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INFLUENCE OF SEAWATER ON STRENGTH OF CONCRETE BEAMS STRENGTHENED WITH GLASS FIBER REINFORCED POLYMER SHEET

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ABSTRACT: Concrete structures close to seawater cannot be avoided in the construction of current facilities and infrastructure. Concrete submerged in seawater will reduce its strength and increase the corrosion rate of reinforcing steel. With Glass Fiber Reinforced Polymer Sheet (GFRP-S) technology, it is possible to increase the strength of concrete and protect reinforcing steel from the effects of seawater corrosion. Several laboratory studies were carried out on GFRP-S coating as an addition and protection against seawater environmental conditions. However, this research is limited by time and equipment, so it is necessary to carry out a finite element analysis. This modeling uses Abaqus CAE 2017 software. The Abaqus modeling results are then validated with laboratory research to find out what percentage of deviations occur. After optimization, several variables were added to determine the load capacity under different conditions. Some additional research variables are the length of immersion of 12, 24, and 48 months. Apart from the period of time, additional variations were made with the thickness of GFRP-S, which was originally only 1.3 mm, increased to 1.5 mm and 1.8 mm. The results obtained were that the immersion time of 12 months decreased the load capacity by 11.21%, the decrease in the immersion time of 24 months was 14.34%, and the decrease in the immersion time of 48 months was 17.63%. The addition of GFRP-S with a thickness of 2 mm increases capacity by 0.89% and the addition of 5 mm GFRP-S increases capacity by 3.74%. This very significant reduction resulted in the beam being recommended for additional repairs or strengthening.

Keywords: Disaster Risk Reduction, Finite Element Analysis, GFRP-S, Load Capacity, Seawater.

1. INTRODUCTION

Concrete is a mixture consisting of sand, gravel, crushed stone, or other aggregate mixed with a paste made of cement and water to form a rock-like mass [1]. Concrete, the prime constituent in solid, requests huge creation, prompting the emanation of carbon dioxide and consequently a worldwide temperature alteration [2,3]. Sometimes one or more additives are added to produce concrete with certain characteristics, such as workability, durability, and hardening time [4]. In simple terms, concrete is formed by the hardening of a mixture of cement, water, fine aggregate (sand), and coarse aggregate (gravel crushed stone) [5]. Sometimes a mixture of other ingredients (admixture) is added to improve the strength of the concrete [6].

Steel bars have been used in reinforced concrete for many years [7-12]. The corrosion of steel reinforcement in reinforced concrete structures is a serious problem, especially when the structures exist in highly corrosive environments, such as coastal environments [13]. Construction of concrete structures in coastal areas even in seawater is not impossible to implement. For structures located in coastal areas, during the manufacturing process contact with seawater is sometimes unavoidable. Concrete structures which are generally located in coastal areas are very prone to damage or degradation of strength due to corrosion that occurs in the reinforcement. Currently, reinforcement technology is developed using fiber-based materials such as Aramid Fiber, Glass Fiber, and Carbon Fiber. One of the properties of fiber material is that it is resistant to corrosion, making it possible to use it in coastal areas [14].

Several studies have been carried out to increase the strength of concrete, one of which is FRP (Fiber Reinforced Polymer). In general, there are three types of FRP materials, namely CFRP (Carbon Fiber Reinforced Polymer), GFRP (Glass Fiber Reinforced Polymer), and AFRP (Aramid Fiber Reinforced Polymer) [15] Optical fiber-reinforced polymer (GFRP) composites are utilized in many of the engineering applications [16]. Glass fiber reinforced polymer (GFRP) bars, due to their relatively low cost and good durability properties, have become a popular alternative to conventional reinforcing steel [17]. The use of GFRP in the form of sheets is currently very common because the price is relatively more economical when compared to other types. Beams reinforced with FRP will increase stiffness, yield limit, and limit strength in studies of reinforcement repairs that have corroded the beam [18]. Other research related to the use of GFRP in beams shows that beams reinforced with FRP as flexural reinforcement in reinforced concrete beams can increase the load up to 75.15% and increase the maximum deflection. Reinforcement using GFRP sheets on reinforced concrete beams that have been loaded results in yielding reinforcement having a higher bending capacity than the original beam [19].

