The main aspects of the bionic bridges building

N V Ivanova, A V Makarov* and S A Kalinovsky
Volgograd state technical university, Academic street, 1, Volgograd 400074, Russia

E-mail: pr.makarov@mail.ru

Abstract. The history of bridge construction has been analyzed. It is revealed that the bionic approach allows to design bridges to the greatest extent harmoniously forming a cultural landscape, public areas of the city and dynamically developing coastline in order to provide a comfortable living space sphere. This is due to the fact that architectural bionics is the direction that allows to borrow the architectural lines and volumes from nature, to create an object that most organically fits into the natural city environment. Some methodological approaches to the bionic engineering structures design and the possibility of their use in the formation of bridge structures in the modern city structure are highlighted. Some solutions of bridge structures elements, which, when used as components of bionic bridges are proposed. They will improve their efficiency from an engineering point of view.

Introduction
The bridges history construction is about ten thousand years. The search for solutions to engineering structures images formation directions common problems is performed in the aesthetic and constructive evaluation of historical bridges [1,2,3,4]. Traditionally, since ancient times, the bridges were the constructions, worn purely utilitarian function – they were used for transport and moving across the rivers, channels, ditches or gullies. The aesthetic aspect of design in relation to the bridge was hardly considered - it was considered that these engineering structures are not in need of any decoration, so only three famous words of the Vitruvius triad “Firmitas, Utilitas, Venustas” (strength, utility, beauty) were related to bridge structures [1]. They were built firmly, exploited for good, and the architectural expressiveness – beauty is not thought of. Over time, the situation changed, and along with other structures bridges built in the capital cities, were decorated with sculptures, towers, colonnades, but these decorative elements were installed on the span structures or approaches, but were not part of the bridge structures themselves.

The attitude of architects to transport facilities has changed with the spread of art Nouveau. Modern bridge building is represented by the St. Petersburg bridge of Peter the Great. The portal frame of this bridge became the only reflection of this style in the Russian transport construction. Smooth transitions, leaves, rounding, lights made of steel – all elements of this style.

The famous architect and theorist of architecture Corbusier saw the architect aesthetics crisis at the time when art Nouveau has exhausted its capabilities. Esthétique de l'ingénieur, Architecture, deux choses solidaires, consécutives, l'une en plein épanouissement, l'autre en pénible régression. L'ingénieur, inspiré par la loi d'économie et conduit par le calcul, nous met en accord avec les lois de l'univers [2]. It was a kind of challenge accepted by the engineers and architects. At the same time, the first bridges world giants began to appear – the main task of the engineers was to block as large spans as possible. And today we can see amazingly constructed bridges. The largest span among suspension
bridges overlapped Cycle bridge Akashi (Japan), the largest span among cable-stayed bridges covered bridge on island Russian (Russia), the largest arch bridge Lupu (China).

In recent years, interesting has become the forming bridge structures new methods application. In the engineering design practice, considerable experience has been gained in the bridge structures new architectural and structural forms creation. Straight lines gave way to smooth, the images evoke associations of movement, the desire of architects to provide soft transitions from artificial to natural has become noticeable. It is possible to mention such interesting buildings as Samuel Brown’s suspension bridge, resembling a spider’s web, Santiago Calatrava’s Mir Bridge, Mira cable-stayed pedestrian bridge across the Kura River in Tbilisi, the serpentine Python bridge in Australian Melbourne, the arched pedestrian bridge a butterfly in the English town of Bedford, a pedestrian Tulip Bridge in Amsterdam and some others. All of them are united by a bionic approach, an ideological and conceptual basis, which is the application of knowledge about wildlife to solve bridge building problems related to design, construction, and monitoring [4].

Thus, at the present aesthetic demands’ development stage, bridges in urban space do not only serve their functional purpose and act as symbols, specific accents and objects for attracting attention. Modern bridges of various purposes and types (recreational, cycling, pedestrian) combine the bionic approach in their images [4-6].

The bionic approach to the design allowed the bridge structures to become truly unique from an aesthetic point of view. However, a number of modern bridges, created in accordance with modern aesthetic trends have inefficient design solutions. Therefore, the authors propose the concept of a bionic bridge with an effective constructive solution.

Substantiation designing of bionic bridge of with effective constructed solutions
Architectural bionics is the postmodernism direction, the main task of which is to solve the architectural and natural environment harmonious symbiosis problem. This is an innovative direction that allows the design of engineering objects to take all the best from nature: reliefs, contours, principles of formation and interaction with the outside world. Thus, there are structures that are a kind of natural extension, not entering into aesthetic dissonance with it.

Bionic bridge is an object that forms the urban space. In many works concerning the issues of new design and riverine territories reconstruction, the need to improve the river cities visual foundations, the post-industrial landscapes transformation in the waterfront socially oriented space, which is usually associated with the bridges’ construction, which starts acting as the urban compositions and public spaces centers [7 -9].

There are the bionics concept implementation examples in the modern landscapes’ creation, for example, the island-palm in Dubai, as well as the construction of modern bridges [10,11]. Bionic approach in the architecture of bridges should be considered simultaneously from the position of saving materials, structural strength, improving the aesthetics of the image of bridge structures and is a promising direction in the development of engineering structures [12-14].

The assessment of their design features is associated with the bridge formation issues. With the bridge construction development there is a shift of priorities from straight, beam, arch or frame structures to the most effective combined.

