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Simulation of the Effect of Sea Water Using Ground Tank to the Flexural Capacity of GFRP Sheet Reinforced Concrete Beams

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Abstract**—**The study conducted a simulation of the effect of sea water to the bonding capacity of GFRP sheet on the concrete beams using a simulation tank. Fiber reinforced polymer (FRP) has been developed and applied in many fields civil engineering structures on the new structures and also for strengthening of the deteriorated structures. The FRP has advantages such as its corrosion resistance as well as high tensile strength to weight ratio. Compared to the other FRP materials, Glass composed FRP (GFRP) is relatively cheaper. GFRP sheet is applied externally by bonding it on the concrete surface. The studies regarding the application of GFRP sheet have been conducted such as strengthening system, bonding behavior of GFRP sheet including the application as reinforcement in new structures. For application to the structures with direct contact to sea environment, a study regarding the effect of sea water to the bonding capacity of GFRP sheet is important to be clarified. To achieve the objective of the study, a series of concrete beams strengthened with GFRP sheet on extreme tension surface were prepared. The beams then were stored on the sea water tank for six months. Results indicated the bonding capacity decreased after six month exposed to the sea water.

Keywords**—**GFRP sheet, sea water, concrete beams, bonding.

I. INTRODUCTION

THE advanced material well known as Fiber Reinforced Plastics (FRP) have been accepted as an alternative materials for the conventional steel reinforcement. Commonly FRP types are glass fiber reinforced plastics (GFRP), carbon fiber reinforced plastics (CFRP), aramid fiber reinforced plastics (AFRP), respectively. The use of fiber materials in the form of Fiber Reinforced Polymer (FRP) for application to the concrete structures offers several desirable attributes, such as resistance to corrosion, high strength, light weight, and ease of handling [1]-[3]. It has been applied to many purposes for civil engineering structures not only for new structures but also for strengthening of the deteriorated structures. Many techniques and method are currently developed for structural strengthening and rehabilitation [4], [5].

In the form of sheet, the FRP may be applied for strengthening of the structure members by bonding it to the concrete surface [6]. Fig. 1 shows the strengthening of the bridge girders using GFRP sheet for shear and CFRP sheet for flexural. Glass fiber sheet as shown in Fig. 2 is most commonly used due to its relatively lower cost compared to the other FRP materials. The GFRP sheet is bonded to the concrete surface to have its advantages in the flexural action of the beams. GFRP sheet can be effectively used to increase the flexural strength by attaching at the extreme tension surface [7]-[9]. Therefore, the bonding of GFRP sheet to the concrete surface plays an important role in order to achieve a good mechanical action. The interaction between GFRP sheet and the concrete surface is a key factor to achieve a mechanical flexural action [8]. Since the bonding action between FRP sheet to the concrete is based on the adhesive action then the aggressive environment may affect to the bonding capacity. Deterioration of the bonding action may cause a premature failure. Many studies have been done to investigate the bonding of GFRP sheet. However, it is still very rarely studies on the effect of sea water to the bonding capacity of GFRP sheet on the strengthened beams due to flexural loadings [7], [8]. This is important to be clarified for the wider application of GFRP sheet especially on the flexural structure that directly contact to the sea environment. The prediction of the bond capacity of bonded GFRP after exposing of sea water environment is important to determine the durability of flexural beams. However, exposing directly to the sea water in the ocean has difficulties due to the mobility of the heavy specimens as well as the safety of specimen. This study proposed a simulation of the effect of sea water exposing to the bonding capacity of GFRP sheet to concrete beams using a concrete.

Fig. 1 Strengthening of Bridge Girder

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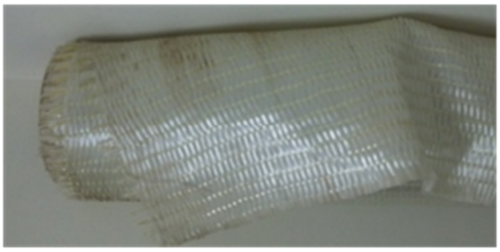

Fig. 2 Glass fiber sheet

II. SIMULATION TANK

A. Preparation of Simulation Tank

The simulation tank was designed with dimension of 1.0 m depth, 4 m width and 8 m long, respectively, as shown in Fig. 3. The tank was open-type that constructed using steel reinforced concrete to allow the air flow and temperature influences the water in the tank.

