UDK 624.2

A CABLE-STAYED FOOTBRIDGE MADE OF GLUED-LAMINATED WOOD – DESIGN, ERECTION AND EXPERIMENTAL INVESTIGATIONS

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1. Introduction

A newly erected footbridge [1 – 3] over the Dunajec River is located in the Pieniny National Park, Poland. The structure is situated between the mountain resorts of Sromowce Nizne (Poland) and Cerveny Klastor (Slovakia) and is situated in a very attractive tourist area. The main goal of this new transport means is connection of recreational regions located on both sides of the border. Before the footbridge's erection, the location of the nearest road frontier crossing forced tourists to make a circumferential journey between both resorts of about 15 km. The footbridge has shortened this journey to only 150 m. The new object is also important because intensive development of this region and improvement of the tourist infrastructure for summer and winter sports are planned in near future. Erection of the cycle-pedestrian footbridge is the first stage of this project.

2. Design process

2.1 Preliminary draft and aesthetic consideration

The basic assumption made by the investor was design a footbridge with glued-laminated wooden deck. The investor's wished to create a footbridge as a landmark structure. Because of low investment funds, aesthetic considerations were limited to the dominant elements – the pylon and supports (Fig. 1).

It was decided that the colours of the footbridge should correspond with the surrounding landscape of the Pieniny National Park. All steel elements and cables are steel-silver. Concrete elements are painted in light-grey colour. All wooden elements have remained in their natural colours (Fig. 2).

It seems that glued-laminated wood for the girders was a proper choice. The structure suits the highland character of the region and the material is friendly for pedestrians.

Fig. 1. Design analysis of an aesthetic aspect of a steel pylon

Fig. 2. The final aesthetic effect achieved

2.2 Superstructure of the footbridge

The footbridge was designed as a cable-stayed structure (Fig. 3 and 4). The main span is 90.0 m long, whereas the side spans are each 10.50 m long. The total length of the deck is 149.95 m.

The wooden deck is attached to a steel pylon with 5 pairs of stays. The distance between anchorages is 15.0 m and is constant along length of the structure. The back stays are anchored in the abutment.

