ARCH FOOTBRIDGE OVER WARTA RIVER IN WRONKI – DESIGN AND CONSTRUCTION

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SUMMARY

The paper presents the concept of dynamic redesign of lively footbridge. The goal was to reduce probable dynamic excitation and change detailed structural concept. After the complex study the new design was created. In effect completely new static and dynamic properties were reached. Static and dynamic assumptions are explained. General information, photos and drawings are presented. The final price of the project amounted to 1.25 million Euro. Recently bridge is in service since December 2014.

Keywords: *Arch footbridge, steel, structure, composite structure FEM analysis, dynamics, load test.*

1. INTRODUCTION

Since the second half of the twentieth century, we notice increasing demand for communication infrastructure in the field of pedestrians and cycling. Pedestrian bridges are becoming more and more popular. In Poland so far footbridges were built over roads and railway lines in urban areas. But recently we observe, more new footbridge been built over the biggest Polish rivers. [1], [2].

The paper presents the history of design and construction of footbridge over Warta river with the arch span of 90 m. The original architectural idea has been realized through the development of an atypical construction. Structural analysis was focused also on steel consumption and costs of the foundation. An important element of the project was to reach dynamic characteristics acceptable for pedestrians. A footbridge was completed in planned period for the amount of ~ 1.25 million Euro. This showing that remarkable structure can be built for reasonable money.

2. ARCHITECTURAL DESIGN

The authors of the architectural concept [3] decided to change the image of the environment and offered a spectacular structure referring to the latest architectural solutions in bridge architecture (Fig. 1). The new bridge connects the northern part of the city with a historical centre. Location of the footbridge improves the comfort and safety of city residents, who so far could use only the road bridge equipped with unsafe pedestrian carriageway. The whole new passage consists of two parts: the main over the river and secondary over flood area. Between them architect had planned additional spectator platform with a unique panorama view to the old town and the wildlife river site.

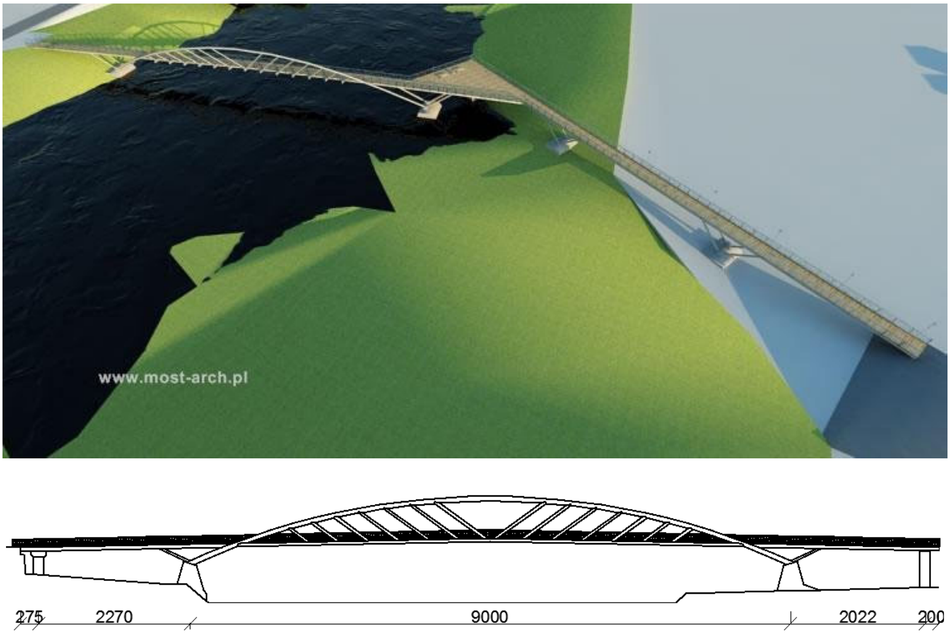

Fig. 1. *The architectural vision and side view of the footbridge. Design: MOST Świderski [3].*

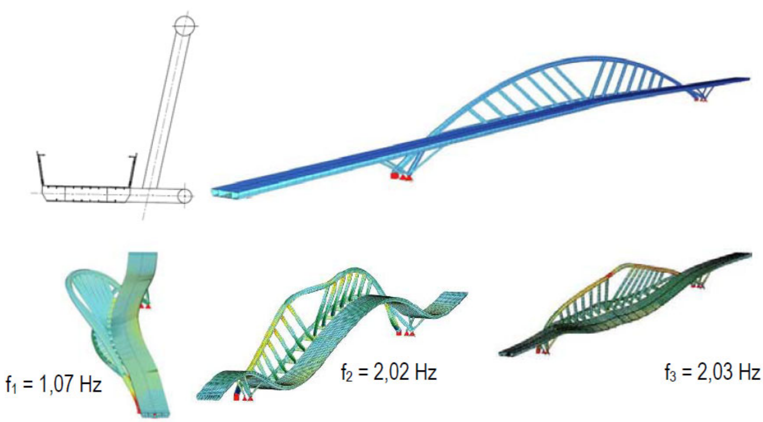

Fig. 2. *Original FEM SOFiSTiK model, cross section and first three eigen forms and frequencies.*

The over river part was designed as continuous beam l= 22,75 + 90,00 + 20,22 m the with main span strengthened by single inclined arch connected width carriageway by inclined beam hangers. Arch has a rigid connection with abutment (Fig. 1). Basic dynamic analysis showed unfavourable range of eigen frequencies [4],[5] (fig.2). Additionally rigid connection of the arch with abutment caused a number of problems related to stress limit in steel and in abutment. Finally contractor decided to redesign structure keeping architect idea (as much as possible).

