Reinforced concrete beam behavior with strengthening of CFRP lamination in the seawater environment

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Abstract. The strength of concrete structures in the seawater environment decreases with the duration of exposure seawater due to high content of chloride compounds. Repairing structures are difficult in marine environments requires creating new methods that are effective, easy to work and economical. One of them is by using CFRP (Carbon Fiber Reinforced Polymer) material which is proven to corrosion resistant. Strengthening is done with external bond CFRP on the area that you want to strengthen. This research was conducted with an experimental method, namely reinforced load concrete beams were given a monothonic load with two points to determine the ultimate load capacity of the beams and then compared with the increase in the CFRP variable layer which the ends were anchored with CFRP U-wrap and given sea water immersion behavior. The results of the flexural test showed that along with the time of sea water immersion there was a decreases in the capacity of the ultimate load from the normal beam and with CFRP reinforcement are on normal test specimen s without reinforcement of 3.12%, concrete with CFRP layers 1, 2 and 3 in sequence are 2.92%, 2.84, and 2.75%. The largest ultimate load capacity with 3 layers of CFRP is 36.23%.

1. Introduction
Along with technological developments, the use of concrete was applied not only on land but also in extreme environmental areas such as sea water areas. Chloride compounds in sea water will result in decreased strength in the concrete and make the reinforcement in it rust causing damage to the concrete [1]. The difficulty of repairing the seawater environment, especially on repairing bridge beams at sea, requires finding a new method that is easy and inexpensive. Strengthening it by using Carbon Fiber Reinforced Polymer (CFRP), CFRP is a lightweight material that is strong and resistant to corrosion. Another advantage is that it is easier to install because it is sheet-shaped so it is suitable for application in the seawater environment. Not much research has been done on beam reinforcement in the seawater environment. Some of them are said there is a decrease in attachment to the FRP with concrete over the duration of the immersion [3,4]. However, even though the bond is reduced CFRP can increase the shear capacity of the beams in the seawater environment for 3 full months in the range of 14-18% of the control beam. Several previous studies have been carried out, namely by using 2 layers of FRP externally and fast debonding occurs before CFRP works optimally [4]. The gap from previous research is that the strengthening of CFRP is only done with 2 layers and without overcoming debonding, therefore research is conducted with different CFRP laminates ranging from 1 to 3 layers and added with U-wrap to overcome debonding that occurs to obtain more complete results from previous studies.
2. Research method
Testing of reinforced concrete beams was carried out by an experimental method. The dimensions of the beam measuring 150 mm x 150 mm x 750 mm and the compressive strength fc' 22.28 MPa. The specimens were given different treatments, namely normal specimens which were not soaked and which would be immersed in sea water for 1 month and specimens that were given CFRP reinforcement with different layers, namely 1 to 3 layers which would be immersed for 1 months in the amount of each specimen of each variable is 3 pieces.

1. Compressive Strength Test
   Testing was conducted to determine the compressive strength to be used in design concrete beam
2. Sea Water Test
   This test is used to determine the characteristics of sea water, to known the content of chloride, pH and another compounds. The seawater is taken from Ancol Bach which is then tested the levels contained therein. Seawater was chosen from Ancol because there is a broken down bridge in the Ancol area and this indicates that seawater is suitable for use as testing material.
3. Flexural Test
   Flexural test using UTM (Universal Testing Machine) to determine the ultimate load capacity of normal beam and reinforced beam with CFRP also the specimen with immersed for 1 month and then will be compare which the strongest.

Flexural testing uses third point load loading on a simple roll-joint pedestal. In the test process is carried out by a monotonic controlled displacement method until the test object collapses. When the hydraulic jack is giving a load, LVDT will record the decrease that occurred. As a result of loading there will be a strain that will be read by the strain gauge and recorded by the data logger.

Figure 1. Reinforced concrete beam design.

Figure 2. Setting up.
3. Results and discussion

3.1. Test results

3.1.1. Compressive strength test results. Concrete compressive strength test results are made in the graph of concrete quality improvement with increasing age of the concrete. The graph will show the value of the compressive strength of concrete has an increase directly proportional to the increasing age of the concrete. The amount of compressive strength will affect the capacity of the concrete beam specimen. The greater the compressive strength value of the beam strength capacity will also be greater. The graph of compressive strength and age of concrete can be seen in Figure 3 below.

![Figure 3. Compressive strength graph.](image)

3.1.2. Sea water test results. Seawater used comes from Ancol. The parameters tested in sea water include calcium (Ca), Magnesium (Mg), Chloride (Cl), Sodium (Na), sulfate (SO4) and Ph. Sea water testing is carried out at the Water Quality Laboratory of the Faculty of Civil and Environmental Engineering, Bandung Institute of Technology.

| No | Analysis parameters | Unit | Testing Method | Analysis Results |
|----|---------------------|------|----------------|-----------------|
| 1  | Kesadahan           | mg/L | APHA-2340-C    | 5.786           |
| 2  | Kalsium             | mg/L | APHA-3500-Ca-B | 784             |
| 3  | Magnesium           | mg/L | APHA-3500-Mg-B | 918             |
| 4  | Klorida             | mg/L | APHA-4500-CI-B | 17.369          |
| 5  | Natrium             | mg/L | APHA-3500-Na-B | 8.3             |
| 6  | pH                  |      | APHA-4500-H+B  | 7.58            |
| 7  | Sulfat              | mg/L | APHA-4500-SO4-E| 1.131           |
3.1.3. Flexural test results. Flexural test results are presented in Table 2.

