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EXTERNALLY POST-TENSIONED STEEL TENDONS WITH GFRP LONGITUDINAL REINFORCEMENT IN CONCRETE BEAMS: A BRIEF REVIEW OF MATERIALS, DESIGN RATIONALE AND SERVICEABILITY

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Glass-fiber-reinforced polymer (GFRP) bars offer corrosion resistance and low mass but have an elastic modulus on the order of 30–50 GPa, far below that of steel. When used alone as longitudinal reinforcement, the low stiffness often leads to large crack widths and excessive deflection under service loads. This brief review examines a composite solution in which GFRP bars are combined with externally post-tensioned steel tendons. The post-tension introduces precompression to counter tensile stresses, while the GFRP bars provide durable tensile capacity after cracking. We summarize material roles, core design rationale for selecting tendon force levels and profiles, essential detailing at anchor zones and deviators, and long-term effects relevant to effective prestress retention. The review frames a compact workflow for practice and research: define serviceability targets, choose an external post-tension profile and force consistent with anchorage and compression checks, and verify crack width and deflection under sustained and variable loading. The combined system directly addresses the crack-control limitation of GFRP-only beams and provides a pragmatic path to improved service performance in aggressive environments.

Keywords: *GFRP bars, external post-tensioning, concrete beams, crack control, serviceability, durability, tendon profile.*

ВНЕШНЕЕ ПРЕДНАПРЯЖЕНИЕ СТАЛЬНЫМИ КАНАТАМИ В БЕТОННЫХ БАЛКАХ С ПРОДОЛЬНОЙ СТЕКЛОПЛАСТИКОВОЙ АРМАТУРОЙ: ОБЗОР МАТЕРИАЛОВ, ПРОЕКТИРОВАНИЯ И ЭКСПЛУАТАЦИОННОЙ ПРИГОДНОСТИ

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Стержни из стеклопластиковой арматуры (GFRP) обладают высокой коррозионной стойкостью и малой массой, однако их модуль упругости составляет порядка 30–50 ГПа, что значительно ниже показателей стали. При использовании GFRP в качестве единственной продольной арматуры низкая жесткость часто приводит к значительной ширине раскрытия трещин и чрезмерным прогибам под действием эксплуатационных нагрузок. В данном кратком обзоре рассматривается комбинированное решение, в котором стержни GFRP сочетаются с внешним последующим натяжением стальных канатов (пучков). Предварительное натяжение создает сжимающие напряжения для противодействия растяжению, в то время как стержни GFRP обеспечивают долговечную несущую способность на растяжение после образования трещин. В работе обобщены роли материалов, основные принципы проектирования при выборе усилий натяжения и профилей канатов, особенности конструирования зон анкеровки и отклонителей, а также долгосрочные эффекты, влияющие на сохранение эффективного предварительного напряжения. Обзор формирует лаконичный алгоритм для практики и исследований: определение целевых показателей эксплуатационной пригодности, выбор профиля и усилия внешнего натяжения в соответствии с проверками анкеровки и сжатия, а также контроль ширины раскрытия трещин

и прогибов при длительных и переменных нагрузках. Комбинированная система напрямую устраняет ограничения балок с армированием только GFRP в части контроля трещинообразования и предлагает прагматичный путь к повышению эксплуатационных характеристик в агрессивных средах.

Ключевые слова: стеклопластиковая арматура (GFRP), внешнее последующее натяжение, бетонные балки, контроль трещинообразования, эксплуатационная пригодность, долговечность, профиль арматурного каната.

Introduction

Fiber-reinforced polymer bars have been introduced as internal longitudinal reinforcement to improve durability where corrosion is critical. For GFRP, the elastic modulus is typically about 30–50 Gpa, close to that of concrete and much lower than that of steel, which makes control of crack width and deflection the governing serviceability challenge in many beams [1].

A practical remedy is to combine GFRP longitudinal bars with externally post-tensioned steel tendons. External tendons are anchored outside the section and, when profiled with deviators, apply a controllable precompression and balancing moment that reduce service-load tensile stresses and crack opening. Design guidance and case histories show that such systems can achieve significant improvements in crack control and stiffness provided that anchorage bearing, deviator pressures, and long-term prestress losses are explicitly verified [2]. This paper offers a concise review of materials, design logic, and detailing for this composite arrangement and outlines the performance measures needed for rapid experimental and field deployment.

