followed by failure of concrete, adhesives or fracture of FRP. There is no difference in behavior between FRP reinforced and non-reinforced FRP beams when the beam is subjected to fatigue loads. The number of failure cycles varies according to the variety of steel reinforcing stresses. The use of FRP can increase the fatigue life of the beam and the increase in the number of CFRP layers can further increase the fatigue life of the beam (Shahawy & Beitelman, 1999) [11].

This study aims to analyze the flexural behavior of reinforced concrete beams with GFRP-S reinforcement

immersed in seawater against fatigue loads. Based on the discussion on the background of the problem, the problem formulation can be described as follows:

a) Resistance of reinforced concrete blocks immersed in seawater with gfrp-s reinforcement against fatigue loads.
b) The variation of seawater immersion time on the bonding capacity of gfrp-s and concrete due to fatigue loads.

2. LITERATURE REVIEW

Sungwoo Shin et al. (2009) have conducted an experimental study on the reinforcement of reinforced concrete structures using Fiber Reinforced Polymer (FRP), the results of the investigation can be summarized as follows: (1) The deflection and stress of reinforced concrete beams with GFRP are generally greater than those that are reinforced with reinforcing steel, (2)) strength of concrete has a negligible effect on crack spacing and crack width, (3) FRP in reinforcing concrete beams in this study is safe for design in terms of deformability.

The use of GFRP on reinforced concrete blocks increases the load capacity when compared to reinforced concrete beams without GFRP reinforcement. The increase in capacity varies with the addition of the number of GFRP layers (Fikri Alami, 2010)[1]. The increase in the average flexural strength that occurs is 84.21% for concrete beams with GFRP reinforcement when compared to those without GFRP reinforcement for normal conditions without interaction with the marine environment. Meanwhile, the conditions of concrete blocks that interact with the marine environment also experience an increase in flexural strength which values vary along with the increase in the test period (Febryana Armitha, 2013) [2].

