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VERITIES OF THE STRING BRIDGE

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Abstract

For centuries, building masters, shaping architectural forms, were guided by certain canons that seem to be extremely important in the case of designing buildings constructed with string structures. In these buildings, the static pattern becomes the basis for the aesthetic creation of the assumption and makes *authenticity of its form*. The elements of the tension structure responsible for the statics of objects are not only a structural matrix, but on the contrary have an important role in determining the shape of this architecture.¹

In the process of suspension and cable-stayed bridge design, certain rules must be taken into account. Therefore, an attempt was made to systematize and verify them.

Keywords: bridges, string structures, rules, verity of form

Streszczenie

Od wieków mistrzowie budowlani, kształtując formy architektoniczne, kierowali się pewnymi kanonami, które wydają się niezwykle istotne w przypadku projektowania obiektów zbudowanych z zastosowaniem konstrukcji cięgowych. W budowlach tych bowiem schemat statyczny staje się podstawą kreacji estetycznej założenia i stanowi o *prawdziwości jego formy*. Elementy struktury cięgnowej odpowiedzialne za statykę obiektów nie są tylko konstrukcyjną osnową, lecz przeciwnie – pełnią istotną rolę w określaniu kształtu owej architektury.

W procesie projektowania mostów wiszących i podwieszonych bezwzględnie należy uwzględnić pewne reguły. Dlatego też podjęto próbę ich systematyzacji i weryfikacji.

Słowa kluczowe: mosty, konstrukcje cięgnowe, reguły, prawdziwość formy

1. INTRODUCTION

In the modern world, beauty is not a general category of aesthetics. It can be considered that it is an open concept, impossible to define precisely. Aesthetes, more and more convinced of the subjectivity of beauty, have come to the conclusion that formulating a general theory of beauty is not possible. The problem is not only in language difficulties, but also in the fact that beauty as an aesthetic value is closely related to non-aesthetic values, mainly with the verity.

In order to improve the aesthetic value of the structure, it is necessary to eliminate undesirable features – incompatible with the overall picture and design features, emphasize the beneficial ones – true and accurate. Therefore, it is necessary to thoroughly rethink the project

¹ Jolanta Tofil, *Architectural Form of String Structures*, doctoral thesis, Faculty of Architecture, Silesian University of Technology 2004.

in terms of its intended function, appropriate form and structure, make drawings and models in the right scale, as well as use the experience gained from already completed objects. Positive effects are achieved by separate assessment of elementary parts of the structure in relation to the whole and the entire structure to a comprehensive solution.

The correct method of shaping objects constructed with string structures cannot be included in templates or patterns applied to ensure that we create perfect buildings. However, you can distinguish certain rules that are useful as guidelines for composing and collating elements of the whole object and serve to verify the concepts:

- *Authenticity of form* – this criterion is required so that the given form evokes true associations, i.e. in accordance with the purpose and condition of the work, indicate the functional qualities and usability of the object. This principle, particularly significant in string constructions, means that the shape of the building should depend on the distribution of forces and the properties of the materials used. In bridges, it should be treated as a superior rule – it includes regulations resulting from the functional purpose and the conditions of construction and operation.
- *Totality criterion* – means a conscious influence on the appropriate association of geometrical or physical elements of a building; because aesthetic experience is conditioned by the visibility of all the elements of form and their interdependence.
- *Simplicity criterion* – recommends to pursue the reduction of the perceived components – the form should be simple, and the number of elements small.
- *Form readability criterion* – this principle complements the previous two, stating that the aesthetic impression is easier to create when the interdependencies of the forms are clear and easily discernible. This principle also requires seeking forms appropriate for the materials used, as well as adapting these forms to the methods of implementation and use. Forms of elements should not blur the function and arrangement of forces.
- *Principle of avoiding emptiness* – means rejecting meaningless and incomprehensible forms. A building attracts attention when it has attractive features. Therefore, forms that do not show differences between individual elements, do not show dimensional proportions and the system of transmitted forces, and do not indicate utility functions and method of execution, should be avoided.
- *Principle of regularity* – includes uniformity features between elements of forms, colors, lights, etc., giving rhythm and proportions. The architectural design of the object consists in grading the expression of regularity features so that they form a harmonious whole.

