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THE NEXT GENERATION OF BRIDGE GIRDERS AND BRIDGE ELEMENTS

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Abstract

Although the pace of new road and railway infrastructure development in Hungary has decelerated in recent years, significant advancements in related research and innovation continue unabated. In 2025, two major research and development projects reached completion, marking important milestones in the field of construction materials and structural engineering. A critical step in these projects was securing valid CE certification, which ensures compliance with European standards and permits the design and commercialization of the developed technologies across the entire European market. One of the groundbreaking outcomes is the initiation of production for carbon fiber composite material (CFCM) and carbon fiber composite cable (CFCC) reinforced concrete kerb elements. These elements represent a global first in their manufacturing and installation processes and are currently implemented on the Flórián Square overpass in Budapest. The primary objective of this research was to enhance the durability of concrete structures by significantly reducing the detrimental effects of corrosion, while simultaneously improving their load-bearing performance. The results demonstrate a successful achievement of these goals, contributing to longer service life and enhanced safety of infrastructure components. Additionally, the research focused on the fabrication and performance evaluation of lightweight aggregate concrete bridge girders, measuring nearly 50 meters in length. This investigation addressed the complex challenge of increasing load capacity while reducing the dead weight of bridge beams. Detailed experimental studies examined the synergy between lightweight aggregates, steel reinforcement bars, and prestressed strands under typical service loads. The findings provide valuable insights into optimizing composite materials and structural designs for future civil engineering applications.

Keywords: precast, bridge beam, carbon fiber, concrete

1 Introduction

Technological advances and research in recent years have clearly demonstrated that, unlike steel, which is prone to corrosion caused by chloride diffusion, carbon fiber composites are completely immune to corrosion, which significantly extends the lifespan of bridges, even to more than 100 years. Based on design and manufacturing experience, recommendations for design safety factors are available, so the expansion of domestic and international regulations is already in progress. The evolution of carbon fiber in civil engineering has branched into three distinct methodologies to address durability, strength, and fire safety. Two research projects with EU and government funding were completed last year in Hungary, with the main objective of researching the application of these materials to bridge construction technology.

According to a study published by Meier [1], the use of CFRP cables began in the 1980s, with the first cable-stayed application occurring in 1996. Research has proven that CFRP is highly suitable for replacing steel cables in long-span bridges due to its low self-weight and high tensile strength. A comprehensive review by MDPI indicates that retrofitting with CFRP plates can increase the load-bearing capacity of bridges by up to 30% [2].

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The same study notes that ductility can improve by 50–73% as a result of carbon fiber reinforcement. Environmental exposure tests found that even four years of outdoor stress did not significantly reduce the load capacity of reinforced beams. Another Swiss case study (E3S Conferences) presents the successful plate reinforcement of a steel lattice bridge built in 1892 [3]. Studies have examined also the behavior of different CF bars under extreme temperature fluctuations and UV radiation. Based on research results, several countries (e.g., USA - AASHTO) now have specific design standards for CFRP bridge applications. Overall, international research consistently identifies CFRP as the future technology for bridge construction and rehabilitation. Another CF technology is the CFCC, with a unique stressing method and special solutions [4], not so popular as CFRP, but very useful for specific areas.
Research at the Budapest University of Technology and Economics (BME) has focused on the structural integrity and long-term durability of CFRP, CFCM, and CFCC materials for over two decades. Hungarian scientists have pioneered the investigation of bond behavior between carbon fiber textiles and high-performance cementitious matrices [5, 6]. The BME laboratory facilities and the bridge beam factories allow for full-scale testing of reinforced concrete beams strengthened with various carbon fiber configurations. A key area of Hungarian research is the seismic retrofitting of masonry and concrete structures using CFCM, which offers better compatibility than resin-based systems. Studies led by György L. Balázs have extensively explored the high-temperature resistance of cement-bonded carbon fibers. The BME has conducted comparative studies on the ductility of steel versus different CF prestressed elements in this research work. Practical applications in Hungary include the reinforcement of historic bridges and industrial silos using carbon textile technologies and various bridge element. Another direction of research is the maximization of geometric possibilities. Until 2025, the FI-150 bridge beam type in our country was the bridge beam family with which the designer could bridge a span of 45 meters. As part of the joint research of BME and Ferrobeton (the manufacturer of the FI beam family), the FI-200 beam family was created, which represents a 200 cm high bridge beam and can bridge a span of 50 meters [7].

