Joint Structural & Architectural Approach towards Human Urbanism

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Abstract

The necessity of joining structural and architectural approaches to reach human-oriented structures and develop contemporary urban environment is presented through several examples. Projects of an airport, a stadium and few bridges as outcomes of collaboration between structural engineers and architects will be overviewed.

Keywords: structural engineer; architect; joined approaches; airport; stadium; bridges.

1 Introduction

The development of the structural concept is the critical part of every structural project. When the structural concept is correct, the structure will be in accordance with the vision of the developing designer, possible to construct, and financially and technically viable, while when it is not correct the structure may easily become a financial and architectural disaster.

The roles for structural engineers and architects in the design of structures change over time. In the time of the construction of the great cathedrals, the Master Builder dealt with all design issues from the artistic and aesthetic to the technical. However, since the time of the Industrial Revolution and with the development in the field of sciences and new materials, distinctions between these two professions are even more evident. Since then the engineer is concerned with technical issues and the architect with architectural issues.

2 Joining different approaches

The quality of structural engineering work is traditionally judged on the practical foundations of efficiency and economy. Efficiency represents minimum of material consumption for assigned safety and economy introduces minimum expenses for assigned persistence, serviceability and durability. By adding an aesthetic component, the structure may become the work of structural art [1]. There are some general principles of beauty based on geometric, sculptural or structural theories. Nevertheless, these aesthetic rules should serve only as a framework [2]. The natural environment could be a promising source of inspiration, because often forms found in nature are aesthetically pleasing and shaped for maximum efficiency, transferring the required amount of force with the least amount of material.

Certain structures such are airports, sport arenas, bridges that are serving to community are often exposed to public judgement, especially the ones in urban surroundings, as they are continuously seen by many viewers and from different angles. Designers of such structures should bring to the design their own creativity, originality, imagination, and intuitive judgement to attribute the artistic enrichment of the structure, in order to design not only reliable, durable and economical structures, but also aesthetically pleasant ones.

On one side, the structural engineer, educated to take into account all the technical aspects, approaches to the design methodologically in order to achieve safety, stability, serviceability, durability and integrity of the structure. On the other hand, the architect, educated to take into account all other non-technical aspects, often think about a new project in terms of developing the vision and idea of the appearance and function of the new structure incorporating financial, cultural, socio-political and aesthetic factors. To reach exceptional structures it will be necessary to establish a team of professionals and joining these two main approaches to reach human-oriented structures and develop contemporary urban environment. Challenges, advantages and outcomes of developing the concept of a structure both by structural and architectural approaches will be presented through an airport, a stadium and few bridge projects.

3 Bridge projects

Bridges are exceptional structures. They are dominant in the environment not only by their dimensions, but also by their service life and the number of users. They serve to community and are visible from different location (on/under the bridge, from close up, faraway, from other roads) and in different conditions (standing, moving: at varying speed and in a variety of vehicles). Nowadays demands put on the new bridges are more and more complex including larger traffic volume, different traffic types on the same bridge, higher constrains in the environments, etc., but all this requirements should not be excuse to design less aesthetically pleasant structures. Moreover, large bridge should not just last, but also provide a lasting legacy of excellence for future generations [3]. Therefore, it is not surprising that for large projects, such is the one for mainland – Pelješac Peninsula Bridge, many different variants were considered and evaluated.

Comparing to the bridge in the landscape, design of city bridges is otherwise challenging due to higher aesthetical demands (respecting adjacent bridges and valuable or historic structures, visibility from different angles) and complex requirements and constraints (higher traffic volume; simultaneous vehicles, railway, pedestrian, bicycle and public transport; water supply, gas and electric power ducts to be carried, structure height restriction). Examples of city bridges, which harmoniously fit into the urban environment on either decent way as Trogir Bridge or representative way as Jarun and Bundek Bridges, will show how their aesthetic values are dependent on its context.

