LIGHTWEIGHT DURABLE COMPOSITE DECK OFFERS SOLUTION ON BRIDGE DYNAMICS

Sébastien LAVANCHY
Project leader / engineer
3A Composites - COLEVO
Lausanne, Switzerland
sebastien.lavanchy@3acomposites.com

Sylvain PLUMEY
Director
Buchs & Plumey Ingénierie SA
Porrentruy, Switzerland
s.plumey@buchs-plumey.ch

Thierry BEUCHAT
Resp. ouvrages d'art et tunnels
République et Canton du Jura
Delémont, Switzerland
thierry.beuchat@jura.ch

Summary

Construction and installation of the new Clavières footbridge over the A16 freeway access lane in Boncourt, Switzerland took place end of 2013. The steel structure of this asymmetric stay bridge is composed of an inclined decentred mast supporting a longitudinal tubular beam. This longitudinal member supports the bridge deck by the intermediary of welded consoles resulting in an aerial and slender bridge design.

An ultra-light COLEVO sandwich composite deck is implemented on the bridge in order to reduce the bridge dead weight to fulfil the structural requirements in terms of bridge dynamics, while keeping the structure slender and aesthetic.

In addition to being extremely lightweight, this FRP-balsa cored sandwich deck solution offers the added benefit of composites for extreme durability. Therefore the sandwich composite deck is answering the bridge owner's wish to have a highly durable and low maintenance bridge.

Finally, the lightweight solution allowed for installing large pre-fabricated bridge sections, including the adhesively bonded deck, thus minimizing the installation time and road closure.

Keywords: Lightweight; FRP sandwich composite; Eigen frequency; Durability; Low maintenance, Fast installation.

1. Introduction

The construction of the A16 freeway close to the Franco-Swiss border includes the construction of a new access road between the Customs platform located on the A16 and the village of Boncourt in the canton of Jura, Switzerland. The Clavières footbridge reinstates the footpath interrupted by the new road infrastructure spanning over a trench section.

This crossing is realized by means of a metal stay bridge with asymmetrical suspension of the deck. The latter consists of ultra-lightweight COLEVO sandwich composite panels.

2. Bridge structural concept

2.1 Structure description

The overall 35.3 m long footbridge has a main portion with a length of 31.8 m which allows for road crossing and a 3.5m access ramp disposed transversally to the main portion *Fig*. 1. The footbridge is extended a few meters beyond its 2 abutments by reinforced concrete slabs covered with pavement layer.

The road crossing is realized by means of an asymmetric cable stayed bridge with a unilateral suspension on the deck's western side *Fig*. 2. The unique steel mast is positioned in the south wall of the trench, at approximately one third of the total span, and is inclined in a vertical plane perpendicular to the bridge. The deck is mounted onto a tubular steel beam supported at both ends, as well as by the mast and the stay at the middle of the main span. The rigging is completed by a retaining stay anchored at the southern end of the main beam and balanced by a buried counterweight. The stays are round sections with a 60 mm diameter.

