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Review paper

FRP bridges in Poland: state of practice

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Abstract: The state of the art in the field of composite polymer bridges in Poland is presented below. Such bridges were built from 1999. Some of them are fully composite polymer structure. Others are developed as hybrid structure. There are two kind of structures: steel girders with FRP deck and FRP girders with concrete deck. Different production methods of FRP elements were used: pultrusion and infusion. Some bridges are the result of research programs, but there are also some commercial projects. Also, the short application history of FRP bridges all over the world is presented and material properties of the construction material are given in the paper. Those materials are much more lighter than steel or concrete. Low weight of FRP materials is an advantage but also disadvantage. It is good from structural and economical point of view because the dimensions of girders, piers and foundation will be smaller. From opposite side to light structure could cause problems related to response of structure against dynamic actions. As a final result the fatigue strength and durability will be reduced. Of course, the high cost of FRP (CFRP especially) limits at the moment range of application. The presented in the paper bridge structures show that despite of mentioned above problems they are now in good conditions and their future life looks optimistic. It could be supposed that modification and/or development of FRP production technologies more better utilizing their properties will create more elegant and useful bridges.

Keywords: FRP, composite polymer, Polish bridges, footbridges.

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1. Introduction

Steel and concrete are the most popular bridge materials in the world. Regarding bridge engineering, it can be said that the 19th century belonged to steel, the 20th century belonged to concrete. Which material will dominate the 21st century? It can be observed the FRP (Fiber Reinforced Polymers) has been gaining more and more popularity. Starting in 1982 from Beijing, where the first composite bridge was built (removed few years ago). More followed soon: bridges of various sizes, mostly made of individually made elements. As soon as it became possible to prefabricate composite elements, there was an explosion of small trussed footbridges. There are no statistics currently kept, but the Market Development Alliance of the FRP Composites Industry in 2003 estimated that in the USA alone there are over 135 composite objects [23] – most of them were truss footbridges. It was also first bridge structure appeared in Poland in 1999 [18]. After more than 20 years, we have many more bridge applications with composite polymer structural elements in Poland. This paper focuses on the more important of them.

It needs to be highlighted the FRP bridges means bridges consist of FRP girders and/or FRP deck but in that case with steel/concrete girders. The piers and abutments are still constructed as concrete ones ones except some exceptions for bridges with FRP pylon.

2. Short history and types of FRP bridge structures

First composite polymer material was produced in 30-ties of XX century when glass fibers were patented. In short time those fibers were combined with especially devoted resins. In 1961 carbon fibers were manufactured and in 1972 aramid fibers were produced. Also in such cases special resin were applied. GFRP, CFRP and AFRP composite polymer were done In this way. Last years it was also basaltic fibers composite added – BFRP [10, 11].

Numerous bridges were built around the world from that time. The first one was build in China in the Miyun district of Beijing in 1982 [19]. It was a highway bridge with GFRP girders (6 sandwich beams) and a concrete deck. The span was 21.0 m and total width was 11.4 m. The deck consisted of two traffic lines for 30 ton vehicles and two pedestrian lines. It doesn't exist anymore – it was demolished because of unexpected connection aging.

The first European FRP object it was Aberfeldy Footbridge built in 1992. Kolding Bridge from 1997 was the first Danish FRP object [7].

One of interesting European object was Ponteresina Footbridge – two span truss structure constructed of prefabricated FRP elementsin1997. The firs span was made with adhesive connection and the second one with mechanical (bolt) joints. The comparison of their behaviour was a part of the research program [7].

Another mile stone bridge made of FRP was West Mill Bridge from 2002. It was the first all-FRP composite bridge on the public highway network in Europe. One of the first European sandwich deck was installed on FRP box girders as a result of research program [7].

The beginning of 21st century was the period when a lot of similar decks were installed in some countries like United States, Korea, Poland, Netherland, Great Britain etc.

As a result of increasing number of FRP objects the classification of FRP bridges in dependence of different use of composite elements could be set. There can be found objects:

- full FRP,
- with FRP girders only (in combination with concrete decks),
- with FRP decks only (in combination with steel, concrete girders),
- with widening FRP decks (FRP decks are widening of existing bridges with),
- with FRP pylons etc. (Aberfeldy, Kolding).

There can be found classic classification in dependence of geometry (beam bridges, arch bridges, truss bridges etc) and function (highway bridges and footbridges). A separate issue is the use of composites in combination with concrete – as reinforcement and as strengthening. And also as an element of suspension ropes. However, this is not the topic of the paper.

3. Material

3.1. Composition and structure of FRP

Composites consist of reinforcement (fibers) and matrix, which includes resin, hardener, fillers and additives. In structural elements fibers are in the form of bundles of monofilaments, the so-called roving, woven and matting (smooth, interlaced or entangled).

In civil engineering industry there are four main types of fibers: glass fibers, carbon fibers, aramid fibers, basaltic fibers, and five types of resins: polyester, vinylester, epoxy, phenolic and acrylic.

Combination of reinforcement and matrix gives different properties of final product. Both ingredients and final product can have different properties, which depends on producer or manufacturer.

Combination of reinforcement and matrix gives also different price of the product. The most common and cheapest FRP material used for structural profiles consists of glass fiberand polyester or vinylester resin and is. In turn composite with carbon fiber is used for tendons and reinforcements. It is combined with an epoxy resin, which has very good mechanical properties.

All structures presented below are based on glass fiber (partially carbon fiber) and polyester or vinylester resins.

3.2. Production methods

There are a lot of production methods of FRP materials. They depend on the industry where these materials are used – from the simplest handmade methods, which can be realized in garage production, through the semi-automatic methods used for non-structural shells (tram cabins, shower cabins etc.), through production of pipelines or round containers to fully automatic production (beam rolled elements).For the civil engineering industry, the two most important methods are VARTM – Vacuum Assisted Resin Transfer Molding and pultrusion.

VARTM is cheap in realization. It is combination of the mold element (made, for example, of plywood for short series or steel for longer production), resin impregnation with and underpressure, which helps in properly resin distribution. The main disadvantage are time of duration (it is mostly handmade work) and risk of local defects because of human factor (so skills and experience of the workers are very important). The main advantage is cheap and easy geometry adjustment for new elements (question of the new mold element only). Most of sandwich decks were made of that way and non-truss girders.

On other hand there is a pultrusion process. It is kind of production line: in the first step the shape of the profile is formed of fibers, then resin is added – this action is done at a suitable temperature, which guarantee proper curing. At the end there is process of hardening (polymerization) and final product is done after a dozen minutes – without any human factor except of initial regulations at the beginning of the process. During the whole operation the reinforcement is tight, what increases elasticity of the final product. Truss elopements are produced in that way. In the world there are two huge manufacturers: American Strongwell and European (Danish) Fiberline and a lot of smaller local producers (most of them in China, but also in Poland and other countries).