Previously, the superstructure was a single structure (split, not split, covering several spans). The design of bionic bridges has changed: it is divided into separate planes: linearly longitudinal sections (fan bridge) linearly cross-sections, segments united by hinges, and sometimes oblique sections (The bridge of Women in Buenos Aires). The peculiarity lies in the fact that the division of the plane is manifested only in motion - in the divorce of the bridge. A special place is occupied by bridges bird. Their constructive image to the greatest extent recedes before visual perception of a construction. Such bridges can be associated with flying birds in their statics, as a bridge (project) across the Danube in Belgrade (Figure 1. a), or in dynamics at divorce (Figure 1. b) Another design feature is the cable-stayed bridge pylon position. It takes different forms: in the form of a harp (James Joyce bridge in
Dublin), in the inclined arrow form, a pylon with a fracture or the letter X (Bridge in San Paulo, Brazil).

However, despite the above mentioned, both straight beams and arches (including those located in series) find their application in the composition of bridges, designed taking into account the bionic approach.

![Figure 1. Bridges in Belgrade over the Danube (draft); in Rhyl, Wales, UK.](image)

Within the bionic approach it is possible to solve the bridge structures strength and stability problems and to introduce the new approaches to the reinforced concrete calculation, metal bridges, allowing to create the original structures. To do this, it is necessary to use modern methods of assessing the structures work, taking into account all the factors of materials influence and properties [15-19]. Modern bridge structures calculation methods incorporated in the software systems will allow to analyze the static, dynamic behavior of even very complex unusual and beautiful bridge structures, and modern high-strength building materials will allow to implement such projects. In other words, it is necessary to constantly improve the bridges structural solutions efficiency as a whole as well as their individual structural elements.

The design solution efficiency can be improved, for example, by selecting the width of the arch spans supporting the roadway construction [20]. In turn, the roadway construction should be carried out with the most effective use of modern materials. So, all modern metal bridges are “monometallic”, that is, all their elements are made of same brand steel. In this case, the most loaded sections have to be made more massive, which increases the weight of the roadway structure, providing significantly greater loads on the supporting elements, for example, arches, as well as foundations and bases. An effective solution here is the bimetallic design of the roadway structures, when the most loaded sections are made of more durable metal than ordinary ones [21].

**Engineering calculations of design solutions and their analysis**

The experimental part was carried out in accordance with the technique proposed by A.V. Makarov [19-21]. It consists in the following: the high strength modern materials use in those sections and proportions that experience overvoltage and the creation of forms that allow to fully use the structural parts unification, as well as allowing to consistently unload overloaded elements.

It is possible to project the economically effective metal superstructure only assuming the durable metal use for sections with great effort. The unification of the structure requires that the spans in all spans be equal. Consider the most widely used three-span continuous span structure of an all-metal bridge loaded with a uniform load $q_{\text{const}}$ (own weight). (Figure 2).

The supporting moment will be: $M_r = -\frac{q\cdot I^2(n^3 + 1)}{4(2n + 3)}$

In the central span, the maximum span moment acts in the middle section, and in the extreme is spaced from the middle by the value $\frac{M_r}{1\cdot n\cdot q}$, as shown in Figure. 2 [22].
We equate the maximum bending moments in the extreme and average spans and obtain the following expression:

\[
\frac{ql^2}{8} - \frac{ql^2(n^3 + 1)}{4(2n + 3)} = \left( \frac{qln}{2} - \frac{M_r}{l} \right) \left( \frac{ql}{2} - \frac{M_r}{lnq} \right) - q \left( \frac{l}{2} - \frac{M_r}{lnq} \right)^2
\]

(1)

**Figure 2.** Scheme of continuous span structure with aligned span bending moments.

Substituting the value of \( M_r \) and solving the transcendental equation with respect to \( n \), we obtain \( n = 0.794 \). At such moments it will be the same.

It is known that arched systems transmit on the foundation and the large thrusts base, which reduces their use range on weak soils. Multi-span arch bridges with equal spans (Figure 3) will render to the foundations of a large horizontal pressure \( H \) in the extreme supports. The perception of such pressure requires a strong foundation capable resisting shear.

**Fig. 3.** Scheme of the arched bridge with equal spans.

Central foundations are experiencing a lot of vertical pressure from adjacent spans, but is free from shear stresses due to the compensation of horizontal effort. In this case, reliable foundations are material-intensive and costly: intermediate due to large vertical loads, extreme because of the huge stay brace.

It is proposed to design the different-sized spans of the arch bridge, gradually reducing the size of the spans from the middle to the abutments. In this case, the adjacent spans spacers are not fully compensated, since in a smaller span the spacers are less due to a decrease in the span on the one hand and an increase in the \( f/l \) ratio on the other. In this case, the intermediate foundations will not become larger. The foundations designed to take heavy vertical load, will take small horizontal load as well. The extreme foundations can be greatly facilitated by a significant reduction in shear forces. The
bridge example shown in Figure 4 shows that in case of successive reduction of spans, the horizontal pressure is distributed between all the foundations.

![Figure 4. The scheme of the bridge with decreasing spans.](image)

Main span at $f/l = 0.1$, $H = 1.25 \text{ql}$. Adjacent span: span $0.8 \text{l}$ then $f/l = 0.125$ and the spread in this case is $1.0$, related to the size of the main will be $0.8 \text{ ql}$. The difference between the horizontal pressure of the main and adjacent span will be $0.45 \text{ ql}$ or $0.36$.

The arch bridge spans reduction by 20 percent consistently allows to align the efforts transmitted to the arches foundations and reduce their size. In addition, the arches with a symmetrical reduction of spans from the middle to the edges are architecturally expressive structures and can be used as the basis of the bridge designed in any architectural style, including the bionic approach use.

**Summary**

1. Bionic bridges are the objects that form space, form the reference points of the urban landscape and create a visual city code.
2. The biotic bridges role is both in the urban development elements integration and in the cultural space creation with a comfortable urban environment due to their special aesthetic orientation.
3. In order to improve the design solutions efficiency, the main load-bearing structures spans optimal ratio variant, as well as the bimetallic design of the bionic bridge roadway structural elements is proposed.

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