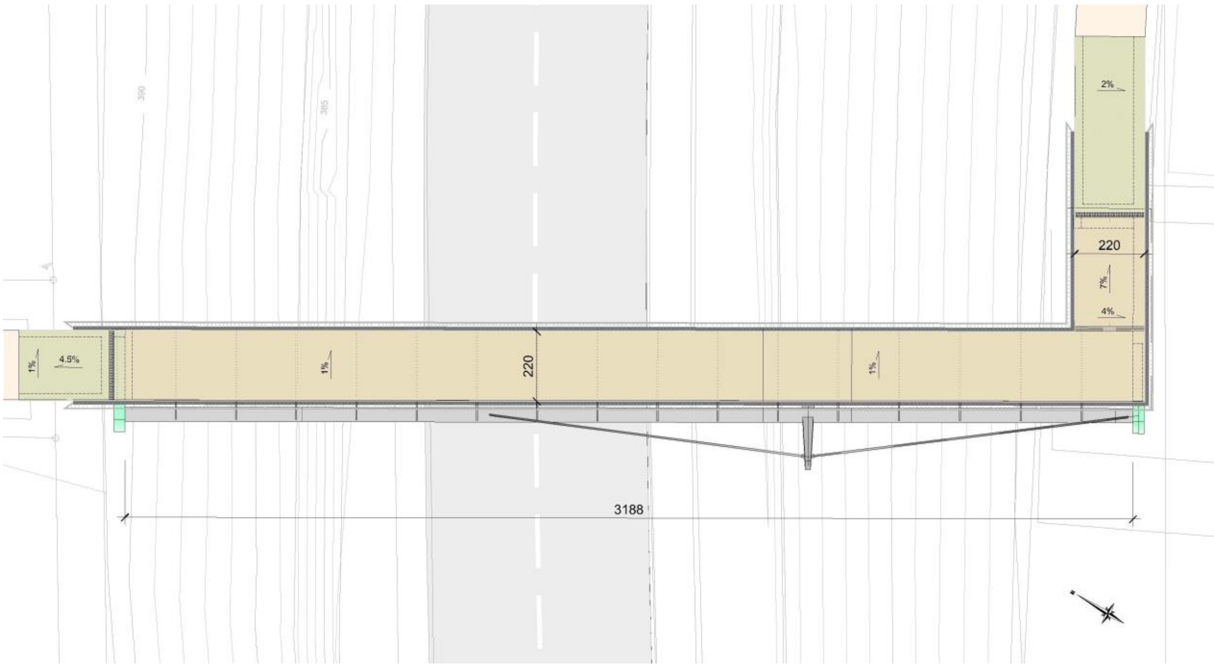

Fig. 1 Footbridge plan view

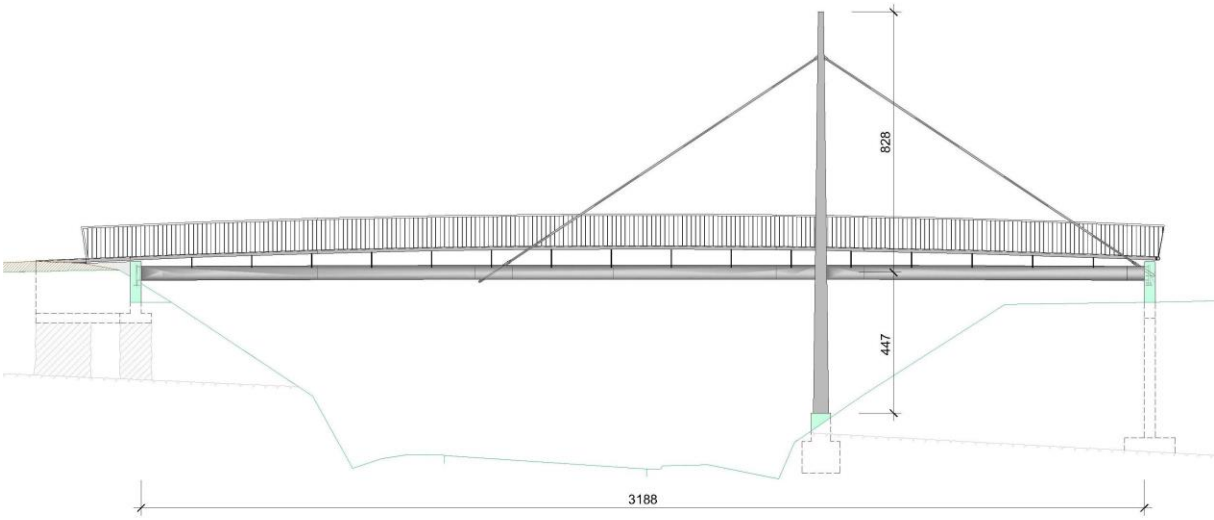

Fig. 2 Footbridge elevation

The bridge deck is supported by transversal steel consoles distanced by 1.91 m and fixed to the main longitudinal beam. The deck eccentricity with regard to the main longitudinal carrying element is therefore balanced by the torsional moment developed into the tubular beam. The adaptation of the consoles geometry allows to follow the retained longitudinal deck profile, which has a circular radius with a high point at mid-span, and to avoid giving camber to the main ROR 457/40 profile.