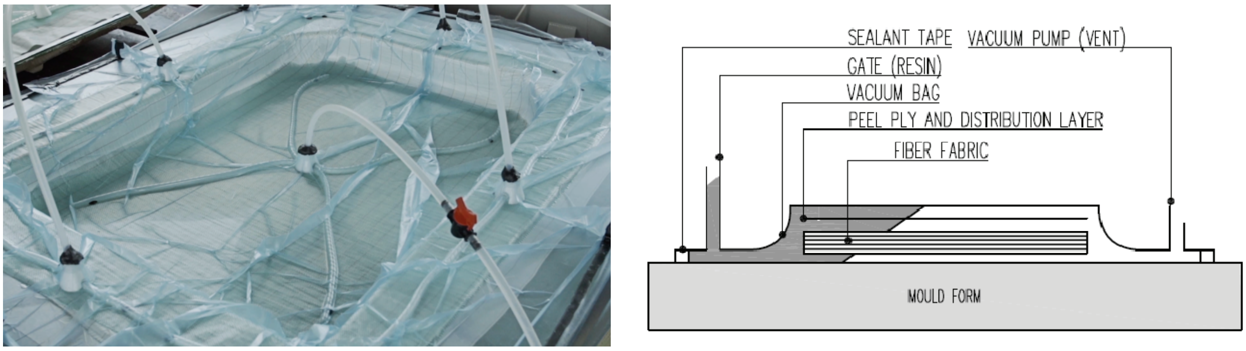

Fig. 1. VARTM process in Mostostal Warszawa [24] and the general scheme of VARTM production method [4]

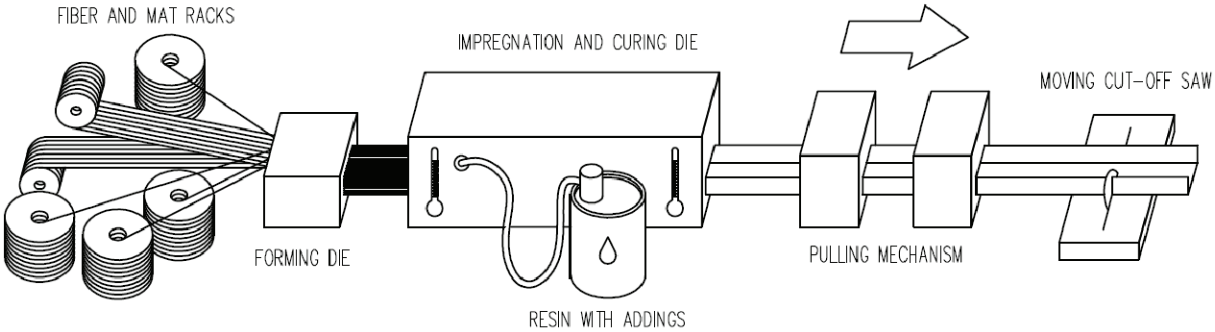

Fig. 2. Pultrusion process scheme [7]

3.3. FRP properties

Required properties for the elements made with the pultrusion method are in European standard EN-13706 “Reinforced plastics composites. Specifications for pultruded profiles” [22]. The standard specifies the minimum requirements for the quality, tolerances, strength, stiffness and surface of structural profiles. The standard divides pultruded structural profiles into two classes: E23 – having the most stringent requirements to quality, E17 – having more lenient requirements to quality [22]. For composite elements made with other methods there are standards as for plastic. Even within the composites produced with the same method of production we obtain different material properties. As a result there is a large spread in the literature, even within the same materials tested by different laboratories [7]. Characteristic values in standards are low because of the high value of standard deviation. With VARTM method the properties should be checked individually due to the methods of test included in dedicated standards. So each time the material and the final product must be tested, paying particular attention to the joints. There are no standards for the joint, only technical instruction prepared by profile producers, which are dedicated only to the range of production of these producers. Also, there is luck of design standards buy in CEN was developed Scientific and Technical Report which synthesizes rules currently available withwin EC countries for the design and verification of whole FRP composite polymer structures. It will be European Standard in the future.

Table 1. Characteristic properties of FRP pultruded material due to EN 13706-3:2002. Reinforced plastics composites. Specifications for pultruded profiles. Specific requirements [22]

Characteristic properties	Unit	Test method	Minimum requirements	
Properties			E23	E17
Modulus of elasticity	GPa	Annex D, EN 13706-2:2002	23	17
Tensile modulus – longitudinal	GPa	EN ISO 527-4	23	17
Tensile modulus – transverse	GPa	EN ISO 527-4	7	5
Tensile strength – longitudinal	MPa	EN ISO 527-4	240	170
Tensile strength – transverse*	MPa	EN ISO 527-4	50	30
Pin-bearing strength – longitudinal	MPa	Annex E, EN 13706-2:2002	150	90
Pin-bearing strength – transverse	MPa	Annex E, EN 13706-2:2002	70	50
Bending strength – longitudinal	MPa	EN ISO 14125	240	170
Bending strength – transverse	MPa	EN ISO 14125	100	70
Shear strength – longitudinal	MPa	EN ISO 14130	25	15

Fig. 3. Full scale laboratory tests of FRP road bridge at Rzeszow University of Technology [24]

4. Full FRP footbridges and bridges

4.1. Truss fotbridge in Łódź – 1999

The first FRP object in Poland. The structure is situated at the outfall with purified water into river Ner in Central Poland, ca. 2.5 m above water surface. Samples of purified water are taken for testing from that footbridge. Typical steel structure would require frequent anticorrosion works in such conditions, like for other structures in the plant. Because of that it was decided on buying a footbridge made of GFRP. Designed by Rambøll, Hannemann & Hojlund GmbH from Germany supported by Beratende Ingeniere VBI from Denmark, produced and assembled by Fiberline Composites A/S from Denmark. It was installed as a whole structure. The footbridge is a truss structure with a lower deck. Load-carrying structure consists of twin truss girders type **N** of construction depth 1.34 m and axial spacing 1.20 m. The structure is 20.0 m long simply supported beam. Maximum distributed service load is 250 kg/m^2 and maximum concentrated service load is 5kN. The structure of the footbridge was made of five different types of pultruted profiles (channel and square) and moulded grid deck plate. Truss joints were made with gusset plates and bolts type M 12-8.8 made of stainless steel AIS / 316 L 1.4571 [18].