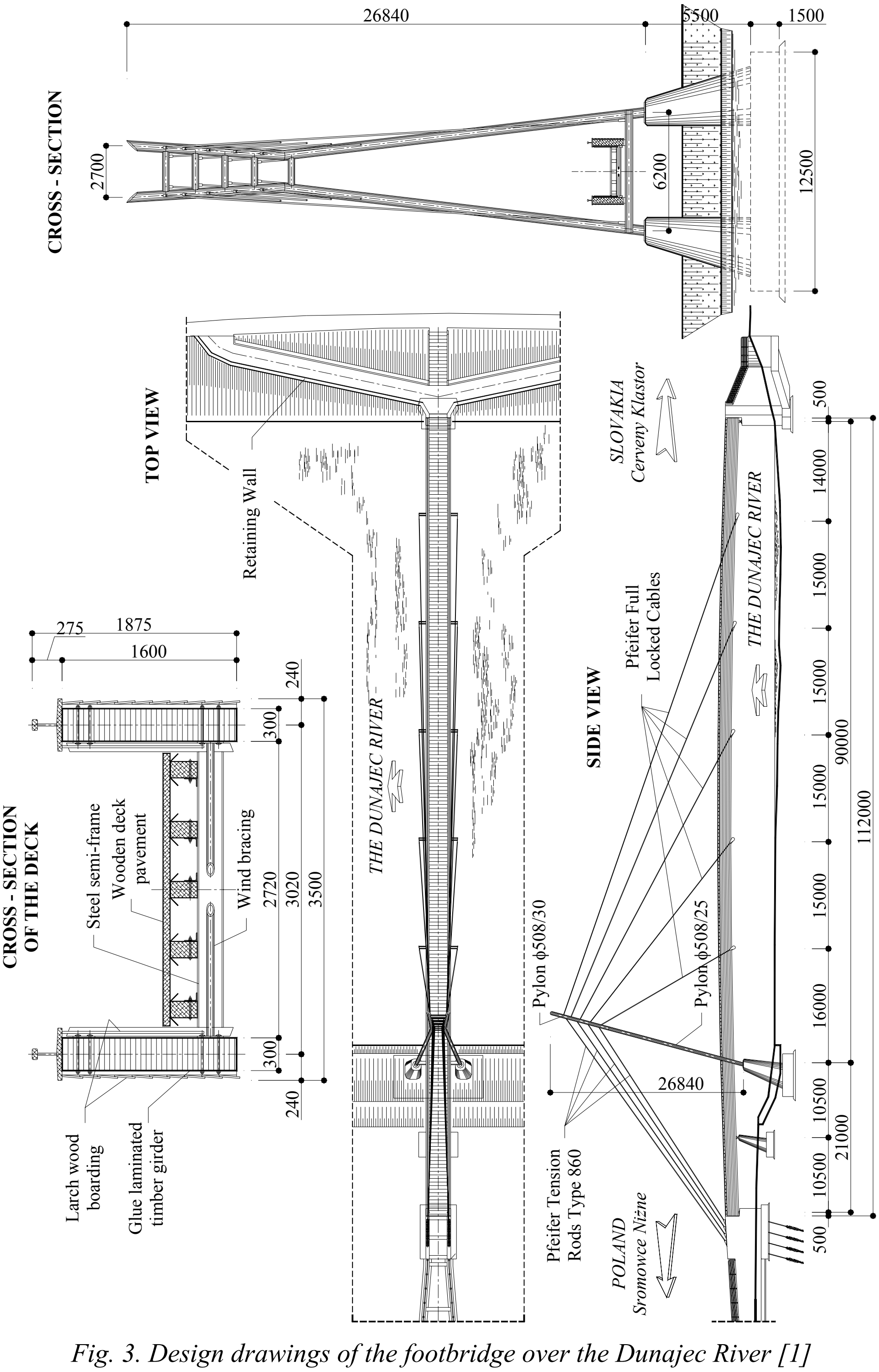

Fig. 3. Design drawings of the footbridge over the Dunajec River [1]