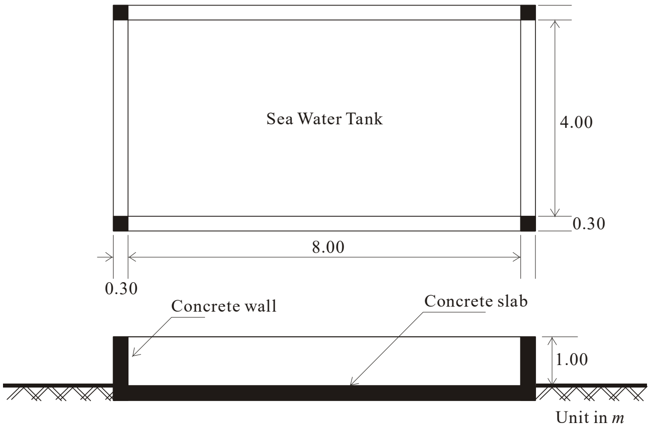

Fig. 3 Simulation Tank Dimension

The construction of tank was started from the casting of the steel reinforced slab and then followed by casting of the steel reinforced wall, respectively. After curing of the tank concrete for approximately one month then the tank was flushed using normal water to clean the tank. Before filling with the sea water, the tank was filled by normal water for about a week to normalize the concrete surface from the alkalinity of the concrete. Fig. 4 shows the tank after flushing with normal water. After flushing by normal water, the tank was filled with sea water using tank truck. The source of the sea water was located approximately 20 m from beach line, as shown in Fig. 5. It should be noted that using sea water, the tank was also flushed twice before final filling to recondition of the tank with the sea water condition.

Fig. 6 shows the transportation of sea water using a tank truck The prepared beam specimens (explained in detail on the Section III) were stored into the water to expose them by sea water (Fig. 7). The specimens were tested after exposing for three and six months, respectively.

Fig. 4 Simulation Tank

Fig. 5 Source of Sea Water for Simulation Tank

Fig. 6 Sea Water Transportation using Tank Truck

Fig. 7 Specimen into the Sea water of Simulation Tank

B. Controlling of the Sea water in the Tank

In order to ensure that the sea water in the tank has close condition with the sea water in ocean, the measurement on the chloride content and pH level was conducted. The measurement was compared to the sea water in the ocean. The measurement was done weekly by taking both water samples in the tank and ocean. The chloride content and pH level of water specimens were measured in the laboratory. Fig. 8 shows the measurement of sea water parameters in the Chemical Laboratory of Hasanuddin University. This measurement is important because there is a possibility that the sea water chloride content and pH in the tank change due to rain water enter into the tank or due to evaporation of water. If the chloride

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and pH measurements in the tank are much change compared to the control sea water, the sea water in the simulation tank is refilled using new sea water.

Figs. 9 and 10 show the measurement results of the sea water parameters for Chloride content and pH level, respectively. At the first month (sixth week) there was a decreasing of the chloride content of the tank sea water. This was caused by heavy rain entered into the tank. This deviation was corrected by refilling the tank by a new sea water and repair the roof to protect the tank from the rain and evaporation. As it can be observed in Fig. 9, the chloride content of the tank sea water after eighth month and so on was approximately close to the control sea water. Fig. 10 presents the measurement of the pH level both sea water in the tank and sea water in the ocean (control sea water), respectively.