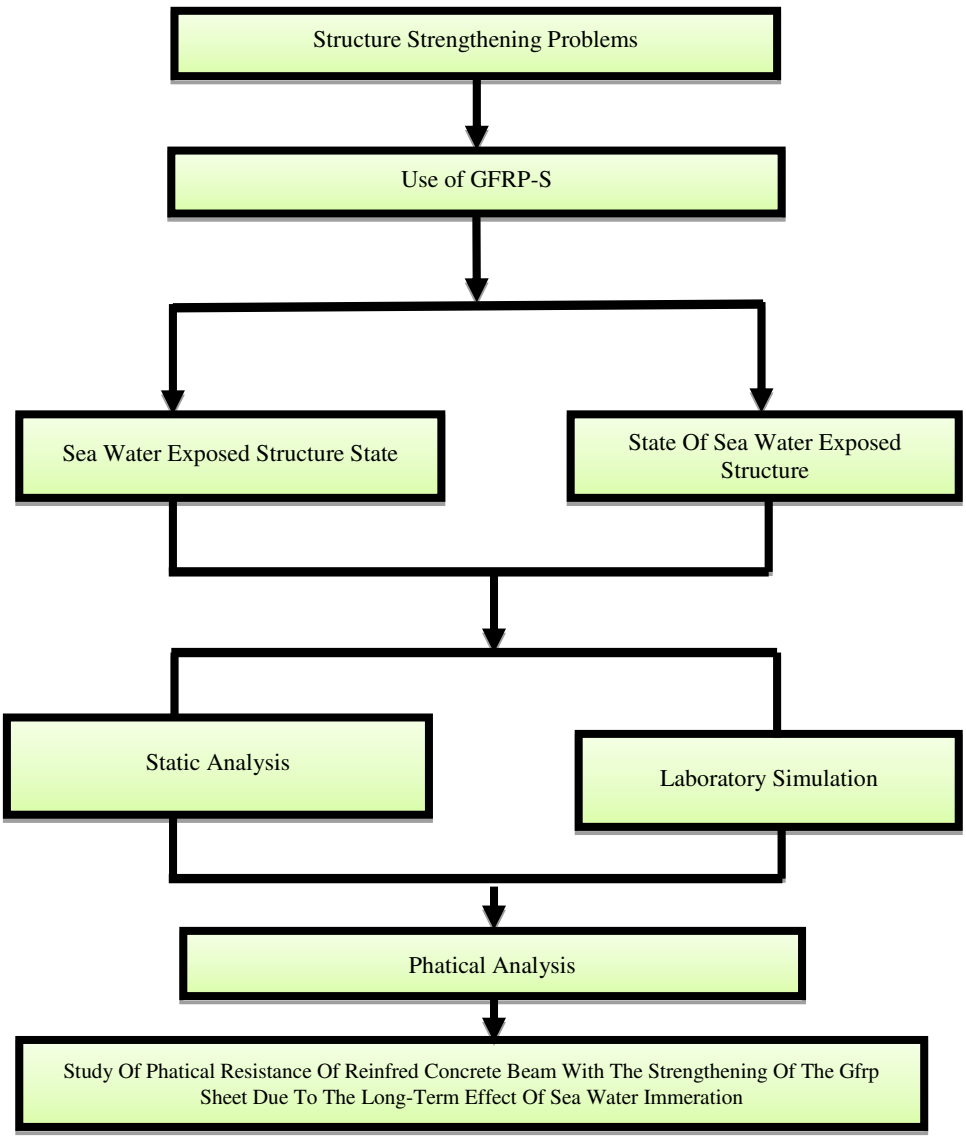

Figure-1. Framework.

3. METHOD

3.1 Research Sites

This research was conducted at the Structural Laboratory of the Civil Department, Faculty of Engineering, Gowa, Hasanuddin University. The research time was carried out in 2011 for 6 months.

3.2 Samples and Testing Methods

This study used 10 samples of concrete blocks with dimensions of 15 cm x 20 cm x 330 cm, where 2 samples were used for the control sample without reinforcement and without seawater immersion (Figure-2a), 2 samples as the control sample with GFRP-S reinforcement without water immersion. sea (Figure-2b). Two samples with GFRP-S reinforcement and had interacted with seawater immersion for the first month of testing. And two samples with GFRP-S reinforcement and interacted with sea water immersion for the sixth month of testing. 1 beam was tested statically and 1 beam was fatigue tested for all samples (Table-1).

Table-1. Variables of static and fatigue specimens.

No	Test Object Code	Explanation
1	BNs-0	Normal beam static test 0 months
2	BFs-0	Beams with GFRP-S strengthening static test at 0 months
3	BFs-1	Beams with GFRP-S strengthening static test for 1 month
4	BFs-3	Beams with GFRP-S strengthening static test for 3 months
5	BFs-6	Beams with GFRP-S strengthening static test for 6 months
6	BNf-0	Normal beam 0 month fatigue test
7	BFf-0	Beams with GFRP-S strengthening 0 months fatigue test
8	BFf-1	Beams with GFRP-S strengthening for 1 month fatigue test
9	BFf-3	Beams with GFRP-S strengthening in 3 months fatigue test
10	BFf-6	Beams with GFRP-S strengthening 6 months fatigue test
11	BFf-3 year	Beams with GFRP-S strengthening of 3 years fatigue test

The specimen uses 2Ø6 in the compressive region and 2D14 in the tensile region. Meanwhile, stirrup reinforcement uses D10-7.7 cm (Figure-1a). Installation of strain gauges for normal beams, two pieces of strain gauges are attached to the tensile reinforcement (Figure-3a). Meanwhile, 3 pieces of strain gauges are installed in the concrete, namely in the compressed area of the beam, in an area of ½ the beam's height, and in the area ¼ the beam's height (Figure-3b).