Studies conducted in relation to seawater immersion are still lacking, given the importance of structural strengthening issues in construction in a marine environment. Therefore, it is necessary to have a further study regarding the problem of strength in GFRP-S due to the influence of the marine environment. This study provides information about the load capacity values that occur in GFRP-S due to the influence of the marine environment for a certain period of time, namely 12 months, 24 months, and 48 months. The type of GFRP-S used has a thickness of 1.3 mm. Several other variables used in this study are the thickness of the GFRP-S which uses three types of thickness, namely 1.3 mm, 1.5 mm, and 1.8 mm. This study is not experimental but uses a simulation of concrete beam elements with the help of the Abaqus software. It is hoped that the study results can be used as a reference for construction planning and further research.

2. RESEARCH SIGNIFICANCE

Modeling of concrete beams with GFRP-S reinforcement has not yet been carried out. This research was carried out by modeling GFRP-S under conditions of being submerged in seawater for a certain duration. This can save time by eliminating the need to do more research. Modifications were made using data from several previous studies so that the output generated from modeling using Abaqus corresponds to the actual situation. It is hoped that this research can shorten the planning time.

3. METHODOLOGY

The research entitled [20] shows that concrete blocks that are installed with GFRP-S and submersed in seawater for a longer time will reduce the bonding capacity of GFRP with concrete. This became a reference in this study to innovate by attaching GFRP-S to concrete beams after being immersed in seawater, this is to prevent a low bond between GFRP and the concrete surface, especially in the tension area. This study used 11 test specimens of reinforced concrete beams with dimensions of 15 cm x 20 cm x 330 cm. In the compression area, reinforcement 2-Ø6 and 2-D14 were installed in the tension area. The stirrup reinforcement is used D10-7.7. The concrete strength f'_c is 25 MPa. Details of the typical test beam specimen are shown in Figure 1.

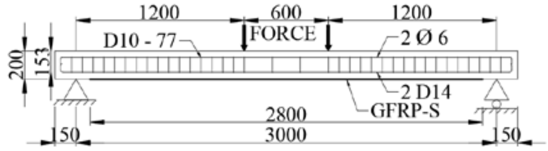

Fig. 1 Details of typical test beam specimen

3.1 Modeling using Abaqus Software

Part modeling is done in Abaqus by entering the geometry that has been imported from the input file. In describing the model to be analyzed, it is first determined the coordinate system to be created [21]. Before carrying out the simulation, the data is entered into the Abaqus module so that all keywords and parameters entered in the input file can be checked for correctness before the running process is carried out. The order in entering data must be considered properly because, between one module and other modules, they are interconnected.

Abaqus is used to simulate the processing results. At this level, Abaqus solves the problems given to the program by performing numerical solutions. To reduce the strength value, a simulation can be carried out by reducing the specifications of each material based on the percentage reduction obtained from Figure 2.

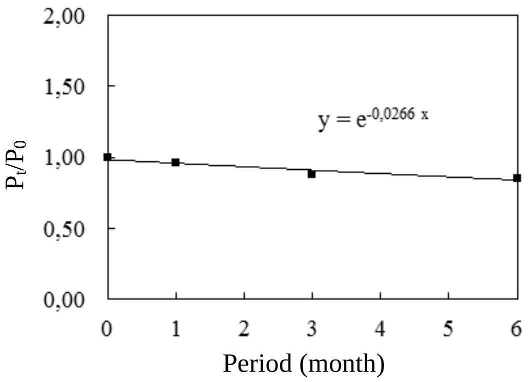

Fig. 2 Exponential Equation for Derivation of Strength

Thus, from Figure 2, the following equation can be obtained

$$\frac{P_t}{P_o} = e^{-0,0266\,x} \quad (1)$$

where P_0 is the initial load capacity, P_t is load capacity at any given time, and x is the period based on the month. This calculation is then used as the strength reduction value for each material except concrete. As for reducing the strength of concrete, based on [18], the following equation is used

$$y = 6.0398\,ln(t) - 9.5152 \quad (2)$$

where y is the percentage degradation of strength and t is the duration of immersion in days. The assumption is that the reinforcing steel is still intact or has not experienced a decrease in strength because the concrete is considered to be perfectly formed without any cracks.