3.1 Mainland – Pelješac Peninsula Bridge

The idea of fixed road link to connect the whole of Croatia has been studied for more than fifteen years. Preliminary project development started in the year 2004. From the very beginning, adverse soil conditions have been known which was confirmed by detailed geophysical and extensive offshore investigations. Additionally the bridge is located in the zone of high seismicity and exposed to high winds. One of the key challenges for the bridge design was navigation clearance. The horizontal navigation clearance was originally specified with 150 m and the vertical clearance with 30 m. At a later stage, it was decided to increase the vertical clearance to 35 m, which was deemed more than enough for ships, which might ever enter the port of Neum. Besides, the bay of Mali Ston is ecologically an extremely sensitive area, where any larger ship traffic might disturb the delicate environmental balance of one of the last European natural habitats of oyster mussel and clam farms. Because of these constraints, it was evident that the total bridge dead weight and especially the dead weight of the superstructure had to reduce, which was done by adopting the steel superstructure. Also relatively long spans were used to limit the number of expensive foundations. Over 10 bridge types, including beams, trusses, arches and cable-stayed bridges, were studied at the preliminary stage and after an evaluation matrix was prepared for them the two alternative solutions were short-listed for the next phase [4]. The choice was based on aesthetical considerations and economic criteria comprising material quantity and erection technology complexity, but also on predicted future maintenance costs of this large project. The continuous steel box type superstructure of uniform depth was assessed as the less complicated for erection. The cable-stayed bridge was deemed slightly more attractive, but more expensive than the beam. The Committee finally selected the continuous steel box type superstructure, finding this alternative the least imposing on the environment.

After the preliminary design, new demands on the navigation clearance were prescribed. The navigation channel was to be 400 m wide with vertical clearance of 55 m. New alternative solutions for the bridge were analysed. All of them were cable-stayed bridges and finally one of them with the main span of 568 m and the steel box type superstructure was chosen [4]. The construction of Pelješac Bridge was already in progress when the project was abandoned in 2012 due to the lack of funds. The client recently requested new economically more viable bridge solutions in order to apply for EU funding. Searching for more economical but still sustainable bridge solution, new terms are specified - a two-lane bridge with median strip and windscreens, 3 m high, to be installed on the bridge to ensure that road traffic can run across even in high wind conditions. Two alternative solutions were proposed, a continuous steel box girder bridge and a multi-span semi-integral extradosed bridge with hybrid deck, both fully respecting the original road alignment and the already constructed bridge parts [5]. The rationale for the continuous steel box girder is its economy and very small weight. Only piers extruding from the sea are architecturally shaped, while the deck is of constant depth with only the main navigation span emphasized by the increase of depth. The multi-span semi-integral extradosed bridge is structurally up-to date, unique in appearance, and resourcefully economical, and thus a very clear reflection of the present times. Such a large and impressive bridge cannot be just high-tech and excellently designed engineering structure without soul and character. Thanks to an inventive approach to the design, with an integral structure, featuring a hybrid deck suspended to six pylons, the bridge meets crucial design criteria of appearance, stability, durability, usability and economy in construction, which should be reflected in subsequent maintenance costs.

At the end, due to the reduced adverse influence on the protected area and reduced construction risks due to three less piers and higher-level deck in the main navigation span, the multi span extradosed bridge was chosen for further design.