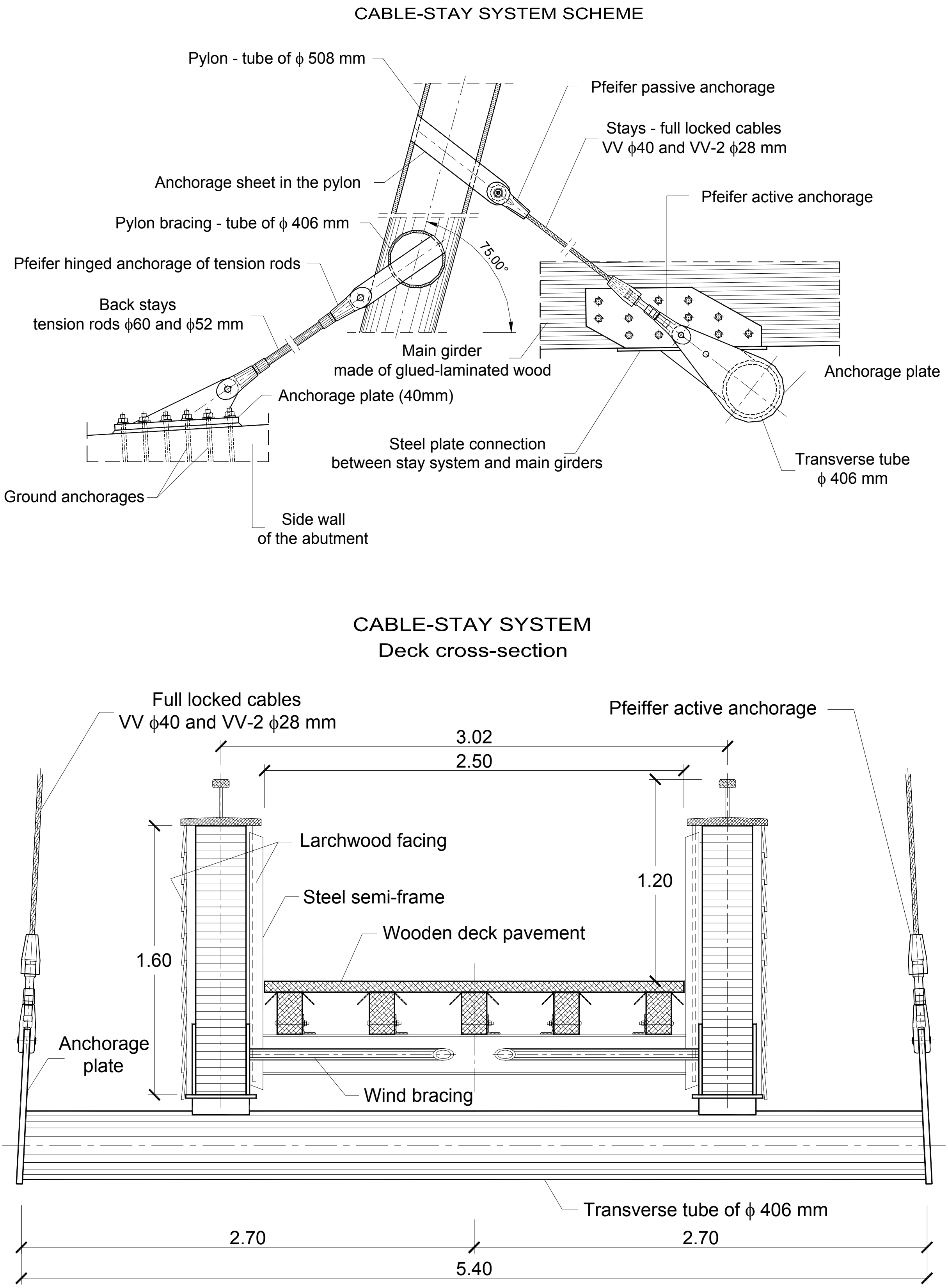

Fig. 4. The cable-stay system of the footbridge over the Dunajec River [1]

The pylon was made of tubes of 508 mm diameter and of 25 / 30 mm thickness. The arms of the pylon are constructed with rectilinear segments, braced by 5 steel tubes of Ø406.4/16 mm. The distance between the arms is 2.70 m at the top of the pylon, 1.70 m at the most narrow part and 6.20 m at the level of fastening to the concrete support. The height of the pylon is 26.84 m above the concrete support. The inclination of the pylon is 75.0^{o} in the direction of the main span.

The deck of the footbridge is constructed with wood with steel elements. The width of the deck is 2.50 m, and the total width is 3.50 m. The total height of the deck is 1.87 m. The deck consists of 2 main girders made of glued-laminated wood braced by steel semi-frames and wind bracing. The girders were designed using pinewood of GL32 class with a rectangular cross section of 1.60 m × 0.30 m. The total length of the wooden girders is 112.0 m. They are protected against atmospheric and biological corrosion by additional, external wooden layers. The 0.27 m high handrails are fixed to the top surface of the main girders. The deck pavement is made of 4.50 cm thick boards supported on 5 longitudinal wooden beams of 0.10 m × 0.20 m cross section. The deck was made of prefabricated segments 15.0 m long. Field joints ware constructed from steel screwed sheets.

A cable-stay system is made of stays manufactured by Pfeifer. Full locked cables of Ø40 mm or Ø28 mm and 1570 MPa ultimate strength are used in the main span and tensioned rods of 860 Ø60 mm or Ø52 mm type are used for back-stays. Passive anchorage in the pylon and active anchorage in cross-bars supporting the deck are employed.

2.3 Static analysis

The static computations were performed using Robot Millennium v. 17.0 software. Two computational models were used, both three-dimensional, differing in the types of elements (bars or bars with plate elements modelling main girders – see Fig. 5). For some elements an offset function was applied to model the proper location of element nodes.

All calculations were conducted independently, using both models. In this way, the results were benchmarked. Selected values of the extreme normal stress in the designed elements are presented in Table 1.

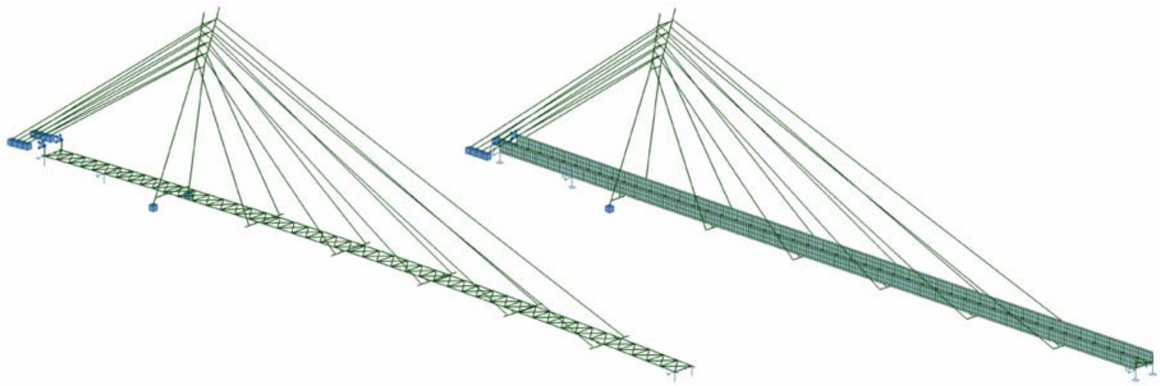

Fig. 5. Illustration of the computational models of the footbridge applied in the design process [1]