Fig. 4. Elevations of the footbridge [18]

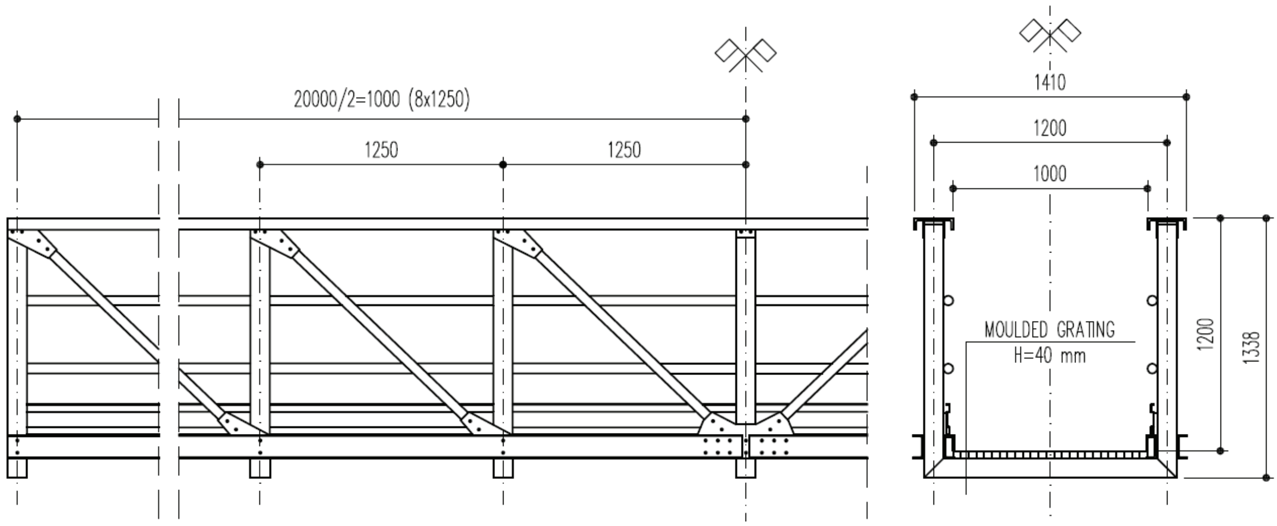

Fig. 5. Longitudinal and cross section of the pedestrian truss bridge [18]

4.2. Emergency Exit footbridge at WUT – 2007

Short bridge – two simply supported beams with the height of 0,24 m id distance of 1,0 m and length of 4.0 m. Balustrade is an independent steel structure, not connected to the span. Deck is made of 40 mm high FRP orthotropic panel (stiffeners perpendicular to the object main axis), which is not connected to the girders. The structure was built as a part of research project for FRP bridges behaviour investigation [25]. Nowadays is used mainly by students to SHM educational tests.

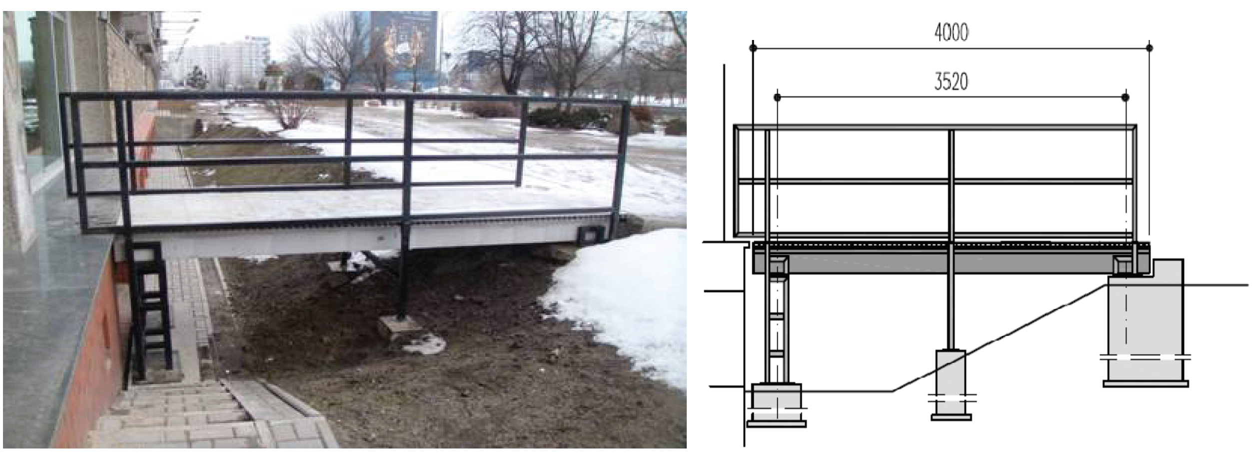

Fig. 6. Longitudinal section and photo of the footbridge [25]

4.3. U-shape footbridge in Pruszcz Gdański – 2015

The footbridge was built in 2015, using infusion technology, as a research object under FOBRIDGE project [1]. During the year 2015 and 2016 the bridge was located at the Gdańsk University of Technology Campus, where it was subjected to a series of load test. Than it was transported to the place over the Radunia canal, enabling a cycle path connection between Pruszcz Gdański and Gdańsk. The footbridge is a GFRP composite, U-shape, simply supported, shell-type sandwich structure. Its dimensions are: 14 m of span length, 2.6 m of deck width and 1.32 m of sides height (handrails). The footbridge is designed to carry the service load of 5 kN/m^2. The structure is made of composite sandwich panels without any mechanical joints or other conventional material elements. Their outer skins are made of GFRP laminate based on vinyl ester flame retardant resin and a core is constructed of polyethylene terephthalate (PET) foam. The support areas are strengthened by GFRP precast elements. The vacuum infusion manufacturing process was applied [2].
The proposed structure is durable, incombustible and weather conditions resistant, which makes it easy to maintain. It is characterized by high structural stiffness and resistance to dynamic excitation. Thanks to its low weight, which is 3,4 tons, is also easy to install. The entire girder is one consistent element produced in one production cycle in standard infusion process.

Fig. 7. Footbridge in Pruszcz Gdański: a) cross-section of the span; b) general view on site [1, 2]

4.4. Sandwich footbridges along GreenVelo – 2015–2016

Several FRP footbridges made of GFRP sandwich slabs have been constructed in Poland recently. Most of them are made with the Dutch technology InfraCore. In the InfraCore slabs dry non-crimp E-glass fabrics and foam core are infused with polyester resin per a design that orients fibers in multiple directions to provide a semi-plastic failure mode with redundant load paths for residual load bearing capacity. With InfraCore, there is no adhesive bonding between the core and skin. The polyurethane foam core acts only as a permanent formwork and is not structural. The skin-stringer construction thus, is not formed by box beams glued to face skins, but instead by multiple Z-shaped two-flanged web structures which are overlapped and then faced to form an extremely robust construction. The fibers in the upper and lower skins and in the reinforcing ribs run in all directions seamlessly so that local damage cannot extend [3].