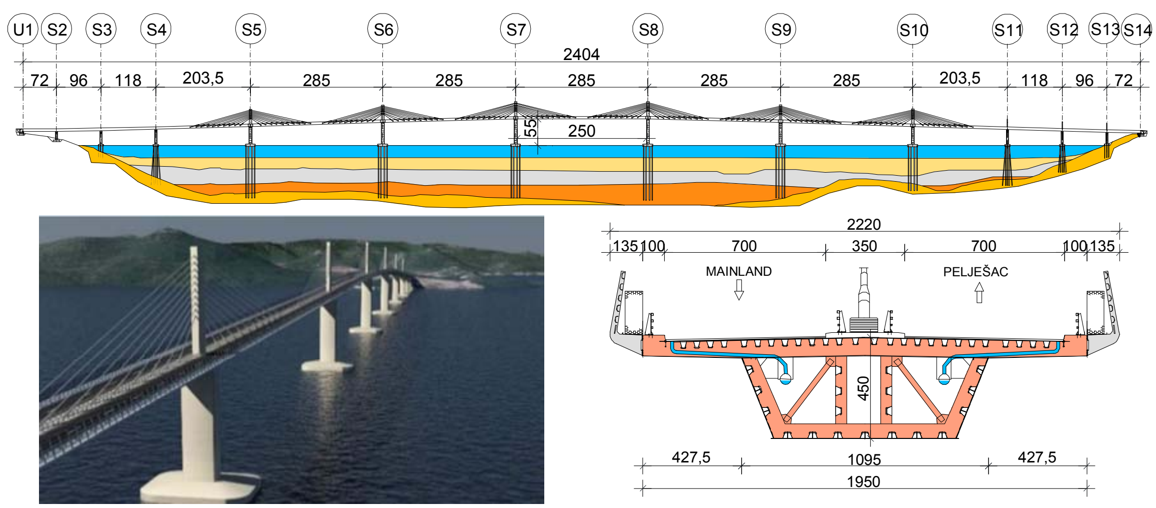

Figure 1. Longitudinal layout, computer rendering and suspended cross section of the final solution for Pelješac bridge: multi-span semi-integral extradosed bridge

3.2 Mainland – Čiovo Island Bridge

The historic centre of the town of Trogir, placed under protection of UNESCO, is directly endangered by an intense road traffic. The construction of a new bridge is of vital significance for an undisturbed development of Trogir and the Island of Čiovo. The longitudinal disposition of the bridge has been selected in accordance with the principles of aesthetics and efficiency, and to enable an optimum blending of the bridge into the urban environment with no wish to impose itself on the vista of the beautiful town of Trogir [6,7].

A girder bridge concept has been adopted because of a very small structural height of the bridge, made necessary due to vicinity of the Split Airport. A harmonious shape of the entire bridge has been achieved by invariable height of the superstructure along the entire length, even at the moveable part of the bridge. The advantage of the steel box cross section of the superstructure (as opposed to the reinforced or prestressed one) lies in a simpler and faster realization, i.e. the monolithic construction of the substructure (foundations, piers and abutments) takes place simultaneously with the workshop fabrication of steel superstructure segments, which can rapidly be assembled into their final position. Additionally, this has enabled definition of greater bridge spans and hence a more spacious look of the bridge for the same superstructure height. Due to considerable reduction of weights, seismic actions have also been reduced in the seismically active zone of Trogir.

Piers are elliptical in cross section. In longitudinal direction, they slightly widen toward the bottom and, in transverse direction, they taper toward the sea level. Piers supporting the moveable part of the bridge are shaped in the same way except that, for structural reasons, they are about 13 m wider in transverse direction, which has been used to provide for pedestrian path balconies and, in the longitudinal direction, the width is about 10 m, which is sufficient to accommodate the bridge lifting mechanism within the piers.

By their shape, material and colour, all parts of the bridge have been selected to place full emphasis at their decent character within the surrounding space. Soft rounded lines have been used for all structural elements, and hence a full harmony between piers and abutments and superstructure has been achieved. The softness of cross-sectional lines avoids sharp shadows, and they have always been present in the Mediterranean.

