

# Classical and Modern Design Solutions in Conceptual Design of a Pedestrian Bridge over Vistula River in Cracow

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**Abstract.** In the paper the design concept of the steel pedestrian bridge over Vistula river in Cracow, Poland has been characterised. The footbridge was designed as a truss structure with steel pipes, Warren truss configuration, arched bottom chord and spans 15.5+120.0+15.5 m. Intensive tourist traffic around the Wawel Castle in Cracow, directed towards the historic Kazimierz district, Wawel Hill and the Old Town Market Place requires the creation of a bridge structure over the Vistula River that will meet both the communication and recreation functions. An additional aim was to design a structure which architectural form will not unduly and negatively interfere in the environment and will join the technical capabilities of the XXI century with the charm of nearby historic buildings.

## 1. Introduction

Footbridges are perceived by architects and engineers as a structures which allows freely realize of their own architectural ideas in a simpler and less expensive way than in the case of bridges for heavy road or rail traffic. However this freedom is not unlimited. The new project must meet the requirements for functionality, comfort and safety. In the case of the structures intended for pedestrians not without significance are also the ergonomic aspects related to adaptation of the structure to physical and psychological traits of people. The aesthetics is also of great importance. *“The design engineer by the joy of their achievements and abilities cannot lose a sense of beauty and a sense of responsibility for creating unsightly buildings”* F. Leonhardt [1].

In the case of location of a designed structure in place with a strong cultural or historical context the development of the project requires special analysis and attention to integrate the new design with the environment and its harmonious incorporation into the city landscape. It is required to perform the view shed analysis relating to the determination of various viewpoints and viewing axis. The analyses should take into account the principles of aesthetics, visual and landscape effects in the context of near and far away perspective, both in relation to external observers and for the direct users of the structure. The analyses should assess: quality of architectural and spatial solutions (attractiveness of the composition and spatial coherence), the correctness of technical and material solutions and their applicability in respect to structural and financial aspects as well as the quality of solutions of the construction details and small architecture forming the architectural fittings of the designed structure or the adjacent area.

The issue of the creation of the pedestrians and bicycle crossings over the Vistula river in Cracow was the subject of the architectural competitions [2, 3, 4] and other related works undertaken by the



engineers and architects [5, 6]. One of the first conceptual work in this area prepared at the beginning of the new millennium in 2002 was the master thesis “Conceptual design of a steel footbridge over the Vistula river linking Vistula Boulevards Volyn and Livonia in the vicinity of the Forum hotel” [7].

The thesis presents an architectural and urban concept of the three-span footbridge with spans length  $15.5 + 120.0 + 15.5$  m designed as a truss structure with steel pipes, arched bottom chord and truss webs configuration in a form of Warren truss. The use of truss system provided a high degree of transparency of the structure and minimally obscures the view of the surroundings. An additional advantage of the use of steel pipes was to achieve a favourable aesthetic effects. A classical form of arch used in the structure fits well with environment and the structure does not dominate in the historic surroundings (figure 1).

## 2. General structural characteristics of the footbridge

The footbridge was designed as a part of the infrastructure of land development belonging to the important rest and recreation area of the city of Cracow in the immediate vicinity of the Pauline Church (minor basilica) and Pauline monastery and the nearby Wawel Royal Castle. On the opposite bank of the river a landmark of the land development is the Hotel Forum with his characteristic architecture. The hotel is closed since 2002 but its monumental body remains the dominant feature on the other bank of the river (figure 1).



Figure 1. Location of the footbridge) view of the Livonia Boulevard (Pauline Church, Wawel Royal Castle visible in the upper left corner), b) view of the Boulevard Volyn (Hotel Forum)

The neighbourhood of the historic buildings had a strong influence on the choice of design solutions. The priority was a harmonious incorporation of the footbridge into the city panorama in the place of location with preserving the existing architectural elements (retaining walls, stairs and ramps, slopes and paths for pedestrians and cyclists).