The general footbridge design is inspired by the Almere footbridge in the Netherlands [1].

The deck is composed of 5 prefabricated COLEVO sandwich composite panels (see chap. 4) that are adhesively bonded onto the steel consoles and on the 2 longitudinal LNP profiles disposed along both sides. The 2.2 m usable width is flanked by two railings slightly inclined outwardly. These railings are made of a tubular steel handrail with vertical round bars welded at their base on a tubular profile. To improve the bridge durability and prevent rainwater runoff into bonded assemblies, this section is distanced by 25 mm from the rest of the deck and only locally connected by welding *Fig*. 3. These secondary longitudinal profiles also ensure the console stability toward lateral buckling and contribute to the bridge's global rigidity.

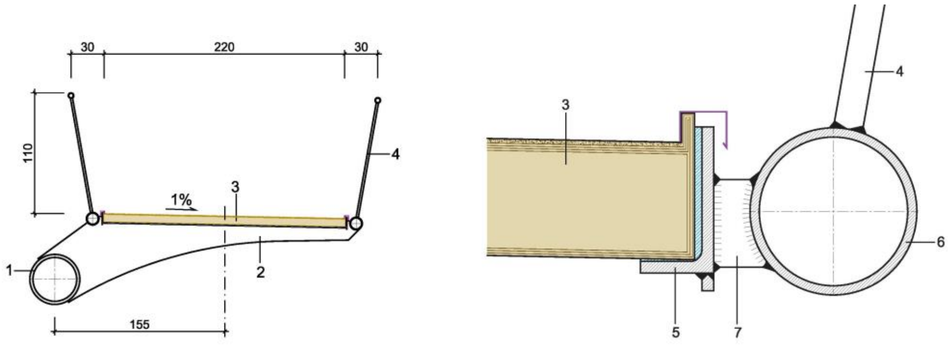

Fig. 3 a) Footbridge cross section; b) Railing connection and deck lateral flange detail, with: 1. Main beam ROR 457/40, 2. Consoles, 3. COLEVO deck, 4. Railing, 5. Lateral LNP profiles, 6. Lateral ROR 114/7 profile, 7. Spacers

The main beam is rigidly connected to the north abutment and to the south wall by means of steel plates embedded into concrete. The north abutment is then a fix point for the structure. Bridge length variation caused by temperature changes are then absorbed by the buried south wall flexibility. The access ramp is disconnected from the main section by using a sliding band. The mast and the abutments are anchored by concrete filled wells directly on the limestone.

2.2 Installation

The welded mast assembly and the 3 principal bridge elements, which include the COLEVO deck and the guardrails, have been fully preassembled in the plant. These 4 elements are then transported by truck to the construction site and installed with a wheel mounted crane. The mast (1) and the rear span (2) are placed first, followed by the main span (3). Finally the access ramp element (4) and the stays (5) are installed. After adjusting and welding of these elements the last composite deck panel (6) is set and bonded in place. *Fig.* 4

A complete pre-assembly of the structure (except the mast) was made at the plant before painting to verify the perfect alignment of the bridge sections and, in particular, the railings.

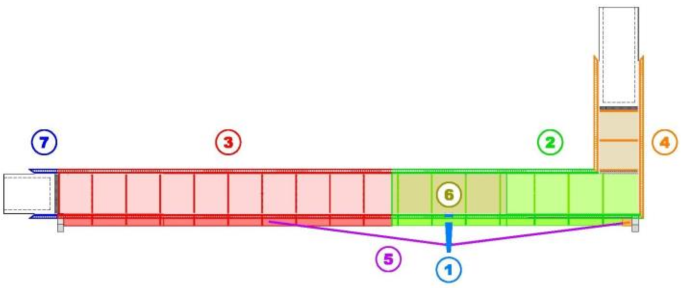

Fig. 4 Installation sequences

2.3 Landscape integration

Since the Clavières footbridge is the first cut-off in the landscape for the drivers arriving in Boncourt from the A16 freeway, the bridge owner expressed the wish to have a footbridge with excellent architectural qualities. Moreover, the new area of activity located nearby has seen implantation of significant companies acting in domains such as watches or micro technologies. Therefore it appears interesting to opt for a modern and lean structure implementing innovative materials to compliment the industrial and economic development of the region.

