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Experimental Testing of Retrofitted Corroded Reinforced Concrete Elements

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DEPARTMENT OF CIVIL ENGINEERING
SCHOOL OF ARCHITECTURE, ENGINEERING, LAND AND ENVIRONMENTAL SCIENCES

Neapolis University Pafos

Bachelor's Degree of Science in Civil Engineering
Bachelor Thesis

Experimental Testing of Retrofitted Corroded Reinforced Concrete Elements

Submitted by Christos Petridis
Supervised by Dr. Ioannou Anthos

Paphos
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The present Bachelor Thesis was submitted in partial fulfillment of the requirements for the Degree of Bachelor of Science in Civil Engineering at Neapolis University Pafos and was approved on 2nd of September 2025 by the members of the Examination Committee.

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Declaration

The present Bachelor Thesis was submitted in partial fulfillment of the requirements for the Degree of Bachelor of Science in Civil Engineering at Neapolis University Pafos. It is a product of original work of my own, unless otherwise mentioned through references, notes, or any other statements.

C.Petridis
……………………
Christos Petridis

Preface

Completing this thesis has been both challenging and deeply rewarding.

I would like to express my sincere gratitude to my supervisor, Dr. Anthos Ioannou, whose expertise, guidance, and unwavering support have been invaluable throughout this journey.

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Finally, I dedicate this thesis to my family, my wife and daughter, whose love, encouragement, and unwavering support have sustained me throughout this important chapter of my professional life.

Christos Petridis
August 2025

Abstract

This thesis investigates the comparative mechanical behavior of conventional concrete and retrofitted reinforced concrete elements strengthened with repair mortars of class R4 and carbon fiber-reinforced polymer (FRP) systems. Corrosion remains a critical challenge to the durability and service life of reinforced concrete structures, making innovative strengthening and rehabilitation methods increasingly essential.

The experimental methodology was developed following an extensive literature review on corrosion mechanisms, structural degradation, and state-of-the-art repair techniques employing FRPs and mortar-based systems. The study involved accelerated corrosion of prismatic concrete specimens, compressive and splitting tensile testing of cylindrical specimens, and flexural testing of repaired prisms across five categories: non-corroded plain concrete, untreated reinforced concrete, corroded specimens and corroded specimens retrofitted using the above-mentioned materials.

The combined use of high-performance mortars and carbon FRPs significantly enhanced the flexural capacity and ductility of corroded specimens. Results confirmed the efficiency of these composite systems in restoring load-bearing capacity and improving structural response under bending. Overall, the findings validate the applied retrofitting strategies as practical and effective solutions for the repair and retrofitting of corroded reinforced concrete elements. Their contribution to mechanical performance and durability highlights their wide applicability in infrastructure rehabilitation. Notably, FRP retrofitting demonstrated exceptional potential, restoring structural integrity and increasing flexural strength by up to three times compared to plain concrete.

Keywords: *Conventional Concrete; Compressive Strength; Tensile Strength; Accelerated Corrosion; Impressed Current Technique; Repair of Corroded Reinforced Concrete Elements; Retrofitting with FRP.*

Περίληψη

Η παρούσα διπλωματική εργασία διερευνά τη συγκριτική μηχανική συμπεριφορά του συμβατικού σκυροδέματος και των ενισχυμένων στοιχείων από οπλισμένο σκυρόδεμα που έχουν επισκευαστεί με επισκευαστικά κονιάματα κατηγορίας R4 και συστήματα πολυμερών ενισχυμένων με ίνες άνθρακα (FRP). Η διάβρωση παραμένει μια κρίσιμη πρόκληση για την ανθεκτικότητα και τη διάρκεια ζωής των κατασκευών από οπλισμένο σκυρόδεμα, καθιστώντας τις καινοτόμες μεθόδους ενίσχυσης και αποκατάστασης ολοένα και πιο απαραίτητες.

Η πειραματική μεθοδολογία αναπτύχθηκε μετά από εκτενή βιβλιογραφική ανασκόπηση σχετικά με τους μηχανισμούς διάβρωσης, την υποβάθμιση των κατασκευών και τις πλέον σύγχρονες τεχνικές επισκευής με χρήση FRP και συστημάτων με επισκευαστικά κονιάματα. Η μελέτη περιλάμβανε επιταχυνόμενη διάβρωση πρισματικών δοκιμίων σκυροδέματος, δοκιμές θλίψης και εφελκυσμού σε κυλινδρικά δοκίμια, καθώς και δοκιμές κάμψης σε επισκευασμένα πρίσματα σε πέντε κατηγορίες: μη διαβρωμένο απλό σκυρόδεμα, ανεπεξέργαστο οπλισμένο σκυρόδεμα, διαβρωμένα δοκίμια και διαβρωμένα δοκίμια που επισκευάστηκαν με τα προαναφερθέντα υλικά.

Ο συνδυασμός υψηλών επιδόσεων επισκευαστικών κονιαμάτων και FRP από ίνες άνθρακα βελτίωσε σημαντικά την καμπτική αντοχή και την ολκιμότητα των διαβρωμένων δοκιμίων. Τα αποτελέσματα επιβεβαίωσαν την αποτελεσματικότητα αυτών των σύνθετων συστημάτων στην αποκατάσταση της φέρουσας ικανότητας και στη βελτίωση της δομικής απόκρισης υπό κάμψη. Συνολικά, τα ευρήματα επικυρώνουν τις εφαρμοσμένες στρατηγικές ενίσχυσης ως πρακτικές και αποτελεσματικές λύσεις για την επισκευή και ενίσχυση διαβρωμένων στοιχείων από οπλισμένο σκυρόδεμα. Η συμβολή τους στη μηχανική απόδοση και την ανθεκτικότητα αναδεικνύει την ευρεία εφαρμογή τους στην αποκατάσταση υποδομών. Ιδιαίτερα, η ενίσχυση με FRP παρουσίασε εξαιρετικές δυνατότητες, αποκαθιστώντας την δομική ακεραιότητα και αυξάνοντας την καμπτική αντοχή έως και τρεις φορές σε σχέση με το απλό σκυρόδεμα.