Seven load schemes were considered. A system of gravity load, equipment load, stays' tension forces and service load was defined as the main loading scheme. Additional loading schemes combined the main load scheme and the (plus / minus) temperature induced load, wind pressure (blowing parallel or perpendicular to the longitudinal axis of the footbridge) and snow load (two possibilities were taken into account: the whole cross-section covered by snow combined without any service load, and deck loading by a 25.0 cm thick layer of compacted snow combined with service load).

Envelopes of the internal forces and normal stresses were generated for all structural elements, on the basis of the above noted load schemes. Selected envelopes of internal forces of wooden girder are presented in Fig. 6.

The design calculations protect the material effort not exceeding the admissible values under normal service conditions. The maximum vertical displacement induced by service loads equals 26.0 cm; this value does not exceed the permissible value.

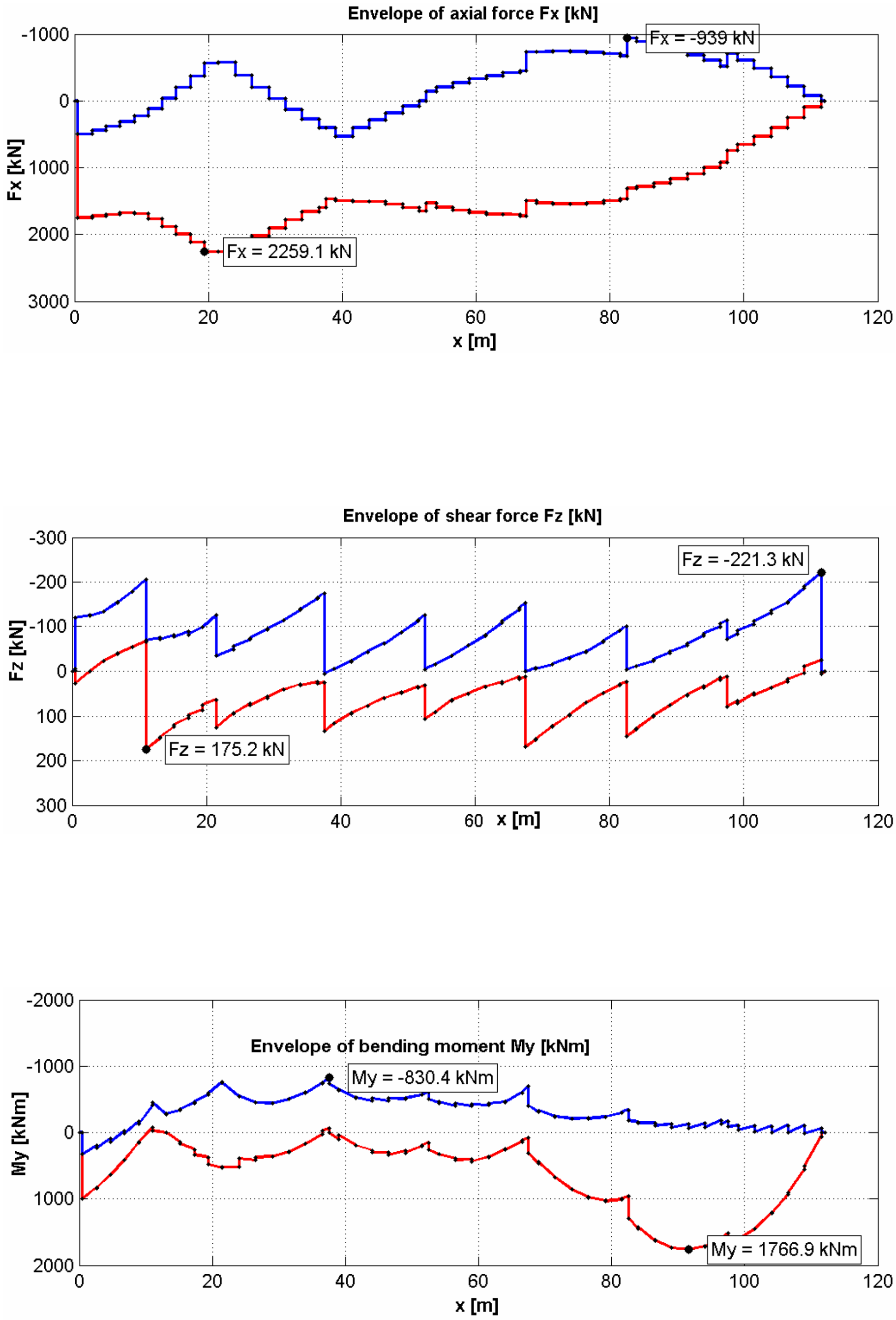

Fig. 6. Envelopes of the internal forces for the main girder of the footbridge [1]

Table 1 *– Extreme values of normal stress for selected structural elements [1]*

Structural element	Cross-section	Model A (bar FEs only) σ_{max} [MPa]	Model B (bars and plate FEs) σ_{max} [MPa]
Pylon	Ø508.0/30 mm	216.9	246.8
Pylon bracing	Ø406.4/16 mm	101.0	101.3
Pylon cross-bar	400×300×25 mm	102.8	112.0
Cross-bars	Ø406.4/25 mm	264.4	263.9
Wind bracing	Ø70.0/10 mm	252.4	247.9
Wooden girders	1600×300 mm	14.4	14.2

3. Erection process

