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Falcon – A Multi-Disciplinary Effort to Promote FRP bridges in Sweden

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ABSTRACT

Sweden has a long history in using fiber reinforced polymer (FRP) composites in marine, transportation and energy sectors. However, when it comes to application of composite materials to build bridge structures, it somewhat falls behind.
Despite several advantages that FRP composites offer, such as high specific strength and stiffness, corrosion resistance and light-weight, their infrastructural applications in Sweden have not been fully understood and yet to be realized. The first efforts to use FRP composites for construction of pedestrian bridges started in 2011, however, due to lack of knowledge about the materials and design of composite structures among engineers, they were halted.
To identify the existing gaps and hindrances, a joint effort project called "Falcon" was realized. The main goal of the project was to realize the first FRP pedestrian bridge and pave the way towards widespread infrastructural application of composites. This paper, presents some findings of the project and a brief description of a few pilot projects realized in the country.

KEYWORDS

FRP bridge, design guidelines, procurements.

INTRODUCTION

At the present, sustainable development is an important aspect in many engineering fields. Construction is, of course, not an exception. Aging and overloading of infrastructure in conjunction with lack of proper maintenance have led to "global infrastructure crisis". Therefore, finding innovative materials and technical solutions to construct infrastructure with longer service life and lower life cycle cost, has been a priority for many bridge authorities and infrastructure owners in European countries, as presented in Mara et al. (2013). In addition, advanced industrialized production as an approach to reduce production cost, is gaining a great deal of interest among industrial communities and engineers. In this respect, off-site manufacturing and on-site assembly is of great importance in bridge construction.
Emerge of fiber reinforced polymer (FRP) composites in construction industry in mid-1970's, opened up new horizons towards achieving abovementioned goals. FRPs are classified as composite materials and are basically composed of two constituents: reinforcing fibers and a polymeric matrix. Depending on the expected mechanical and durability characteristics, different types of fibers and matrices can be combined. Common FRPs used in construction include carbon, E-glass and aramid fibers. Matrix is often a thermosetting resin such as epoxy or polyester. Lately, natural fibers and bio-based resins have been researched, but due to concerns regarding the long-term performance, and often inferior mechanical properties of bio-based composites, they have not been realized in commercial projects.
The possibility of combining different types of fibers and matrices offers the great advantage of "tailor-ability" in the sense that the "right" constituents can be mixed to get the "right" properties. FRP composites have superior mechanical properties such as very high specific strength and stiffness and very good durability characteristics. The light weight of FRPs is very attractive when it comes to prefabrication, as it provides the possibility for off-site manufacturing and on-site assembly. When compared to other European countries such as UK and Netherlands, infrastructural application of FRPs in Sweden somewhat falls behind.
This paper, presents results of a research project carried with the aim to identify technical and management problems towards widespread application of FRPs as well as activities to facilitate the acceptance of FRP composites as a reliable and cost-effective alternative to traditional building materials such as steel and concrete. Sweden has a long history in using fiber reinforced polymer composites in marine, transportation and energy sectors. Despite the advantages offered by FRPs, the experience and the knowledge among different industries

about design and manufacturing of FRP components, FRPs have not yet found their place in Swedish construction sector yet.

PREVIOUS EFFORTS

Structural engineers in Sweden are generally not educated about FRP as a construction material so it is not surprising that there has not been a pull from the construction industry to explore the possibilities provided by FRPs as a building material. The initial efforts were made by the composite industry (especially manufacturers and material providers), searching for new market areas in 2010. Architects also found new opportunities in using the material to create complex geometries and tried to "promote" such solutions. The problem, however, was the lack of knowledge among architects about the material which created unrealistic expectations without considering the technical and practical limitations. The idea of using FRP for building pedestrian bridges in Sweden, initiated in 2013. Two examples of these ideas were Kaponjär bridge (Figure 1) proposed by Ramböll consultants and Architect bridge (Figure 2) by ELU consultants. Even though the concepts were very attractive from architectural point of view, the complexity involved in the design and manufacturing of these concepts, halted both projects.
A learned lesson from these failures was that it was the lack of knowledge about the FRP materials in the engineering community and among clients which did not allow the realization of these projects.

