Application of 630-MPa High-Strength Reinforcing Bars in Construction: A Data-Driven Comprehensive Benefit Assessment

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Abstract. The construction sector's carbon footprint demands urgent material innovation. Using Building Information Modeling (BIM) integrated with structural analysis, we conducted a comparative design study of basement ceiling beams (35,558 m²) in a Chinese residential project. Results indicate that 630-MPa high-strength reinforcing bars reduce steel consumption by 27.12% compared with conventional HRB400 bars, achieving comprehensive cost savings of 11.51% (¥528,948 or ¥14.87/m²). This material substitution reduces 349 tonnes of CO_2 emissions and decreases upstream resource extraction by 320 tonnes of iron ore, 134 tonnes of standard coal, and 1,033 tonnes of water. While limited to a single case study, these findings suggest that 630-MPa reinforcement represents a promising technology for construction decarbonization that warrants further validation across diverse structural applications.

Keywords: Construction industry; Energy conservation; Emission reduction; 630-MPa high-strength reinforcement; BIM; Comprehensive benefit assessment

1 Introduction

1.1 Research Background

Strengthening energy conservation and emission reduction constitutes a core strategy for mitigating global climate change. As a major energy consumer and carbon emitter, the construction sector's green transformation is pivotal to achieving carbon neutrality goals [1]. In structural engineering, increasing steel bar strength grades directly reduces steel consumption per unit building area, thereby mitigating substantial resource depletion at the source [2].

Research and application of high-strength steel bars have achieved significant progress globally. Developed nations have widely implemented 500-MPa-grade steel bars

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and are advancing 690-MPa grades, demonstrating substantial material savings in high-rise buildings and long-span bridges [3]. Projects utilizing 600–700-MPa-grade steel bars achieved material reductions exceeding 28% [4][5]. In China, the 2024 release of the Technical Specification for Application of Hot-Rolled Ribbed High-Strength Reinforcing Bars (Grade 630 MPa) (T/CSPSTC 143-2024) provides critical technical basis for large-scale deployment.

1.2 Research Gap and Objectives

Although preliminary technical standards for 630-MPa high-strength steel bars have been established, comprehensive evidence of their benefits in practical engineering applications remains insufficient [6]. This study addresses this gap by quantitatively comparing the comprehensive benefits of employing 630-MPa high-strength reinforcing bars versus traditional HRB400 bars using a specific residential project as a case study.

2 Methodology

2.1 Case Project Description

Basement ceiling beams of a typical Chinese public complex were selected for analysis, covering 35,558 m² with 127 beam elements (spans: 4.2m to 9.6m). Design parameters include: 50-year service life, Class I structural safety, seismic fortification intensity of 7 degrees (0.15g), and C35 concrete. This comparative study evaluates HRB400 hot-rolled ribbed steel bars (baseline) versus 630-MPa high-strength hot-rolled steel bars (alternative).

2.2 BIM-Based Comparative Design

We implemented a comprehensive BIM workflow with parametric reinforcement design enabling automated recalculation when switching between reinforcement grades. The design strength for HRB400 is 360 MPa (400/1.1—where 1.1 represents the material partial safety factor per GB 50010-2010), and for 630-MPa grade is 545 MPa (630/1.15—with a higher safety factor of 1.15 specified in T/CSPSTC 143-2024 to account for reduced ductility characteristics), as shown in Table 1. Both designs satisfied crack width limits (≤0.2 mm for this exposure class) and deflection requirements per Chinese code provisions. Specifically, while high-strength reinforcement reduces the required steel area, it results in higher tensile stress (σ_s) under service loads111. To address this, crack width calculations were performed using the quasi-permanent combination of actions as per GB 50010-20102. The results confirmed that the high bond-slip performance of the 630-MPa ribbed bars effectively controlled the crack distribution despite the higher operating stress levels. Anchorage lengths were increased by 15% for 630-MPa bars to ensure adequate bond performance.

Table 1. Representative Beam Span Configurations

No.	Beam Span	Section	HRB400 Configuration	630MPa Configuration	Steel Reduction
1	7.2m	300×700	9C25 (6 top/3 bottom)	6M22/3M20	23.4%
2	8.4m	350×800	10C25 (3 top/7 bottom)	3M20/7M22	28.1%
3	9.0m	350×800	11C25 (4 top/7 bottom)	4M20/7M22	28.1%
4	9.6m	400×900	13C25 (6 top/5 mid/2 bottom)	12M22 (6 top/6 bottom)	21.8%
5	6.0m	300×600	6C25/2C22	7M22 (5 top/2 bottom)	19.3%
6	5.4m	300×600	5C25	3M22+2M20	24.6%