Fig. 8 Measurement of sea water parameters

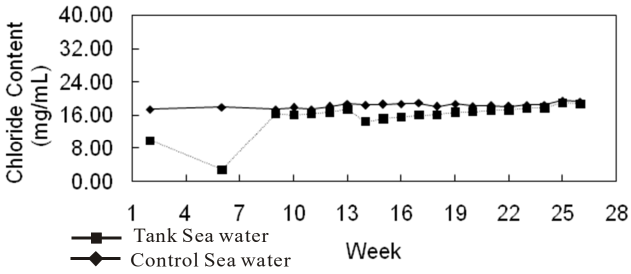

Fig. 9 Measurement of the Chloride Content

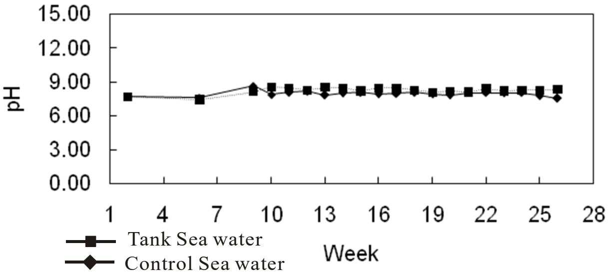

Fig. 10 Measurement of the pH Level

III. Concrete Beam Specimens

A series of concrete beams were prepared to investigate the effect of sea water to the flexural capacity of GFRP sheet reinforced beam. The specimens were divided into two groups, which are the specimens for simulation tank and the specimens to be exposed directly in the ocean as the control specimens, respectively. The details of specimens are presented on Fig. 11.

The cross section of beam specimen was 100 x 120 mm with the total length of 600 mm. All specimens were pre-cracked by a notch of 10 mm along the width of beams at the span center to localize the crack when loading. Un-continuous D10 steel reinforcement were applied in both side of the beam with the space of 20 mm between them (Fig. 11) to avoid concrete failure or cracks on the shear span. The concrete beams were cured for 28 days before the application of the GFRP sheet. The cylinders as well as beam specimens for rupture test were also prepared to determine the material properties of concrete. Table I presents the material properties of the concrete. Compressive strength of concrete at 28 days was 22.2 MPa with Young of Modulus of 22.14 GPa. The rupture strength of concrete was 3.3 MPa.

The application of GFRP sheet were conducted based on the manufacturer procedures [10]. Firstly, the bottom surfaces of the beams were smoothed by a disk sander. The epoxy resin was applied on the GFRP sheet placed on the table using a soft roller to impregnate all the fibers in the resin. The epoxy resin was applied on the treated surface using a soft roller before patching of the impregnated GFRP sheet to the treated surface. The patched GFRP sheet was positioned with the application of slight pressure using a soft roller. The beams were then cured again for 3 days to allow the hardening of resin. Table II shows the material properties of the manufacturer data sheet of glass fibers and GFRP, and Table III shows the manufacturer data sheet of epoxy resin, respectively [11], [12]. The GFRP used in this study was composed by E-Glass and epoxy resin. The GFRP has tensile strength of 575 MPa with elastic modulus of 26.1 GPa. Fig. 12 shows the prepared GFRP strengthened concrete beam specimens.

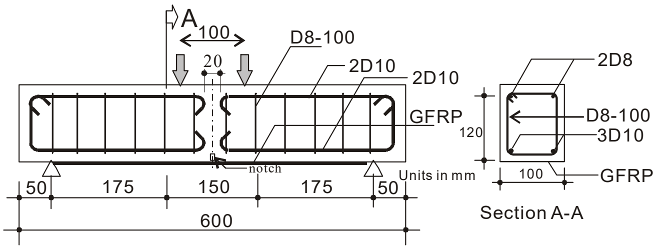

Fig. 11 Beams Specimen Detail

TABLE I
Material Properties of Concrete

Items	Properties
Compressive Strength (MPa)	22.2
Modulus Young (GPa)	22.14
Rupture Modulus fr (MPa)	3.3

TABLE II
Material Properties of Glass Fiber and GFRP

Items	Glass Fiber	GFRP
Type	SEH-51A	-
Tensile Strength (MPa)	3240	575
Modulus Young (GPa)	72.4	26.1
Laminate Thickness (mm)	0.36	1.3

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TABLE III
MATERIAL PROPERTIES OF EPOXY RESIN

Items	Properties
Tensile Strength (MPa)	72.4
Modulus Young (GPa)	3.18
Bonding Strength* (MPa)	2.12

* *Based on the tensile test*

Fig. 12 GFRP Strengthened Concrete Beam Specimens

IV. TEST SETUP FOR INVESTIGATION

In order to investigate the validity of the sea water tank in simulating the effect of sea water to the flexural capacity of the GFRP strengthened concrete beams, the beam specimens were also exposed directly in the sea water of the ocean at the place of sea water source for water tank. Fig. 13 shows the specimens on the ocean. The specimens were hanged using plastic ropes to avoid the specimens moving due to sea wave.