Λέξεις-κλειδιά: *Συμβατικό Σκυρόδεμα· Θλιπτική Αντοχή· Εφελκυστική Αντοχή· Επιταχυνόμενη Διάβρωση· Τεχνική Εφαρμοζόμενου Ρεύματος· Επισκευή Διαβρωμένων Στοιχείων Οπλισμένου Σκυροδέματος· Ενίσχυση με FRP.*

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1. Introduction

Concrete remains the most widely used construction material globally, due to its versatility, durability, and relatively low cost. However, despite its extensive use, reinforced concrete (RC) structures are susceptible to deterioration over time, particularly when exposed to aggressive environmental conditions such as chloride ingress, carbonation, or freeze–thaw cycles (Neville, 2011; Mehta & Monteiro, 2014). The degradation of reinforcement caused by corrosion is one of the most significant durability challenges, as it compromises both the service life and the structural performance of RC members. With the above in mind, in Cyprus in particular, many structures especially near the coast are exposed to the cloride environment. This cause corrosion and generate an engineering challenge that directly motivated the scope and idea of the present research.

To address this issue, researchers and practitioners have investigated a wide range of repair and strengthening strategies. Traditional repair techniques often involve patching with cementitious mortars or coatings, which may provide temporary improvements but are not always sufficient to ensure long-term durability (EN 1504-3, 2005). More advanced solutions, such as the application of fiber-reinforced polymers (FRPs), have been increasingly adopted because they provide high tensile strength, corrosion resistance, and ease of installation (ACI 440.2R-17, 2017; Teng et al., 2002). Nonetheless, the long-term effectiveness of these methods depends on several factors, including bond quality, surface preparation, and exposure conditions. FRP systems were selected as a primary retrofitting technique in my study, applied on corroded RC specimens, as a continue experimental research of previous retrofitting techinques tested at Neapolis University of Pafos (NUP). This approach give us the opportunity to directly evaluate the FRP's system ability to restore strength and ductility under conditions representative to the Cypriot coastal environment.

In parallel, the development of innovative cementitious materials such as engineered cementitious composites (ECCs) or strain-hardening cementitious composites (SHCCs) has opened new avenues for structural rehabilitation. Unlike conventional concrete, ECC exhibits strain-hardening behavior and multiple micro-cracking under tensile loading, which enhances ductility and energy absorption capacity (Li, 1998; Li, 2003). These properties make ECC an attractive repair material, particularly when applied to corroded or damaged RC elements. Although ECC was initialy considered within the scope of this research, a continuation of previous research from N. Tzavellos (NUP Thesis, 2023), the experimental program ultimately emphasis on FRP retrofitting. Nevertheless, the comparative insights from ECC literature provided a valuable reference framework, and gave us the chance to evaluate alternative repair materials. All in all, this research aims to provide an understanding in the rehabilitation strategies focus on the FRP systems, since the use of them, at the moment, is limited in Cyprus.

The importance of evaluating repair and strengthening techniques extends beyond durability concerns; it also involves structural performance under service and ultimate loads. International standards, such as EN 1992 (Eurocode 2) and EN 12390, provide testing and design frameworks that ensure reliability and comparability of results. However, many experimental studies have shown that the behavior of repaired or retrofitted elements may deviate from idealized models, particularly when corrosion damage is severe or when bond conditions are compromised (El-Maaddawy & Soudki, 2003; Pham & Al-Mahaidi, 2004). In this research, the experimental procedures were carried out in the Engineering Laboratory of Neapolis University Pafos (NUP) strictly in line with EN testing standards. A crucial adherence to ensure that the obtained results were not only reliable and reproducible but also directly comparable to international benchmarks, strengthening the credibility of the findings and their alignment with established design practices.

In this context, the current research investigates the mechanical behavior of plain concrete and reinforced concrete specimens subjected to accelerated corrosion and subsequent repair or strengthening. Both conventional and advanced techniques, including FRP retrofitting, were examined through a series of laboratory experiments conducted at Neapolis University Pafos (NUP). The study aims to provide comparative insights into the effectiveness of these approaches, focusing on compressive and tensile performance, flexural capacity, and failure mechanisms. What makes this work particularly distinctive is its integration of accelerated corrosion testing with subsequent FRP strengthening, enabling a direct evaluation of how deterioration and repair interact in realistic service conditions an approach not commonly combined in previous experimental programs.

The findings of this research are intended to contribute to the broader understanding of structural rehabilitation and to inform practical guidelines for improving the resilience of RC infrastructure. By situating experimental results within the framework of European standards and recent literature, the study seeks to highlight both the limitations of existing repair practices and the potential benefits of innovative materials and methods. Ultimately, the goal is to bridge the gap between laboratory research and real-world applications, offering practical solutions to extend the service life of reinforced concrete structures exposed to deterioration. Finally, the contribution of the current research, is particularly relevant to the Cypriot Construction Industry, taking into consideration the coastal environment, along with the use of reinforced concrete (RC) widly, makes the corrosion-related damage a challenge, underscoping the need of reliable repair strategies.