Bridge over the motorway A27, steel truss with a FRP deck

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Abstract

In the Netherlands a bridge is built crossing the motorway A27 near Utrecht. This bridge was constructed as a combination of steel and FRP, with a total length of 140 meters. The bridge is made of a steel truss girder and a deck of FRP (composite).The connection of the composite deck to the steel truss girder was a challenging part. To solve this problem two load-paths are introduced. The first is made with an adhesive compound, the second with a pin-hole connection. Also the location of the bridge with the foundation inside a polder construction with highly compressible soil was a challenge to solve. The use of a jet grouting was necessary to solve this problem.

Keywords: Composite, FRP (Fiber reinforced polymer), steel, bridge, hybrid, jet grouting

1 Introduction

Composite (FRP) material has been used for many years in the aircraft construction and in wind turbines. For several years is composite an up and coming material in civil engineering in the Netherlands. In structures such as bridges and locks the composite material is an alternative material use beside the existing materials such as steel, concrete and wood. In the Netherlands in the last few years several large projects have been built with composite material. In this article the bridge over the A27 near Utrecht (installed in 2012) is described.

2 Project: bridge over the A27

Over the A27 motorway lay two railroad bridges, one railway bridge is currently being used as a road bridge. The bridges where built in 1982 and are already foreseen for future track doubling. Due to the track doubling between Houten and Utrecht Central Station in 2014 from two to four tracks, the bridge used by road traffic will be converted back to a bridge for rail traffic. The current road bridge is a main bicycle route between Utrecht and Houten and serves local traffic in both directions. To maintain the connection for local automotive and bicycle traffic a new bridge is being commissioned by the rail infrastructure owner ProRail and the ownership will be transferred to its new owner Rijkwaterstaat (department of public works, part of ministry transport and environment).

2.1 Sensitive ground

The A27 motorway near Utrecht is located in a low lying landscaped. With a so-called artificial polder construction consisting of foil (about 6 m below ground level) as groundwater barrier. Against uplift the foil is covered with soil with there up the motorway. The ground structure above the foil isn't strong enough for a traditional slab foundation and a pile foundation was also not possible: due to the water-repellent foil. For an alternative foundation, with minimal pressure the bridge must be as light as possible. In an earlier stage of the project a complete concrete bridge (weight 2650ton) was designed with 7 supports. But due to the ground conditions this design was not possible. Therefore a steel bridge was studied. The outcome of this study was a bridge on three supports.

Figure 1. Overview of the location of the existing and new bridge (blue line)

The architect proposed a composite deck between two steel main girders. In collaboration between Movares (the engineer) and Fiber Core Europe (manufacturer composite elements) the design of the bridge was made. During the preliminary design-phase a comparison was made between a composite and a steel deck. Initially were ProRail and Rijkswaterstaat reserved for the use of composite deck, but in terms of innovation and the need for a lightweight construction they were willing to accept the proposed composite bridge deck that has not previously been used for road traffic. The bridge has a low weight thus could be prefabricated and assembled on the construction site. The bridge was placed in just two overnight closures of the motorway A27.

2.2 Force distribution through floor and diagonals.

The truss girders consist of a top and bottom cord with vertical and diagonal members. The diagonals of the truss girders are all oriented in the same direction, referring to the angled crossing with the motorway. The bottom cord of the truss girders are connected with the composite deck without additional steel: the floor provides the transfer stability to the bridge. As a result of this the steel structure is lighter. The dimensions of the cords (overall) are robust chosen to create a robust look to the bridge. The wall thicknesses of the elements are determined per cross-section taking into account practical matters such as the workability and the costs.