The erection process of the footbridge started in April 2006 and finished after 5 months in August 2006. Erection of concrete elements, i.e. foundations, abutments, supports and retaining walls, consumed majority of this time, while assembling of the deck and pylon (including the initial tensioning operation) lasted only 3 weeks. Such a short erection time resulted from the prefabrication technology used for this object.

The deck is made of prefabricated elements of 24.75 m + 5x15.01 m + 12.18 m lengths. The segments were delivered by lorries from the prefabrication factory in Germany to the construction place, and then they were positioned by a mobile crane on temporary supports and assembled. The connections of the segments are made using steel plates and screw joints (Fig. 7), and filled with epoxy resin.

The pylon was lifted and placed in the proper position by a mobile crane. Because of its inclination, the pylon was immediately secured by one pair of back stays (Fig. 7). It was strongly required due to possible wind impact.

The stays were installed pair by pair, starting from the shortest. During this operation, the tension forces of cables and position of the pylon's top was measured and checked up on the tension programme. The deck was lifted successively from the temporary supports.

Fig. 7. Assemling of the footbridge deck on temporary supports (July 2006)

4. Experimental investigations

The authors' team had performed a large number of dynamic tests of the footbridge. In the experiments 10 accelerometer gauges and a laser device (see Fig. 8) were used. It was sufficient to register the dynamic response of the footbridge in the vertical and horizontal directions and then to restore modal shapes corresponding to the lowest natural frequencies (see Fig. 9).

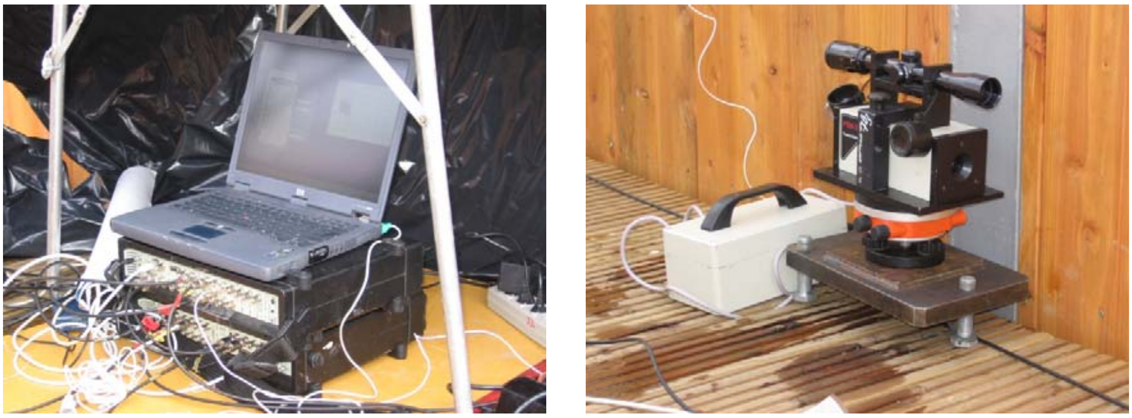

Fig. 8. Measurement devices (Bruel & Kjaer amplifiers and Noptel OY PSM200 laser device)

