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Effect on Capacity of RC Beam and Column Strengthened with Fibrwrap® System by Cyclic Exposure to Water and Salt Water

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Abstract: *Fiber Reinforced Polymer (FRP) is a popular technique that is used to strengthen and repair existing structural elements due to its high strength to weight ratio, fatigue resistance, non-corrosiveness and ease of handling and application at the site. The objective of this research is to study the effect of reinforced concrete (RC) beam and column externally strengthened with glass fiber reinforced polymer (GFRP) sheets after exposing to cyclic wet-dry of water and salt water. The GFRP was applied on tension face of RC beam to improve flexural strength and wrapped around RC column to increase the compressive strength. Then the strengthened specimens were exposed to different exposure conditions such as outside climate, cyclic wet-dry water, cyclic wet-dry sea liked water and cyclic wet-dry sodium sulfate (Na_2SO_4) solution with duration 1000 hours, 2000 hours and 3000 hours. The result of this experiment showed that the strengthened concrete structure exposed to various exposure conditions FRP could still improve strength. All strengthened RC beam exposed to various exposure condition did not show significant variation compare with unexposed specimens for the same exposure conditions. After exposed for 3000 hours to cyclic water and sodium sulfate (Na_2SO_4) solution, strengthened RC column start to decrease the ultimate load due to degradation on GFRP strengthening system. The most effect exposure condition is cyclic wet-dry sodium sulfate (Na_2SO_4) solution.*

Keywords: Cyclic; Exposure; FRP; GFRP; RC; Strengthening; Wet-dry

1. INTRODUCTION

The use of Fiber Reinforced Polymer (FRP) for externally bonded strengthening has gained popularity for infrastructure in the past decade. There are researches have been done confirming that FRP could be used to strengthen the structural element by (M.R. Islam et al., 2005; B.DeVino et al.; C.S Ping et al.; S. Sithpisey, 2017; C. Phearin, 2018; M. Menglay, 2017). In civil engineering applications, the concrete structure such as bridge, water tank, silos, pipelines, port, etc. are often contact to environmental conditions such as salt water, fresh water, ground water, embed in soil which may cause degradation on reinforced concrete and FRP strengthening system. It can also influence the mechanical properties and durability of this composite materials. There are researches by (R Delpak and al., 2002) tested to assess the strengthening of degraded beams due to environmental attacks. Two degraded beams were tested which had been submerged in a sulphuric acid (of pH 2) for 19 months and then ambient cured for 15 months. Moreover, T.H. Almusallam (2006) conducted beam specimens to investigate the durability of reinforced concrete beams strengthened with GFRP sheets after exposed to different environmental condition such as outside environment, wet-dry normal water, wet-dry saline (NaCl) water, and wet-dry alkaline (NaOH) for a specific period of time. H.A. Toutanji

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and W.Gómez, 1997 tested concrete beams in a wet-dry environment which were strengthened with GFRP and CFRP sheets bonded to tension faces using different types of epoxy. A. S. EI-Dieb and al., 2012 studied on the long-term performance (18 months exposure) of RC elements (beams and slabs) externally strengthened with CFRP sheets and strips after being exposed to different exposure conditions in the United Arab Emirates. L. Zhang and al., 2011 studied the durability of concrete square-section column wrapped with CFRP in the wet-dry environment. In addition, A. Kootsookos et al., 2011 studied CFRP and GFRP, with polyester and vinylester matrices, immersed in seawater at a temperature of 30 °C and showed that the carbon composites displayed better durability. other research by Yingwu Zhou and al., 2015 studied on bond behavior of FRP-to-concrete interface under sulfate attack and M.F. Green and al., 2000 focused on freeze-thaw effects on the bond between concrete and CFRP plate.

The objective of this research is to study the effect of reinforced concrete (RC) beam and column strengthened with glass fiber reinforced polymer (GFRP) sheets after exposing to outside climate, cyclic wet-dry water, cyclic wet-dry sea-liked water and cyclic wet-dry sodium sulfate solution Na_2SO_4 with duration 1000 hours, 2000 hours and 3000 hours.

2. EXPERIMENTAL PROCEDURE

2.1 Specimens and Materials Properties

The dimension of concrete beam was 1200 mm length, 100 mm width and 200 mm depth. The reinforcement of beam included two longitudinal deformed bars with diameter 12 mm at the top with the 6.5 mm diameter round bars stirrups distributed at 50 mm spacing. The RC beams were flexural strengthened with one layer of GFRP with properties as shown in Table 1. The GFRP was applied on the tension surface of RC beams as shown in Fig.1. For dimension of column was 600 mm height and square section (100x100 mm). Four of the 10 mm diameter deformed bar were placed in column with the ties spacing of 200 mm of diameter 6.5 mm of round bar. The RC columns were fully wrapped by GFRP and the minimum overlap is 150 mm as shown in Fig.2.