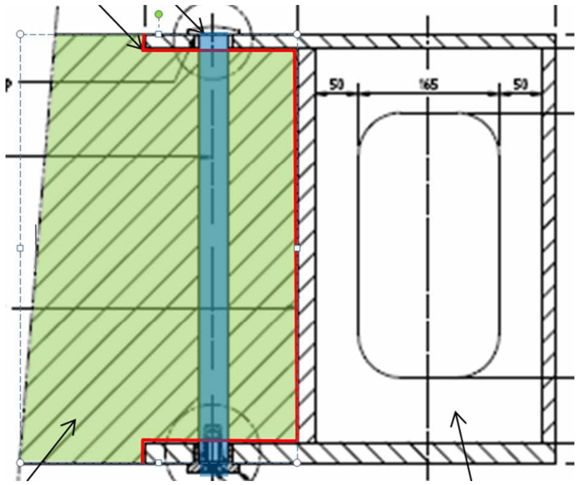

Figure 2. Cross section of the lower cord and the deck

The top cords are coupled to a wind bracing. All the truss members are standard hot-rolled rectangular tubes, except the lower cords which are composed RHS-profiles consisting of two outstanding plates on the bottom and top sides which are for the connection of the composite floor. Due to the crossing angle (45°) of the bridge the main girders are shifted relative to each other. The supports of the bridge are universal movable pot bearings. At the mid-point the structure is held with a pin attached to the floor in all directions. At the abutments the bridge is fixed transversely because of collision forces. In longitudinal direction the bridge can move freely.

Figure 3. Placing a composite part between the steel girders

2.3 Composite in seven sections

The bridge deck is prefabricated in seven sections, according to the vacuum injection technique: the polyurethane foam core parts, and glass fiber mats are stacked dry, evacuated and then saturated with resin which then hardens. The core parts are interspersed with glass fiber mats so after hardening they form web plates in the span direction of the deck (between the steel trusses, perpendicular to the travel direction). In that way the structural integrity is ensured even if the foam perish.

The deck is in the constructive sense a sandwich (which means: structural skins with fibers in the span direction with a lightweight core that carries only transverse forces) but has been largely improved by the additional web plates and that covers all of the internal corners with continuous glass fiber mats. Which mean that also in the long term the deck is guaranteed to be insensitive to impact loads.

This technology is patented and registered as Infracore. In anticipation of a Euro code for dimensioning of fiber reinforced plastics the Dutch CUR 96 guideline is used in the design process. The thickness of the sandwich is adapted to the available building height for the deck. Tests have verified that the stress fluctuations (cyclic loading) are so low that there is no risk of damage due to fatigue. The upper side of the deck is finished with an epoxy-bonded wear layer. The bottom side is provided with a paint coating for aesthetic reasons. Maintenance consists only consists of spray-cleaning in order to avoid mold growth, and the possible repair of the wear layer.

In addition to the roadway for cars and bicycles is a raised pavement. This is like a lid - also composite - over a sunken gutter where drainage, cables and pipes are.

The deck is prefabricated in segments of 24,5x6,2m the greatest possible dimensions for the factory and transport.

3 Connections

Hinged or sliding joints in the steel and between steel and composite are from preservation and service life view not acceptable, because the moisture between the two parts would cause corrosion of the steel. Therefore all structural components are firmly connected and fully sealed. The connection between the composite and steel parts deserves for this reason particular attention. This connection should withstand the tolerances in thermal expansion between steel and composite. In particular at the bridge ends this will result in large forces in the connection.

In the middle of the bridge no shear stress exists between both structural parts because both are subjected to the same elongation (or normal stress through the forced displacement). This builds up at the ends of the bridge and as a result there are shear stresses present in this zone.

Assuming there is a spring between the steel beam and the composite surface which can be found with the aid of differential equations that the stiffer the spring, the smaller the initiation length for the shear stress. This results in the larger stresses at the bridge ends

The lower cord of the truss has a U-shape. The composite floor connects in from both sides in this U-shape so that the forces are transferred from the deck to the truss girders. The intermediate space between the U-shape and floor is injected with resin for a full adhesive connection. This bond is strong enough to absorb the full force distribution. There are a number of reasons to apply a second load path in the connection. These reasons are:

1) Extra safety in construction because of the unfamiliarity with the composite material in civil construction;
2) This is the first bridge in which the steel and composite work together as a hybrid construction and therefore there is no risk taken with the connection;
3) The adhesive bond site is present in an uncontrolled location;
4) The connection is made on site;
5) Guarantees for the required service life of 100 years can't made by manufacturers.