3.2 Parameter and Specimens

Another variable used in this research is the thickness of GFRP-S, which was originally 1.3 mm thick, and then tried adding a thickness of 1.5 mm and 1.8 mm. Apart from increasing the thickness of GFRP-S, the immersion time was continued, namely 24 months, 48 months, and 96 months. The parameters used in the concrete material in this research are the concrete damage plasticity model. In this model, two types of steel strength are used, namely f_y 400 MPa for the main reinforcement and f_y 210 for the stirrups. The GFRP-S material is used according to the following specifications.

Table 1 GFRP-Sheet Material Specifications

Properties	Test Value
Poissons Ratio, V_{12}	0.278
Shear Modulus, G_{12}	3.8 GPa
Longitudinal Shear Modulus, E_1	39 GPa
Tensile Modulus 90º from Main Direction of Fiber, E_2	8.6 MPa

Table 2 Research Variation

Specimen Code	GFRP-S Thickness (mm)	Duration of Immersion (month)
BA_0		0
BA_6		6
BA_{12}	1.3	12
BA_{24}		24
BA_{48}		48
BB_0		0
BB_6		6
BB_{12}	1.5	12
BB_{24}		24
BB_{48}		48
BC_0		0
BC_6		6
BC_{12}	1.8	12
BC_{24}		24
BC_{48}		48

Another variable used in this research is the thickness of GFRP-S, which was originally 1.3 mm thick, and then tried adding a thickness of 1.5 mm and 1.8 mm. Apart from increasing the thickness of GFRP-S, it was continued with immersion times of 24 months, 48 months, and 96 months. From above, a resume can be made and listed in Table 2.

Several parameters are set in steps when creating a model with Abaqus. In making GFRP-S parts, input parameters are determined in Abaqus, using a "shell" shape with a "planar" type, which can be seen in Figure 3.

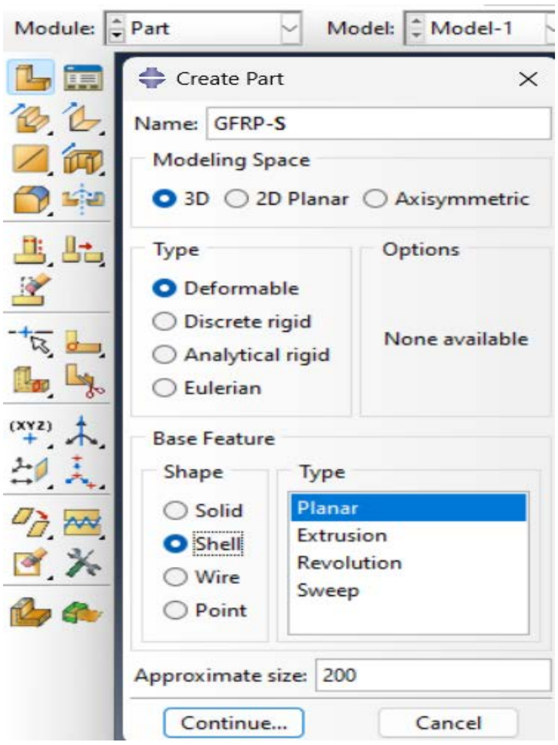

Fig. 3 GFRP-S "Part" input

The dimensions of GFRP-S that have been determined in Figure 1 are 2800 mm long, and the width follows the beam 150 mm. so it can be modeled as in Figure 4.