Two displacement and 10 acceleration time-histories of the footbridge were measured according to the experiment programme. In situ tests have proved satisfactory behaviour of the footbridge in normal service conditions; accelerations did not exceed the admissible limits. The maximum accelerations were 0.20 m/s^2 in walking conditions and 1.10 m/s^2 in jogging and fast running conditions. Synchronization of pedestrian activity caused higher dynamical response of the structure, e. g. up to 2.20 m/s^2 in synchronized walking conditions, 3.14 m/s^2 in synchronized jogging conditions and 4.19 m/s^2 at some vandal excitations like deliberately crouching. However, at vandal excitations only capacity conditions should be satisfied; human comfort criteria could be exceeded.

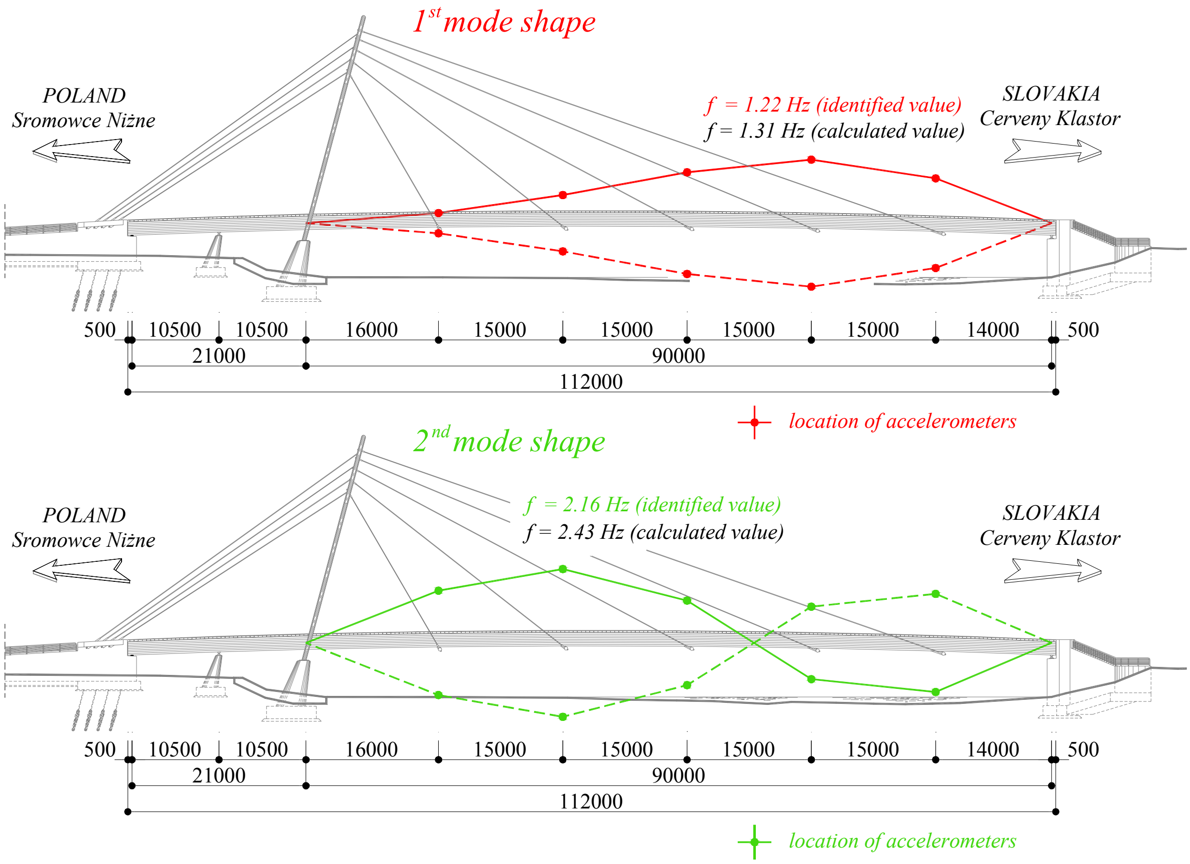

Fig. 9. Identified 1st and 2nd vertical flexular modal shapes

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