In order to good fitting of the footbridge in the environment and to avoid domination of the historic nature of the place the footbridge was designed as a spatial truss structure with arched lower chord (figure 2). The use of the form of the arch introduces association of the object with the historical context of the surrounding buildings. Openwork structure of the truss girders causes the illusion of transparency and minimally obscures the view of the surroundings. In functional terms the footbridge fits into the existing system of pedestrian and bicycle paths.

Before the adoption of the final shape of the structure several patterns of structural geometry were studied differing from each other by the geometry of the arch and longitudinal slope of the footbridge deck (figure3).

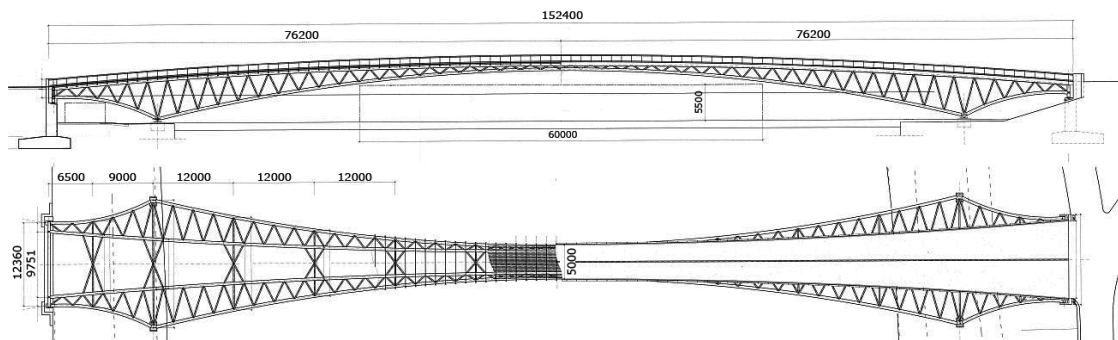


Figure 2. Conceptual design of the footbridge over the Vistula river in Cracow (longitudinal section and top view)

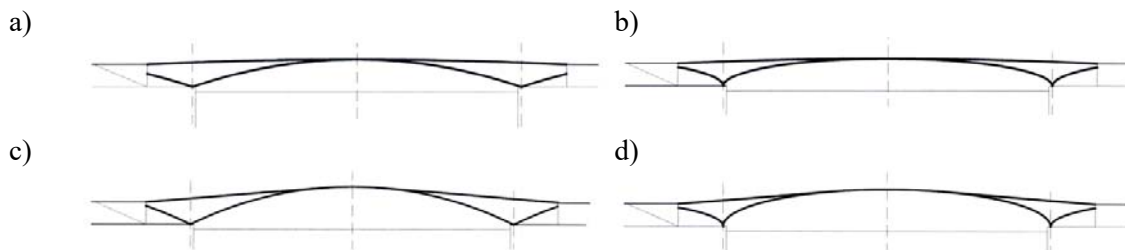


Figure 3. Concepts of the longitudinal section of the footbridge a) circular arc, the longitudinal slope max 2%, b) an elliptical arc, the longitudinal slope max 2%, c) a circular arc, the longitudinal slope max 8%, d) an elliptical arc, the longitudinal slope max 8%

Finally, because of the required vertical clearance for ships the structural scheme with the bottom chord in the form of a circular arch and with maximum longitudinal slope of 8% were accepted (figure 3c). The grade line of the footbridge deck was shaped in a vertical circular arch of radius  $R = 900.0$  m. Lower chord of the truss was shaped in vertical circular arch of radius  $R = 255.0$  m.

The footbridge was designed as a three span structure with spans  $15.5 + 120.0 + 15.5$  m. The cross section of the footbridge consists of two steel flat trusses inclined at an angle of  $45^\circ$  and an orthotropic steel deck supported on the upper chord of the trusses (figure 4).