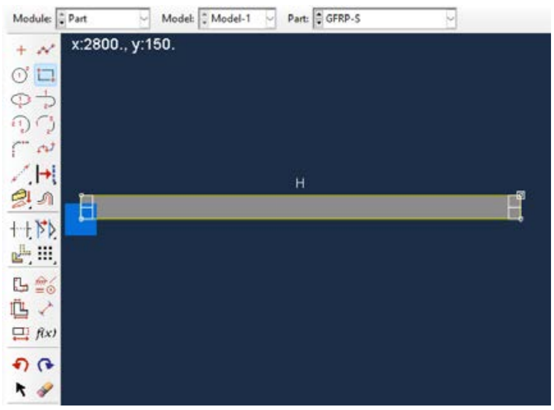

Fig. 4 GFRP-S geometry

After that, in the "Property" section, data is entered according to Table 1. The next step is to enter the properties that have been created using the "property section" menu. To assign properties to a part, use the "create composite layup" menu, then set the number of layers, thickness, and fiber direction following the material sample. The step can be seen in Figures 5 and 6.

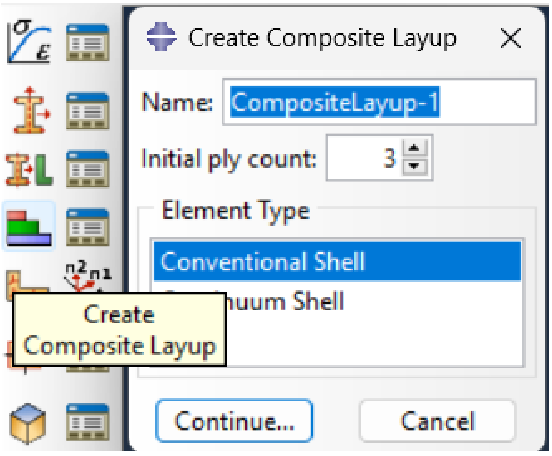

Fig. 5 GFRP-S Composite Layup Menu

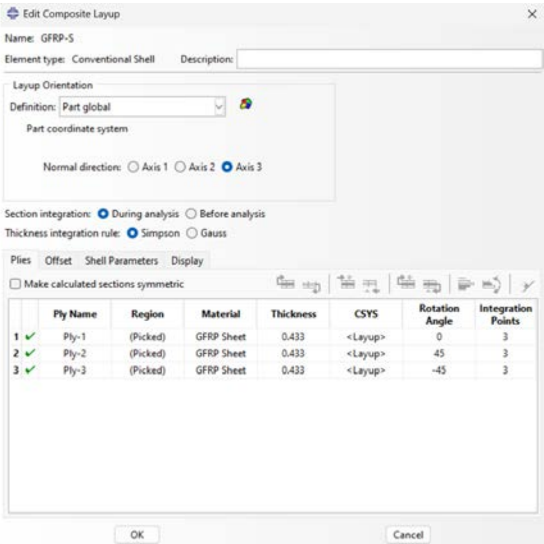

Fig. 6 GFRP-S Composite Layup Input

After all the items have been created, they are then applied to each part using the "assign section" command. The next step is the “assembly” menu. The assembly menu is the stage for combining all the parts that have been made. All parts are inserted one by one and arranged according to the geometry in the plan, which can then be seen in Figure 7.

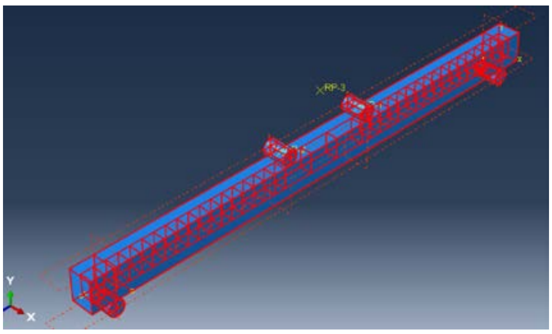
Fig. 7 Beam Assembly Details

The next perimeter used is "interaction". Interaction is used to define the interaction between parts because there is a GFRP-S layer at the bottom, and there is a specific interaction that uses epoxy material. The epoxy used is assumed to be 0.3mm thick. The input carried out can be seen in Figures 8 and 9.