Note: C = HRB400 conventional reinforcement; M = 630-MPa high-strength reinforcement

2.3 Calculation Models

2.3.1 Economic Cost Model.

Total Cost = (Reinforcing Steel Quantity × Reinforcing Steel Unit Price) + Auxiliary Material Costs + Construction Measures Costs + Management Fees

Unit prices: HRB400 (4,400 yuan/tonne), 630-MPa (5,670 yuan/tonne), with 3% wastage factor based on industry standard GB 50500-2013 for reinforcement engineering. It should be noted that this economic model focuses on direct material and construction costs; indirect costs such as worker training, supply chain logistics, and long-term maintenance are not included in this analysis.

2.3.2 Environmental Impact Model.

Environmental Impact Reduction = (HRB400 Usage - 630-MPa Usage) × Emission Factor

Emission factors per tonne of steel: 1.550 tonnes iron ore, 0.650 tonnes standard coal, 5.000 tonnes water. Per tonne standard coal: 2.600 tonnes CO_2, 1.600 kg SO_2, 9.000 kg NO_x[7].

3 Results

3.1 Material Savings

While meeting identical structural performance requirements, total usage of 630-MPa grade amounts to 555.06 tonnes, representing a reduction of 206.52 tonnes compared with 761.58 tonnes for HRB400—a 27.12% decrease. Reinforcement weight reductions ranged from 19.3% to 28.1% (mean: 24.6%, SD: 2.8%, n=6 representative beam configurations). While this sample represents typical beam spans encountered in the project, statistical inference is limited; the reported statistics are descriptive rather than inferential.

3.2 Economic Benefits

This material consumption reduction translates directly into economic cost savings. Based on detailed cost calculations (incorporating 3% reinforcement wastage), a comprehensive economic comparison between the two schemes is presented in Table 2.

Table 2. Comprehensive Economic Comparison Analysis of HRB400 and 630-MPa-Grade High-Strength Reinforcing Bars.

Comparison Items	HRB400 Scheme	630-MPa Grade Scheme	Change
Total Reinforcement Consumption (tonnes)	761.580	555.060	-206.52 tonnes (-27.12%)
Procurement cost (RMB)	3,451,480.6	3,241,605.9	-209,874.7 yuan (-6.08%)
Settlement Cost Savings	—	—	+319,073.4 yuan
Total cost savings	—	—	+528,948.05 yuan(+11.51%)
Savings per square metre	—	—	+14.87 yuan

[a] Settlement cost savings = (HRB400 usage - 630-MPa usage) × settlement cost per tonne (¥1,500) × (1 + 3% wastage rate)

[b] Total cost savings = (HRB400 procurement cost - 630-MPa procurement cost) + Settlement cost savings + (Auxiliary material & construction savings estimated at ¥50/tonne saved)

Despite higher unit price of 630-MPa bars, substantial usage reduction achieved 11.51% comprehensive savings.

3.3 Environmental Benefits

Reinforcement usage reduction yields not only economic value but also profound resource and environmental benefits. Based on this study's computational model, incorporating 27.12% material saving rate and authoritative emission factors, reduction in resource consumption and pollutant emissions can be quantified.

Calculations reveal that 206.52 tonnes of steel saved through employing 630-MPa-grade high-strength reinforcing bars in this project effectively reduced consumption of critical upstream resources including iron ore, coal, and water, while substantially decreasing emissions of pollutants including carbon dioxide, sulphur dioxide, and nitrogen oxides. Detailed comparisons of these resource and environmental benefits are presented in Table 3.

Data clearly demonstrate significant potential of high-strength steel reinforcement in advancing green construction practices. The 206.52 tonnes of steel saved in this case study equates to reduction exceeding 320 tonnes in iron ore mining, 134 tonnes in standard coal consumption, and more than 1,000 tonnes in water usage. From an environmental perspective, this translates to direct reduction of approximately 349 tonnes of carbon dioxide emissions. For China's construction sector, currently navigating a critical phase toward dual carbon goals, this represents tangible contribution. Such emissions reductions achieved through material innovation at project inception constitute substantial societal value unaccounted for in conventional cost analyses.