The construction of a cable stay bridge with a mast creates a real landmark. The mast allows hikers to identify and to recognize the road infrastructure crossing point.

3. Bridge structural design

The structural design of the footbridge steel structure is mainly driven by the mastering of the structure's dynamic behaviour under the pedestrian action.

The Swiss standard SIA 260 recommends to stay clear from Eigen frequencies located in the range between 1.6Hz and 4.5 Hz for vertical vibrations, and to avoid frequencies below 1.3 Hz for transversally horizontal vibrations [2].

For the retained conception, the most critical vibration mode, represented on *Fig*. 5, results from vertical deformations in the main span combined to a transversal displacement of the mast tip. The conducted structural analysis showed that the deck mass, the mast flexural rigidity, and the main beam flexural and torsional rigidities were predominantly influencing the fundamental natural frequency. Thus the selection of the dimensions and thicknesses of the different elements has been made in order to obtain a vertical Eigen frequency above 4.5 Hz. This objective was able to be achieved by use of an ultra-lightweight deck structure (≤ 0.45 kN/m²). Limiting the deck weight allowed the realization of an elegant and slender structure.

The transversal horizontal vibrations, presented on *Fig*. 6, were not critical. Thanks to their mechanical properties and to the adhesive bonding to the steel structure, the COLEVO deck panels create a significant plate effect and considerably increase the footbridge's rigidity.

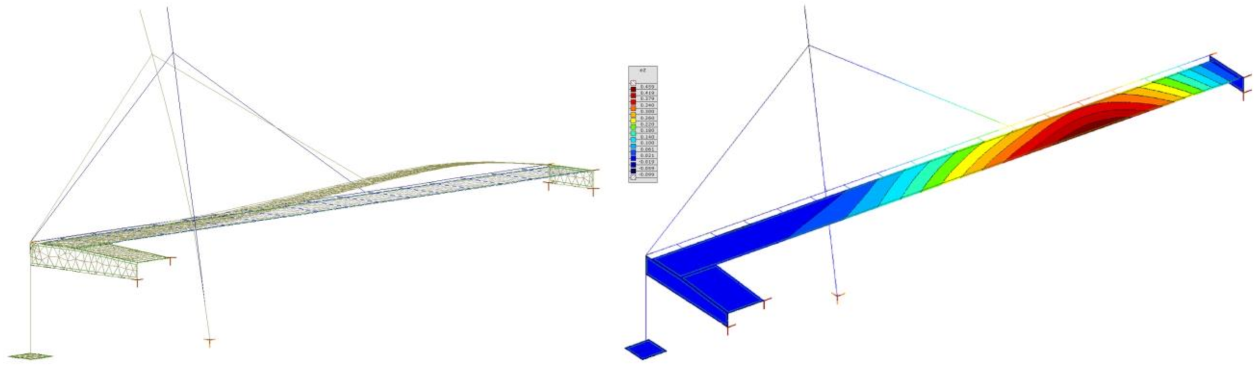

Fig. 5 a) Eigen mode for vertical vibrations calculated using a 3D shell model (Software Axis VM, f = 4.56Hz); b) vertical displacements

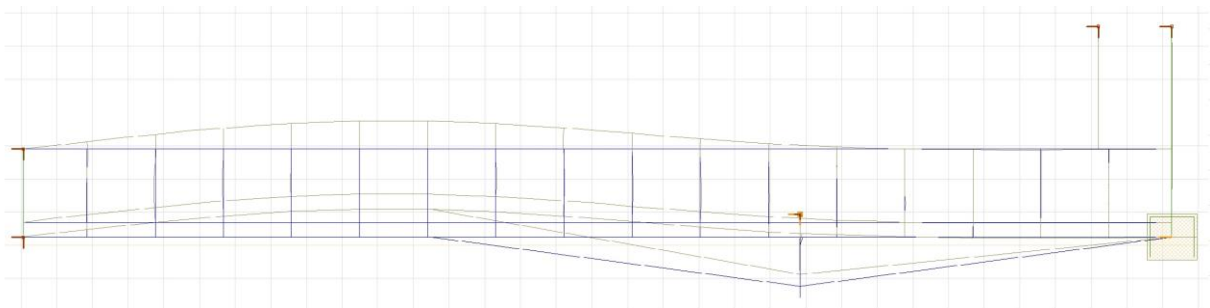

Fig. 6 Eigen mode for transverse horizontal vibrations calculated using a 3D shell model (2.81Hz without plate action)