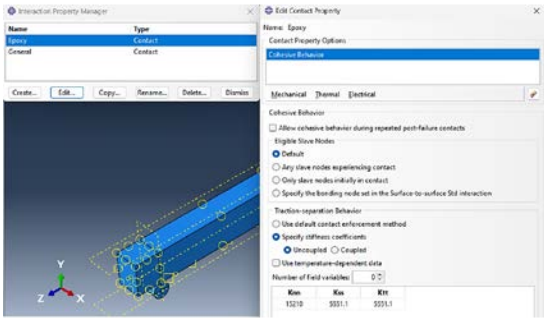
Fig. 8 Interaction Property of Epoxy

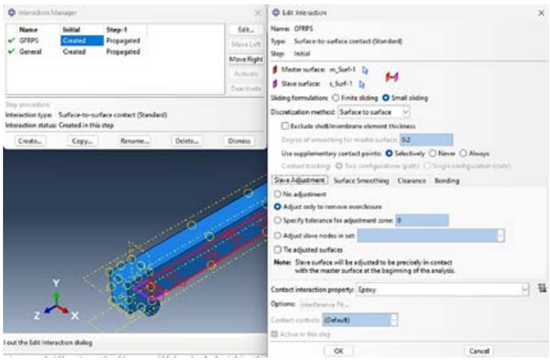
Fig. 9 Interaction GFRP-S with Beams using Epoxy Material

Apart from designing the interaction between GFRP-S and the beam, load interaction is also needed so that the load works as desired. Another interaction provided is the interaction between concrete and reinforcement. That can be shown in Figure 10 for load interaction and Figure 11 for interaction between concrete and reinforcement.

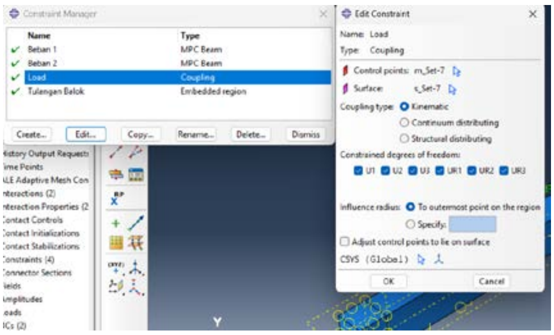
Fig. 10 Load Interaction

After finding that all interactions have been fulfilled, the next step is to define the load and support. The load defined in this study uses a static load by considering the displacement value. Meanwhile, the support used is fixed in the area below the steel support. This step ensures that the model obtains comprehensive results as is done in the laboratory. Load definitions are shown in Figure 12. Meanwhile, support definitions are shown in Figure 13.

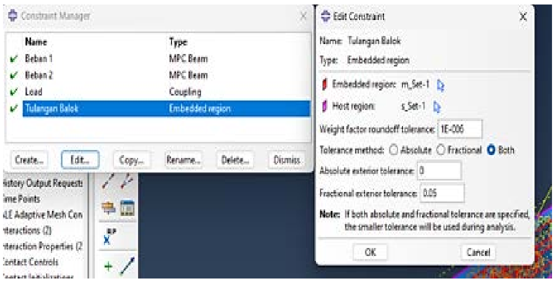

Fig. 11 Concrete and Reinforcement Interaction

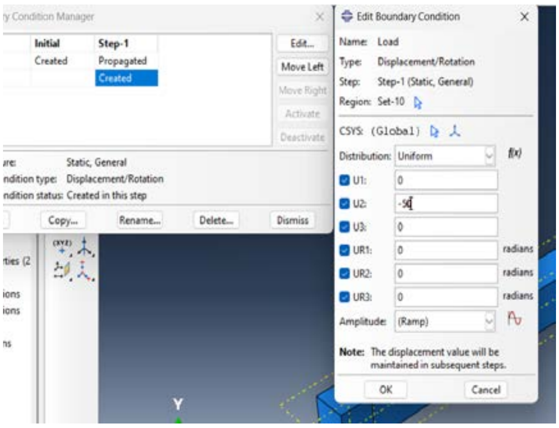

Fig. 12 Load Definition

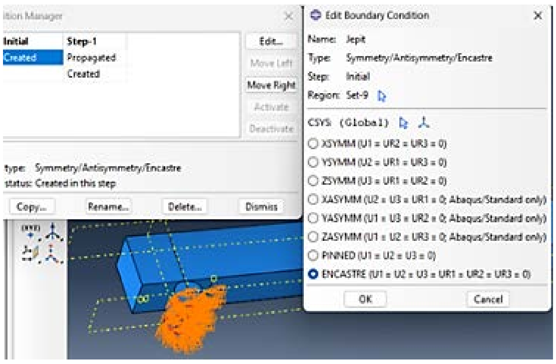

Fig. 13 Load Definition

The load value is made minus so that the load direction is correct, while the determination of the value of 50 mm is due to previous experiments, before the displacement reaches 50 mm, the load capacity has reached the maximum value.