The alternative load path consists of a second type of connection which can also absorb all forces occurring in the connection if the glue connection for any reason whatsoever should fail. This second connection is a pin-hole connection. Wherein a pin with a diameter of 45 mm protrudes through the upper and lower steel plate of the U-profile of the bottom cord and the composite deck. The composite and the steel pen are thereby modeled by using a FEM model with volume-elements in order to analyze the influence of the forces in this connection and the transfer of force through it.

Both the adhesive compound as the pins are dimensioned on the basis of the dead weight, the traffic loads and the temperature load. The thermal expansion coefficient of the composite is by buildup of the fiber as much as possible adapted to that of the steel, stresses due to thermal expansion are thereby limited. It was in this project not possible, due to the specific preconditions of this project, to make the thermal expansion equal to that of steel.

The pin connection consists of 6 pins with a center to center spacing of 250mm near the connecting lower cord and the diagonal and between these locations the pins have a center to center spacing of 500mm over a distance of 4m.

In the last truss fields, the pins are fitted in matching holes so that there is no resin, and the shear force is transferred directly through compressive strain to withstand the forces out of the thermal expansion.

Figure 4. Pin-hole connection

4 Injections reinforce the soil

The bridge is planned at an incision in the landscape. Because of the high ground water level, the incision is realized with the aid of a foil structure, a so-called artificial polder construction. The ballast material on the film is provided by means of sand nourishment. The original soil consists mainly of sand. Through the use surrounding soil as a ballast material and by the application method with sand replenishment layers are formed above the foil with highly compressible soil.

In order to have a well-considered design it was necessary to get a good impression of the presence of the compressible layers. There are multiple probes and mechanical drilling carried out. The presence of the foil and the vulnerability of the polder system for this type of research (risk of water puncture sealing layer) it was necessary to stop this investigation approximately 1m above the foil. Therefore it was necessary that any foundation concept take into account an uncertain ground layer (sand or clay) in this meter.

For the traditional slab foundation the compressible layers and the risk related to uplift off the ground when digging proved that this type of foundation could not be applied. Due to the presence of the foil construction is the application of a pile foundation unacceptable.

A complication of the foundation design is that the new bridge is parallel to the existing structure. This structure was built together with the polder construction. The foil connection to the structure is realized by means of a clip closure. From this closure it was not known how this would react to any additional stretch in the foil and the connection as a result of the new foundation. After a study it is determined that a strain increase of 10% or more would be an unacceptable risk.

The analysis of difficult soil conditions and the risks of leakage have led to the design of an in the ground formed foundation block with dimensions of 16m x 15m at the middle pillar and 5m x 10m by the abutments. The length of the jet grout columns ranged from 4m to 10m depending on the location. In this variant, a highly dispersed load on the foil is achieved by a large foundation surface as well as a large surface wall with friction. The technique of jet grouting makes it possible to form a foundation without excavation of ballast material. (Due to the minimalist design is an excavation of 0.4m already a significant risk for uplift).

Risks regarding the jet grouting are:

1. Piercing the foil;
2. Damage to foil by excessive pressure / vacuum;
3. Damage to adjacent motorway due to Crimping of the soil:

To reduce these risks, it was decided to stop the grout columns 1m above the foil and equip the grout gantry with physical limitations. To reduce the risk regarding grout pressure on the surroundings it has been chosen for a mono-jet system. With this system it is possible to realize smaller column diameters. The mono-jet is preferred because of the risk of under- and or over-pressures in the bi-jet system.

In support of this concept a model was calculated with Plaxis 3D. On the basis of this model the foundation has been proven to be sufficiently rigid. The increase of the strain in the foil was 4.9%. At the height of the clamp structure the increase was 0.3%. This increase is considered to be acceptable.

