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Fiber-Reinforced Polymer Bridge Design in the Netherlands: Architectural Challenges toward Innovative, Sustainable, and Durable Bridges

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A B S T R A C T

This paper reviews the use of fiber-reinforced polymers (FRPs) in architectural and structural bridge design in the Netherlands. The challenges and opportunities of this relatively new material, both for the architect and the engineer, are discussed. An inventory of recent structural solutions in FRP is included, followed by a discussion on architectural FRP applications derived from the architectural practice of the author and of other pioneers.

1. Introduction

Despite the fact that the building industry tends to be more conservative than other sectors such as the automotive or aerospace industries, innovative materials and new techniques are finding their way into bridge construction in the Netherlands. One of the most promising group of new material in bridge design is fiber-reinforced polymer (FRP). FRPs are composite materials that consist of a polymer matrix reinforced with fibers. The fibers can be glass, carbon, basalt, or aramid, although other fibers such as paper, wood, or plant fibers have also been used. The polymer is usually an epoxy, vinyl ester, or polyester thermosetting plastic. The fibers and the matrix exhibit different physical and chemical properties that, when combined together, create a strong and rigid composite material.

Ever since the first FRP footbridge in Harlingen in 1995, practice in the Netherlands has shown a growing interest in this new material for bridge design. This interest has resulted in a significant number of realized bridges in which FRP has been applied. The bridge examples discussed in this paper show FRP being used both for the main load-bearing structure and in a more complimentary way, such as for modular edge elements and bridge deck systems. Although the pioneer years of FRP bridge design in the Netherlands were dominated by straightforward load-bearing boards, this author will prove that FRP has a great deal to offer in terms of the aesthetic appearance of a bridge.

The Netherlands has an extremely high density of roads, railway lines, and waterways. It is therefore no wonder that the country contains an excessively high number of traffic bridges and footbridges today, with most having been constructed after the Second World War [1]. Since the war, traffic intensity has grown by tenfold while design codes and regulations have become stricter, especially in terms of wear, dynamics, and fatigue. This development has resulted in a high number of post-war bridges being at the end of their technical life. Replacement is expensive, and since public authorities have been forced to downsize their organizations due to the economic recession, there is little budget for maintenance [2].

Therefore, when new bridges are being built, the question arises of whether traditional materials such as concrete and steel are still the best choice, both in terms of rational engineering arguments and for cultural and aesthetic reasons. New materials have

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been developed in the field of bridge design, one of which is FRP.

Although a significant number of FRP bridges have been built in the Netherlands over the past 20 years, it is noticeable that aesthetics were considered as a legitimate issue for only a handful of them. Most of these designs are extremely straightforward, massive structures that do not visibly show the fact of dealing with a new and innovative material. These bridges are mere slabs across the water; in the few cases that aesthetics are considered, the new materials are used to imitate traditional materials such as wood (i.e., for parapets or deck planks) or steel. This tendency to refer to a traditional application is reminiscent of the first iron bridge designs, in which traditional wood connection details were indiscriminately translated into iron.

In order to answer the question of what FRP has to offer in the architectural design of a bridge, it is first necessary to identify how the use of FRP can change the appearance of a bridge, and what kind of shapes and tectonic applications of FRP can do justice to this relatively new material in bridge design. The goal of this paper is to set out a path that will enable designers, architects, and engineers to take FRP bridge design up to the next level, not just using this new material as a pragmatic engineering choice, but embracing it as an architectural challenge.

In order to understand what *can be*, we first need to know what *is*. Therefore, Section 2 investigates how engineers have pioneered FRP, including different typologies and production methods. This paper discusses and evaluates the aesthetic merits of these methods. Section 3 then addresses different opportunities and challenges for aesthetic improvement by evaluating the author's work and the work of other pioneers in the field.

2. Engineers' solutions in fiber-reinforced polymer (FRP)

A retrospect of the evolution of FRPs shows that engineers, rather than architects, were the first to experiment with this new material. The aerospace, marine, and automotive industries initially introduced these plastics decades before architects adopted them. As early as 1940, Henry Ford produced a pioneering composite car from hemp fiber and resin under the motto: "ten times stronger than steel" (Fig. 1 and Fig. 2). Plastic materials gradually began to attract other sectors as well, including product design, architecture, and construction. Architectural practices such as Future Systems Architects realized the potential of the molding technique in producing new forms, and developed futuristic FRP houses and structures. However, regarding bridge design, none of the early FRP designs considered the aesthetic potential of the material.

Driven by issues such as maintenance and durability, bridge engineers seeking alternatives to traditional construction materials found that FRPs offered comparable and often superior properties (Table 1). One of their strongest advantages is their low density, which results in reduced mass. Comparative case studies in this author's practice have shown that the average FRP composite bridge is about half the weight of a steel bridge, with the same performance; and it is five times lighter than its concrete equivalent. This benefit regarding weight also results in reduced energy and cost in

Fig. 1. Henry Ford demonstrated his hemp car on impact (Ford, 1940).

Fig. 2. Engineers from the aerospace, maritime, automotive, and sports industries have preceded bridge engineers in their use of FRP.