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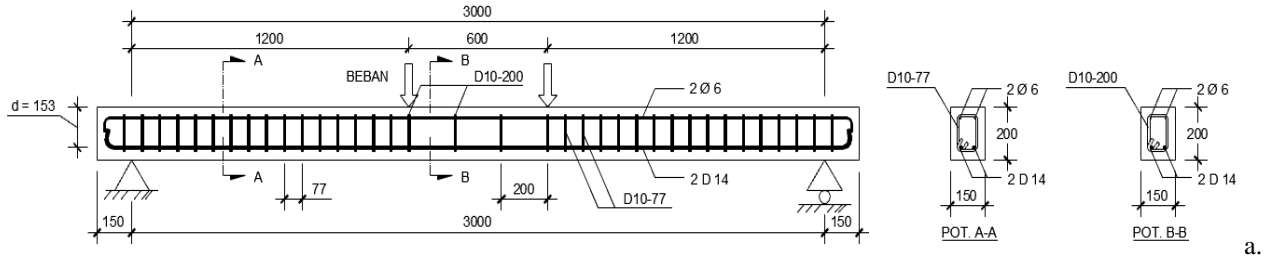
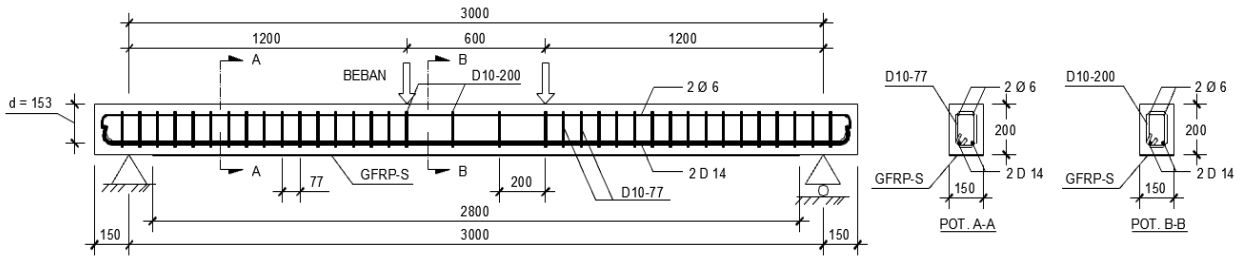
Appendix



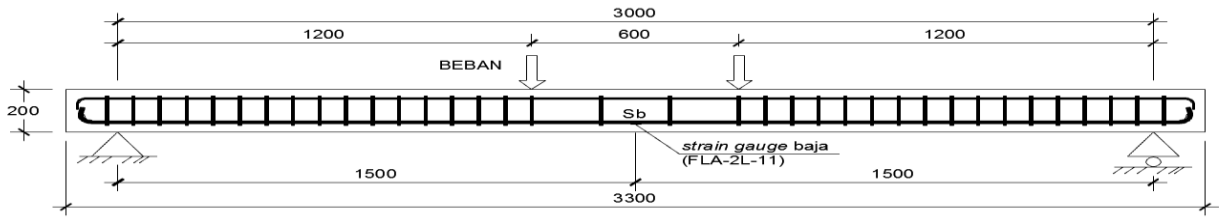
a.

Normal beam

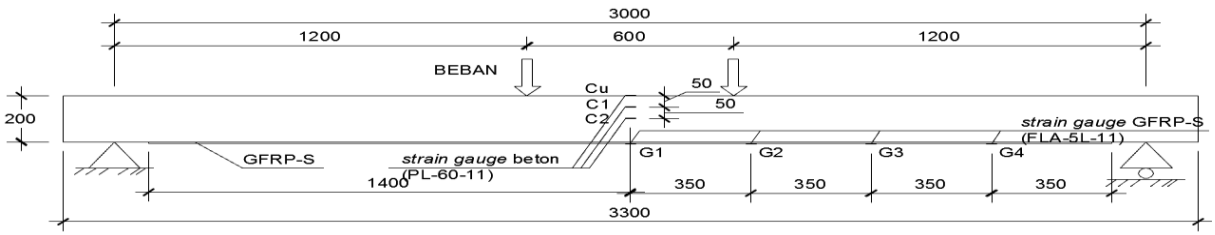


b. GFRP-S beam

Figure-2. Design of Test Beams.



a. Steel strain gauge



b. Concrete strain gauge and GFRP-S

Figure-3. Position of Strain Gauge in Steel, Concrete and GFRP-S for Beam Types with GFRP-S Reinforcement.

