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The Design and Development of a Novel FRP Reinforced Bridge

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Summary

The Oppegaard Trial bridge forms a part of the R&D project Eurocrete, which is a large European research programme, with the objective to develop the use of non-metallic reinforcement in concrete structures. Both ordinary and post tensioned reinforcement is made of non-metallic composite materials, which makes the bridge the first of its kind built in Europe. Erection of the bridge structure demonstrates the possibility of designing and constructing a bridge with solely non-ferrous reinforcement.

1. Introduction

Corrosion of reinforcement represents a permanent threat against reinforced concrete's durability. Renovation of concrete structures is often attended with considerable costs. In Europe, more than 25 % of all concrete bridges are deteriorated due to carbonation or chloride attack, and the annual costs of corrosion are estimated to 700 millions ECU. Substantial resources are therefore utilised to improve the quality of structural concrete. There is however, little doubt that a reinforcement material that does not corrode and can resist aggressive environments would be the simplest solution. Future maintenance costs have become essential to the owner of any structure. Hence the potential for non-ferrous material as a replacement or supplement to conventional steel reinforcement is considerable, particularly for structures in aggressive environment, such as most bridges.

Eurocrete is a 4-year (1994-1997) 2.8 million ECU European research project, with the objective to develop the use of non-ferrous reinforcement in concrete structures. The research programme comprises several full-scale trial structures that will help assessing the behaviour and durability of the reinforcement in a realistic environment. One of these trial structures is a 10 m long service bridge located on a golf course outside Oslo (Fig. 1).The purpose with the field trial is:

- → to monitor and assess long-term behaviour of the FRP reinforcement in a realistic environment
- → to monitor immediate short term behaviour
- → to supplement laboratory tests
- → to validate theoretical models and analytical approaches for response predictions
- → to demonstrate the possibility of making a steel-free concrete bridge

In order to achieve the objectives with the trial structure, the bridge is equipped with instrumentation that will register deflection and displacements.

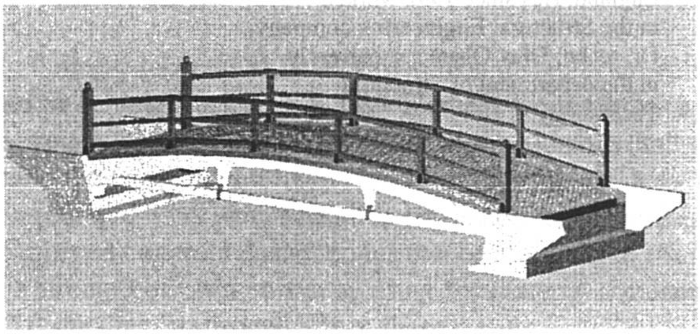

Fig. 1 Rendered image of the golf course service bridge

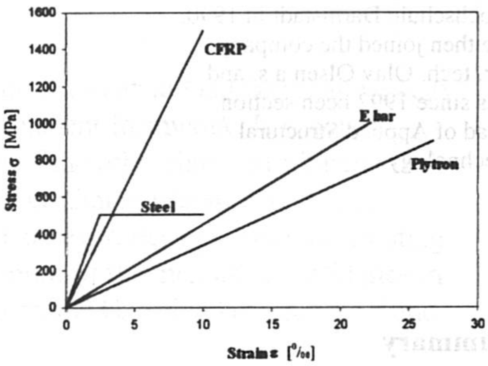

Fig. 2 Stress / strain diagram for FRP materials used

2. FRP Reinforcement

FRP reinforcement consists of glass, aramid, carbon or other synthetic fibres impregnated with a thermoset or a thermoplastic resin. For the use of FRP as non-ferrous reinforcement in concrete bridges these materials posses several assets due to material properties such as high tensile strength, low weight and good durability characteristics. However, most FRP elements exhibit a relatively low modulus of elasticity compared to steel (Fig. 2). Furthermore, the lack of yielding involves a brittle ultimate state of FRP reinforced concrete elements.

2.1 Reinforcement materials

Two types of Glass Fibre Reinforced Plastic (GFRP), developed in the Eurocrete project, is selected for use in the trial bridge. *Plytron* bars made of E-glass and polypropylene are used as shear links. The *Eurocrete reinforcement bar* (*E* bar) which is a composite with higher stiffness and strength is adopted as main reinforcement. These bars are made of E-glass and vinylester matrix. For the post-tensioning of the bridge Parafil tendons were utilised. The tendons are made from a parallel arrangement of aramid fibres and are sheathed with an extruded polyethylene. At each end the filaments are anchored to conical bored end terminators by means of spikes [Fig. 6].

Material properties for the FRP materials used in the bridge are listed in Tab. 1.