4. COLEVO composite deck

4.1 Concept and materials

COLEVO composite deck is based on a sandwich structure concept with thin, dense, resistant and rigid face material bonded on both sides of a thick low density core resulting in a very stiff and resistant lightweight plate. With this configuration the face material carries the bending loads while the core material carries the shear and compression loads perpendicular to the sandwich plate. As a core material, balsa wood is an outstanding natural and renewable lightweight material, presents anisotropic properties. Orienting the wood fibres perpendicular to the deck plane takes advantage of the high specific compression and shear strength of this core material which perfectly fits this application.

For the Clavières deck span configuration, with the load requirements defined in the SIA 260 for pedestrian applications, the sandwich structure combines a 70 mm BALTEK® VBC core which is a structurally bonded balsa laminated veneer core with two 3.6 mm Glass Fibre Reinforced Polymer (GFRP) face sheets. In sandwich structures using GFRP face material it is also possible to align the reinforcement fibre according to the main load direction to optimize the panel structural behaviour to meet the application requirement. In the present case the deck panels are plate supported, therefore the face fibre reinforcement orientation is perfectly balanced along and across the deck to obtain a sandwich panel with isotropic properties.

Fig. 7 Typical COLEVO sandwich deck cross section,
with end grain BALTEK® VBC core encapsulated into GFRP laminate

The balsa core is covered on all sides by the GFRP laminate *Fig*. 7. The industrial vacuum infusion process used to produce the sandwich elements ensures a perfect core-skin bonding as well as non-porous and perfectly sealed laminate providing a life time protection of the balsa wood core against moisture. The upper surface of the composite deck is covered by a 4 mm polymer concrete pavement providing homogenous antiskid wearing surface *Fig*. 8. The pavement is applied directly in the factory in a controlled and clean environment ensuring the best conditions to obtain good adhesion to the composite substrate as well as an ideal even surface. To enhance the intrinsic composite durability the deck lower side and edges are coated with 2k UV resistant top coat.

The fully finished and ready to install deck panels weight as little as 43 kg/m^2, including the pavement.

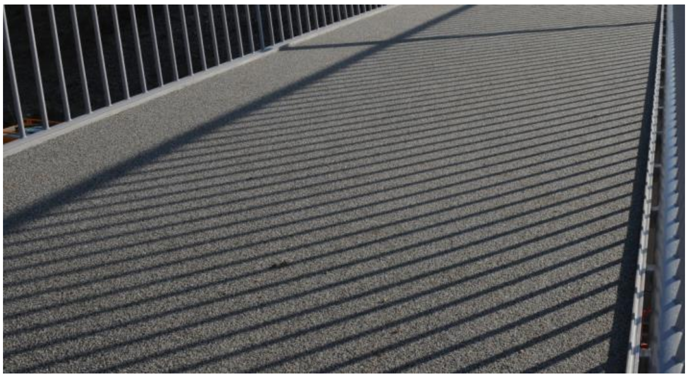

Fig. 8 Composite deck with polymer concrete pavement,
and composite flanges along both sides for water drainage

The polymer composite moulding flexibility allowed for the creation of flanges along the 2 lateral edges of the bridge deck to collect and drain water towards the bridge ends *Fig*. 3b & 8. Integrating such details into the corrosion resistant composite deck elements offers the advantage of limiting the exposure of steel structure to aggressive agents that can be contained in surface water.

4.2 Deck structural design

The deck structural design is based on Swiss standards SIA 260 and SIA 261, known to be close to Eurocodes, and it defines the structure and loading requirements [3]. The SIA 265, for wood construction, is used to verify the load capacity of the balsa wood core [4].