Beams with GFRP-S reinforcement for the installation of strain gauges on the GFRP-S layer, are installed as many as 4 pieces which are installed from the center position of the beam and spread each at a distance of 35 cm to the end of the beam (Figure-2b). Casting of test objects using a ready mix with a compressive strength of f'c of 25 Mpa. The type of GFRP used is a type of GFRP-S, type SEH-51A, a product of Fyfe Co.

The beam specimens were tested for sinusoidal type fatigue loading with a frequency of 1.5 Hz to collapse with a minimum load of 4 kN and 19 for normal beams and 4 kN and 24 kN for GFRP-S beams. The data obtained from this test include load data, concrete strain, steel strain, GFRP-S strain and deflection. All test data readings are connected to the data logger. Strain measurements were carried out using a strain gauge. Deflection measurements were performed using the LVDT (Linear Variable Displacement Tranducer). LVDT is placed in the center of the beam to measure the maximum deflection value at the center of the span.

4. RESULT

4.1 Static Test and Normal Block Fatigue Test for 0 Months

Normal beam deflection values without seawater immersion due to static loads with a load of 4 kN and 19 kN are 1,914 mm and 10,825 mm, while those due to

fatigue loads are 2,432 mm and 12,325 mm. The stress values of concrete due to static loads are 151 x 10^{-6} and 752 x 10^{-6}. Meanwhile, due to fatigue load 174 x 10^{-6} and 834 x 10^{-6}. The tensile values of steel due to static loads are 239 x 10^{-6} and 1305 x 10^{-6}, while those due to fatigue loads are 289 x 10^{-6} and 1433 x 10^{-6}. Initial crack occurs in normal beam with static load is 9,613 kN, steel reinforcement experiences a yield of 25,9029 kN and a maximum load of 27,5719 kN. The number of normal beam cycles to fatigue load is 635,100 cycles.

0 Month GFRP-S Static Test and Block Fatigue Test

The deflection values of the GFRP-S beam without seawater immersion due to static loads with a load of 4 kN and 24 kN are 1.139 mm and 11.965 mm, while those due to fatigue loads are 1.923 mm and 12.353 mm. The stress values of concrete due to static loads are 107 x 10^{-6} and 845 x 10^{-6}. Meanwhile, due to fatigue load 149 x 10^{-6} and 893 x 10^{-6}. The tensile values of steel due to static loads are 90 x 10^{-6} and 1259 x 10^{-6}, while those due to fatigue loads are 213 x 10^{-6} and 1476 x 10^{-6}. The value of the GFRP-S strain due to static loads is 158 x 10^{-6} and 1889 x 10^{-6}, while those due to fatigue loads are 207 x 10^{-6} and 1589 x 10^{-6}. Initial crack occurred in GFRP-S beam with a static load of 11.6162 kN, the reinforcing steel experienced a yield of 33.5803 kN and a maximum load of 42.9934 kN. The number of GFRP-S beam cycles for 0 months to the fatigue load of 1,231,860 cycles.

1-Month GFRP-S Static Test and Block Fatigue Test

The deflection value of GFRP-S beam immersion in seawater for 1 month due to static load with a load of 4 kN and 24 kN are 1.244 mm and 11.312 mm, while those due to fatigue load are 1.706 mm and 11.283 mm. The stress value of concrete due to static load is 176 x 10^{-6} and 1023 x 10^{-6}. Meanwhile, due to fatigue load 161 x 10^{-6} and 805 x 10^{-6}. The tensile values of steel due to static loads are 119 x 10^{-6} and 1150 x 10^{-6}, while those due to fatigue loads are 187 x 10^{-6} and 1316 x 10^{-6}. The value of the GFRP-S strain due to static loads is 225 x 10^{-6} and 1953 x 10^{-6}, while those due to fatigue loads are 288 x 10^{-6} and 1932 x 10^{-6}. Initial crack occurred in GFRP-S beam with a static load of 11.6162 kN, the reinforcing steel experienced a yield of 33.5803 kN and a maximum load of 42.9934 kN. The number of GFRP-S beam cycles 1 month to the fatigue load of 1,000,000 cycles.

