Fiber Reinforced Polymer (FRP) Rebar: A Strategic Imperative for Sustainable and Resilient Global Infrastructure

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Abstract—**The global construction industry is undergoing a transformative shift from traditional carbon steel reinforcement to advanced composite materials, driven by the need for high-performance, cost-efficient infrastructure. This report provides an exhaustive technical and economic evaluation of Glass Fiber Reinforced Polymer (GFRP) rebars, with a specific focus on their application within the Pune Metropolitan Region. Through a synthesis of material science and pultrusion manufacturing data, the study evaluates GFRP as a high-strength, economically viable alternative to Thermo-Mechanically Treated (TMT) steel.**

A central economic investigation was conducted through a case study at the Bellavita project in Pune, where GFRP was substituted for steel in non-structural partition walls. The findings demonstrate that GFRP's lightweight nature leads to a significant reduction in reinforcement mass, directly translating to lower logistics expenses and an accelerated installation speed. These operational efficiencies provide a clear economic incentive by reducing on-site labor hours and equipment requirements.

From a direct cost perspective, while unit prices vary, the overall project economy is enhanced through the elimination of anti-corrosion treatments and the reduction of structural dead load. This transition is further supported by the regulatory framework of IS 18256:2023, ensuring standardized quality for market adoption. The report concludes that the strategic integration of GFRP, led by innovative manufacturers like Abhuva Innovation Private Limited, offers a superior economic directive for the construction sector, delivering immediate value through enhanced productivity and material optimization.

I. INTRODUCTION

1.1 The Engineering Challenge

The durability of reinforced concrete (RC) is historically contingent upon the alkaline protection of the internal steel reinforcement. However, the global construction industry is now witnessing a systemic failure of this protection mechanism, particularly in chloride-laden environments. The resulting electrochemical oxidation—corrosion—leads to the formation of ferric oxide, an expansive product that generates internal hoop stresses exceeding the tensile capacity of concrete. This process results in delamination, spalling, and a premature reduction in structural service life.

1.2 The Composite Alternative: FRP

To circumvent the inherent limitations of carbon steel, Fiber Reinforced Polymer (FRP) has been engineered as a high-performance substitute. By utilizing a pultruded matrix of continuous fibers (Glass, Basalt, or Carbon) bound by thermosetting resins, FRP provides an internal reinforcement system that is chemically inert. Unlike steel, which is isotropic and ductile, FRP is an anisotropic, linear-elastic material characterized by high tensile strength-to-weight ratios and absolute resistance to chloride-induced corrosion.

II. PROBLEM STATEMENT

The primary barrier to the widespread adoption of FRP is not its performance, but the required drastical shift in structural engineering. Traditional design codes are predicated on the ductility of steel where material yielding provides a visual warning of impending failure. FRP, however, does not yield; it is a brittle material with a lower modulus of elasticity than steel. This necessitates a transition from strength-governed design to serviceability-governed design, where crack widths and deflections become the primary limiting factors. Furthermore, the industry must move further not only evaluating Capital Expenditure (CAPEX) but also Life Cycle Cost (LCC), a Total Cost Ownership model to accurately reflect the 75-to-100-year longevity of composite structures.

III. RESEARCH DESIGN

Methodology:

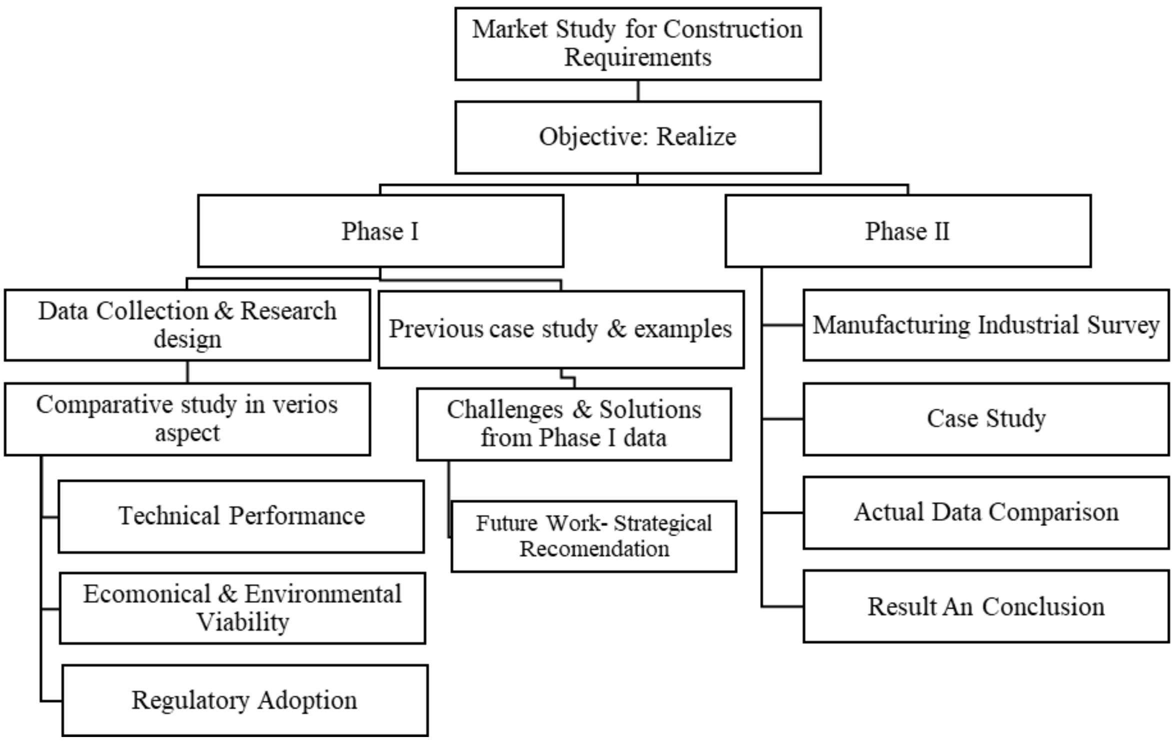

Figure 1 Methodology

3.1 Phase I: Foundational Research and Comparative Synthesis This phase establishes the theoretical baseline through a systematic literature review and technical benchmarking.

Literature Survey: Identifying structural challenges and documenting existing composite solutions.

Baseline Comparison: Evaluating FRP versus steel across mechanical performance, economic viability, and environmental sustainability.

Sustainability Frameworks: Formulating the criteria for Capital Expenditure (CAPEX) & Life Cycle Cost (LCC) and embodied carbon analysis.

3.2 Phase II: Industrial Actualization and Validation This phase focuses on the practical application and validation of FRP within the Indian construction sector.

Industrial Liaison: Collecting primary manufacturing data and aligning material properties with site-specific requirements.

Laboratory Validation: Synthesizing quantitative test results from premier institutions and accredited laboratories.

Case Study Synthesis: Analysing real-world mock-up data and infrastructure projects to verify economic viability and field performance.

Study Area- The construction industry is adopting GFRP (Glass Fiber Reinforced Polymer) rebar to eliminate rust and reduce carbon emissions. While Indian Road Congress (IRC) guidelines currently focus on infrastructure, this trial bridges the gap for residential use.

Project & Mock-Up

Location: Tower 8, Bella Vita, NIBM, Pune (12.5-acre site, Pune).

Scope: In a 1:1 diameter test, 8mm GFRP replaced traditional steel in 28th floor non-structural partition walls between column P1 and P7

Figure 1 Geographical Location Bella Vita, NIBM, Pune.

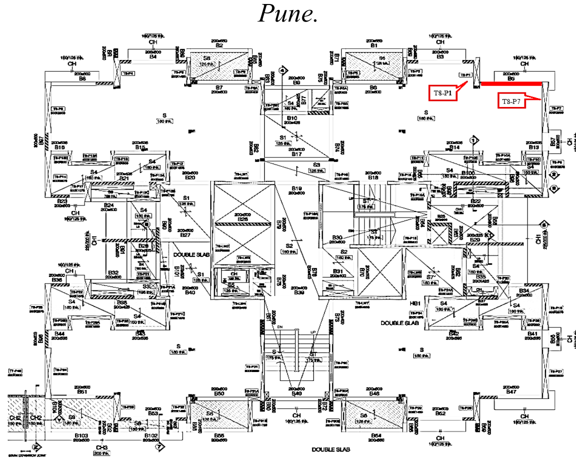

Figure 2 Structural Details & NSW P1-P7 Location

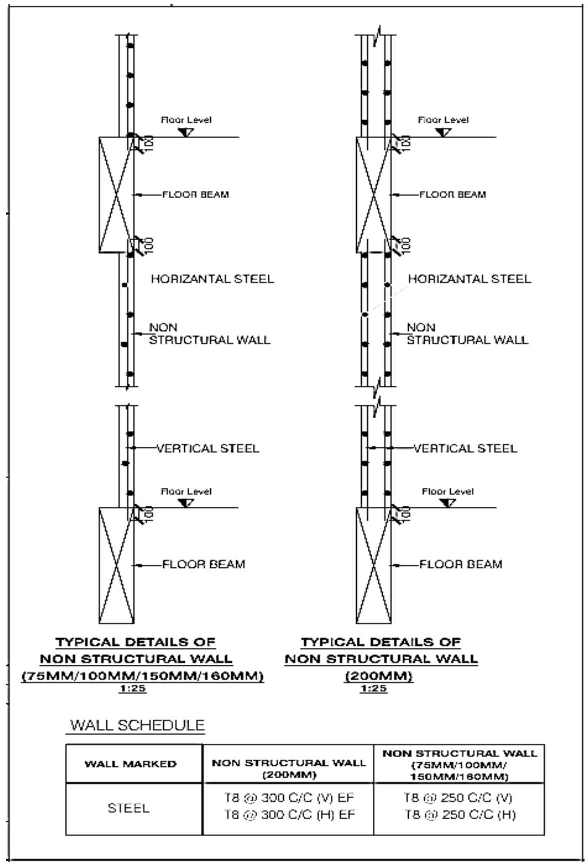

Figure 3 Typical NSW Details

IV. DATA ANALYSIS OF RESULTS

The initial segment of the trial focused on the typical residential floor slab. For the NSW Bet P1 to P7, the wall dimensions were identified as 0.85m(L)x 0.15m(W)x 2.45m(D). The original 8mm steel reinforcement required vertical and distribution bars with specific cutting lengths.

