HYBRID APPLICATION OF EXTERNALLY BONDED GFRP AND UNBONDED POST-TENSIONING FOR RC BEAMS: A PRACTICE-ORIENTED REVIEW AND DESIGN GUIDANCE

Liu Qian[1], Andrei Tur[2]

[1] аспирантура, Brest State Technical University, Brest, Belarus,tg5682647234@163.com, +375259202817

[2] PhD , Head of the Department of Architecture, Brest State Technical University, Brest, Belarus

Abstract. Externally bonded glass-fiber-reinforced polymer (EB-GFRP) and unbonded post-tensioning (UPT) can be combined as a hybrid application for reinforced-concrete beams to elevate service performance and durability. This paper consolidates practice-oriented guidance on selecting effective prestress, detailing interfaces and anchorages, anticipating failure mechanisms, and addressing durability. Two operating windows are defined: a low-to-moderate prestress range that prioritizes crack-width control with preserved rotational capacity, and a moderate-to-high range that delivers larger deflection reductions subject to verified compression limits and anchor-zone reinforcement. The resulting guidance distills checks and detailing notes that support specification and site implementation of hybrid EB-GFRP + UPT applications.

Keywords: glass fiber reinforced polymer; unbonded post-tensioning; reinforced concrete; serviceability; cracking; anchorage

INTRODUCTION

Externally bonded glass-fiber-reinforced polymer (EB-GFRP) has become a routine option for concrete members, with established guidance detailing material characterization, design checks, surface preparation, and installation procedures that govern service performance and durability [1]. International consensus documents on externally applied FRP further consolidate terminology, typical failure mechanisms (interfacial debonding, cover delamination, end-peeling), and detailing rules that are directly relevant when EB-GFRP is deployed alongside other systems [2].

Unbonded post-tensioning (UPT) provides a controllable compressive bias that can be tuned to limit tensile stresses, delay cracking, and reduce service deflections while preserving continuity and ease of replacement. When EB-GFRP and UPT are applied together as a hybrid application, tendon-induced compression lowers interface demand for the laminate, and the laminate augments tensile capacity and crack bridging at the most stressed fiber. The design emphasis therefore shifts from capacity upgrading to serviceability management, stiffness recovery, and durability.

Although EB-GFRP and UPT are mature when considered separately, guidance tailored to their joint application remains dispersed. Practical issues that require explicit treatment include effective prestress selection, anchor-zone detailing and confinement, limits on compressive strain and local bearing, laminate termination and anchorage design, and durability under sustained compression, temperature, and moisture cycling [1,2].

This paper presents practice-oriented guidance for the joint application of EB-GFRP and UPT in reinforced-concrete beams. It consolidates checks and detailing notes from existing guidance [1,2], summarizes expected failure mechanisms with corresponding control measures, and organizes effective-prestress choices into two operating windows aligned with project service objectives and interface/anchorage capacity. The aim is to support specification, review, and site implementation.

MATERIALS AND METHODS

Terminology and baseline checks follow international guidance for externally bonded FRP and practice manuals for unbonded post-tensioning to ensure consistent definitions of tendons, ducts, anchorages, laminate types, effective prestress, and stress increase in unbonded tendons [1,2].

A narrative review was conducted to identify peer-reviewed studies on RC beams using hybrid application of EB-GFRP with unbonded tendons that report service-level responses—crack width, mid-span deflection, and tendon force or stress increase—under monotonic or quasi-static loading [3]. Bonded PT cases, FRP-only schemes without UPT, and studies lacking service measurements were excluded.

From eligible studies, we extracted geometry, internal steel ratios, tendon profile and eccentricity, jacking force and effective prestress (with stated losses), EB-GFRP properties and anchorage details, anchor-zone reinforcement, loading and instrumentation, observed failure modes, and any environmental conditioning. Results are synthesized qualitatively with consistent units and definitions; no meta-analysis was performed. Cross-checks against [1,2] were used to keep detailing notes and limits aligned with established guidance.

RESULTS

Beams relying only on externally bonded GFRP (EB-GFRP) are frequently governed by serviceability because the laminate's elastic modulus yields modest stiffness gains relative to internal steel; this trend is reflected in measured crack widths and mid-span deflections across experimental programs on GFRP-RC beams [4]. When unbonded post-tensioning (UPT) is introduced, mechanics-based studies show that the stress increase in unbonded tendons depends on member deformation demand and reinforcement ratios, which guides selection of effective prestress in the hybrid application [5].

Interface reliability remains decisive. Intermediate crack-induced debonding and end-peeling are sensitive to surface preparation and termination details; these must be verified, especially when sustained compression from UPT is added [6]. Tests on RC beams with unbonded tendons demonstrate that sustained compression can reduce service crack widths and deflections, while higher prestress levels elevate anchor-zone and local bearing demands [7]. These observations support the use of two operating windows for effective prestress in practice, balancing crack control, stiffness recovery, rotational capacity, and local detailing.

Table 1 summarizes complementary roles of EB-GFRP and UPT in the hybrid application. Table 2 outlines prestress operating windows and expected service outcomes; to avoid over-interpretation, the ranges are indicative only and should be checked against project-specific limits and detailing.

Table 1. Complementary roles and common properties of EB-GFRP and UPT for hybrid application in RC beams

Item	Externally bonded GFRP (EB-GFRP)	Unbonded post-tensioning (UPT) in plastic ducts	Design implication

Primary function	Tensile reinforcement at the outer fiber with corrosion resistance	Span-wise compression for crack and deflection control	Functions are complementary
Stiffness and strength	High tensile strength; moderate elastic modulus	Very high tendon strength; high system stiffness	Service performance hinges on balanced selection
Bonding condition	Adhesive interface at concrete surface	Sheathed tendon unbonded within duct	Different strain compatibility governs stress development
Typical risks	Intermediate crack-induced debonding; end-peeling if termination is weak	Anchor/bursting demand; local crushing at high prestress	End/anchor detailing governs reliability
Durability aspects	Good resistance to corrosion/chemicals	Tendons protected by sheath/duct or grout (if bonded)	Both contribute to life-cycle performance

Table 2. Prestress operating windows and expected service outcomes for hybrid EB-GFRP + UPT application in RC beams

Objective	Initial effective prestress (as % of tendon ultimate strength)	Expected crack control	Expected deflection change	Ductility tendency	Typical checks
Serviceability-focused application	≈ 30–50%	Clear reduction at common service loads	Moderate reduction	Rotational capacity generally preserved	EB-GFRP termination and interface detailing; anchor seating/friction losses
Tight service targets with higher compression	≈ 45–65%	Very strong reduction	Large reduction	Potential reduction in rotation capacity if compression zone is over-stressed	Compression-block limits; anchor-zone reinforcement and local bearing checks

CONCLUSION

Externally bonded GFRP (EB-GFRP) and unbonded post-tensioning (UPT) form a complementary hybrid application for managing serviceability and extending durability in reinforced-concrete beams. Tendon-induced compression raises the cracking threshold and suppresses deflection, while the laminate provides tensile capacity and crack bridging at the outer fiber. Effective outcomes depend on selecting a suitable prestress operating window and matching details to that choice. A low–to–moderate effective prestress is suited to crack-width control with preserved rotational capacity; a moderate–to–high level can deliver larger stiffness recovery when compression limits are checked and anchor-zone reinforcement is upgraded. Interface reliability remains decisive: surface preparation, laminate termination and end anchorage, seating and friction losses, and local bearing in anchor zones should be verified during design and confirmed during execution.

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