The first Polish footbridges with a layered structure were built in 2015–2016 as part of the implementation of the GreenVelo Eastern Bicycle Trail in the Warmian-Masurian Voivodeship. Four composite footbridges were built in communes of Lelkowo, Kiwity, Gołdap and Frombork. All footbridges are slab structures [12] made in the Netherlands by FiberCore and delivered to Poland as a whole or in assembly elements. The first footbridge was built in Lelkowo commune. It is an object with a span of 7.0 m and a total width of 6.0 m, including a 5-meter road. The passage of agricultural vehicles is allowed on the bridge, therefore the structure was designed for class C (load capacity 30 t) according to PN-S-10030 (1985). During the construction of the footbridge, the existing abutments of the old structure were used, only the renovation and adaptation of the heads was performed [8]. The span was delivered from a factory in the Netherlands in two parts (Fig. 8), which were then glued in dedicated locks.

Fig. 8. Bicycle bridge of the Dutch InfraCore system in the commune of Lelkowo: half of the slab structure; finished object [12]

In the Kiwity commune, the footbridge was built along the bicycle route running along the old railway embankment. The footbridge is located in the place of a partially demolished railway viaduct, where only stone abutments remain. The supports of the new footbridge in the form of reinforced concrete slabs on a lean concrete base are located outside the existing stone abutments. The bridge is 10.0 m long and 2.5 m wide (Fig. 9). The thickness of the composite slab span, made in the InfraCore technology, is 0.24 m. The weight of the footbridge span structure is approx. 3.0 tons (approx. 120 kg/m^2).

Fig. 9. Bicycle footbridge of the Dutch InfraCore system in the commune of Kiwity [12]

Another footbridge in InfraCore technology was built in the Gołdap commune over the Gołdapa River [12]. The 16.0 × 4.3 m slab span was transported from the factory in its entirety and suspended from a steel arch (Fig. 10). The last of the footbridges – the longest of all – was built in the Frombork commune over the Bauda River. The total length of the facility is 61.0 m (Fig. 10). The weight of the main span of the footbridge is approximately 7.5 tons, what gives 175 kg/m^2, while the weight of the ramp spans is approximately 120 kg/m^2.

Fig. 10. Bicycle footbridge of the Dutch InfraCore system in the commune of Gołdap – transport of the span and general view [12]

Fig. 11. Bicycle footbridge of the Dutch InfraCore system in the commune of Frombork [12]

4.5. Bridge in Nowa Wieś nearby Rzeszów – 2016

The first Polish road bridge fully made of FRP composites is situated in Rzeszow along the urban road over a small local stream. This is a 10.7 m long single-span simply supported bridge with 7.7 m wide deck, carrying 2 × 2.5 m wide roadway and two 0.75 m and 1.1 m wide sidewalks (Fig. 12). Its nominal carrying capacity amounts 300 kN according to the Polish bridge standard. The all-composite bridge superstructure is formed by four FRP composite girders with an overlying 0.13 m thick FRP sandwich deck slab. The deck slab is bonded to the top flanges of the girders with epoxy adhesive. The deck equipment consists of two lightweight concrete sidewalk slabs reinforced with GFRP bars and encompassed by stone curbs and polymer cornice plates, thin insulation and pavement layer, two expansion joints and steel balustrades. Eight elastomer bearings are used to support the FRP span on the RC abutments. The solid abutments are placed on 10 micropiles with diameter of 110 mm and length of 4.0 m [13].

The FRP girders have an U-shaped cross-section with slightly inclined webs, two top 220 mm wide and 15 mm thick flanges and one bottom 340 mm wide and 15 mm thick flange. The maximum width of the girder amounts 1380 mm and the depth is 715 mm. The top and bottom flanges are made of solid GFRP composites whereas the webs are made in form of the sandwich panels with PVC foam layer in-between two GFRP laminates. To increase the torsional stiffness of the FRP girder and to prevent buckling of webs, nine internal diaphragms are placed and bonded along the length of the girder. The diaphragms are made in form of 46 mm thick sandwich plates with a structure similar to the webs. The sandwich bridge deck slab consists of two 12 mm thick GFRP laminates and 105 mm thick PUR foam core stiffened with the internal vertical GFRP ribs. All composite superstructure was fabricated by the VARTM infusion technology and epoxy resin was used as a matrix of all composite parts [14].

Fig. 12. Bridge in Nowa Wieś nearby Rzeszów – during transport and final look [13]

5. Bridges with FRP girders – Bridge in Błażowa nearby Rzeszów – 2015

The first Polish hybrid road bridge made of FRP composites and concrete is situated in southeast part of Poland, near Rzeszow, along the local road over a small river. Its nominal carrying capacity is 40 tonnes according to the Polish bridge standard. This is a 22.0 m long single-span simple supported bridge with 10.5 m wide deck carrying 2 × 3.5 m wide roadway and 1 × 2.0 m wide sidewalk (Fig. 13). The bridge superstructure is formed by four FRP composite girders with an overlying 0.18 m thick lightweight concrete 35/38 slab, reinforced longitudinally and transversally with two layers of 12 mm GFRP bars. The slab is connected to FRP box-girders through galvanized steel shear connectors which are welded to small steel plates and fastened to top flanges with epoxy adhesive. Finally, the support zones of the FRP girders are filled with concrete to form support cross-beams and to ensure transverse stiffness of the whole span. Steel shear connectors fastened to the webs inside boxes are used to create a composite action between the FRP composite and concrete in the support zones. The deck equipment consists of two concrete sidewalk slabs with safety barriers, polymer curbs, conventional insulation and stone mastic asphalt (SMA) pavement layers, drainage and expansion joints. Four elastomer bearings are used to support the span on the abutments. The solid abutments are founded on 10 continuous flight auger (CFA) piles with 0.60 m diameter and 5.0–7.0 m length [15].The FRP girders have a U-shape cross-section with slightly inclined webs, maximum width of 1550 mm and depth of 1020 mm. Each top flange is 350 mm wide and the bottom flange of the box is 735 mm wide. The top flanges and the webs have a thickness of about 28 mm, while the bottom flange is 20 mm thick (Fig.13) To increase the torsional stiffness of the girder and to prevent shear/bending buckling of its webs, six internal diaphragms are placed along the length of the girder. The diaphragms are built as sandwich panels with a structure similar to webs. Similar sandwich panels are also bonded to the top flanges of the girder to be used as a stay-in-place formwork during concrete slab casting [16].

Fig. 13. Bridge in Błażowa nearby Rzeszów – single girder tests at Rzeszow University of Technology and side view of the bridge [16]

6. Footbridges and bridges with FRP deck

6.1. Footbridge in Gądki nearby Kórnik – 2007

This is the steel arch pedestrian bridge with composite polymer deck in the central span, concrete-steel and concrete beams for access spans (Fig. 14 and 15). Access spans are composite (steel-concrete) and reinforced concrete. The length of whole structure is 260 m. The main arch girder is designed as a steel box girder inclined by 17° rendering a balance with 28° inclined brace with radius equal to 400 m. Span of the arch is 40 m with cushion of 16 m. Deck girder does not follow deck centerline. The hanger system is considered of Macalloy type M30 bars.