The Tyfo® S Epoxy was used to bond interface between concrete surface and GFRP have properties as shown in Table 2. The epoxy was prepared by mixing together between A-component and B-component epoxy until uniformly blended. The mixing ratio of epoxy is 100 component A to 42 component B by volume or 100 component A to 34.5 component B by weight.

The concrete mix design that used was to cast concrete beam and column for the design compressive strength of cylinder 20 MPa as shown in Table 3.

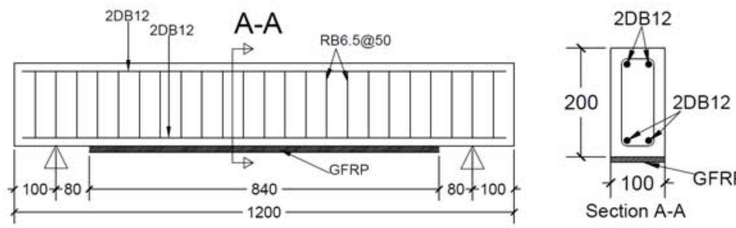

Fig.1. Dimension of RC beam specimens

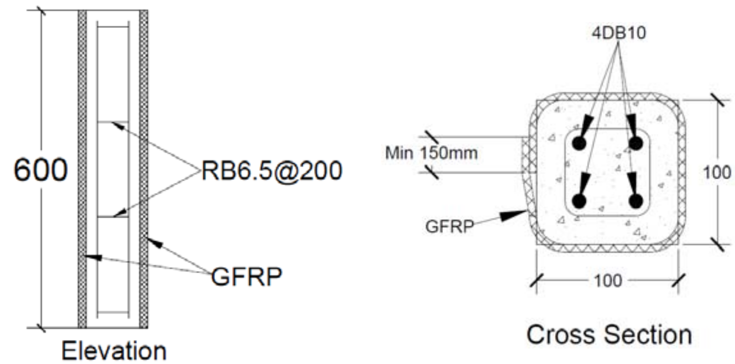

Fig.2. Dimension of RC column specimens

Table 1. Properties of Tyfo® SHE-25A fabric

Property	Tyfo® SHE-25A
Ultimate tensile strength (MPA)	417
Tensile modulus (GPa)	20.9
Thickness (mm)	0.5
Elongation at break (%)	1.76

Table 2. Properties of Tyfo® S Epoxy

Property	Tyfo® S Epoxy
Tensile strength (MPA)	72.4
Tensile modulus (GPa)	3.18
Flexural strength (MPa)	123.4
Flexural modulus (GPa)	3.12
Elongation at break (%)	5

Table 3. Concrete mix design

Property	20 MPa (cylinder)
Gravel (kg/m^3)	1050
Sand (kg/m^3)	20.9
Cement (kg/m^3)	274
Water (kg/m^3)	190

2.2 Exposure Condition

Symbols were used to represent the identification's specimens as shown in table 4. There are two types of controlled samples and four typical exposure conditions such as outside climate, cyclic wet-dry water, cyclic wet-dry sea-liked water and cyclic wet-dry water sodium sulfate solution (Na_2SO_4) with different durations and each type of test was prepared by 3 specimens. For the sea-liked water and sodium sulfate solution were mixed by different amount of two chemical composition as shown in Table 5.

For outside climate exposure, the specimens were placed outside the room. For the wet-dry cyclic exposure, the specimens were immersed into tap water, sea liked water and sodium sulfate solution, after that the solution were pumped out in the morning to dry the specimens during day time and pumped in the evening to wet specimens during night time

Table 4. List of symbols' specimens

Property	Symbols
Controlled specimens (without strengthened)	NoFRP
Controlled specimens (without strengthened)	FRP
Outside climate	OS
Cyclic wet-dry water	CW
Cyclic wet-dry sea-liked water	CN
Cyclic wet-dry Na_2SO_4 solution	CS

Table 5. The chemical composition for salt solution

Constituent	Sea-liked water	Sodium sulfate solution
NaCl (g/L)	24.53	-
Na_2SO_4 (g/L)	4.09	50

2.3 Testing Specimens

After each exposure condition was completed, the specimens were tested in civil engineering laboratory at Institute of Technology of Cambodia (ITC). The three-load point flexural test was used to test on flexural capacity of strengthened beam as shown in Fig.3. The column specimens was used to test the compressive strength and the compression load value was shown in gauge of this machine and was recorded by visual operator as shown in Fig.4.