Figure 1. Concept of Kaponjär FRP bridge over Rosenlundskanal in Gothenburg. Picture courtesy of Ramböll

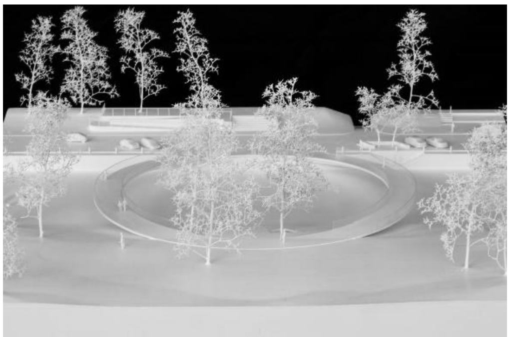

Figure 2. Concept of Architect bridge in Haga area in Gothenburg. Picture courtesy of Erik Andersson Architects

THE FALCON PROJECT: A MULTIDICIPLINARY EFFORT

It was soon realized that to create the foundation for application of FRPs in bridges, a comprehensive and multi-disciplinary work with contribution of all players was needed. In this context, Falcon, "future advanced light-weight construction (2016-2018)", a joint effort project with total budget of 640 k Euro funded by VINNOVA and co-funded by industrial consortium partners. It is coordinated by Swerea Sicomp (a leading Swedish research institute in FRP composites) and was initiated to identify the hindrances towards the infrastructural application of FRP composites and facilitate the acceptance of FRP solutions by paving the way towards realization of the first FRP bridge in Sweden. The project consortium consists of 14 partners from universities, research institutes, bridge designers, manufacturers, material suppliers and clients.
The main objective of the project was to implement the best practice for design and procurement of FRP bridges. In this regard, a draft of "technical client demands" along with a background document were prepared in accordance with Swedish national regulation (TRVKbro 11) for design and procurement of bridges. The main aim of these documents was to establish a framework for clients to process innovative technical solutions not covered by Eurocodes within the existing legal boundaries.

THE WAY TOWARDS WIDESPREAD APPLICATION OF FRPS IN SWEDEN

FRP Deck for the bascule road bridge 261

Bridge 261 located in the city of Malmö, is a two-lane bascule steel bridge composed of two supporting side trusses and a steel decking system built in 1953. The orthotropic steel deck in the bridge had dimensions of 8.9m x 32.9m and was degraded due to corrosion over time. Visual inspections also revealed multiple cracks in the asphalt layer, a typical problem due to local bending of the top plate in orthotropic decks, which added to maintenance cost of the bridge, see Figure 3. Therefore, the refurbishment of the bridge was necessary. The client needed a fast assembly solution as the bridge was located on one of the main roads in the city and considerable traffic disruption would have taken place if the bridge had been closed for a long time. It was decided to use FRP solution to accelerate the operation and provide a more durable solution compared to a steel alternative.

Circumstances of the project necessitated using tailor-made FRP sandwich panels. To keep the cost low, glass fibers and polyester matrix were chosen. The design and manufacturing of the deck panels was carried out by the Dutch supplier FiberCore Europe.

Figure 3. Wear of the surface and transverse cracks in the orthotropic steel deck, Photo courtesy of Per Andersson

Figure 4. Cross section of the sandwich panel used as new decking system

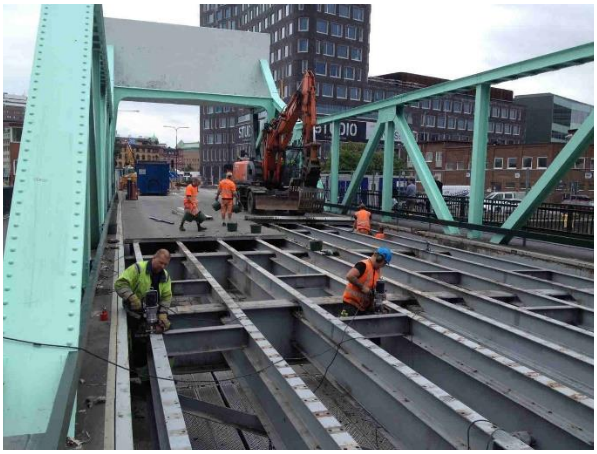

Figure 5. Removal of the old steel deck and preparation of the stringers for installation of FRP panels, Photo courtesy of Per Andersson