There are no currently established design standards for GFRP structures and adhesive bonding, therefore, BÜV and EUROCOMP are used as reference for the sandwich face sheet laminate design and material safety factors to be applied [5],[6].The material coefficients for creep and ageing are defined and applied for a bridge deck life of 100 years.

The deck structural design is analysed using 3D layered shell finite elements and analytical verifications are done to validate local details.

4.3 Structural adhesive bonding

The 5 composite panels composing the 85 m^2 deck are adhesively bonded to the steel structure *Fig*. 9. Special care is given to the adhesive joint structural design. Since the longest panels are up to 9.6 m the temperature changes or gradient throughout the deck, in combination to the differential thermal expansion between composite and steel, result in significant relative displacements and implies adhesive shear loading. Specific investigations showed that a minimum adhesive joint thickness is required to ensure the adhesive shear deformation stays below the maximum allowed limit. This minimum thickness is guaranteed during installation by use of specially developed spacers.

Fig. 9 Composite deck element installation and adhesive bonding on steel substructure at metallic construction plant

The adhesive system and the procedure for steel and composite surface preparation has been selected and tested in collaboration with Sika Service AG Switzerland. The aim was to find a material combination that can ensure a good adhesion over the structure's life time as well as to fulfil the steel corrosion protection requirements. The selected material solution did not require additional efforts in painting operations and only required limited preparation and priming.

Adhesive bonding ensures a perfect deck to steel structural connection and offers the advantage of load transfer distributed to a large area avoiding local load introduction into the composite that would occur with mechanical fastening. Moreover, the adhesive layer allows to compensate for the geometric tolerances of the steel structure and to ensure ideal supporting of the composite plate. Expansion joints are created by leaving a gap between the sandwich panels and also along the lateral sides. These joints are filled with PU based soft sealant.

Fig. 10 Clavières footbridge installation

5. Bridge owner expectations on durability

The financial equalization and tasks sharing between the Swiss Confederation and the cantons were reformed in 2008. It generates a transfer of ownership of national highways from the canton to the Confederation; the latter will, after construction, redistribute to local authorities the secondary highways structures for maintenance. It was therefore important for the community of Boncourt that the Clavières footbridge integrate construction details and materials that enhance the bridge durability and reduce maintenance.

The footbridge durability is ensured by a full coating of the steel structure with efficient corrosion protection. The selected 2k coating system, with a total dry film thickness of 300 µm, fulfils the EN ISO 12944 standard for exposure to atmospheric corrosion class admitted between C3 and C4 with a life time of 40 years. Special care is also put on construction details to avoid water stagnation on steel taking into consideration the recommendations of SIA 2022 publication [7], [8].

The composite deck is intrinsically corrosion resistant. Its continuous and watertight surface allows proper handling the water drainage towards the abutments and also protects the underlying steel structure.

6. Conclusion

The Clavières footbridge in Boncourt, Switzerland has been designed and built with the aim of achieving remarkable architecture. Implementation of the ultra-lightweight COLEVO deck on this landmark bridge allowed moving away from critical Eigen frequency range while keeping the bridge identity with a lean, aerial and slender structure.

Special care was given to construction details to enhance the bridge durability with the aim of reducing bridge maintenance. Use of innovative composite deck materials with intrinsic corrosion resistance offered a durable solution and allowed integration of detailing that improved the steel structure protection against corrosion. Even though application of composite materials in bridge construction is relatively recent, the experience gained with these materials in other fields of application such as marine, wind energy or mass transportation allows for 100 years of life expectancy.

This lightweight deck solution also allowed to fully preassemble the bridge sections in plant and to ship them fully finished onsite. The full bridge installation, including mast and stays, took place within a day under alternated traffic. Full traffic interruption was only required during 2 hours for the installation of the major span over the road.

The Clavières footbridge is a good showcase where the lightweight and durability benefits of sandwich composite decks are fully used. Long span footbridges, bridge widening, road bridge live load increase or reduction of construction time are other examples where COLEVO decks become technically and economically the most interesting solution.

7. References

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