2 Carbon fiber vs steel

All major construction chemical companies have a technology solution and regulated design and use instructions for polymer-reinforced carbon fiber (CFRP) sheet reinforcements. Cement and composite based technologies (CFCM and CFCC) do not yet have one, but the process is underway to enable their use in larger projects where environmental conditions warrant it.

2.1 CFRP

Carbon fiber reinforced polymer (CFRP) remains the most widely used solution for external reinforcement of concrete bridge beams. CFRP is manufactured by impregnating carbon fiber tows with epoxy resin to create high-stiffness laminates or sheets. The primary mechanical advantage of CFRP is its ultimate tensile strength, which can exceed 3,000 MPa in high-stress applications. However, the standard design methodology warns that the effectiveness of CFRP is limited by the “peel-off” stress of the concrete substrate. Design experience shows that CFRP-strengthened beams often fail suddenly when the concrete cover separates under high shear stress. To mitigate this, manufacturers have developed “near surface mount” (NSM) CFRP bars that are embedded in grooves in the concrete.

2.2 CFCM

Carbon fiber cement matrix (CFCM), also known as FRCM, was developed to overcome the thermal and vapor barrier limitations of CFRP. CFCM uses a carbon fiber textile grid embedded in a high-performance inorganic cement-based mortar. The production of CFCM requires a special “wet-on-wet” application process to ensure that the mortar completely surrounds the carbon grid. During its production, care must also be taken to ensure the final useful length and how the bar surface is formed. Research has shown that CFCM retains up to 80% of its capacity at 400°C, while CFRP completely breaks at 100°C. Despite the lower bonding efficiency, CFCM may be preferred for tunnels and bridges where fire safety regulations are strict, or the risk of concrete corrosion is very high.

2.3 CFCC

Carbon Fiber Composite Cable (CFCC) is also a specialized form of carbon fiber used primarily for prestressing and stay-cables. CFCC strands are manufactured through a complex process of twisting carbon fiber yarns and resin pultrusion. The Tokyo Rope Manufacturing guidelines emphasize that CFCC offers a weight reduction of 80% compared to equivalent steel cables. A major design hurdle for CFCC is the “anchorage zone” where the cable must be gripped without crushing the transverse carbon fibers. Innovative “wedge-type” or “potted” anchors have been developed to transfer massive tensile forces from the CFCC to the bridge abutments. The fatigue life of CFCC is significantly higher than steel, withstanding over 2 million cycles at high stress ranges without failure.

3 Bridge beams nowadays in Hungary

3.1 Traditional bridge beams

The evolution of bridge construction technology over the past decades can be clearly traced in the development of the geometric and load-bearing properties of bridge girders [8]. The FP, FPT, ITG, FCI and then FI bridge girder designations (figure 1) defined the geometric properties of the girders as well as their maximum length (table 1). Currently, 44.8-meter-long bridge girders are used in road and railway construction. Therefore, the optimization of the cross-sectional height and the utilization of the spans was also raised during the experimental work.

Table 1 The bridge beam “family” and their properties in Hungary [10]

Type of Bridge beam	High [cm]	Max Length [m]	Max weight with max length [t]	Specific weight [kN/m]
FPT	130	34.8	39.2	11.278
ITG	110	32.8	27.3	8.323
FCI	120	32.8	29.1	8.875
FI	150	44.8	56.5	12.617