Main body

1.1 Material differences and role allocation

GFRP bars provide high tensile strength, low density, and corrosion resistance, but their elastic modulus (typically on the order of 30–50 GPa) is far lower than steel, so pre-cracking stiffness is limited and service-load crack-width/deflection control is poor; in the composite arrangement considered here, GFRP mainly contributes durable tensile capacity after cracking, while externally post-tensioned steel tendons, anchored outside the section, deliver high stiffness and controllable precompression before service loading to suppress tensile demand and crack opening (see Table 1) [1; 3].

Table 1. – System roles

Component	Before cracking (service)	After cracking	Notes
Concrete section	Compression block; cover and durability	Compression block; shear transfer	Check extreme-fiber compression and local bearing at hardware
GFRP longitudinal bars	Minor stiffness contribution due to low E	Durable tensile capacity; residual strength	Detail end zones to prevent debonding/splitting
External steel tendons	Precompression and balancing moment	Share tension via eccentricity	Verify anchorage/deviator bearing and losses

1.2 Design rationale: prestress level and tendon profile

In practice, the effective tendon force is selected within a workable band that balances serviceability gains and detailing demands; a lower-to-medium level is appropriate when crack-width

control with ductility reserve is the priority, while a medium-to-higher level achieves stronger reductions in midspan crack width and deflection provided anchorage bearing, local crushing, global compression, and deviator pressures are explicitly verified; a straight profile minimizes losses, whereas a draped (parabolic) profile with one or two deviators increases midspan eccentricity for more effective service-load balancing (see Table 2) [4; 5].

Table 2. – Prestress–profile selection

Target	Effective level ($\approx f_{pu}$)	Tendon profile	Must-check items
Crack control with ductility reserve	0.30–0.45	Straight or mild drape	Anchorage bearing; extreme-fiber compression; expected losses
Strong crack/deflection suppression	0.45–0.65	Draped, 1–2 deviators	Anchor/deviator bearing; local crushing; curvature radius; friction losses

1.3 Detailing and long-term effects

Anchor zones should use bearing plates and closed transverse reinforcement to prevent bursting and local crushing, and deviators must be proportioned for local bearing pressure and minimum curvature radius; for the GFRP termination in the tensile zone, mechanical end-clamps or U-wraps are recommended to mitigate end debonding and splitting; design and evaluation must also account for shrinkage, creep, temperature effects, and strand relaxation through an explicit loss model and monitoring plan (e.g., tendon force at lock-off and during service, crack width in the constant-moment region, and midspan deflection), with provisions for re-tensioning where significant losses are anticipated [6; 7].

Conclusion

This brief review addresses the central limitation of GFRP longitudinal reinforcement in concrete beams, namely low elastic modulus and the resulting difficulty in controlling crack width and deflection under service loads. Combining GFRP bars with externally post-tensioned steel tendons provides a practical path to restore service stiffness while preserving the durability advantages of GFRP. Within this composite arrangement, two effective prestress windows are recommended. A lower to medium level, approximately 0.30–0.45 fpu, is suited to applications that prioritize crack control with reserve ductility and comfortable margins in anchorage and compression checks. A medium to higher level, approximately 0.45–0.65 fpu, can further suppress crack growth and midspan deflection provided that anchorage bearing, local crushing, global compression, and deviator pressures are explicitly verified. Profile selection should follow the demand envelope: straight tendons minimize losses and simplify execution, while a draped layout with one or two deviators increases eccentricity where it is most needed for service-load balancing. Reliable performance depends on careful detailing of anchor zones and deviators, adequate end anchorage for GFRP to mitigate debonding and splitting, and explicit management of long-term losses from shrinkage, creep, temperature variation, and strand relaxation, with provision for re-tensioning where warranted. Taken together, these measures form a compact workflow that is immediately transferable to parametric testing and field deployment: define service targets, choose the prestress level and profile consistent with detailing and compression checks, and verify crack width and deflection with instrumentation over time.

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