Table 3. Resource and Environmental Benefits

Indicator	HRB400 Solution	630-MPa Grade Solution	Reduction
Resource Consumption			
Iron ore (tonnes)	761.58 × 1.550 ≈ 1180.45	555.06 × 1.550 ≈ 860.34	320.11 tonnes
Standard Coal (tonnes)	761.58 × 0.650 ≈ 495.03	555.06 × 0.650 ≈ 360.79	134.24 tonnes
Water (tonnes)	761.58 × 5.000 ≈ 3807.90	555.06 × 5.000 ≈ 2775.30	1032.60 tonnes
Pollutant Emissions			
Carbon dioxide (tonnes)	495.03 × 2.600 ≈ 1287.08	360.79 × 2.600 ≈ 938.05	349.03 tonnes
Sulphur Dioxide (kilograms)	495.03 × 1.600 ≈ 792.05	360.79 × 1.600 ≈ 577.26	214.79 kilograms
Nitrogen oxides (kg)	495.03 × 9.000 ≈ 4455.27	360.79 × 9.000 ≈ 3247.11	1208.16 kilograms

[a] Emission factors: Iron ore 1.550 tonnes/tonne of steel; Standard coal 0.650 tonnes/tonne of steel; Water 5.000 tonnes/tonne of steel; CO_2 2.600 tonnes/tonne of standard coal; SO_2 1.600 kilograms/tonne of standard coal; NO_x 9.000 kilograms/tonne of standard coal.

4 Discussion

4.1 Interpretation of Key Findings

The 27.12% reduction reflects real-world constraints including minimum reinforcement ratios and serviceability requirements. This reduction creates systemic benefits: reduced reinforcement density improves concrete compaction and durability, while construction advances toward industrialized practices [8].

Regarding serviceability considerations, the use of higher-strength reinforcement results in reduced steel area for equivalent capacity, potentially leading to increased service-load stresses and wider crack widths. In this study, crack width calculations confirmed compliance with the 0.2 mm limit specified for the environmental exposure class. The maximum calculated crack width under quasi-permanent load combination was 0.18 mm for the 630-MPa design versus 0.15 mm for HRB400, remaining within acceptable limits. Deflection checks similarly satisfied span/250 requirements. These serviceability verifications are essential for practical implementation and should be explicitly addressed in future applications of high-strength reinforcement.

4.2 Comparative Analysis

This study supports existing global research. A New York project using 700-MPa steel bars achieved 28% material reduction-closely matching our 27.12% savings [5]. This consistency confirms the universal material-saving potential of high-strength steel bars. Recent studies on sustainable construction materials further validate these findings [9-10].

4.3 Implications for Practice

For developers, using 630-MPa high-strength steel bars proves economically beneficial-demonstrating that "high-strength" doesn't mean "high-cost." This research provides a quantifiable path for achieving carbon goals through material upgrade alone [11][12].

From a practical implementation standpoint, the current state of 630-MPa bar production in China has transitioned from experimental to standardized manufacturing following the 2024 release of T/CSPSTC 143-2024. While 'limited market availability' was previously a barrier, major domestic steel mills have now established the capacity to supply these bars for large-scale projects. For practitioners, the slight lead time required for procurement is offset by the logistical efficiency of transporting nearly 27% less material weight to the site.

4.4 Limitations

This single case study focused on basement ceiling beams requires validation across more structural types. Several limitations should be acknowledged: (1) The economic analysis excludes indirect costs such as worker training, supply chain considerations, and potential regional price variations for 630-MPa bars which currently have limited market availability; (2) The environmental assessment employs a cradle-to-gate approach using industry-average emission factors rather than product-specific Environmental Product Declarations (EPDs); (3) Seismic ductility performance of 630-MPa bars under cyclic loading reqauires further experimental validation; (4) Long-term durability and maintenance implications were not assessed. Future research should include multiple projects across residential, commercial, and industrial buildings, adopt dynamic cost models, incorporate supply chain analysis, and conduct comprehensive life cycle assessment with clearly defined system boundaries [13]. Furthermore, future studies should specifically investigate the correlation between localized steel strain and long-term deflection in 630-MPa reinforced members to provide more granular design guidelines for high-load applications.

5 Conclusion

(1) Technical and Economic Viability: 630-MPa-grade high-strength reinforcing bars achieve 27.12% reduction in reinforcement usage while maintaining structural safety, yielding 11.51% overall cost savings (¥528,948 or ¥14.87/m^2).

(2) Environmental Benefits: Reduced material consumption translates to substantial decreases in upstream resource usage (320 tonnes iron ore, 134 tonnes standard coal, 1,033 tonnes water) and emissions (349 tonnes CO_2).

(3) Systemic Value: Adoption catalyzes systemic innovation through structural design optimization and construction technique advancement.

(4) Scope and Future Directions: These findings are derived from medium-span structural beams (4-10m) in a single residential project within a specific seismic design context (intensity 7, 0.15g). Broader applicability requires validation through multi-

project studies encompassing diverse structural types, regional markets, and seismic conditions.

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