The investigation of the effect of the sea water was conducted by loading the specimen under four-points bending test as shown in Fig. 14.

Fig. 13 Specimens on the ocean

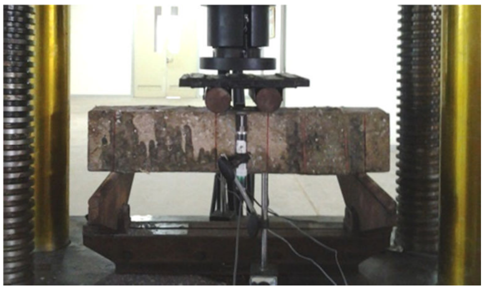

Fig. 14 Test Setup of Beams Specimens

The effect of sea water was investigated after exposing to sea water for three and six months, respectively. Two LVDTs and strain gauges on the GFRP sheet as well as on the compression surface were attached to monitor the behavior of the specimen during loading.

V. RESULTS AND DISCUSSIONS

A. Beam Stiffness

Investigation on the effect of the sea water to the beam stiffness was conducted by observe the load-deflection relationship of the loaded specimens. Figs. 15 and 16 show the load-deflection relationship of specimens after three and six months of exposing, respectively. Generally, it was noted that both specimens (tank and control specimens) propagated in similar stiffness up to failure. Flexural stiffness is depend on the flexural action of the beams (Fig. 17) which is the couple action between the compressive stress and the tensile stress of the beams [13], [14].

After concrete cracking, the couple action was developed by the compression force on the compressive concrete and the tension force on the tensile GFRP sheet, as it may be written in (1). The increasing of the applied load was followed by the increasing of the stress of GFRP and concrete to achieve equilibrium internal forces, as:

$$\mathrm{Mn} = \mathrm{T_f} \times \mathrm{z} = \mathrm{Cc} \times \mathrm{z} \qquad (1)$$

where, *Mn* is flexural moment, $\mathrm{T_f}$ is forced acting on GFRP sheet, C_c is forces acting on the concrete compression section and $z = (h - \frac{1}{3}a)$ is arm between $\mathrm{T_f}$ and $\mathrm{C_c}$, respectively.

From Figs. 15 and 16, it may be observed that the load-deflection relationship consist of two stiffness. The stiffness decreased when the applied load achieved to approximately 15 kN. The stiffness (P/Δ) of the first step was approximately 19.05 kN/mm, and the stiffness of the second step was 13.64 kN/mm. From this observation, it may be concluded that the sea water is not influence the beam stiffness. The simulation tank specimens had similar pattern of load-deflection relationship compared to the ocean sea water specimens.

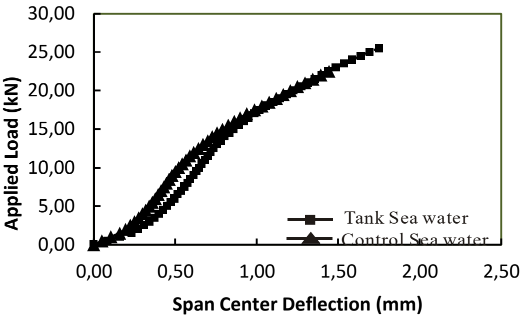

Fig. 15 Load-Deflection after 3 months exposing

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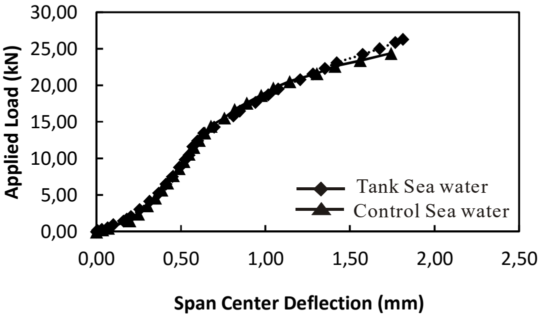
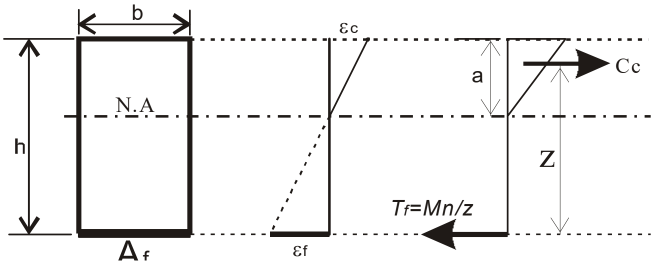