Table 1 Weight Comparison between Steel & GFRP

Bar Description	Diameter (mm)	No. of Bars	Cutting Length (m)	Total Length (m)	Steel Weight (kg)	GFRP Weight (kg)
Vertical Bar	8	4	2.65	10.6	4.187	1.06
Distribution Bar	8	11	0.81	8.91	3.519	0.891
Total Wt for Wall P1-P7 (KG)					7.706	1.951

- Rate calculation-
  - Reinforcement Steel-

TMT Steel rate including=
= 60,000.00 Rs/MT
= 60.00 Rs/Kg

- Total cost of reinforcement steel=

= Steel Weight (kg) of NSW Bet P1 to P7 (As per BBS) x TMT Steel rate including (Rs/Kg)
= 7.706 x 60.00
= 462.36 Rs.

  - GFRP-

GFRP Rate Including =
=1,50,000 Rs/MT
=150.00 Rs/Kg

- Total cost of GFRP=

= GFRP Weight (kg) of NSW Bet P1 to P7 (Replacement) x GFRP rate including (Rs/Kg)
=1.951 x 150.00
=292.65 Rs.

Results after Substituting 8mm GFRP for the 8mm steel across this sample mock up:

- Achieved a **37%** reduction in direct material costs by transitioning reinforcement from steel to GFRP, lowering unit costs from ₹462.36 to ₹292.65.
- Achieved a **75%** reduction in primary reinforcement mass (7.706kg to 1.951kg) by transitioning to GFRP, resulting in an estimated 30–50% savings in transportation, labour, and installation time and also reduced more than **50%** CO_2 Emission.

Based on the performance of this sample mock-up, the hypothetical replacement of all non-structural steel reinforcement with GFRP is projected to substantially reduce overall project expenditure.

The Tower 8 Bar Bending Schedule (BBS) provides a comprehensive data set for comparing the mass of the reinforcement cages before and after the material substitution. The analysis covers the Ground Floor (GF), typical residential floors (+28), and specialized areas such as the Terrace and Lift Motor Room (LMR).

Table 2 Tower 08 Weight Comparison between Steel & GFRP

Description	No. of elements	Weight of steel (Kg)	Total Weight of Steel (Kg)	Weight of GFRP (Kg)	Total Weight of GFRP (Kg)
Tower 8 NS Wall Ground floor Slab	1	498.42	498.42	127.44	127.44
Tower 8 NS Wall Typical floor Slab	28	538.15	15068.2	137.60	3852.8
Tower 8 NS Wall Terrace floor Slab	1	740.18	740.18	189.26	189.26
Tower 8 NS Wall Terrace floor Slab	1	166.93	166.93	42.68	42.68
Total			16473.73		4212.18

Project Expenditure Rate Analysis

- Rate calculation-
  - Reinforcement Steel-

TMT Steel rate including=
= 60,000.00 Rs/MT
= 60.00 Rs/Kg

- Total cost of reinforcement steel=

= Total Steel Weight (kg) of NSW (As per BBS) x TMT Steel rate including (Rs/Kg)
= 16,473.73 x 60.00
= 9,88,423.8 Rs.

  - GFRP-

GFRP Rate Including =
=1,50,000 Rs/MT
=150.00 Rs/Kg

- Total cost of GFRP=

= Total GFRP Weight (kg) of NSW (Replacement) x TMT Steel rate including (Rs/Kg)
=4,212.18 x 150.00
=6,31,827 Rs.

Results after Substituting 8mm GFRP for the 8mm steel across this sample mock up:

- Achieved a 37% reduction in direct material costs by transitioning reinforcement from steel to GFRP, lowering unit costs from ₹9,88,423.8 to ₹6,31,827.
- Achieved a **75%** reduction in primary reinforcement mass (16473.73kg to 4212.18kg) by transitioning to GFRP, resulting in an estimated **30–50%** savings in transportation, labour, and installation time and also reduced more than **50%** CO_2 Emission.

V. CONCLUSION

FRP performance for design shift**:** It clarified the material composition of Glass, Carbon, and Basalt FRPs, emphasizing their core benefits: high corrosion resistance, low weight, and electrical non-conductivity.

Quantified FRP for economic and environmental aspects: this case study demonstrates significant advantages: the use of GFRP results in a 37% cost savings during the initial estimation phase alone. From an environmental perspective, the 75% reduction in reinforcement weight substantially lowers CO_2 emissions, successfully fulfilling our primary objective.

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