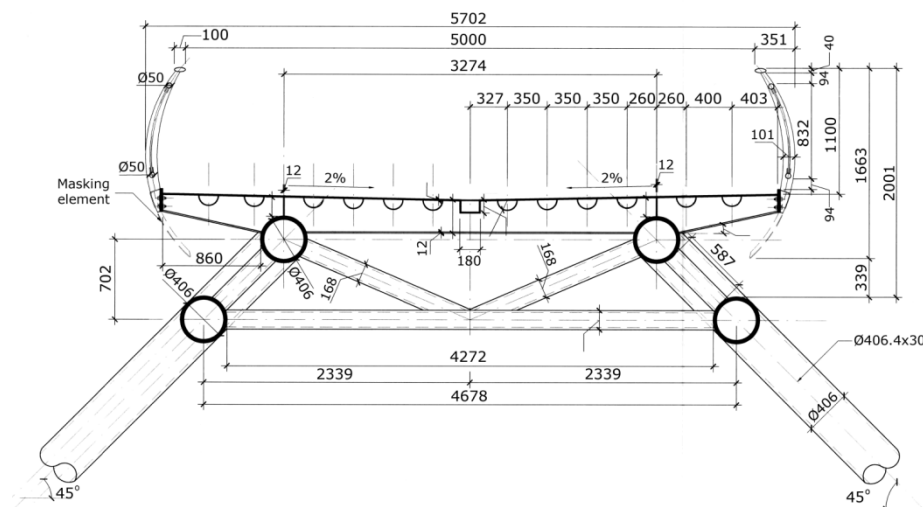


Figure 4. Cross section of the footbridge in the middle of the main span

The main truss girders were designed as a truss with variable height and triangular web configuration without vertical posts (Warren truss) with nodes spaced at equal distances of 3.0 m along the upper and lower chord. The height of the trusses vary from 1.30 m to 5.82 m within the side spans and from 5.82 m to 0.70 m within the main span (figures 4 and 5). The trusses were braced transversely by means of cross members in the form of spatial trusses placed over two pillars as well as in the short side spans (9.0 m from pillars) and along the main span at distances of 12.0 m (13 cross members, figure 2 – top view).