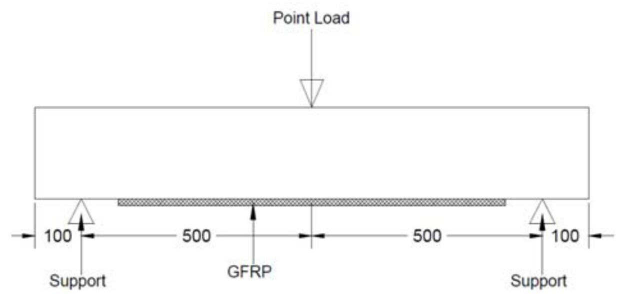

Fig.3. Three point flexural test of RC beams specimens

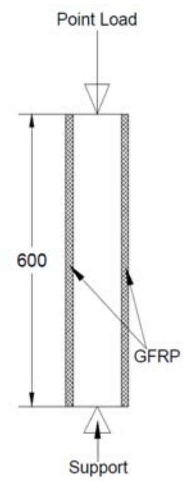

Fig.4. Compressive test of RC column specimens

3. RESULTS AND DISCUSSION

In this section, the experimental result of testing RC beam and column specimens was presented and discussed.

3.1 Beam specimens result

The ultimate force of testing result of beam specimens are presented in Fig.5, was used to study the behavior of flexural strengthening beam with GFRP exposed to environmental condition. The failure mode of each specimens was observed during testing as shown in Fig.6. The main observation of tested beam showed that

- The failure mode of most strengthened beam with GFRP are peeling off of the GFRP sheet as shown in Fig.6 due to debonding interface between concrete substrate and FRP and none specimens have tensile rupture of GFRP sheet.

- The externally bonded with GFRP on the tension surface of unexposed beam could increase 16 % of ultimate load compare with the unstrengthen beam.
- All ultimate load of exposed beams increased from 7% to 26 % compared with unexposed beam.
- After exposed for 1000 hours to various exposure condition did not show significant variation than unexposed beam as shown in Fig.5. For strengthened beam exposed 2000 hours and 3000 hours to outside climate, cyclic sea liked water and cyclic sodium sulfate solution increase dramatically compare to strengthened beam exposed 1000 hours. It could be attributed from gain strength of concrete after 28 days and minimum effect on performance of FRP strengthening system.
- According to result after exposed 1000 and 3000 hours the cyclic water exposure did not have significant variation could be due to minimum degradation on concrete and the FRP strengthening system.

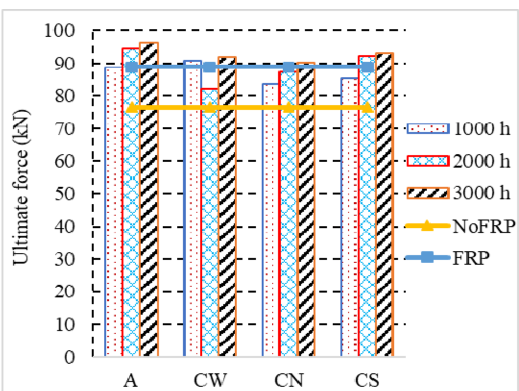

Fig.5. Ultimate load of all beam specimens after exposed

Fig.6. Peeling off GFRP sheets

Table 6. Ultimate load of testing RC beam specimens exposed 1000 h

Typical specimens	Avg (kN)	St (kN)
NoFRP	76.57	3.17
FRP	88.96	0.58
OS	88.86	3.69
CW	90.81	1.76
CN	83.55	4.51
CS	85.31	4.68

Avg, average; St, standard deviation

Table 7. Ultimate load of testing RC beam specimens exposed 2000 h

Typical specimens	Avg (kN)	St (kN)
NoFRP	76.57	3.17
FRP	88.96	0.58
OS	94.68	1.07
CW	82.23	1.24
CN	87.46	4.17
CS	92.18	1.40

Avg, average; St, standard deviation

Table 8. Ultimate load of testing RC beam specimens exposed 3000 h

Typical specimens	Avg (kN)	St (kN)
NoFRP	76.57	3.17
FRP	88.96	0.58
OS	96.25	0.65
CW	92.12	1.50
CN	90.18	1.28
CS	93.04	1.66

Avg, average; St, standard deviation

3.1 Column specimens result

The maximum compressive force of testing result of column specimens are presented in Fig.7, was used to evaluate the performance of compressive strengthening column with GFRP exposed to environmental condition. The failure mode of each specimens was observed during testing as shown in Fig.8. The main observation of tested column showed that

