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Case study

Utilization of CFRP for strengthening RC columns in marine environment

Alaa Alsaad[a,*], Gulan Hassan[b]

[a] Head of Structures Dept., AH Consultants, Dubai, UAE
[b] Department of Civil Engineering, College of Engineering, University of Duhok, Duhok, Iraq

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ABSTRACT

This paper reports the results of an experimental investigation of the utilization of carbon fiber reinforced polymer (CFRP) to concrete marine structures. The study involved testing reinforced concrete (RC) columns. A total of 32 specimens were grouped and investigated to evaluate the performance of CFRP wrapped RC circular columns in a marine environment. The specimens were immersed for different periods in crude oil or seawater, which are common conditions for marine structures. The specimens were identical and had a diameter of 150 mm and an overall height of 550 mm. Period of immersion was the main test parameter and the investigation focused on the performance of the columns wrapped with CFRP in terms of load capacity, deformation and ductility. The test results showed that the ultimate load capacity of the RC columns wrapped with CFRP was not noticeably affected by immersion in crude oil or seawater. However, there was a significant reduction in ultimate axial displacement and radial strain. Hence, there was a significant negative effect of immersion in crude oil or seawater on the ductility of RC columns confined with CFRP.

1. Introduction

In the past few decades, many types of materials have been developed for the repair or strengthening of reinforced concrete (RC) structures, driven by the demands of the construction industry arising from the existence of concrete problems, such as deterioration, and the need for post-strengthening of structures to ensure their safety and serviceability [1]. Among these materials, fiber reinforced polymer (FRP) has been widely used in construction engineering [2,3] because of its tensile strength, corrosion resistance, and easier handling, in addition to the economic advantages [4,5].

RC elements in marine structures are often exposed to an aggressive marine environment with high humidity and seawater attack in addition to the effects of materials like crude oil. The effects of the marine environment on RC, especially cracking and deterioration, are very harsh and more notable than in other environments [6,7].

Many studies have investigated RC strengthened using FRP. These studies have covered many aspects of FRP-wrapped RC columns, including mechanical properties like strength capacity and ductility [8,9] and durability [10–12]. Chastre and Silva [13] investigated the mechanical behavior of RC circular columns confined with CFRP to evaluate the effects of some parameters, including the diameter of the columns and the number of CFRP layers. They proposed an equation to predict the compressive strength capacity and deformation of circular RC columns wrapped with CFRP, based on their experimental data and the results of other researchers [14–16]. Toutanji [17] reported improvements in strength and ductility due to the confinement of RC columns with

* Corresponding author.
E-mail address: alaa.a@alhashemi.ae (A. Alsaad).

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Table 1
Properties of CFRP and epoxy resin (as per manufacturer).

Material	Tensile E-modulus (MPa)	Tensile strength (MPa)	Ultimate elongation	Density (gm/cm^3)
CFRP	238000	4300	1.8%	1.76
Epoxy Resin	4500	30	0.9%	–

CFRP. The author also investigated the effects of exposure to wet/dry cycles using seawater, and the results exhibited no significant change in strength and only slight changes in ductility (5–15% in terms of ductility ratios).

The main goal of this paper is to investigate the effect of the marine environment on the behavior of RC strengthened with CFRP sheets in the short term. The purpose is to evaluate the aggressiveness of crude oil and seawater on the performance of RC columns wrapped with CFRP and those unwrapped for the same period of exposure. However, the main focus is on the effect of immersion in crude oil or seawater on CFRP-wrapped columns.

2. Experimental program

2.1. Materials

Portland cement concrete was produced in the laboratory according to the ratios of the adopted mix design and used for casting all specimens. Moist curing was used for at least 28 days. Two groups of RC columns were cast to study the effects of crude oil and seawater on the behavior of CFRP-wrapped columns. The average values of concrete compressive strengths at 28 days were 45 MPa and 41 MPa for Group A and B, respectively. The concrete mix proportions were 1:1.5:2 (cement: sand: gravel) by weight, with a water- cement ratio of 0.45. Crushed natural gravel with a maximum size of 10 mm and natural sand were used as coarse and fine aggregate, respectively.

A unidirectional carbon fiber reinforced polymer (CFRP) from the SIKA Company was used for the wrapping of column specimens, and ASIKAdu-330 adhesive was used in the wrapping process. Table 1 shows the properties of the composite materials according to the manufacturer.

The crude oil used in this investigation was Iraqi heavy type collected from the Tawka Station, while the seawater was collected from the Mediterranean Sea, Antalya, Turkey.

2.2. Specimen layout and test set-up

A total of 32 specimens were grouped and investigated to evaluate the performance of CFRP-wrapped RC circular columns in the marine environments explained in Table 2. All the specimens were identical. The diameter of the cross-section was 150 mm and the height of each column was 550 mm. Deformed steel bars with yield strength of 420 MPa were used for longitudinal and transverse reinforcing with nominal diameters of 10 mm and 5 mm, respectively. A schematic of an RC column specimen is shown in Fig. 1(a).

One layer of CFRP sheet was wrapped manually around the RC column with the fiber orientation around the circumferential direction and an overlap length of 100 mm. Additional 50 mm strips of CFRP sheet were installed at the ends of each specimen in order to prevent premature failure. Two weeks after wrapping, the specimens were immersed in crude oil or seawater for different periods, as per the experimental program.

Table 2
Details of tested specimens.

Group	Specimen	Strengthening	Immersion condition	Number of specimens
A1	O-CN-WO	Without	Control (no immersion)	2
	O-30d-WO	Without	30 days in crude oil	2
	O-60d-WO	Without	60 days in crude oil	2
	O-90d-WO	Without	90 days in crude oil	2
A2	O-CN-CFRP	With CFRP	Control (no immersion)	2
	O-30d-CFRP	With CFRP	30 days in crude oil	2
	O-60d-CFRP	With CFRP	60 days in crude oil	2
	O-90d-CFRP	With CFRP	90 days in crude oil	2
B1	S-CN-WO	Without	Control (no immersion)	2
	S-7d-WO	Without	7 days in seawater	2
	S-30d-WO	Without	30 days in seawater	2
	S-90d-WO	Without	90 days in seawater	2
B2	S-CN-CFRP	With CFRP	Control (no immersion)	2
	S-7d-CFRP	With CFRP	7 days in seawater	2
	S-30d-CFRP	With CFRP	30 days in seawater	2
	S-90d-CFRP	With CFRP	90 days in seawater	2