The final step is to create a mesh from each part and create a job so that the model can begin to be analyzed by Abaqus. Mesh or meshing is done to divide the part into small parts so that the Abaqus application can analyze what happens to each small part. The smaller the mesh created, the more detailed the output obtained.

4. RESULTS AND DISCUSSION

After modeling was carried out based on the data that had been obtained, the results were obtained which can be shown in Figures 14 to 17.

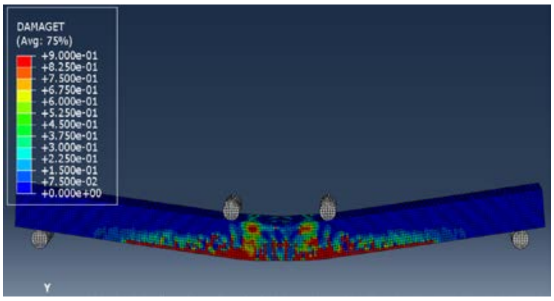

Fig. 14 Crack Pattern from Modelling

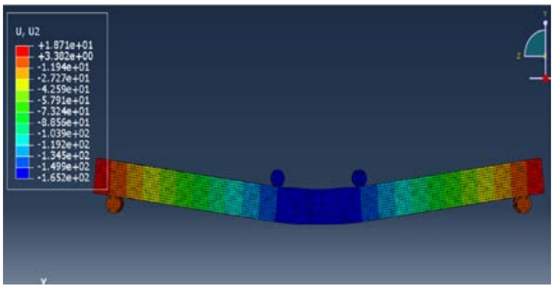

Fig. 15 Displacement Pattern from Modelling

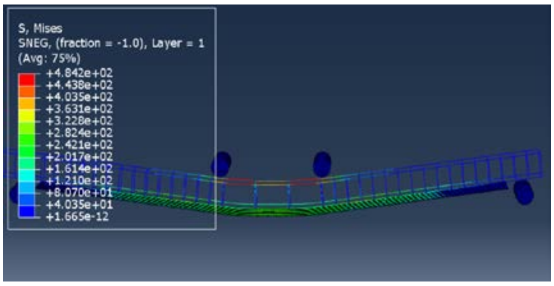

Fig. 16 Strain Pattern from Modelling

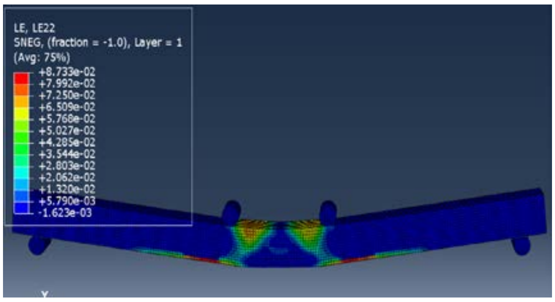

Fig. 17 Stress Pattern from Modelling

It can be seen that the failure was in the debonding between the beam and GFRP-S with many crack patterns occurring in the mid-span deflection area. As validation, the model is then broken down into several parts to analyze whether the modeling of each part is appropriate. After the "Running Job" was carried out, the graphic results were obtained as in Figure 18.