3. FINAL STRUCTURAL DESIGN

After the complex study the new design was created (fig. 3). Additional rod hangers were added crossing original ones. Rigid connection with abutment was abandoned and carriageway was used as a tie-beam. Side spans were redesigned as composite structures and arch tube below the deck on both sides of the bridge was filled with concrete. In effect completely new static and dynamic properties were reached (fig.4). First vertical eigen form is still in critical range (less than 2,3 Hz) but from recent experience we know that vertical excitation under 2,1 Hz is highly unlikely.

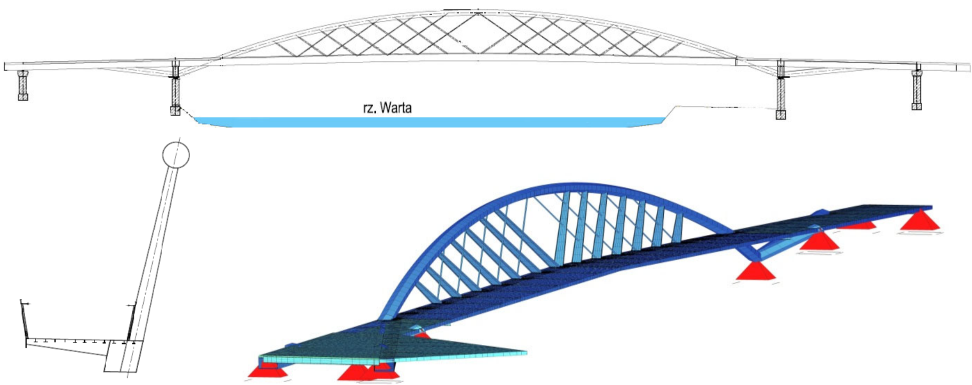

Fig. 3. *Modified design. Elevation, cross section and FEM SOFiSTiK model.*

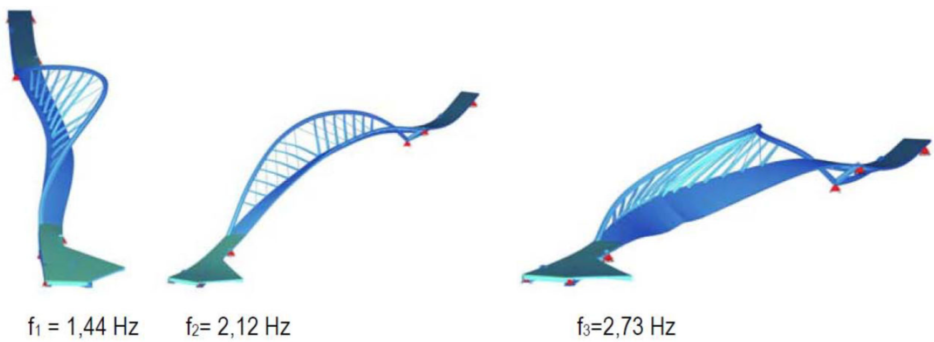

Fig. 4. *Eigenforms and frequencies after redesign of superstructure.*

4. NUMERICAL DYNAMIC TESTS

To predict a dynamic behaviour of a bridge several numerical dynamic tests were done. First the FEM model was calibrated with damping (log. decrement) δ = 0.0503. Next step was a dynamic simulation of pedestrian action. Several cases were considered:

- pedestrian flow partially synchronized, freq. of walk f = 1.492 Hz (test PF1),
- pedestrian flow partially synchronized, freq. of walk f = 2.00 Hz (test PF2),
- pedestrian flow partially synchronized, freq. of walk f = 2.121 Hz (test PF3),
- purposeful action– crouching of 10 people with freq. f = 1.492 Hz (test C4),
- purposeful action– crouching of 10 people with freq. f = 2.121 Hz (test C5).

For pedestrian flow test a load formula defined in [6] was used:

$$L_{ns}(t) = \frac{BW\{N + M \times A[sin(\omega_h t) + 0{,}25\sin(2\omega_h t + \pi) + 0{,}25\sin(3\omega_h t + \pi)]\}}{F_b} \tag{1}$$

where

$L_{ns}(t)$	load in time [kN]
BW	body weight, BW = 0,75 kN
N	number of people on the bridge, $N=gF_b$
F_b	total deck area
g	the density of pedestrians, g = 1,14 [persons/m^2]
M	no. of synchronized ped. $M = \sqrt{N}$
A	dynamic factor, A=1,3
ω_h	pacing rate
t	time

Selected results are presented below (Fig. 5).