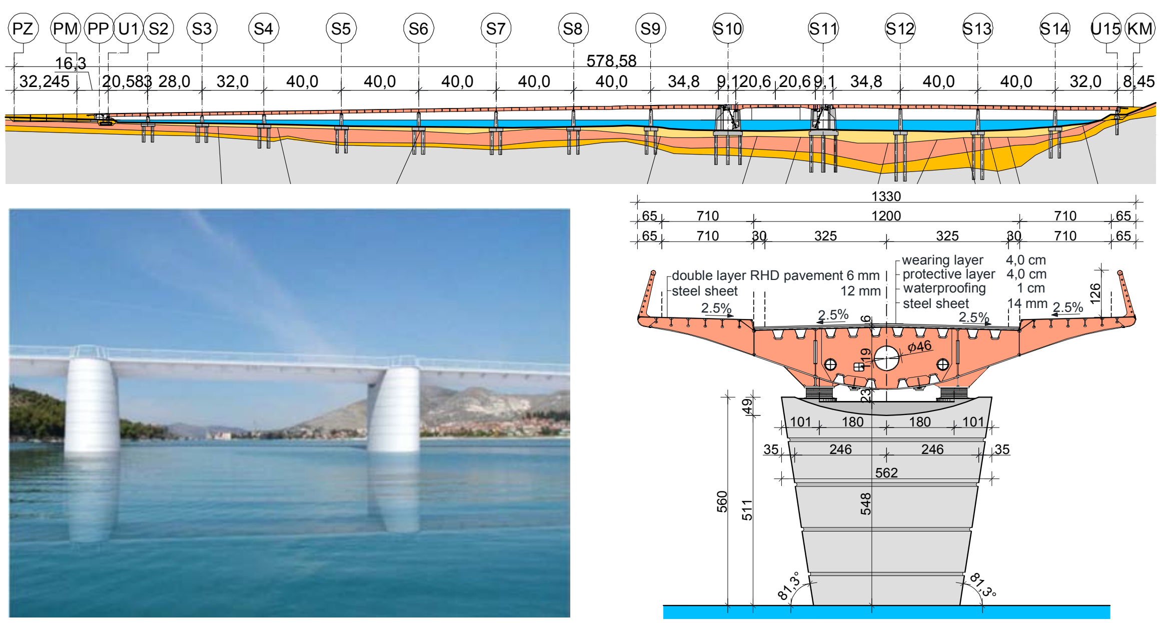

Figure 2. Trogir – Čiovo Bridge: longitudinal layout, computer rendering showing spaciousness of the bridge enabling a good view of the old town and cross section at immoveable parts of the bridge

3.3 Cable stay Jarun City Bridge

The Jarun Bridge has been designed to improve traffic connections between certain districts of the capital as an urban bridge and hence contains the structure with recognisable original characteristics, well harmonized with the urban environment.

The concrete pylon on the right-side bank is shaped as a broken plate member. In the tie anchoring zone, it is perforated with a set of rectangular openings of a carefully selected inclination. Below the tie level, the pylon features a roof-shaped solid cross section all the way down to the opening provided for the passage of light railway through the pylon, while under the pavement the pylon assumes once again its solid cross section [8]. Respecting the vertical urbanism and cultural heritage, pylon height of 88 m does not surpass the tallest building in the Zagreb City, the historical cathedral. Attractiveness of the concrete pylon is archived by giving special care to its design. The pylon inclined shape is based on the “tug of war” position (man’s position during rope pulling). Six vertically shaped openings on the upper part of the pylon, providing the necessary lightening of the structure, offer continues game of shadow, both day and night [3]. In the transverse direction, the bridge is 42 m in width, and features a light urban railway in the middle, and three traffic lanes for each direction of travel, and pedestrian and bicycle paths. Superstructure is a continuous box type prestressed girder with five chambers and constant depth. As consistency of form is an important aesthetic consideration, the columns, comprising two concrete wall piers with variable dimensions in both directions, are designed in harmony with the pylon and the superstructure.