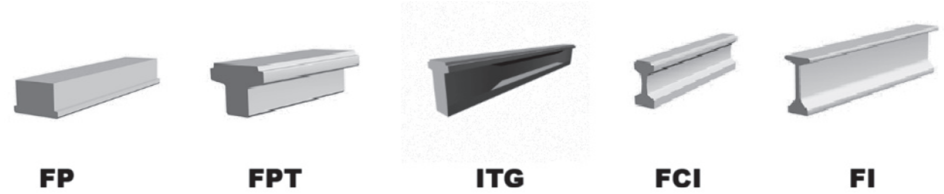

Figure 1 The different types of bridge beams [10], where FP: Ferrobeton (Manufacturer) Pontterv (Designer); FPT: Ferrobeton (Manufacturer) Pontterv (Designer) T (cross section); ITG: I (cross section) Támasztó (Support) Gerenda (Beam); FCI: Ferrobeton (Manufacturer) Composit I (Cross section); FI: Ferrobeton I (Cross section)

3.2 The developed new bridge beams

The war in Ukraine has highlighted the important role bridges play in everyday life. Attempts to destroy them and the scarcity of repair technologies have put prefabricated long-span bridge girders in a new light. In our research, we aimed to develop the maximum bridge girder that can be prefabricated and transported by road. This is not only a geometric limit, but also a weight limit. The self-weight of the beams made of C60/75 strength concrete, traditionally used for long-span FI 150 bridge girders, would have been too high for a 200 cm high girder. Therefore, we experimented with different additives and aggregates in order to reduce the total weight of the beam by 15-20 tons. Based on the results of extensive laboratory and batching plant experiments, we decided on Certyd [11]. Certyd has a lower bulk density than traditional aggregates (620-750 kg/m^3), so when designing the recipe, the correlation between compressive strength and density of hardened concrete had to be taken into account in order to optimize these two properties.

3.2.1 Playing with the lines

It is clear to civil engineers what geometric possibilities the moment diagram created by external and internal loads creates. The use of this possibility has been limited in the case of prestressed beams until now, because the appropriate technology was not available. Steel strands are flexible enough to be played with a few degrees of deviation in order to utilize the load more effectively. This cannot be solved with CF technologies. The inclined strand template was co-created in the framework of the experiment, and the fracture results confirmed the validity of the technology (figure 2). The only problem is the occupational safety risk, because the inclined line also means that the seating of the tension-holding wedges must be perfectly solved, otherwise the probability of an accident at work (which in the case of prestressed strands is usually fatal) increases dramatically [9].

Figure 2 The steelstructure and the strainline marked with red line

3.2.2 Changing geometries and their consequences

The further development of the FI 150 bridge girders used today (150 cm high and usually 44.8 meters long) raised several technological questions that affect manufacturability:

- Can the support end withstand the tension caused by the necessary strands? (yes)
- What will be the dead weight - what can be transported by road? (max 90 tons)
- Can the strength of the concrete be further increased without significant additional costs? (depends on...)
- What forces arise in the tensioning frames and the tensioning bed if all rows are utilized for production efficiency? (Sum 3000 tons for both line – just alone production line 1800 tons)

We managed to provide answers to all these questions and prove the correctness of the calculations through experiments. We faced many challenges during the research and tests (figure 3), but we managed to create the designed beams and the test loads were also successful [7].

Figure 3 The test load in April 2025

3.3 Changing the strain type - how can we use the CFCC technology

The CFCC technology itself is not very different from the traditional steel strand solution. The essence of the technology is that we replace the steel strand with the CFCC strand in the section in the supporting structure. This can be solved quickly in theory, but in practice it cannot be solved easily without the patented process of Tokio Rope. The research that started in the middle of COVID 19 was finally successfully concluded, but the current technological solution is not yet market-oriented, so it is very unlikely that we will apply it in Hungary. In countries where saltwater exposes the reinforced concrete structure to daily use, it can be a viable solution [12].