Understanding and applying the above assumptions is a necessary condition, though not sufficient, for the constructed facility to be socially accepted and consistent with the design assumptions. For complete success, you also need the artist's commitment, his knowledge, experience, internal sense of beauty, in other words all that we call the designer's "master class". It is also important to know the environment in which the object is to be located, some knowledge of cultural conditions – history and regional traditions, and knowledge of all economic factors.

Principles should never be treated separately or even more selectively because they affect overlapping and complementary areas. It should be realized that these rules apply not only to the object, but also to each of its parts separately, as well as the environment of which the designed object is an element. It should also be remembered that full consideration of the principles of correct shaping is necessary both in the initial phase, when the form and overall

proportions of the building are outlined, and in the final phase, when deciding on the details that also have a significant impact on the appearance.

2. STRING STRUCTURES

Based on the analysis of string structures, it is also possible to determine general principles affecting the *authenticity of form* of designed engineering objects with this type of structure:

- Current, more accurate knowledge of the actual work of the structure indicates that synthetic forms are excellent in terms of structural efficiency. Therefore, the criterion of the *authenticity of form*, basic for string structures, in principle guarantees them a yield value. Buildings in which string structures are used are a case in which real rationality turns out to be identical to visual rationality.
- The most important is *order* – it concerns the system order and the order of lines and edges. In the field of bridge construction, this means choosing a specific structural system (e.g. suspended or cable-stayed), but not a mixed system. Chaos usually doesn't create beauty in architecture.
- It is important to follow the principles of *selecting the right proportions* – the interdependence of the geometry of the string system, its form and structure, and other building components is very important. In bridges, it means the harmony of proportions between: the span length and the object height, the clear span and the construction height, etc. Sometimes the contrast leads to beauty, e.g. the impression of slender beam can be emphasized by the thickness of the supports.
- Striving for *simplicity and purity of construction* – avoid all useless additions and ornaments. String structures are received positively when their structure consists of only the necessary elements.
- *Functionality and usability* are indispensable – considering the aesthetic qualities of a technical product only makes sense if it fulfills its task.
- It is important to *adapt the architectural form of the object to the surrounding environment* – this applies to:
 - the structural system,
 - the materials used,
 - the proportions of dimensions and cross-sectional shapes of the elements,
 - the chiaroscuro and colors.
- Shaping the structure so that it can be *erected with the simplest possible methods* – so it is important to use appropriate materials relative to the adopted structural system. The final product should express the special features of the material, e.g. its high strength results in considerable slenderness.
- *Economic factors* should be taken into account in the design process – omitting this issue may result in the structure not achieving perfection in terms of appearance and the engineering thought it contains.
- *Constant development of the form of construction together with the progress in science and technology.*
- *Creative activities and intuition* have a significant impact on design – they allow to discover and develop new forms, often better in terms of execution and design than traditional ones.

3. BRIDGES

Since ancient times, bridges have been referred to as works of engineering art. Although, this term in the Middle Ages also defined various types of mechanical devices, the performance of which went far beyond the capabilities and knowledge of the average builder, but it proved that the construction of bridges went beyond the sphere of craft activity, falling within the scope of creativity.

This means that this is a field containing, in addition to very important technical thought, also features perceived in aesthetic categories, including the aforementioned authenticity of the form of individual elements of the object, as well as the general expression of the building. Bridges are shaped not only as a result of rational actions, but also emotional associations. This is facilitated by both the communication and integration functions of these buildings, as well as their landscape impact, especially strong in the case of large-scale constructions.

Along with the continuous development of communication and urbanized areas, more and more bridge structures are created. They become an element of aesthetic individual and collective reception, in relation to the bridge itself, as well as the space of which they are an integral component. Designing bridges is therefore an important architectural, engineering and urban issue. For this reason, bridge structures belong to the small group of engineering works in which architectural demands regarding function, structure and form can be fully met. Their form should be the result of strict compliance with the function and the shaping of its elements based on static and strength analyzes. In most cases, a bridge designed in this way should be beautiful. However, in the most expressive works of bridge construction there is something elusive that does not fall within these frames – there is a load of artistry, talent and intuition of both the designer and the contractor. This justifies the view that this sphere of engineering is an art, the art of building bridges.

Greater than average bridge expression is achieved by some compromise between its function and static-strength optimization, and the specific thinking of the engineer-creator in a given era. This applies mainly to his feelings in the emotional association of individual building elements and the entire object with the environment, with natural or artificial space, i.e. urbanized environment. However, there are no strict recipe for beauty as well as for the universal positive aesthetic reception of a given bridge structure. However, based on experience, it is possible to determine certain conditions and factors, compliance with which in the design phase creates the chance that a given object will be received in a positive way, and even with admiration.