	E	f_u	α	$\emptyset$	ρ
	[GPa]	[MPa]	[K^{-1}]	[mm]	[g/cm^3]
Plytron	23.4	520		9	1.4
Eurocrete bar (E-bar)	45.0	1000		13.5 / 22	2.2
Parafil tendon	126	1926	-7.7×10^{-6}	40	1.4

Tab. 1 Material properties

3. Design Aspects

The trial bridge was designed in accordance with the Norwegian concrete code NS 3473 [1] using supplementary provisions developed within the Eurocrete project [2]. The most relevant aspects are summarised in the following:

- A material coefficient of 3.3 is used for both types of ordinary reinforcement at ULS, while a factor of 2.0 is applied to the prestressing material. The relatively high material factors are applied to compensate for the uncertain long term effects of the FRP bars.

- Since the FRP reinforcement will not be sensible for corrosion attack, the concrete cover is reduced from a normal requirement of 50 mm to 25 mm, where the required cover is that necessary to ensure the load transfer between the concrete and reinforcement.

- Owing to the high corrosion resistance the limiting crack width is related to structural integrity and aesthetics rather than to durability. This warrants a relaxation of the normal crack width criteria from 0.2 to 0.5 mm.

- Using the basic approach for minimum reinforcement common in most codes, the strength of the concrete is replaced by an equivalent amount of reinforcement. For FRP reinforcement this amount is increased by a factor equal to the material coefficient.

- Anchorage and splicing are conservatively calculated using the bond characteristics of plain bars.

- The reduced stiffness of the longitudinal reinforcement needs to be accounted for in computing the 'concrete contribution' to the shear resistance. This effect is considered by reducing the area of longitudinal reinforcement by the factor E_{FRP}/E_{STEEL}.

4. Bridge Design

The trial bridge is erected at the Oppegård golf course located near Oslo in connection with the extension of the course from 12 to 18 holes. With a total length of 10 m the bridge is spanning over a stream separating the new laid course from the former. Apart from pedestrians the bridge accommodates a service vehicle with a total axle load of 5.5 tonne.

The main criteria for the choice of the structure were architectural quality of the bridge, its harmonisation with the site and the ambient distinctive golf course aesthetics. Additional design

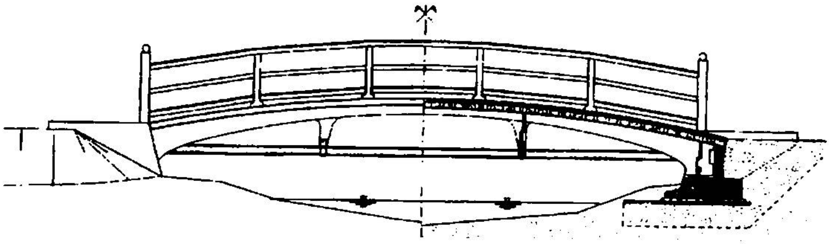

Fig. 3 Elevation and longitudinal section of the trial bridge

considerations were the requirement for prefabrication for optimum control and the intended field testing. Preference was given to a girder bridge with an arched shape. Owing to the low stiffness of the main GFRP bars, the application of prestressing was inevitable. To add to the innovative nature of the project it was decided to use FRP also for the tendons.

4.1 Edge girders

Two separate concrete edge girders carrying a wooden bridge deck constitute the bridge's superstructure (Fig. 3). The edge girders are independently resting on two conventionally reinforced abutments superficially founded on gravel beds. The statical system of the edge girders is that of an arc with a subtending post-tensioned concrete chord. Sagging necessitated the latter to be suspended by means of two conical concrete ties.

The curved compression chord has a rectangular cross section with a constant width of 300 mm and a depth increasing from 280 mm at mid-span to 650 mm at the supports. Three continuos E bars Ø22 mm on each face provide the longitudinal reinforcement, whereas Ø9 mm Plytron bars, formed as conventional double-legged steel links, were used for the stirrups. The formability of these bars allowed the use of FRP also for reinforcing the suspension members.

Due to the predominant compression, only minimum reinforcement was provided in the lower chord. Four Ø13.5 mm E bars constitute the minimum longitudinal reinforcement. As a consequence of the small dimensions of the chord measuring only 250 × 150 mm, the Plytron bars proved however not suitable for the intended stirrup configuration. Thus special purpose-made composite links were used. The links were manufactured by roving a rectangular profile from which the continuos links subsequently were cut.

The application of the Parafil system as internal, unbonded tendons required special anchor sleeves to be made allowing the free movement of the end terminators during post-tensioning. The encapsulating sleeves (Fig. 6) were made from two cylindrical halves which were joined around the terminators and welded prior to the installation of the cable into the formwork. Between the sleeves a PVC duct is protecting the tendon from the surrounding concrete. The tendons were tensioned to approx. 30 % of the short term nominal breaking load (90 tonne). The residual working load due to creep, shrinkage and relaxation is estimated to be approx. 22 % of NBL which necessitates the girders to be re-tensioned prior to the bridge is opened for traffic.