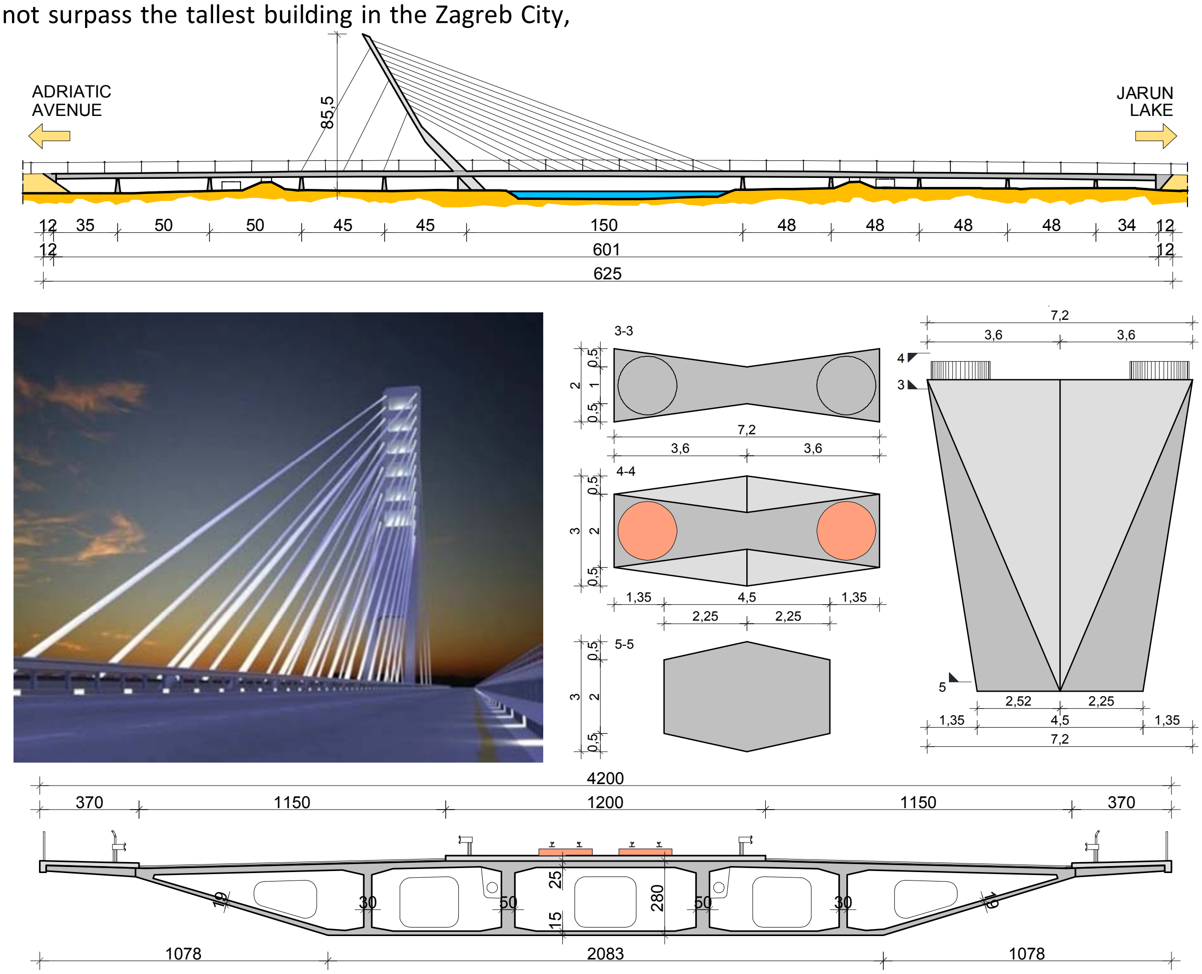

Figure 3. Jarun City Bridge: longitudinal layout, night view, variable size piers and wide cross section

3.4 Continuous space girder Bundek Bridge

The main expected feature of this bridge was its incorporation into its urban surroundings [9] while at the same time trying to foresee what the architectural future would be like. All options were taken into account to ensure the expected improvement particularly in urban design, conservation of natural assets, advancement of traffic communications between the Sava River banks and development of existing and construction of new sports and recreation facilities. The urban character of Bundek Bridge can be seen from its vertical organisation and the importance accorded to public space amenities and surrounding areas. The structure of the bridge provides for longitudinal communication on two levels. The upper deck is foreseen for the road traffic composed of two separate pavements each 11,5 m in width and central median 7 m in width accommodating the light railway route. The bottom level of the bridge accommodates a pedestrian path that is directly connected with pedestrian areas on the banks by means of ramps, stairways and elevators. An interesting feature of the pedestrian path is its floor and railing realized in glass, which will create a striking visual connection with the river and its banks. Approach ramps rise very slightly toward entrance portals of the Bundek Bridge, which enables a highly favourable and attractive visualisation of surroundings of the above-described central urban space – new city centre. The superstructure is a spatial continuous steel girder made of the systems of inclined intersecting arches (frames). They have been formed by vertical intersection of longitudinal shells. Shells are warped surfaces formed of elliptical segments. There are three families of arches: arches above the pavement surface, arches at the pedestrian walkway, and arches of the concrete deck slab. Arches are positioned in both directions, at every 15.5 m along the bridge axis. The arches are 60.2 m in span, and are placed at 40°, and 140°, as related to the bridge axis.