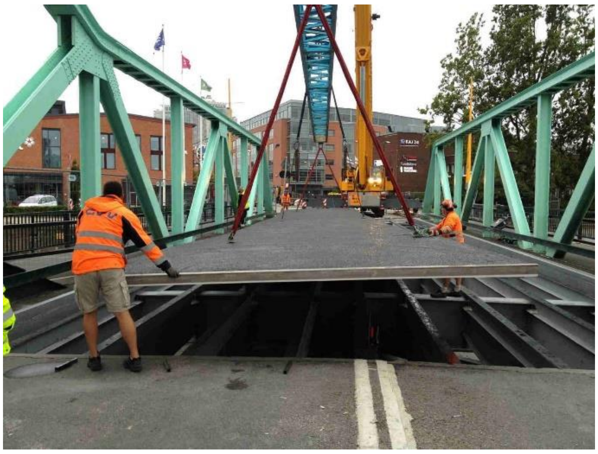

Figure 6. Installation of FRP deck panels, Photo courtesy of Per Andersson

The deck panels in this project had a height of 105 mm with face sheet thickness of 19mm on the top and 17mm in the bottom, see Figure 4. To avoid on-site joints in the perpendicular to the length direction, two longitudinal panels were manufactured with dimensions of 32.9m x 4.44m with total areas of 292m^2. The old steel deck was firstly removed from the bridge (Figure 5). In the next step, the holes on the steel girders were prepared by slightly enlarging them. The panels were then placed on the girders and connection were made using hollo-bolts. The project was completed in summer 2016.

FRP deck for rehabilitation of the university bridge

The university bridge in Malmö is a two-span asymmetrical cable-stayed swing bridge with a main span of 25 m and a 15 m long back stay span. The total length of the bridge is ca. 76 m including approach spans. The width of the bridge is 16 m, including 2 lanes of carriageway and 2 lanes for pedestrians and cyclists. The bridge was built in 2004. Already in 2015, signs of deterioration in wooden planks covering the pedestrian lines were observed. Deformation of the planks had caused uneven surface of the walkway and was a potential threat for the users, see Figure 7.

Figure 7. Deterioration of the wooden planks on sidewalks of the university bridge, Photo courtesy of Per Andersson

Figure 8. FRP panels installed on sidewalks, Photo courtesy of Per Andersson

The municipality of Malmö decided to replace the wooden planks with a more durable alternative. At the same time, there was a need for a lightweight solution not to disturb the balance of the spans as modifying the counterweight was not an option in this project. FRP deck panels with thickness of 65 mm produced by FiberCore Europe were installed on steel stringers spacing at 1.12m. 6 deck panels with width of 3 m were put alongside each other to cover the whole length of the bridge, see Figure 8. The project was completed in 2017.

Pedestrian bridge 254 – The first FRP pedestrian bridge in Sweden

The original bridge 254 in Malmö was a pedestrian timber bridge built in 1981. The bridge had undergone a considerable degradation and was classified as not safe for use. In 2016, the municipality of Malmö decided to replace the bridge. Different alternatives, including full concrete slab and concrete slab on steel girders were studied.

Figure 9. Proof loading of the composite beams during manufacturing, Photo courtesy of Composite Design

Figure 10. Installation of the bridge, Photo courtesy of Composite Design

The results from life cycle cost analyses on different concepts demonstrated that an FRP bridge would be the least expensive choice for this project. Composite Design, a Swedish FRP manufacturing company, took over the project. The superstructure of this bridge consists of seven sandwich beams glued together creating an FRP composite deck. Each beam consists of four smaller beams, laminated together to form a longer beam. The beams were created using lightweight concrete (Siporex) core wrapped with prepreg carbon fibre fabrics. Each beam was 505 mm wide and 420 mm high and had 11 layers of carbon fiber on the top and bottom with thickness of ca. 0.95 mm for each layer (total skin thickness of ca. 10.5 mm) and 3 layers of carbon fiber on the sides, ca. 2.3 mm.
The FRP bridge is 3.5 m wide, 17.62 m long and has area of 62 m^2. Each beam was loaded with 4.2 tons at the workshop to check if they fulfill the requirement for stiffness and deformation, see Figure 9. The bridge was installed in March 2017 and the mounting operation took only one hour, Figure 10.

Neptuni Bridge

Neptuni Pedestrian bridge shall be the next FRP bridge project to be started in the beginning of 2018 in city of Malmö, Figure 11. It will have a span of 15 m with variable width from 4.6m in the widest part to 2.4m in the narrowest section, see Figure 12. The main incentive for choosing FRP was the lower life cycle cost of this concept in comparison to steel and concrete alternatives.