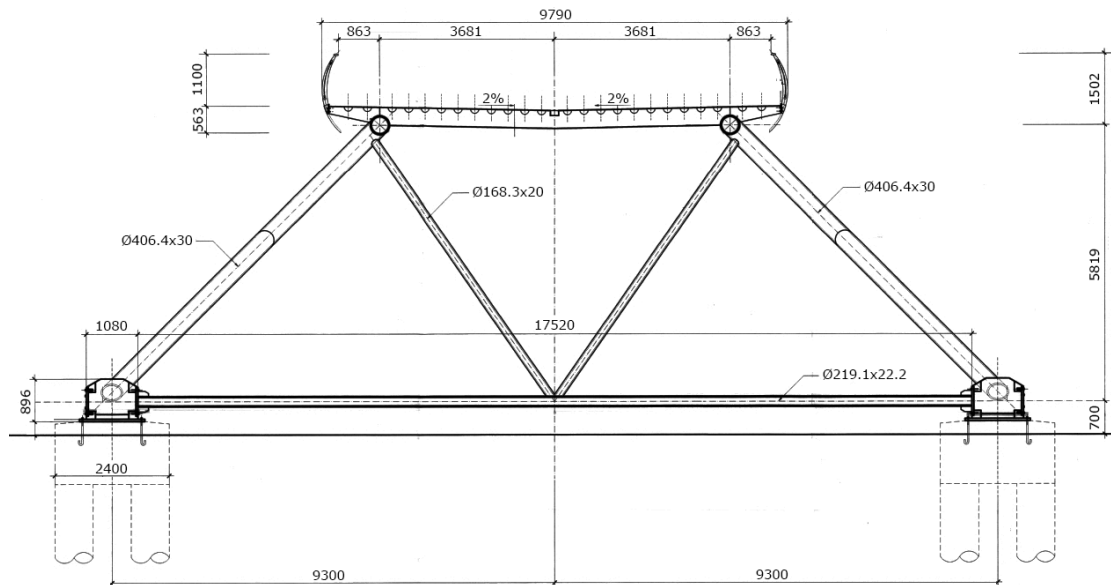


Figure 5. Cross section of the footbridge over the pillars

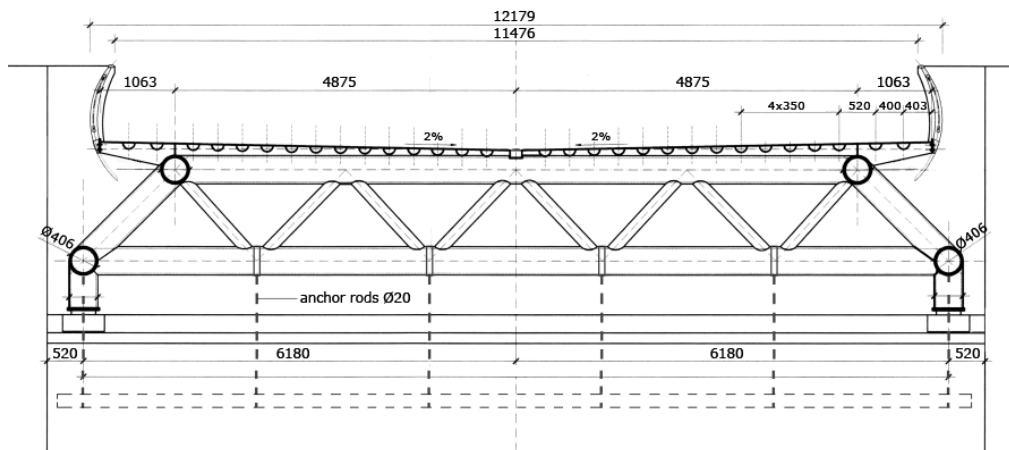


Figure 6. Cross section of the footbridge over the abutments

Short side spans of the footbridge due to the occurrence of negative reactions detaching the structure from abutments were designed as anchored in the abutments by means of high strength rods Ø20 mm connected with truss cross members (figure 6).

Intermediate supports of the main truss girders was located in the area of the Vistula river embankments. They were designed in the form of pinned support with constructional cast steel. Due to the location of the supports near to pedestrian walkway and bicycle path the required vertical clearance for pedestrians and cyclists under side spans of the footbridge was provided by choosing a suitable

curvature of the lower chord of the trusses. Moreover, adopted location of the intermediate supports within the Vistulan Boulevards carry the risk of periodic flooding of the structure by flood waters. To avoid this in modified concept a modern solution of vertical lifting of the footbridge was proposed. The footbridge was supported by a set of synchronized hydraulic jacks placed in the area of the intermediate supports and abutments (figure 7). In periods of high water level of the Vistula river the hydraulic jacks can lift the structure above the flood water.

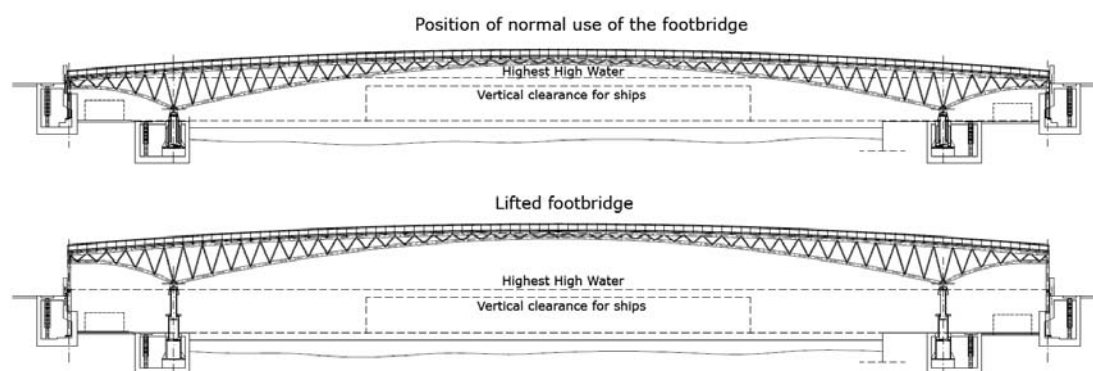


Figure 7. The concept of lifting of the footbridge with a set of synchronized hydraulic jacks

An example of a similar solution, successfully implemented in modern movable road bridge is a hydraulic lift system used in Great Wharf Road Bridge in London.