Concrete access ramps are separated from main structure with expansion joints. The horizontal stability of the structure is improved with stabilizers linking concrete ramps with composite steel concrete spans, coupling horizontal displacements of their ends.The deck of the main span is curved in plane with 80 m radius. Walking surface is made of pulltruded composite polymer planks. The planks are 6 m long and average span is around 1,5 m. They are supported by plate cantilever cross-beams. Every second cross-beam is also supported by a hanger. Cross-beams are capped with side beam coupled with curb. Barrier columns are fixed to the crossbeam ends. Access spans with steel-concrete composite construction have 16 cm thick concrete deck. Main materials used for the superstructure include S355J2 structural steel and C35/45 class concrete. The arch supports are designed with C40/50class concrete. Main span deck is made of pulltruded composite polymer planks. Footbridge is founded directly on spot footing, except for main arch supports. Main arch is founded on prefabricated RC piles. This solution was chosen because of its good effectiveness in semi-condensed sands, which form the soil profile under the structure. Piles are inclined by 4:1 and they are designed to carry horizontal thrust of the arch and to conserve balance of the whole structure. Each end of the arch is founded on 9 piles, 9 m long [6].

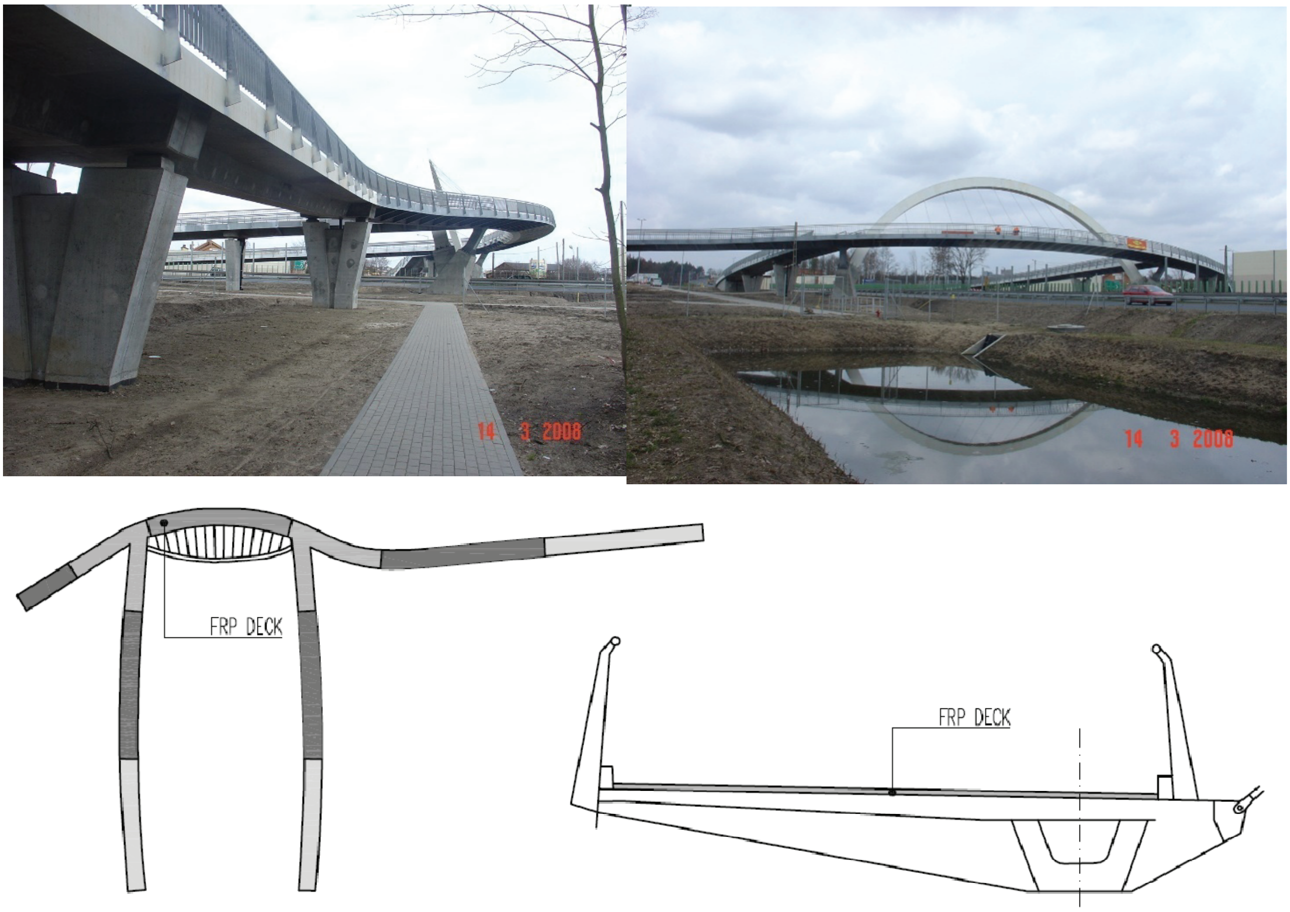

Fig. 14. View and cross section of the main span with FRP deck [6]

Fig. 15. Assembling of of FRP deck [6]

6.2. Footbridge in Ozorków – 2020

A small park footbridge over a local stream was constructed in Ozorków (Fig. 16) [8]. The steel superstructure with the length of 17.0 m and the useful width of 2.5 m was made of two girders with architectural shaping connected with cross-beams in bottom flange level. On the bottom flanges of the girders the GFRP panels were supported to create a lightweight deck. The 41 prefabricated panels with the dimensions of 240 × 2500 mm were connected by bolts to steel superstructure. The thickness of the GFRP panel is 70 mm. Each panel consists of a sandwich construction with a GFRP upper and lower face with a respective thickness, separated by a PUR foam core. The face laminates are composed of E-glass fibres and a polyester matrix.

Fig. 16. FRP panels, top view and side view of the footbridge [8]

6.3. Footbridge in Rzeszów – 2021

To create the new pedestrian and cyclist connection of two banks of Wislok river in Rzeszow, it has been decided to use the existing supporting bridge for two heat pipelines. The continuous beam superstructure of the bridge with the lengths of 22,7 + 30,0 + 23,4 m is made of two welded steel I-girders of 1230 mm in depth. The superstructure carries two pipelines with 800 mm in diameter, supported on steel grid placed on bottom flanges of the girders. To adapt this structure to a footbridge conditions two main measures were designed and implemented: steel girders strengthening by a depth enhancing with additional T-sections and construction of a lightweight deck supported on the girders and connected with their upper flanges (Fig. 17). The deck in made of several dozen of a GFRP panels. The bridge deck panel consists of a sandwich construction with a GFRP upper and lower face with a respective thickness, separated by a PUR foam core. The upper and lower faces are connected by inner webs and are evenly distributed over the width of the bridge deck. The edge of the bridge deck was constructed with a straight edge to accommodate the local force introduction due to the steel handrail. Therefore the thickness of the edges is larger than that of the upper and lower faces. Finally, on top of the upper face and over the useful surface area of the bridge, a bituminous surfacing was applied. The laminates in the web-core GFRP footbridge are composed of E-glass fibres, a polyester matrix and multiple PUR foam cores. For the production of the deck panels, the vacuum assisted resin transfer moulding (VARTM) technique is used, aiming for a fibre volume percentage of the resulting laminates between 50 and 60%.