- The failure mode of strengthened column with GFRP occur on tensile rupture of GFRP sheet along direction as shown in Fig.8.
- The externally wrapped with GFRP on the surface of column could improve 83 % of ultimate load compare with the unstrengthen column
- All ultimate load of exposed column increased from 31% to 76 % compared with unexposed column
- The strengthened column after exposed 1000 hours the ultimate load decreased from 17% to 29 % compare with unexposed column. It could be attribute from variation compressive concrete strength in different batch between exposed 1000 hours and unexposed.
- For column exposed 2000 hours and 3000 hours to various exposure condition increased gradually compare to column exposed 1000 hours to same exposure condition except exposure to cyclic water and cyclic sodium sulfate. It could be attribute from minimum effect on FRP strengthening system and gained compressive strength of concrete after 28 days.
- For column exposed 3000 hours to cyclic water and sodium sulfate the ultimate force start to decrease that could be effect of exposure condition on performance FRP strengthening system and concrete degradation. For column exposed 3000 hours to cyclic water decrease ultimate could be due to rate of diffusion into FRP strengthening system that cause loss strength of GFRP (CEB, 2001). Further, for column exposed 3000 hours to cyclic sodium sulfate solution decrease ultimate could be due to reaction between sodium sulfate with chemical composition of glass fiber that cause loss strength of GFRP.

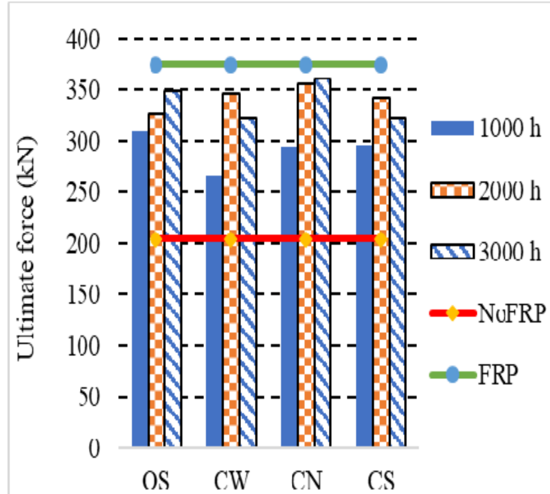

Fig.7. Ultimate load of all column specimens after exposed

Fig.8. Rupture along direction of GFRP of strengthened column

Table 9. Ultimate force of testing RC column specimens exposed 1000 h

Typical specimens	Avg (kN)	St (kN)
NoFRP	204.33	9.88
FRP	374.67	2.62
OS	311.00	12.03
CW	266.67	7.59
CN	295.00	22.73
CS	295.33	19.69

Avg, average; St, standard deviation

Table 10. Ultimate force of testing RC column specimens exposed 2000 h

Typical specimens	Avg (kN)	St (kN)
NoFRP	204.33	9.88
FRP	374.67	2.62
OS	326.33	12.12
CW	346.00	23.37
CN	355.67	27.35
CS	342.67	5.54

Avg, average; St, standard deviation

Table 11. Ultimate force of testing RC column specimens exposed 3000 h

Typical specimens	Avg (kN)	St (kN)
NoFRP	204.33	9.88
FRP	374.67	2.62
OS	348.67	9.46
CW	322.00	12.68
CN	360.33	6.94
CS	322.00	12.03

Avg, average; St, standard deviation

4. CONCLUSIONS

After the result was discussed, this research showed that

- Even though strengthened specimens exposed to various exposure condition GFRP strengthening system still increase the ultimate load compare with unexposed strengthened specimens.
- After specimens exposed 3000 h, the experimental result showed that column specimens have more effect than beam specimens.
- The reduction of strength of exposed strengthened concrete structure could be due to the degradation on the concrete and FRP strengthening system
- The most effect exposure condition on FRP strengthening is cyclic wet-dry sodium sulfate (Na_2SO_4) solution.

After we finish this research, the result presented that environmental have effect on the strengthened concrete structure. Moreover, the typical of FRP and epoxy also have influence on the strengthening concrete structure due to the composite work of each materials. The further research is mentioned to study more about performance durability of FRP as showed below as such

- Study the long-term effect on FRP strengthening system exposed to environmental exposure conditions to observe performance durability.
- Investigate microstructural on FRP strengthening system after exposed to environmental exposure condition to identify mechanism of degradation.
- Study effect on other size of RC specimens exposed to environmental exposure condition under applying service load to represent the actual structure.
- Study on effect of other typical FRP and epoxy that exposed to environmental exposure condition.

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