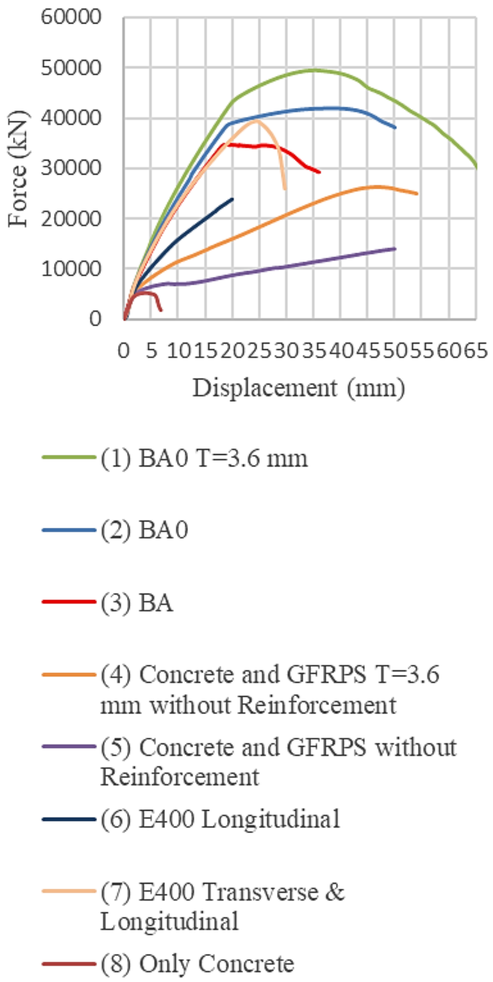

Fig. 18 Force vs Displacement Curves Obtained from Analytical Models

According to validation modeling, it was found that in model 1 [4], if GFRP-S was given an increase in thickness to 3.6 mm, there was an increase in load capacity [6] from the initial model 2 which was 1.3 mm thick. Modeling using only reinforced concrete [14] which is given in model 3 has a smaller value than the initial modeling [6] in model 2, this is appropriate considering that the area of longitudinal reinforcement is reduced by removing GFRP-S. For modeling only beams and GFRP-S in model 5, the results are reduced from modeling only reinforced concrete, because f_y is much smaller than steel reinforcement [22]. After that, concrete was tried only with 3.6 mm thick GFRP-S [18] in model 4 and got greater results than model 5 [19].

The next step is to change the longitudinal tensile modulus value to be adjusted to the same as the concrete reinforcement, the result is that model 6 [22] is still lower than ordinary reinforced concrete, the indication of wisdom is to change the tensile modulus in the transverse direction to make it uniform like the longitudinal direction [23] in the model 7. With model 7, we get an elastic graph that coincides with model 3, and then the plastic area has differences according to the material used. Model 7 gets higher results because the longitudinal area is higher than the longitudinal area of the model 3 [14]. The conclusion is that every change entered gives different results, so it is indicated that the modeling is valid or appropriate.

Next step, variables will be added when model validation is successful. The variables used in this research are the duration of seawater immersion and the addition of the thickness of GFRP-S. The degradation of material due to seawater environment is obtained from Equation 1 which then results in a decrease of the input material values from GFRP-S and Epoxy. Meanwhile, the decrease in beam strength that is input using Equation 2 using concrete damage plasticity is the stress and strain value. After running using Abaqus with limits and material input adjusted to the conditions for the length of immersion, the resulting curves are shown in Figure 19.

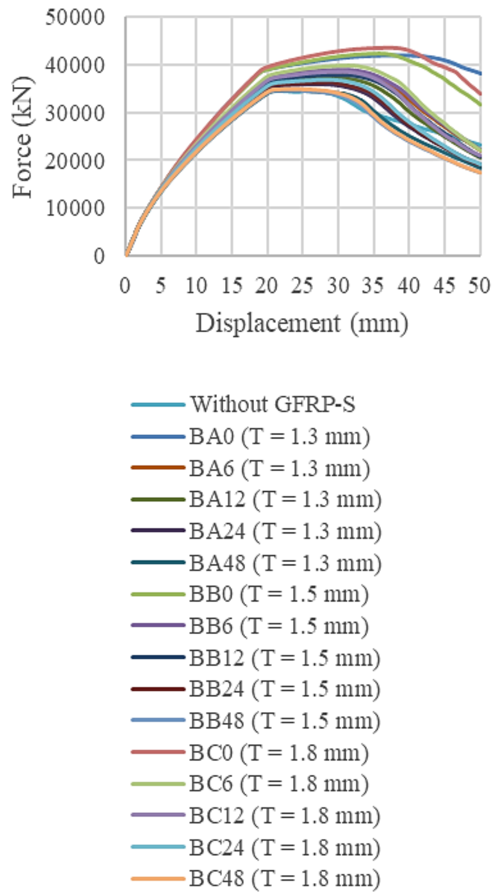

Fig. 19 Relationship of Displacement vs. Force

After obtaining all the curves in Figure 19, the maximum values can be summarized in Table 3 and then can be further inputted into Figure 9 to simplify analysis.