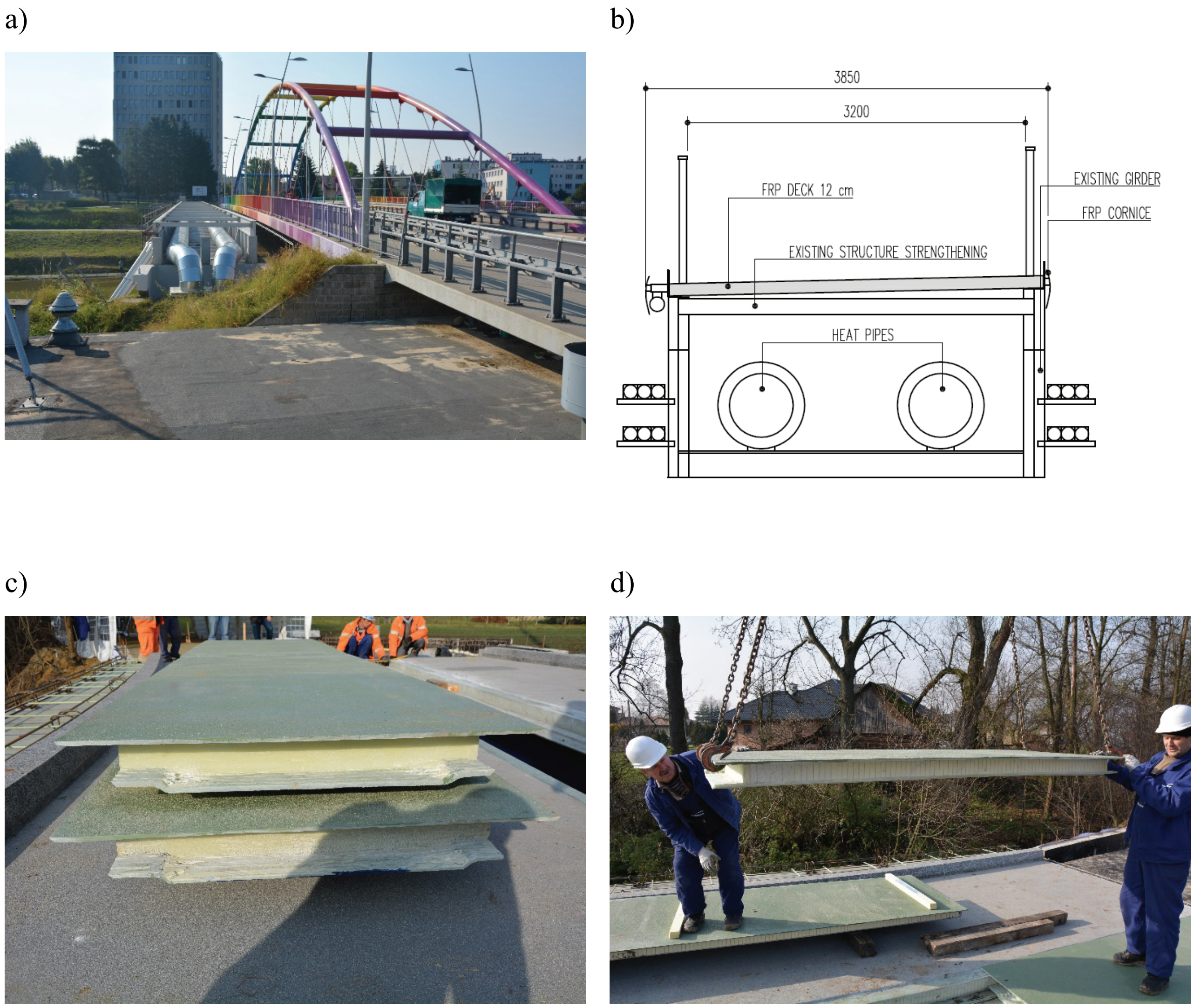

Fig. 17. Footbridge under construction and cross section of the main span with FRP deck

6.4. Bridge in Czapielsk – 2017

In Czapielsk, a footbridge was installed along the existing bridge on Słonecznikowa Street (Fig. 18). The footbridge extends the existing bridge with a sidewalks that will be used by pedestrians and cyclists. The footbridge is 2.0 meters wide and over 12.0 meters long. The structure was attached to the existing bridge over the Reknica River [27].

Fig. 18. Footbridge under construction [27]

7. FRP sidewalks for bridge widening

7.1. Bridge in Rzeszów – under Construction

The existing bridge over Wisłok river in Rzeszów had to be widened to fulfil the requirements to add a 2,5 m wide bike path along the street passing over the river. The bridge has four simply supported spans with the length of about 23,5 m. The existing superstructure consists of 8 precast prestressed concrete beams covered with the RC deck slab. To achieve the main goal of bridge modernization without weighing down the bridge supports, a lightweight FRP composite footbridge has been proposed. The new footbridge is placed through the elastomer bearings on steel brackets attached to the concrete bents of existing pillars. The all-composite footbridge superstructure is formed by two FRP composite girders with an overlying 120 mm thick FRP sandwich deck slab. The deck slab is bonded to the top flanges of the girders with epoxy adhesive.

The FRP girders have an U-shaped cross-section with slightly inclined webs, two top 220 mm wide and 15 mm thick flanges and one bottom 340 mm wide and 15 mm thick flange. The maximum width of the girder amounts 1380 mm and the depth is 715 mm. The top and bottom flanges are made of solid GFRP composites whereas the webs are made in form of the sandwich panels with PVC foam layer in-between two GFRP laminates. The sandwich bridge deck slab consists of two 12 mm thick GFRP laminates and 105 mm thick PUR foam core stiffened with the internal vertical

GFRP ribs. All composite superstructure was fabricated by the VARTM infusion technology and epoxy resin was used as a matrix of all composite parts.