Fig. 16 Load-Deflection after 6 months exposing



(a) Cross Section (b) Strain diagram (c) Couple action

Fig. 17 Internal Couple Action of Flexural Beams

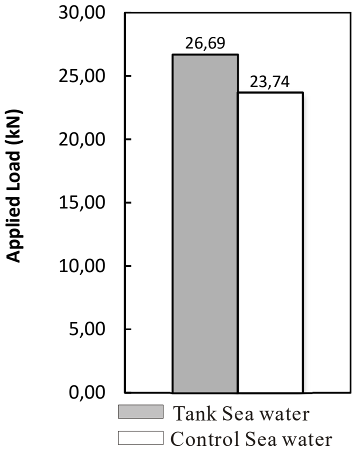


Fig. 18 Flexural Capacity after 3 months exposing

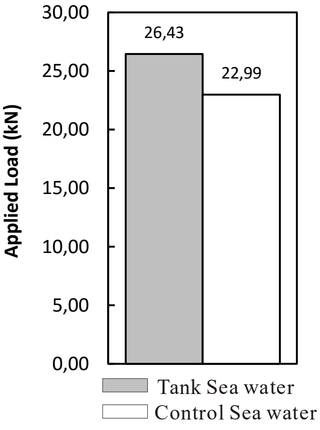


Fig. 19 Flexural Capacity after 6 months exposing

Fig. 20 Failed Specimen due to delamination of GFRP Sheet

B. Load Flexural Capacity

Figs. 18 and 19 show the histogram of the load flexural capacity of the specimens after exposing to sea water for three and six months, respectively. The grey color shows the load capacity of the specimens exposed in the simulation tank, and the white color shows the load capacity of the specimens exposed directly in the ocean. Generally, it can be observed that direct expose in the ocean has more influence to the load flexural capacity than the simulation tank. The failure of specimens was caused by the delimitation of the GFRP sheet, as shown in Fig. 20. It should be notes here, that the average flexural capacity of the specimens before exposing was approximately 27.05 kN. For the specimens after three month of exposing, the load capacity of the specimen on the simulation tank was 26.69 kN, while the specimens exposed directly on the ocean was 23.75 kN, respectively. For the specimens after six month of exposing, the load capacity of the specimen on the simulation tank was 26.43 kN, while the specimens exposed directly on the ocean was 22.99 kN, respectively. This indicated that the sea water affected the load flexural capacity of both specimens. Exposing for three month, the sea water simulation tank caused the decreasing of load capacity for approximately 2.3%, and sea water on ocean was 15.0%, respectively. This indicated that the sea water on ocean has more influence to the load flexural capacity than the sea water in the tank. This may be caused by the effect of sea wave that not exist in the simulation tank.

VI. CONCLUSION

The sea water tank may be used to simulate the effect of the sea water to the flexural capacity of GFRP strengthened concrete beams. The measurement on the chloride content and pH level should be conducted to ensure that the sea water in the tank has close condition with the sea water in ocean that should be regularly monitored.

The sea water is not influence significantly the beam stiffness. Sea water in the simulation tank had similar influence with the ocean sea water to the specimens' stiffness. The stiffness (P/Δ) of the load-deflection of specimens shows that the first step was approximately 19.05 kN/mm, and the second step was 13.64 kN/mm. However, the sea water affected the load flexural capacity of both specimens. Exposing for three month, the sea water of simulation tank caused the decreasing of load capacity for approximately 2.3%, and sea water on ocean was 15.0%, respectively. The sea water on ocean has more influence to the load flexural capacity than the sea water in the tank. This may be caused by the effect of sea wave that not exist in the simulation tank.

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