Review

Advancements in Sustainable Prestressed Concrete Bridge Technologies: A Comprehensive Review

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Abstract: Advancements in prestressed concrete bridge technology have increasingly focused on sustainability in response to growing environmental concerns. This review examines recent innovations in integrating recycled concrete aggregates (RCA) and supplementary cementitious materials (SCMs) within prestressed concrete to conserve resources, reduce waste, and lower carbon emissions. Sustainable prestressing techniques, including the use of fiber-reinforced polymer (FRP) tendons and shape memory alloys (SMAs), increase the durability of prestressed concrete bridges, extend service life, and minimize maintenance needs, thereby reducing environmental impact. Key methodologies, such as lifecycle assessment (LCA) and performance-based design, are highlighted for their roles in optimizing structural performance while reducing the ecological footprint. Despite the benefits, barriers to widespread adoption remain, including technical limitations, economic challenges, and regulatory constraints. To address these issues, this review proposes further research on material development, updated design guidelines, cost–benefit analyses, and supportive policy initiatives. The findings confirm that integrating sustainable materials and advanced technologies in prestressed concrete bridge construction offers environmental advantages without compromising structural integrity. Collaborative efforts among engineers, researchers, policy-makers, and educators are essential to overcoming these barriers and advancing sustainable, resilient infrastructure.

Keywords: sustainable prestressed concrete; recycled concrete aggregates; supplementary cementitious material; fiber-reinforced; lifecycle assessment; environmental impact; structural durability

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1 Introduction

The construction industry is increasingly emphasizing sustainability to address environmental concerns such as resource depletion, high energy consumption, and greenhouse gas emissions. Prestressed concrete bridge construction, a critical component of infrastructure development, is no exception. Recent advancements in prestressed technologies aim to enhance sustainability, incorporate green designs, and set the stage for future innovations [1-5]. Figure 1 provides an overview of these advancements, showcasing key milestones and innovations that have shaped the industry.

Prestressed concrete bridges offer several advantages over traditional reinforced concrete structures, including improved load-bearing capacity, material efficiency, and enhanced durability [6-13]. However, conventional prestressed concrete relies heavily on nonrenewable resources and energy-intensive materials such as cement and steel, contributing significantly to environmental degradation [14-16]. This reliance presents a challenge in aligning bridge construction practices [17] with global sustainability goals [18-21].

In response to these challenges, researchers and engineers have explored the use of sustainable materials and innovative technologies in prestressed concrete bridges [22-24]. The incorporation of recycled concrete aggregates (RCA) and supplementary

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