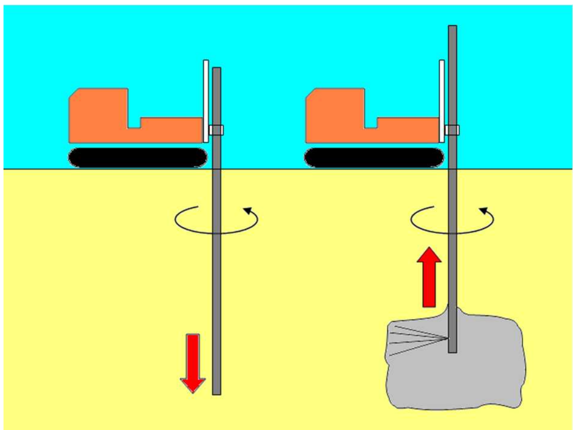

Figure 5. Apply of the jet grouting

5 Execution

5.1 Temporary construction site

The area for the track doubling Utrecht Houten was available to be used as an assembly area, in the longitudinal direction on the south-east side of the bridge.

On this construction site a temporary support structure was made. On this structure the bridge could be built with respect to the final shape and the height and width of the bridge. First the trusses that were prefabricated (incl. Preservation of zinc-aluminum) in lengths of 24 m, the trusses are placed slightly apart, so the deck segments could easily be placed and linked. Then the truss girders are pushed towards each other so that the flanges of the bottom core slides around the floor (see figure 2). The steel girder and composite deck are then connected with glue and pins.

Because of the cold conditions (-15 ° C) a tent was constructed so that the injection of the resin could take place at the required 10 ° C. The top braces are attached with injection bolts and then the anti-vandal wire netting and lighting where installed.

5.2 Three SPMTs in two nights

For the installation of the complete, assembled bridge there are two options: drive in and hoisting. Because of the risk of damaging the water-repellent membrane by the stamps of the cranes, the construction will be driven-in in two nights (March 2012) with closure of the A27.

The bridge is picked up from the construction site with a SPMT (Self Propelled Modular Transporter) on two points and then moved into position. The bridge is rigid and strong enough, so no special facilities were needed.

Figure 6. Position of the bridge after the first night

In the first night the bridge is positioned to the edge of the upper slope with an overhang towards the A27. The third SPMT is already built on the A27, which picks up the overhang of the bridge and moves it to the median. The bridge is parked here for one day while the motorway is reopened for traffic. The second night the bridge is further moved to the rear SPMT and ultimately positioned on the edge of the embankment. Here, the bridge is then taken over by another transporter on the A27, were it is positioned on its final location. In the following period, the bridge is further completed. The finishing compromised of the installation of cables in the cable duct, the application of pavement and the connecting of the lighting.

Figure 7. End result

5.3 Project data

- Location: A27, Utrecht
- Commissioner: ProRail
- Architecture: architektenburo irs. Vegter, Leeuwarden
- Engineering: Movares, Utrecht
- Execution: Heijmans Infra, Rosmalen
- Engineering composite: FiberCore Europe, Rotterdam
- Execution steel structure: Hillebrand, Middelburg

5.4 Technical data

- Main dimensions: 140x6,5 m
- Total weight of the bridge: 400 ton
- Weight composite: 140 ton
- Weight steel 260 ton

Figure 8. End result

6 Conclusions

The conclusive result of this project is to prove a combined steel-composite construction is possible. Main focus is the connection between the two parts. This connection is important for the collaboration may occur in the construction in which large forces appear. In particular, because of the differences in material properties (stiffness and thermal expansion), the forces could increase.

For the strengthening of the ground in a difficult situation with a polder construction is to strengthen the ground with the aid of jet grouting proved to be a good solution. It should be analyzed well before for the influence of the forces from the construction and the effect of the application of the foundation on the foil construction.

In the Netherlands long blocking of main roads and major waterways are unacceptable for economic reasons. This requires construction methods that enable fast building so that bridges can be placed with a minimum disruption of the road. This leads to some challenges for constructors and engineers. The required installation method requires a lot of preparation to do this.

7 References

[1] Article in magazine “Bouwen met Staal” nr. 232 april 2013