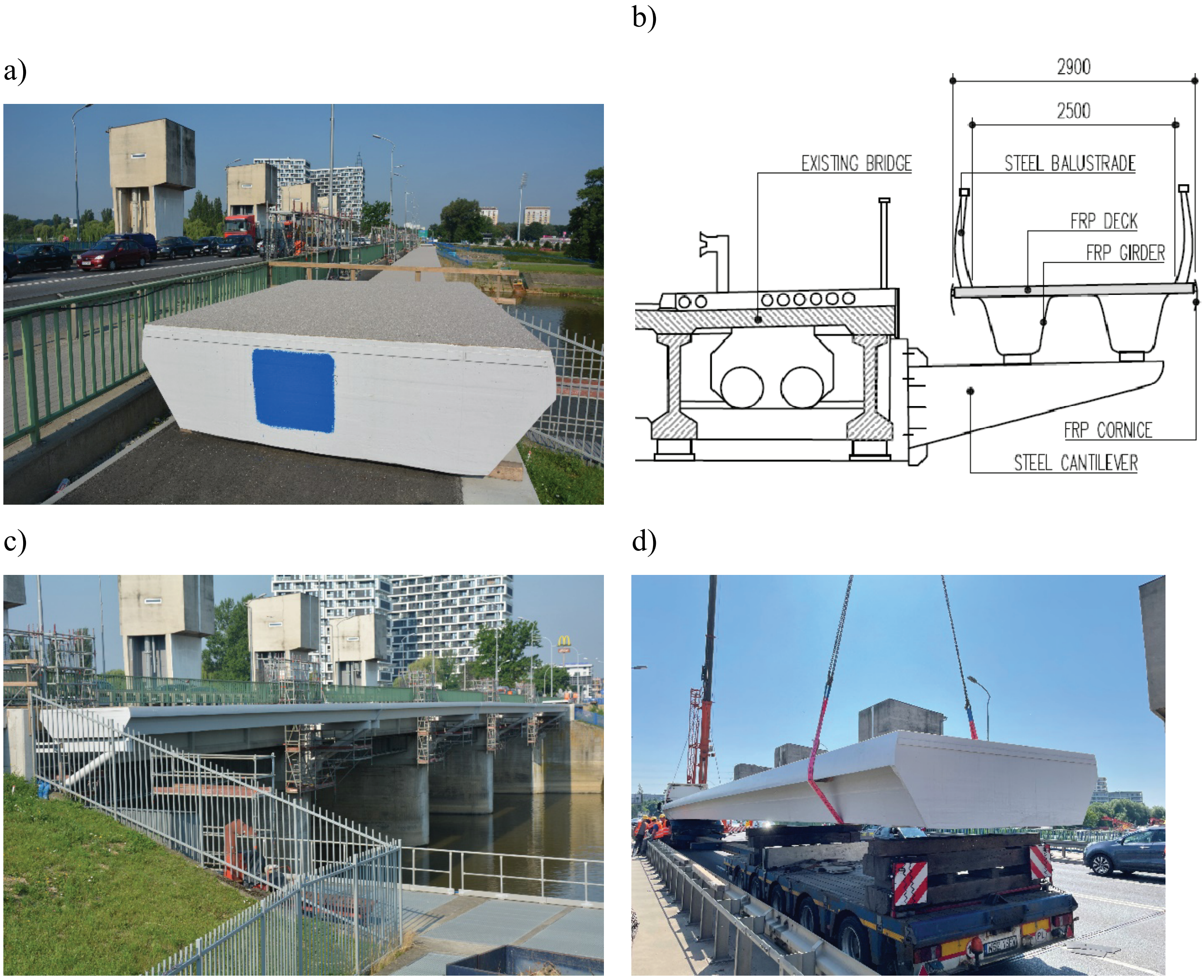

Fig. 19. Footbridge under construction and cross section of the cantilever with FRP deck

7.2. Bridge in Toruń – 2021

One of the next investments involving the use of composite is the renovation and widening of the historic J. Piłsudski across the Vistula River in Toruń (Fig. 20). In the initial phase of the analyzes, the construction of completely new orthopedic deck cantilever was considered. Because of the high costs of suspended media relocation, it was decided to extend the cantilevers. And for this purpose, to reduce the permanent loads, a sandwich deck made of GFRP was designed with spacing of the supports to 6.5 m. The structure of the bridge is a railway bridge moved from Kwidzyn, in which the structural solutions of all elements were previously adapted to railway loads (including cantilevers for technological loads corresponding to this type of the bridge). Regardless of these conditions, it was decided to strengthen the connection of longer cantilevers (with lightweight GFRP deck) for higher utility loads, including the possibility of passing temporary road traffic of passenger vehicles during the renovation. Ultimately, due to the designed detour with the temporary bridge over the Vistula River, such a need to organize the works was not necessary [17].

a)

b)

c)

d)

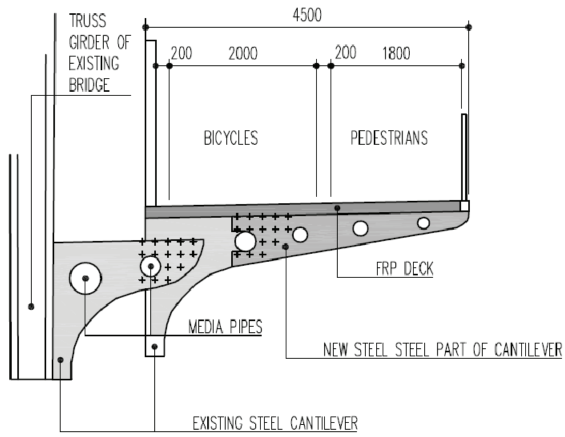

Fig. 20. The old cantilever and cross section of the new cantilever with FRP deck [15]

8. Conclusions

The state of the art in the field of composite polymer bridges in Poland was presented in the paper. Also, the short application history of FRP (Fiber Reinforcement Polymers) bridges all over the world, the construction material itself, the production methods are presented too. Those materials are much more lighter than steel or concrete and have good resistance against corrosion. Low weight of FRP materials is an advantage but also disadvantage. It is good from structural and economical point of view because the dimensions of girders, piers and foundation will be smaller. From opposite side to light structure could cause problems related to response of structure because of dynamic actions. As a final result the fatigue strength and durability will be reduced. Of course, the high cost of FRP (CFRP especially) limits at the moment range of application.

The presented in the paper bridge structures show that despite of mentioned above problems they are now in good conditions and their future life looks optimistic. It could be supposed that modification and/or development of FRP production technologies more better utilizing their properties will create more elegant and useful bridges.

References

[1] Chróścielewski J., Miśkiewicz M., Pyrzowski Ł, Wilde K., "Composite GFRP U-shaped footbridge", Polish Maritime Research, Special Issue 2017 S1 (93) 2017 Vol. 24, pp. 25–31.

[2] Chróścielewski J., Miśkiewicz M., Pyrzowski Ł, Sobczyk B., Wilde K., "A novel sandwich footbridge – Practical application of laminated composites in bridge design and in situ measurements of static response", Composites Part B Vol. 126, 2017, pp. 153–161.