Figure 11. Concept of the Neptuni bridge in Malmö, Photo courtesy of municipality of Malmö

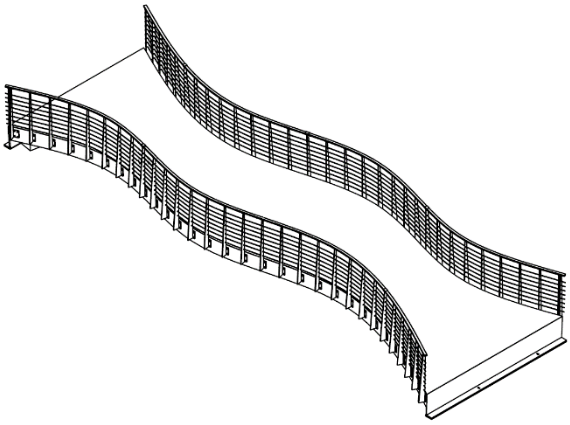

Figure 12. 3D illustration of the Neptuni bridge

SUMMARY AND CONCLUSIONS

FRP composites provide several benefits in bridge construction including: (i) flexibility in geometry and material choice (which of course come at a greater design effort, time and cost), (ii) lightweight, which offers smaller substructure, easier transport, faster installation and, all in all, off-site manufacturing and on-site assembly in addition to better quality, (iii) high specific strength and stiffness as well as good durability leading to resilient structures with large safety margins and low maintenance cost.

This paper presents the latest efforts in Sweden to increase the acceptance of FRP composites as a reliable, cost effective and sustainable building materials by authorities and infrastructure owners. At the present, according to investigations made in Falcon project, a good deal of interest at Swedish Transport Administration and local municipalities to use FRP composites in future bridge projects exists. The main reason is found to be the pressure on infrastructure owners, due to deterioration and consequent large maintenance costs of their assets. Dissemination activities such as demonstrations and workshops arranged in Falcon project, have led to an increased awareness about FRP technology for infrastructural use. Based on the learnings from the outcomes of the project, three main areas for improvement can be speculated:

- **Engineering education:** As mentioned earlier, bridge designers in Sweden, generally have very limited knowledge regarding FRP materials. In authors' view, it is the structural designer's knowledge which determines suitability of FRP for a certain project with specific circumstances in the first place. Providing teaching materials, design examples, coordinated workshops shall be an essential step towards creating the culture of using FRP in infrastructure in Sweden.
- **Lack of design codes and guidelines:** Lack of codes and regulations on design of FRP bridges adds to the difficulty associated with acceptance of FRP as a construction materials by major clients such as Swedish Transport Administration. Public procurement is strictly governed by laws and regulations so, in that sense, there is no difference between procuring a concrete bridge and an FRP bridge. The difficulty lies in technical questions such as reliability, accuracy of design models, durability and maintainability. It is believed that upon release of the "Technical Specifications" for FRP structures, which is under preparation by WG4 in CEN Technical Committee 250 - Structural Eurocodes in 2020, Ascione et al. (2017), a large part of technical and legal issues with acceptance of FRP solutions will be eliminated and new market opportunities for FRP constructions in Sweden will be arisen.
- **Integrated industrial manufacturing:** The level of interest from FRP manufacturers in other engineering disciplines has a direct relationship with the infrastructure market potential and attractiveness. However, FRPs are fundamentally innovative materials. They have not been resulted from improvement or modification of traditional construction materials. The supply chain of FRP structures is completely separated from those being used in civil engineering projects. At the present, there is a good potential interest among FRP manufacturers, especially from marine related, to enter FRP bridge market. However, the relationship between the FRP

manufacturers and bridge design offices has not yet been realized. It of great importance for FRP manufacturing industry to comprehend the specific technical demands put by designers for bridge structures as the nature of bridge structures is completely different from types of products they use to deal with. This is mainly due to more serious consequences of failures and stringent legal issues. Manufacturing tolerances, defect sensitivity and transportation handling are three main areas of consideration which need to be improved. This is where the authors believe the role of universities and knowledge-based SMEs to connect the design offices to manufacturers will be pronounced.

Finally, Falcon is evaluated to be a great step forward and, as almost all the pilot FRP projects in Sweden, were initiated, procured and conducted with direct or indirect support of the expert team in the consortium. This support will continue for future projects as the great potential for FRP materials is realized in Sweden by all involved stake holders. A potential that can lead to considerable cost saving, less impact on the environment and creating new job opportunities.

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