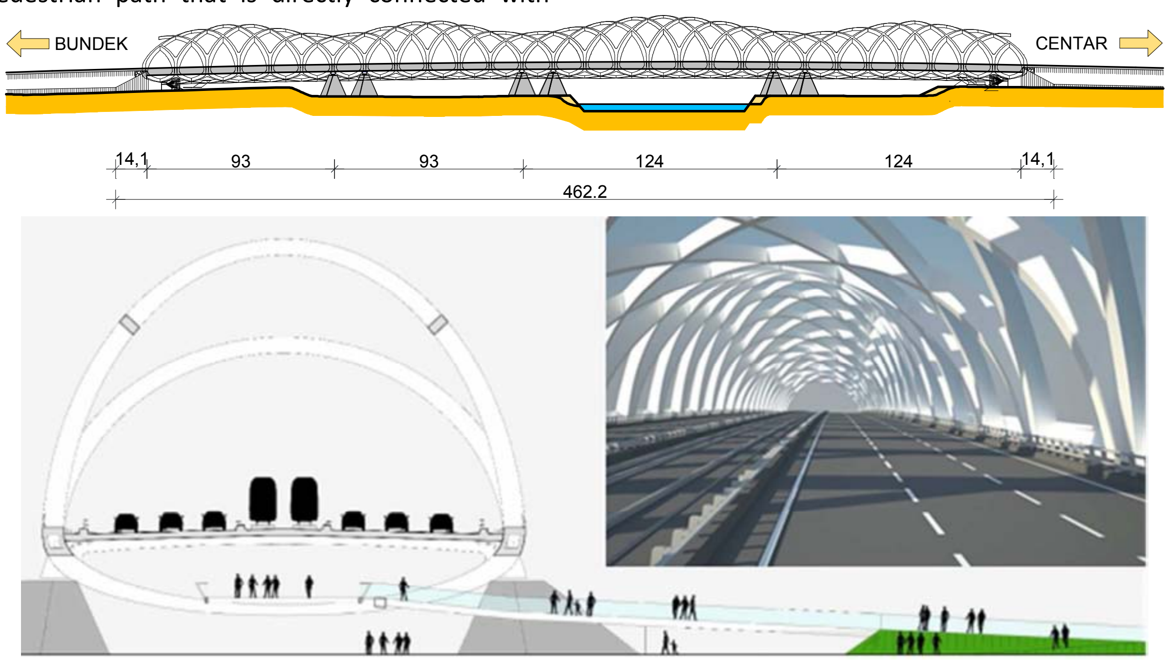

Figure 4. Bundek City Bridge: longitudinal layout, vertical organisation of space and view of steel structure

4 New Zagreb airport terminal

The economic activity and a growing number of air travellers prompted the expansion of the Zagreb international airport.

The previously described Bundek Bridge is located on the main road connecting the airport and the city and the similarity with the bridge design was actively pursued.

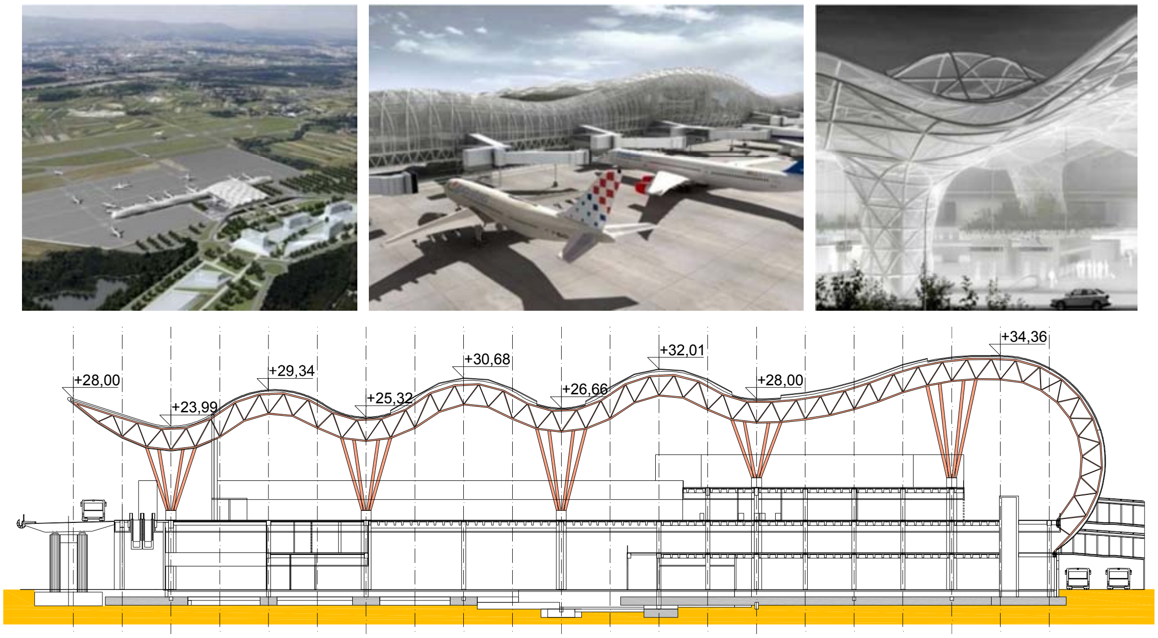

Figure 5. Zagreb Airport passenger terminal: aerial view, airplane stands, part of the roof, one of the building cross-sections transverse to the pier length

As an airport is not only a transport infrastructure but also a place where many users find their business and private interests, various aspects including town planning, environmental protection, architecture, structural solution, functionality, and traffic requirements, were harmoniously balanced to form this terminal building solution. The terminal building represents, in combination with development of the surrounding space, a new line in the expansion of the city of Zagreb.