| Code   | Ultimate Load (Pu) kN | Displacement when Pu (mm) | Failure     |
|--------|-----------------------|--------------------------|-------------|
| BN0    | 98.66                 | 8.2431                   |             |
| BN1    | 95.58                 | 8.4500                   |             |
| B0C1   | 121.79                | 7.9136                   | Debonding   |
| B0C2   | 132.07                | 7.1504                   | Debonding   |
| B0C3   | 146.58                | 6.4836                   | Debonding   |
| B1C1   | 109.88                | 7.1304                   | Debonding   |
| B1C2   | 119.88                | 6.0446                   | Debonding   |
| B1C3   | 130.25                | 5.1709                   | Debonding   |

3.2 Discussion
From the results of the concrete strength test obtained by compressive strength at 28 days at 22.28 MPa. Seawater test results obtained pH 7.58 and chloride (Cl) levels of 17.396 mg/L which is high. Chloride levels will affect the strength of concrete when concrete is directly and continuously exposed to chloride. Concrete will experience a decrease in strength along with the length of immersion [1]. This is indicated in the flexural testing which can be seen in Table 2 along with the duration of the immersion of the ultimate load capacity to decrease.

From the results of testing the flexural capacity of the ultimate load on a normal beam without a submersion (BN0) 98.66 kN has decreased at one month immersion to 95.58 kN like before research said the capacity ultimate will decreases along time sea water immersion [5]. Likewise in different layers of CFRP variables, namely CFRP without immersion (B0C1, B0C2, and B0C3) sequentially 121.79 kN, 132.07 kN, and 146.478 kN while in CFRP 1 month immersion (B1C1, B1C2, and B1C3) sequentially became 121.79 kN, 132.07 kN, and 146.478 kN while at CFRP the immersion for 1 month (B1C1, B1C2, and B1C3) 109.88 kN, 119.88 kN and 130.25 kN. This shows that there is a tendency to decrease in ultimate load along with the increase in sea water immersion and it can also be seen that there is still an increase in concrete without reinforced soak which is then reinforced by CFRP and the largest layer having an ultimate load capacity is B1C3 at 3 layers.

Deflection value of beams at ultimate load on normal beams marks immersion is 8.42 mm and an increase in immersion 1 month is 8.45 mm. Significant differences can be seen between normal beams and reinforced beams and given the behavior of sea water immersion, namely at B0C1, B0C2, and B0C3 respectively 7.91 mm, 7.15 mm, and 6.48 mm while the B1C1 immersion test object, B1C2 and B1C3 are 7.13 mm, 6.04 mm and 5.17 mm. It can be seen a decrease in deflection because the concrete has experienced a collapse before the CFRP works optimally [6].

Figure 4 shows the load-deflection relation curve on normal beam without specimens, normal blocks with 1 month immersion, layers with CFRP reinforcement layers 1 to 3 without immersion and beams with CFRP reinforcement layers 1 to 3 with 1 month immersion tend to be the same. Judging from the stiffness, changes in stiffness from normal to strengthened, namely an increase in the value of stiffness and increase with the number of layers of CFRP, if the depth of 1 month stiffness decreases significantly, especially in the beam reinforced with CFRP. The pattern of load-deflection relationship shows the characteristics of brittle failure especially in CFRP with 3 layers. This is supported by the results of observations on the beam failure that occurs because the beam collapses before the CFRP works optimally, and it can also be seen from the graph that there is a sudden decrease in the release of CFRP from the concrete surface. The dominant flexural crack propagation occurs in the middle of the span of the test specimen. This crack pattern is characteristic of concrete failure due to bending [7].
However, in the case of load failure and maximum deflection, U-wrap approved specimens with CFRP results are similar to specimens that are reinforced in 2-sided packages with continuous CFRP results. Overall, it can be considered that U-wrap or 2-sided reinforcement with continuous CFRP greatly increases the shear capacity and structural protection of RC beams. Obtained from continuous CFRP applications according to a reliable and efficient U-wrap for beams that require 3 months saltwater approval [8].

4. Conclusion
Based on the results of research and analysis, it can be concluded:
- The effect of sea water immersion does not have an impact on reducing the capacity of concrete limit but it is very influential on the strengthening of CFRP due to the decrease in strength from the bond of CFRP to concrete.
- The decrease in limit load capacity that occurs in normal blocks soaked for 1 month with normal beams without immersion is 3.12% and beams with reinforcement without immersion and with 1 month immersion also decrease, but there is still an increase in normal beams for 1 month immersion with beams which was given reinforcement and soaked for 1 month. The largest limit load capacity on reinforced and immersed beams for 1 month in 3 layers of CFRP.
- CFRP can be used in the repair and strengthening of concrete structures in the ocean environment and it is proven that it can increase the value of the flexural capacity of concrete structures.

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