3.1. ADAPTING THE BRIDGE TO THE SURROUNDINGS

It should be remembered that among all communication installations, a poorly designed bridge interferes most with the environment. Undoubtedly, the individual character of the design is very important, however, an equally important factor in the aesthetic shaping of the bridge is to capture the compatibility of its size and form with the landscape layout in which it is to be built. The bridge should not only be attractive when looked at but should give the recipient the feeling of a finite whole harmonizing with the environment, whether artificially shaped or when it is constituted by a natural environment. This is an indispensable feature of every properly designed bridge.

This inseparable connection of the object with the environment entails the need to use the appropriate scale and shape, as well as the individual selection of materials from which it will be made. A vast landscape will require a bolder approach than an intimate rural environment, even if in both cases the nature and size of the obstacles are the same.

In modern cities, the designed structures should be as readable, simple as possible, with clear and geometrically unambiguous forms. Recommended solution are string bridges that create the impression of lightness and boldness.

Among repetitive objects (but not identical, such as overpasses over motorways), it is advisable to make a special, even extravagant structure. An unusual object can easily become a sign in space – a landmark that determines the rhythm of travel.

The location of the bridge in the horizontal and vertical plan is an important issue. In the past, due to the lack of technical means, the bridge dictated the conditions for routing the road. Whenever possible, it was constructed at right angles to a river or other obstacle. Also, the grade line on the bridge was led in an arc with a small radius. Nowadays, the design of the bridge is governed by the arrangement of the road line. It is advisable to extend the grade line in a vertical arch along the entire length of the bridge, even when a large radius is formed.

It should be mentioned that water obstacles occurring in both natural and artificial environments place additional constructional requirements for designers. At the same time, however, they give a special chance to shape a bridge crossing with high aesthetic values. The reflection of an object in a water surface can become a source of positive emotional feelings. Elements such as the side silhouette, forming the bottom of the spans and the shape of support units, i.e. the support, the support area of the span and e.g. a lantern or pylon have a special share in this acceptance. It is important to analyze the reflection of buildings in water at different times of the day and night and even at different times of the year in combination with natural and artificial lighting. This applies in particular to city bridges, but also to all those that play the role of a place mark in the landscape.

3.2. BALANCE OF FORCES

The principle of verity requires adaptation of bridge shapes to external and internal forces. The dependence of shapes on systems of forces is the subject of structural design both in terms of determining their forms and checking strength. It should be noted that this relationship is of fundamental importance in aesthetics along with the relationship between road shape and vehicle traffic as well as bridge and obstacle shapes. The above relationships are of great importance for the readability of the bridge's form and are achieved by highlighting its characteristic features.

The readability of force systems in the shape of a structure requires simplicity of shape, and thus avoiding excessive numbers of elements and excessive diversity. Readability also requires good visibility – absolute avoidance, accidental application of various elements on the image plane. According to the principle of the whole, the legibility of the object requires the visibility of entire elements. The elaboration of expression of bridge structure elements should be based on compliance with these principles. The task of expressing the shape dependence on the system of forces is to emphasize the elements constituting separate wholes according to the type of forces transferred.

The development of the expression of the force system includes the stability and deformability of the elements. One of the basic and most subtle topics of stability and force distribution is the shape of supports. This is a significant example of visual sensitivity to stability shown in shapes. Expression of columns is usually stronger than other structural elements such as beams.

In no type of bridges does architecture depend so clearly on the balance of forces as in suspended and cable-stayed bridges. This is due to the special simplicity of their systems and systems of forces operating in them. In these bridges, the force signs are visible in every element. Tie rods only have tensile forces, while supports only have compressive forces. The ability to transfer bending moments through the platform and stiffening beams is hardly visible, due to the small dimensions of the elements of these parts compared to suspension elements. The shapes of the main structural elements of suspension and cable-stayed bridges: strings and supports, are adapted to the forces constantly in these operating systems and indicate their systems with particular clarity. These elements show the harmony of their shapes closely adapted to the forces of gravity.