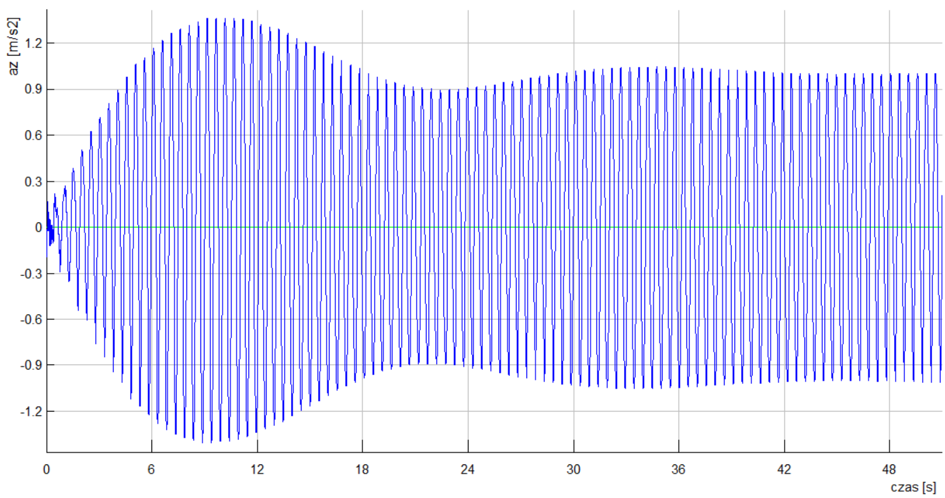

Fig. 5. *Test Pf3 max. vertical acceleration of the deck – stabilization ~1 [m/s2].*

For purposeful crouching a load formula defined in [6] was used:

$$F(t) = BW[A(\cos(\omega|t| - \phi)e^{-|t|v} + 1] \tag{2}$$

where:

BW	body weight, BW=0,75 kN
A	dynamic factor, recognized A = 1,3
ω	recognized ω=2πf, f=2.4 Hz
φ	phase shift recognized as φ = 0.25
v	numeric damping $v = \sqrt{16T}$
T	time period
t	time t ϵ <-T/2,T/2>

Selected results are presented below (fig. 6).

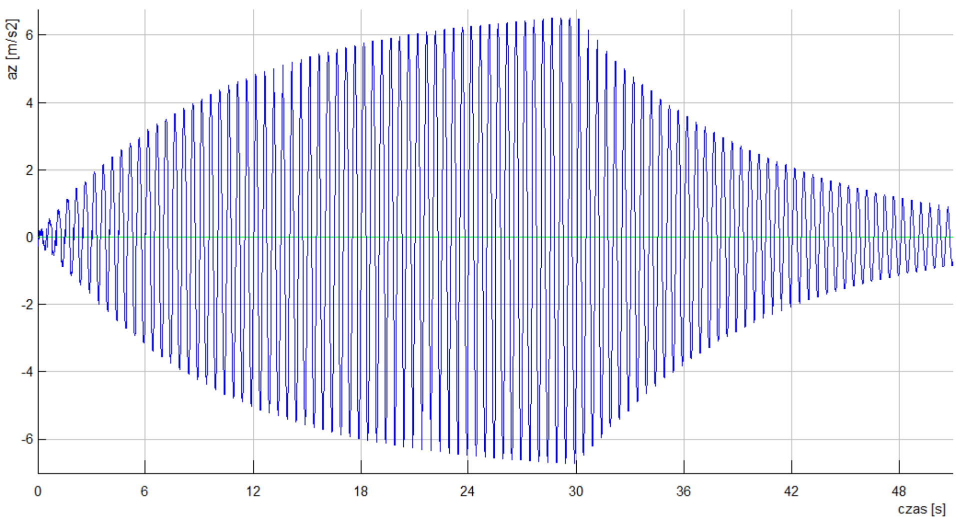

Fig. 6. *Max. vertical acceleration on deck – test C5 – max=6.515 [m/s2].*

Presented numerical simulation of dynamic response of the footbridge gave a good (save) prediction of dynamic behaviour of the footbridge. Site test made later on the bridge, ended with positive results [7]. Comfort requirements were reached.

5. CONSTRUCTION PHASE

The construction began before the design work had finished. The steel structure was manufactured in sections, integrated on-site and assembled on supports. Success in the assembly work has been achieved thanks to the precise workshop documentation and technology. A spectacular part of the construction stage was the installation of the main span (Fig. 7). The entire assembly was designed by a team of GTI Gdansk.

***Fig.** 7. Erection of the main span (photo: Ryszard Bugaj).*

6. CONCLUSIONS

Footbridge over the River Warta in Wronki was opened to service in planed time. The symbolic opening took place on 12.20.2014 year. The investment was characterized by the team spirit and good cooperation between the investor, architect and structural designers. Changes in structure were treated as the next step in of the creative development of the bridge. In effect city of Wronki got the new quality which changed radically aesthetic and functional conditions on the Warta river bank in the city of Wronki (Fig. 8).

Fig. 8. *Footbridge just before opening.*

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