[3] De Corte W., Jansseune A., Van Paepegem W., Peeters J., "Structural behaviour and robustness assessment of an InfraCore inside bridge deck specimen subjected to static and dynamic local loading", Proceedings of the 21st International Conference on Composite Materials, Xi'an, 2017.

[4] Dong C.J., "Development of a process model for the vacuum assisted resin transfer molding simulation by the response surface method", Composites: Part A Vol. 37, 2006, pp. 1316–1324.

[5] Grotte, B., Karwowski W., Mossakowski, P., Wróbel, M., Zobel, H., Żółtowski, P.: Steel, arch footbridge with composite polymer deck. „Wroclaw Bridge Days" - „Footbridges – Architecture, design, construction, research". 29–30 November 2007, pp. 135–146.

[6] Grotte B., Karwowski W., Mossakowski P., Wróbel M., Zobel H., Żółtowski P., "Steel, arch footbridge with composite polymer deck with suspended composite polymer deck over S-11 highway nearby Kórnik", InżynieriaiBudownictwo 1-2/2009, pp. 69–73.

[7] Karwowski W., "Material - structural conditions of joints in FRP bridges", Ph. D. thesis, Warsaw University of Technology, Warsaw 2011.

[8] Madaj A., "Composite polymer bridges. New structural solutions of bridge girders", Mosty 3/2015, pp. 58-60.

[9] Mossakowski P., Wróbel M., Zobel H., Żółtowski P. ‚Pedestrian steel arch bridge with composite polymer deck. IV International Conference on "Current and future trends in bridge design, construction and maintenance". Kuala Lumpur. Malaysia. October 2005.

[10] Mylavarapu R., Patnaik A., Puli K., R. K., "Basalt FRP: A new FRP material for infrastructure market?", Proceedings of 4th International Conference on Advanced Composite Materials in Bridges and Structures, Canadian Society of Civil Engineers, Montreal, 2004.

[11] Patnaik A., "Applications of basalt fiber reinforced polymer (BFRP) reinforcement for transportation infrastructure". Developing a Research Agenda for Transportation Infrastructure, TRB November, 2009.

[12] Pilarczyk K., "Application of composite panels InfraCore inside bridge structures", Mosty 5/ 2019, pp. 74–75.

[13] Siwowski T., Kaleta D., Rajchel M., "Structural behaviour of an all-composite road bridge", Composite Structures 192: pp. 555–567, 2018.

[14] Siwowski T., Rajchel M., Własak L., "Experimental study on static and dynamic performance of a novel GFRP bridge girder", Composite Structures Vol. 259, 2021.

[15] Siwowski T., Rajchel M., Kulpa M, "Design and field evaluation of a hybrid FRP composite – lightweight concrete road bridge", Composite Structures, Vol. 230, 2019.

[16] Siwowski T., Rajchel M., "Structural performance of a hybrid FRP composite – lightweight concrete bridge girder", Composites Part B Vol. 174, 2019.

[17] Wąchalski K., "The design of renovation and widening of the J. Piłsudskiego bridge across Vistula river in Toruń, Poland", Mosty 1/2021, pp. 50–56, (in Polish).

[18] Zobel H., Karwowski W, Wróbel M., „GFRP pedestrianbridge", Inżynieria i Budownictwo nr 2/2003, pp. 107–108, (in Polish).
[19] Zobel H., "Composite Polymer Bridges", Proceedings of 50-tie Conference „Scientific and Research Problems in Civil Engineering", Krynica 2004, Vol I, pp. 381–410 (in Polish).
[20] Zobel H., Grotte B., Karwowski W., Wasiliew P., Wrobel M., Zoltowski P.: Pedestrian steel arch bridge with composite polymer deck and CFRP stays. *IABSE Symposium "Metropolitan Habitats and Infrastructure"*. Shanghai, China. September 2004. pp. 88–89 + CD.
[21] Zobel H., Karwowski W., Bridge composite polymer decks. *Inżynieria i Budownictwo* 11/2005, pp. 594–598. (in Polish).
[22] PN-EN 13706-3: 2004 Composite polymers. Technical Specifications for the profiles produced with pultrusion method. Part 3: Detailedrequirements.
[23] http://www.mdacomposites.org/, 2005.
[24] Information Materials of the Mostostal Warszawa S.A. "Com-bridge – construction of the FRP structure", 2016.
[25] Report of the Research Project "Material and structural conditions for joints in bridge structures made of FRP profiles realized in the Faculty of Civil Engineering at Warsaw University of Technology". The project realized in 2005–2008 and financed by the Polish Ministry of Education and Science.
[26] https://fiberline.com/, 2021.
[27] https://www.kolbudy.pl, 2021.

Mosty kompozytowe w Polsce – aktualna sytuacja

Słowa kluczowe: GFRP, FRP, kompozyty polimerowe, kładka dla pieszych, most

Streszczenie:

W ciągu ostatnich lat przed mostowcami otworzyły się nowe możliwości. Dzięki lekkim, a przy tym bardziej wytrzymałym i trwalszym materiałom mogą oni zbliżyć się do granic nieosiągalnych dla materiałów tradycyjnych. Materiały te – polimery wzmacniane włóknami (FRP – z ang. Fiber Reinforcement Polymers) – do tej pory stosowane były z powodzeniem w lotnictwie, przemyśle kosmicznym, przy produkcji samochodów i łodzi. Dzięki niskiemu ciężarowi własnemu pozwalały na polepszenie osiągów oraz oszczędność paliwa. Bodźcem ograniczającym dość znacząco zastosowanie polimerów w innych dziedzinach była ich cena – wyższa od cen innych materiałów (np. metali) oraz wymagania odnośnie technologii układania i obrabiania. Kompozyty polimerowe (FRP) ze względu na swoje korzystne właściwości znajdują coraz szersze zastosowanie w mostownictwie. Materiały te, w przeciwieństwie do materiałów tradycyjnych odznaczają się małym ciężarem własnym, dużą wytrzymałością, odpornością korozyjną (zwłaszcza na sól). Obawy przed zastosowaniem FRP wiąże się przede wszystkim z brakiem doświadczeń, jeśli chodzi o trwałość tego materiału i wysokim kosztem (zwłaszcza włókien węglowych). Zaprezentowane w artykule rozwiązania konstrukcyjne dowodzą, że pomimo różnych ograniczeń technicznych i środowiskowych oraz komunikacyjnych sprawdzają się podczas eksploatacji. Należy przypuszczać, że po nabraniu pewności co do trwałości kompozytów polimerowych i opracowaniu nowych kształtów profili oraz ich połączeń, a także modyfikacji istniejących technologii produkcji lub wymyślenia nowych jeszcze lepiej wykorzystujących właściwości tych materiałów mosty z nich wykonane wpiszą się na stałe w polski krajobraz.

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