The new Zagreb Airport passenger terminal consists of the main building, two tubular extensions (piers) for passenger communication – one at each side of the main building, and eight bridges extending from the main building and piers toward the runway. The architectural form is represented through its volume and surfaces, while the construction model is represented through a grid of load-bearing elements, with two distinctive structures, the concrete structure and the steel structure. The main building has the bottom reinforced-concrete structure with ground floor+3 floors and the right and left piers with ground floor + 2 floors. The roof structure of the main passenger terminal building and piers is a steel space truss structure. Maximum plan dimensions (shadows) of the steel roof structure of the main building (with the protrusion) are 152.3 m in the direction perpendicular to the piers, and 151.2 m in the direction along the piers. The shape of the roof is wavy in both directions, and it is oval (to coincide with the pier shape) at the façade facing the runway. The disposition of the roof structure of piers has been harmonized with the disposition of the roof structure of the main building.

5 Lapad City Stadium

The multifunctional Lapad City Stadium in Dubrovnik has a rectangular horseshoe design with roofed spatial tubular stands open on one side. They enclose the playground from three sides thus protecting the field from winds. The structural elements, stands and the roof are integrated in one structure. The elliptical oval shape of the roof is continued below the stands into the main bearing structural elements. The distance of the main elements in form of the bent letter Y is 8.0 m. The main structural elements in the stands area are perforated steel I shaped girders transmitting the load by a truss system.

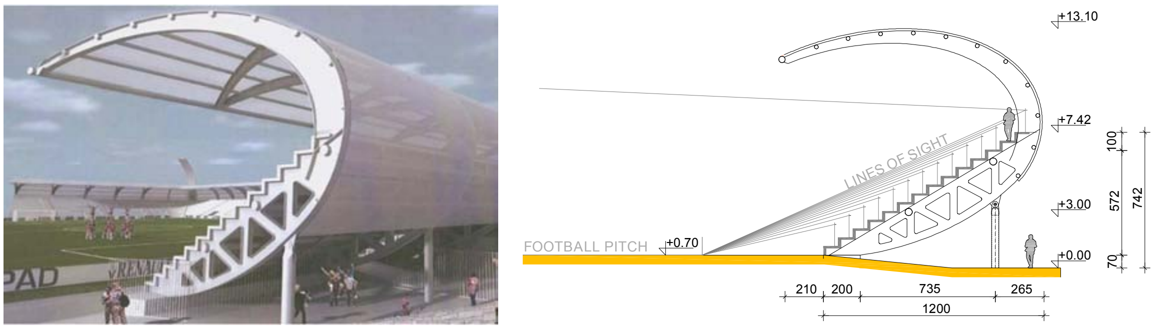

Figure 6. Elliptical shape of the Lapad City Stadium stands

The adjacent free cantilever arms are bent I shaped girders connected to form a truss structure with a regular diagonal filling in the plan view. The total height of the structure is 13.1 m and the total layout width is 14.4 m. When analysing the load bearing structure of the stands an outer skin (which keeps the external environment out and ˝holds˝ the contents in) and a rigid main structure (which is visible from below) may be distinguished. This arrangement gives strength and flexibility. The outer skin of the roof can be renewed over time and, if locally damaged, can be replaced.

6 Conclusions

The structural engineer is traditionally educated to achieve safety, stability, serviceability, durability and integrity of the structure. The architect is educated to think more about the appearance and function of the new structure incorporating financial, cultural, socio-political and aesthetic factors. The necessity of joining structural and architectural approaches to achieve simultaneously the beauty of form and efficiency of structure in contemporary urban surroundings is elaborated through an airport, a stadium and few bridge projects. Those projects are the results of working team of professionals with different backgrounds, understanding and respecting each other and bringing their own creativity, originality, imagination, and intuitive judgement into joint design.

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