Table 3 Maximum Load Capacity of Beams

Specimen	Displacement	Force
	mm	N
Without GFRP-S	19.72	34714.40
BA_{0} (T = 1.3 mm)	38.51	41938.90
BA_{6} (T = 1.3 mm)	30.11	38268.30
BA_{12} (T = 1.3 mm)	28.71	37239.60
BA_{24} (T = 1.3 mm)	27.03	35923.00
BA_{48} (T = 1.3 mm)	23.97	34547.10
BB_{0} (T = 1.5 mm)	35.79	42311.20
BB_{6} (T = 1.5 mm)	30.74	38944.10
BB_{12} (T = 1.5 mm)	30.15	37844.10
BB_{24} (T = 1.5 mm)	29.18	36352.70
BB_{48} (T = 1.5 mm)	22.16	34620.90
BC_{0} (T = 1.8 mm)	37.11	43507.30
BC_{6} (T = 1.8 mm)	31.40	39798.80
BC_{12} (T = 1.8 mm)	30.55	38542.60
BC_{24} (T = 1.8 mm)	27.60	36843.00
BC_{48} (T = 1.8 mm)	23.78	34870.20

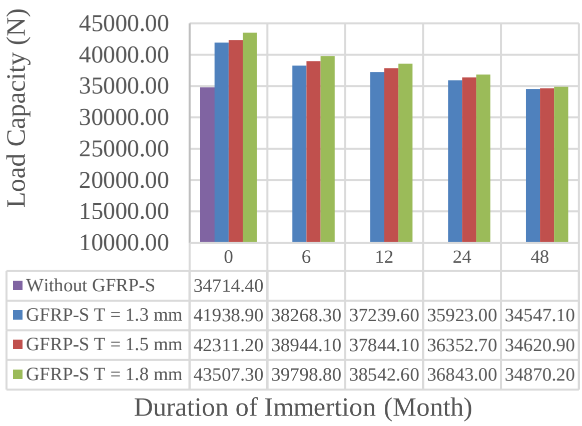

Fig. 20 Relationship of Load Capacity against Immersion Duration

Based on Figure 20, there is an increase in load capacity of 20.81% from beams without GFRP-S to beams using GFRP-S. There was a 17,63% decrease in the load capacity when soaked for 48 months, in other words, 82,37% of the remaining capacity could not be recommended for use. The addition of GFRP-S from 1.3 mm to 1.5 mm increases capacity by 0.89%. Meanwhile, if it is increased from 1.3 to 1.8, the capacity will increase by 3.7%. Based on [24] for concrete without GFRP-S under fully submerged conditions, the concrete experiences a decrease in capacity of 23% at 28 days. The highest strength reduction is always accompanied by adhesive/steel interfacial debonding [25].

5. CONCLUSION

The model can be used for predicting the material degradation of beam capacities due to seawater, and it can be concluded as follows:

1. The load capacity of beams with GFRP-S is 20.81% greater than beams without using GFRP-S, so the addition of GFRP-S affects increasing the duration of beam use.
2. For 6 months of immersion, there was a decrease in load capacity of 8.75%, at 12 months, there was a decrease in load capacity of 11.21%, at 24 months of immersion, there was a decrease in load capacity of 14.34%, and at 48 months the decrease was 17.63%. It is recommended for additional repairs or strengthening.
3. An increase in thickness of 2 mm GFRP-S increases capacity by 0.89% and an increase of 5 mm GFRP-S increases capacity by 3.74%. Additional thickness does not have a significant effect on the life and the capacity of the beam. These results validate the previous research [20].

6. ACKNOWLEDGMENTS

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