### 3. Assessment of the aesthetic value of the footbridge

An important aspect considered in detail at the stage of the footbridge concept development were the issues of bridge aesthetics. The concept was developed assuming that spatial values of the object often do not depend on the application of advanced design solutions but the composition skills of the designer and skilful use of the principles of aesthetics. The most important of these principles are:

**Table 1.** The principles of aesthetics [8]

Principles of aesthetics	Description
<b>The principle of the form visibility</b>	To induce an aesthetic impressions all elements in the form and their interdependencies should be visible
<b>The principle of the form simplicity</b>	To induce an aesthetic impressions the number of elements in the form must be sufficiently small in order to ensure visibility of interdependence of elements in the form
<b>The principle of the form clarity</b>	To induce an aesthetic impressions, combination of components in form should be easily visible
<b>The principle of the form regularity</b>	Rhythmic forms favour the induction of aesthetic impressions
<b>The principle of avoidance of the cognitive void</b>	To induce an aesthetic impressions, form must meet the cognitive aspirations of the observer

The proposed architectural and aesthetic form of the footbridge fits well into cited principles of aesthetics. Simple, classic arched structure with a regular internal structure is clear in form and devoid of dissonance. As the arch structure the footbridge corresponds well with other arch bridges over the Vistula River in Cracow (Jozef Pilsudski Bridge, Kotlarski Bridge, Father Bernatek footbridge, new railway bridges waiting for construction). Perhaps, in the near future, arch bridges become distinguishing feature of Cracow bridges over the Vistula River.



#### 4. Detailed constructional features of the footbridge

The footbridge was entirely designed as a steel structure made of constructional steel and high-quality stainless steel used for architectural details. Upper and lower chords of the trusses were designed with steel tubes Ø406.4x30 mm. In areas of intermediate supports required wall thickness of the lower chord reached 55 mm, which goes beyond the typical range of wall thickness of the steel pipes. The web members of the trusses in the vicinity of intermediate supports were designed with tubes Ø193.7x20 mm. The web members in the span were designed with tubes Ø168.3x16 mm. Transverse bracing of the truss girders within the span were designed with tubes Ø168.3x26 mm and over the intermediate supports with tubes Ø219.1x22.2 mm (lateral beam) and tubes Ø168.3x20 mm (spatially arranged beams).

The orthotropic deck of the footbridge was designed with steel sheet with a thickness of 12 mm stiffened by semi-circular longitudinal ribs designed with halved steel tubes  $\frac{1}{2}$ Ø193.7x8 mm. Moreover, the deck was supported by means of T-section transverse ribs (beams) with height of 295 mm made of steel sheets with a thickness of 12 mm and arranged along the span at a distance of 1500 mm. The transverse beams were connected with upper chord of the truss girders. The usable width of the deck vary from 11.5 m at the abutments to 5.0 m in the middle of the main span. The footbridge railings were designed with high quality stainless steel of closed elliptical profiles. In order to mask the construction of the deck, at the both edges of the deck the aluminium masking element were placed over the entire length of the span.

As a part of the concept development a static-strength analyses were performed. The results of analyses confirmed the correctness of the design solutions. The calculations were performed using characteristic value of a crowd loading of 4.0 kN/m<sup>2</sup>. Maximum material effort of the sections of the truss girders reached 98% of the design strength of steel. Effort of the elements of the orthotropic deck ranged 20-40% of the design strength of steel.

#### 5. Conclusions

The developed concept is characterized by simple and aesthetic form harmonizes with the neighbouring buildings. Simple and clear structural system elaborated using the classical forms of the arch, and truss structure enabled effectively fit the footbridge to the surrounding buildings and avoid its domination in the environment.

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