5. Construction

The FRP reinforcement for the compression chord were pre-assembled outside the formwork. Owing to the thermoset resin used in the Plytron bars, the stirrups can be formed correspondingly to conventional steel stirrups using a new concurrent heat-bend-twist technique. The Eurocrete bar can not be bent in the same way, but the moderate curvatures allowed for elastic bending of the bars. Installation of the pre-assembled rebar units into the formwork followed easily by hand power due to the low weight of the FRP bars (Fig. 4).

The edge girders were monolithically casted one by one with the side face down. After demolding and still in the lying position, the girders were post-tensioned to 40 % of the initial working load and temporarily locked off. The tendons were stressed to the target stress level after to the girders had been lifted in upright position and the selfweight was activated. The edge girders (Fig. 5) were transported on a truck from the pre-casting plant to the erection site. With a crowfoot hoisting wire the 4 tonne girders were lifted onto the bearings without causing additional moments in the concrete chord.

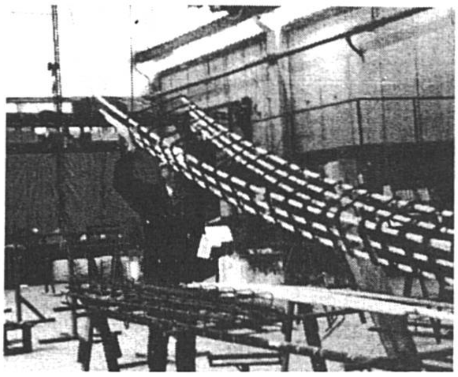

Fig. 4 Weight demonstration.

Fig. 5 Transportation of the edge girders to site

6. Instrumentation and monitoring

The documentation of the 'real-life' behaviour of the FRP reinforcement - immediate and long-term - has been of paramount interest in performing the field experiment. Measurement data from the performance monitoring provide valuable correctives to the wide range of scaled laboratory tests conducted within the Eurocrete programme. A vital link between theory and practice is further found through the comparison of the observed behaviour to the design predictions, validating the theoretical models and analytical approach employed for the response predictions.

6.1 Instrumentation

The field instrumentation is arranged for deformation and deflection monitoring, which includes measurements of concrete and reinforcement strains together with level readings. For the monitoring of concrete deformations both edge girders were equipped with internal strain gauges. The strain gauges, all of the type vibrating-wire, were located in the mid-span section of each girder, distributed in pairs to three different levels. Fig. 5 depicts the general arrangement of the instrumentation (concrete strain gauges) installed in the reference girder.

Warranting special attention is the implementation of a set of new reinforcement strain gauges especially developed for the project by *Geonor*. The reinforcement gauge is based on the vibrating wire concept with the prestressed wire suspended between two steel muffs fixed to the bar. In both chords the longitudinal FRP reinforcement bars were equipped with the rebar transducers placed in the centre of the girder. A simple and inexpensive method was adopted for measuring the span deflections. An array of level studs cast in on top of each girder constitutes the measure points, from which level readings are taken.

As the acquisition of load performance data is ongoing, an interpretation of the 'real-life' behaviour will be presented at the conference.

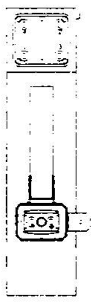

Fig. 5 Arrangement of strain gauges at midspan

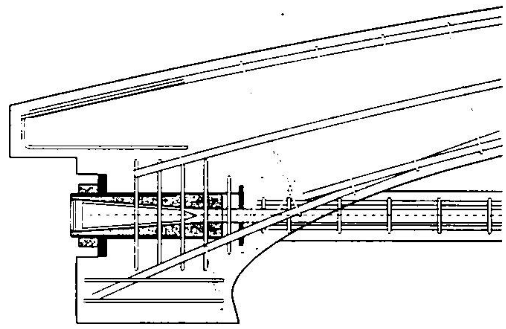

Fig. 6 Anchor zone

7. Conclusion

The erection of the Oppegård trial bridge demonstrates the feasibility of the application of FRP reinforcement as supplement or even instead of steel. Owing to the inherent assets of non-ferrous composites, these materials have potentials to become prominent construction materials fighting the corrosion related deterioration of concrete structures. The vistas of a widespread use FRP is however overshadowed by the fact that there is a total shortcoming of international standards for testing, approval and quality control. Moreover the key advantages of FRP are so far lost in high material and manufacturing costs. There are however, several ongoing R & D projects continuously working to form a basis for future codes and regulations that will handle provisions for the use of FRP as a reinforcing material. Furthermore, material and manufacturing cost will decrease with a higher demand. For increased flexibility in design and construction special attention should be devoted the development of efficient mechanical applications, such as connectors, end anchorages etc.

References

[1] Norwegian Standard NS 3473 E: Concrete structures, Design rules. 4th edition , Nov. 1992.

[2] *Clark, J. L., O'Reagen, D. P., Thirugnanendran, C.*: Modification of Design Rules to Incorporate Non-ferrous Reinforcement. Eurocrete Report, January 1996.