3-month GFRP-S Static Test and Block Fatigue Test

The deflection values of the GFRP-S beam immersion in seawater for 3 months due to static loads with a load of 4 kN and 24 kN were 1,420 mm and 11,054 mm, while those due to fatigue loads were 1,595 mm and 11,751 mm. The stress value of concrete due to static load is 131 x 10^{-6} and 854 x 10^{-6}. Meanwhile, due to fatigue load 196 x 10^{-6} and 1022 x 10^{-6}. The tensile values of steel due to static loads are 116 x 10^{-6} and 1113 x 10^{-6}, while those due to fatigue loads are 194 x 10^{-6} and 1596 x 10^{-6}. The value of the GFRP-S strain due to static loads is 316 x 10^{-6} and 2136 x 10^{-6}, while those due to fatigue loads are 228 x 10^{-6} and 1858 x 10^{-6}. Initial crack occurred in GFRP-S beam with a static load of 12.4174 kN, the reinforcing steel experienced a melting load of 36.8515 kN and a maximum load of 42.0588 kN. The number of cycles of the GFRP-S 3 beam for the month of the fatigue load is 909,779 cycles.

6-Month GFRP-S Static Test and Block Fatigue Test

The deflection value of GFRP-S beam immersion in sea water for 6 months due to static load with a load of 4 kN and 24 kN is 1.334 mm and 11.039 mm, while due to fatigue load 1.793 mm and 11.927 mm. The stress value of concrete due to static load is 104 x 10^{-6} and 745 x 10^{-6}. Meanwhile, due to fatigue load 143 x 10^{-6} and 855 x 10^{-6}. The tensile values of steel due to static loads are 136 x 10^{-6} and 1278 x 10^{-6}, while those due to fatigue loads are 172 x 10^{-6} and 1118 x 10^{-6}. The value of the GFRP-S strain due to static loads is 161 x 10^{-6} and 1560 x 10^{-6}, while those due to fatigue loads are 287 x 10^{-6} and 1829 x 10^{-6}. The initial crack occurred in the GFRP-S beam with a static load of 19.325 kN, the reinforcing steel experienced a melting load of 31.820 kN and a maximum load of 44.149 kN. The number of GFRP-S 6 month beam cycles to the fatigue load of 1,000,000 cycles.

5. DISCUSSIONS

This research shows that the installation of GFRP-S can increase the bending capacity of the beam, reduce the deflection value that occurs in the beam, reduce concrete strain, and reduce steel strain and can increase the number of cycles in the beam against static loads and fatigue loads.

It can also be seen that the variation of sea water immersion for 1 month, 3 months and 6 months can reduce the deflection value that occurs in the GFRP-S beam against the GFRP-S beam without seawater immersion due to static loads and 24 kN fatigue loads. While the deflection value due to fatigue load increases when compared to the deflection value due to static loads. The attachment capacity of GFRP-S due to fatigue load which was immersed in sea water for 1 month and 6 months due to fatigue load decreased by 9.36%.

6. CONCLUSIONS

Based on the results of the research that has been done, the following conclusions can be given. There was an increase in the stiffness value of the beam with GFRP-S reinforcement with normal beams without seawater immersion (0 months) due to the 19 kN fatigue load, which was 14.564%. The use of GFRP-S can increase the fatigue life of the blocks. The variation of sea water immersion for 1 month, 3 months and 6 months can increase the stiffness value of the stiffness of GFRP-S blocks which are not soaked due to fatigue load of 24 kN, namely 5.046%; 5,149%; 3,604%. Meanwhile, the stiffness value decreased when compared to the static load, namely 3.142%; 3,818%; 5,941%; and 7,451%. The ductility value of GFRP-S blocks immersed in seawater for 1 month and 6 months due to fatigue load decreased by 7.61%. The attachment capacity of GFRP-S which was

immersed in seawater for 1 month and 6 months due to fatigue load decreased by 9.306%.

Suggestions that can be given include, among other things, it is necessary to carry out further research with the frequency of fatigue loading that is adjusted to conditions in the field in general. In addition, in preparing reinforced concrete beams, it is necessary to pay attention to proper construction techniques in order to obtain the expected results.

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