3.4 The developed new bridge edge elements

Compared to traditional reinforced concrete structures, the advantage of CFCM technology can be exploited most in bridge structures. The harmful effects of ice and snow melting agents used during winter road maintenance works, which cause corrosion of reinforcing steel, can be minimized with this technology if the area of application is chosen appropriately. The deterioration process of Budapest’s bridges and overpasses has accelerated dramatically in recent years due to decision-making that overshadowed professional arguments. Therefore, during the renovation tender of Flórián tér, they were pleased that there is a technological solution that eliminates one of the neuralgic points of damage caused by winter road maintenance. After the preparation and validation of the national technical assessment of products made with the technology, this solution can be used anywhere where the environmental exposure classes justify it. In the national technical assessment, we defined two product groups with fundamentally different mechanical loads:

- self-supporting structure (AVCP 4)
- structure capable of carrying a statically useful load (AVCP2+)

The bridge kerb belongs to the first group, as shown in figure 4. A simple angle iron support is cast into the monolithic track structure, which fixes the bridge kerb element and also serves as an additional anchor for later work. The concrete is plastic fiber reinforced, so stirrups could also be omitted. We used a silicone template for production in order to ensure that the elements were perfectly uniform.

Figure 4 The silicon molds of Bridge kerb elements

4 Conclusion

Successfully completed research projects have shown that the primary efficiency of CF technologies lies in their high strength-to-weight ratio, which drastically reduces logistics costs and the need for heavy assembly machines. Although the initial material costs are higher, their long-term economic efficiency is proven by the significantly lower maintenance requirements and longer structural life. We have reached the limit of the geometric and weight constraints of bridge beams, which can be considered a milestone in the case of reinforced concrete and composite concrete structures - just like the sonic limit effect in aviation. Environmental loads are tolerated more effectively, but not all technologies are suitable for every application. Here too, the eternal principle applies: there is no perfect technology, you always have to find the solution that is most effective.

References

[1] Meier, U.: Carbon Fibre Reinforced Polymers in Bridge Engineering, IABSE Congress Report, 18 (2012) 31, DOI: 10.2749/222137912805110411

[2] Vijayan, D. S., at al: Carbon Fibre-Reinforced Polymer (CFRP) Composites in Civil Engineering Application – A Comprehensive Review, Buildings, 13 (2023) 6, 1509 DOI: https://doi.org/10.3390/buildings13061509

[3] Hossein, H., Nussbaumer, A., Masoud, M., Elyas, G.: Strengthening of Steel Connections in a 92-Year-Old Railway Bridge Using Prestressed CFRP Rods: Multiaxial Fatigue Design Criterion, Journal of Bridge Engineering, 26 (2021) 6, 04021023, DOI: 10.1061/(ASCE)BE.1943-5592.0001714

[4] Yamashita, H.: Carbon Fiber Composite Cable, Mechanical Engineering Congress Japan, January 2019, DOI: 10.1299/jsmemecj.2019.F04202

[5] Balázs, L.G., Csurgai, F., Sólyom, S.: Bond of CFCM – a new form of bond, Conference Paper Conference: Bond in Concrete 2022 – Bond, Anchorage Detailing, Stuttgart, Germany, July 2022.

[6] Solyom, S., Balázs, G.L.: Bond of FRP bars with different surface characteristics, Construction and Building Materials, 264 (2020), 119839, DOI: https://doi.org/10.1016/j.conbuildmat.2020.119839

[7] Bencze, Z.: Hídgerenda-fejlesztések a Ferrobeton Zrt.-nél, Beton, 33 (2025) 5

[8] Bedics, T., Kovács, T., Dubrovszky, G.: The design method of FI 150 bridgebeam, Concrete Structure, X/2 (2008), pp. 34-41

[9] Bencze, Z.: Nonplus ultra aka beam with bent strands made from light concrete, 24th International Conference on Civil Engineering and Architecture 2020, pp. 15-19, online, 13 June 2020.

[10] Bridgebeam types, https://ferrobeton.hu/hidepites, 31.01.2026.

[11] Lightweight prefabrication, structural strength, cost reduction, https://certyd.eu/, 31.01.2026.

[12] Bencze, Z., Dubróvszky, G., Balázs, L., Sólyom, S., Novoszáth, T., Bedics, A., Szabó, J.: Szénszál erősítésű feszítőpászmás tartók kísérleti gyártása a Ferrobeton Zrt.-nél, Beton, 29 (2021) 3, pp. 16-17