The features of regularity are visible in the lines of the strings, in their parallelism, in the equal spacing maintained for structural reasons in both hanging (hangers) and suspended (harp string) systems. The system with strings converging in the vertices of the columns (radial, fan-shaped) instead of the rhythm of parallelism has a rhythm of angles occurring between them. Finally, the poles usually have uniformity features in a straight and vertical line. All these uniformity and rhythm systems increase the expression of the force system. It is emphasized by the lightness of the structure, resulting from the great strength of the materials used and the minimal cross-sections of the strings – tensile elements, and therefore not requiring increased rigidity.

Braces between pairs of columns of the same supports transfer considerable forces. In former bridges, they were often belts of powerful trusses, so contrary to the great advantages of the architectural forms of suspension bridges. At present, these braces have forms suitably adapted to the overall aesthetic expression and rather indicate that pairs of columns constitute one structural whole.

Stay bars with a low height in relation to the span are clearly associated with the platform, and the whole drawing gives expression to the road and does not distort the drawing of the system of forces.

Cable-stayed bridges have a different architecture than suspension bridges – there are no ropes hanging freely and indicating the continuity of the span system. The system of converging or parallel strings, according to Wasiutyński, gives the impression of a part of the mechanism, not of the systems adapted to bear gravity.² This sentence probably results from the views prevailing at the time these statements were made. The viewer of that time was not used to this type of modern constructions and was only gradually getting used to them. The shapes of steel or reinforced concrete columns were adapted to the condition of equal strength, changing their cross-sections according to the exponential function – wider at the base than at the apex. This variability gives the right expression of the balance of forces.

² Z. Wasiutyński, *O architekturze mostów*, Państwowe Wydawnictwo Naukowe, Warszawa 1971.

3.3. CHIAROSCURO AND COLORS

The play of light and shadows on the string structure is an important factor in aesthetic reception. It depends on the location of the object relative to the world, but also on the shape of the structure. Chiaroscuro factor is very important in the case of bridges as water crossings due to the reflection in their mirror.

Lighting is used to focus the attention of the viewer, and blackout – to invert it, properly designed illumination can significantly emphasize the basic advantages of the object.

The problem of chiaroscuro is also related to the color of the building, which should be analyzed separately for individual components of the structure. Metal elements acquire the color foreseen by the designer, the possibilities of color selection are great. However, it should be remembered that the object is received better when the entire supporting structure is painted in one color. In case of bridges good effects has a color variation for acoustic barriers, balustrades, handrails and lanterns. The colors of the handrails should be different from the colors of the metal supporting elements, because the role of the handrails is different from the role of these elements. Since the handrails carry less strength, their color should be brighter. A good solution is to make a handrail made of stainless steel because the best visual effects are achieved by matching the colors to the natural material properties or their interpretation features.

Attention should also be paid to the issue of matching colors with types of forces. Like all aesthetic issues, this is also the subject of experience. Color dependence on forces is associated with the dependence of color on the type of material. The principle of verity requires a differentiation of the color of concrete elements from steel, as well as systems of forces. It is obvious that the differentiation of materials coincides to some extent with the differentiation of forces, therefore the selection of colors for the material and forces should be solved together. The experience gained in this case suggests some statements:

- light colors give the impression of lightness and greater strength; however, do not paint the metal parts of string systems white because this color doesn't seem to explain anything without giving any expression;
- natural colors are best received in concrete and stone structures; the texture of the concrete and the method of stone processing are also important, which affects the reception of the intensity of the color;
- there is full freedom in choosing the color of metal elements; this statement is due to the need to distinguish metal from concrete by color in accordance with the principle of verity;
- metal elements should have darker or more intense colors than the colors of concrete elements to emphasize their small cross-sections;
- the last statement concerns the possibility of coating metal elements with coatings of any materials to protect them against corrosion.

This implies that in the string systems light colors should be used to emphasize the strength and lightness of the cable-stayed or suspended structure. A very good aesthetic effect is also given by the use of very intense colors for the load-bearing elements (e.g. painting the bridge structure orange – the Golden Gate bridge in San Francisco (Ill. 1), giving the load-bearing structure an intense yellow color – Renault Center in Swindon (Ill. 2), etc. It goes without saying that the choice of color depends on the landscape against which the

object appears. Intense colors are appropriate in an environment with strong play of light, while glaring in a dimly lit landscape.

4. SUMMARY

In the process of bridge design, certain canons must be taken into account. One of the basic elements affecting the authenticity of the object is high quality. It means the best quality of construction and finishing materials used, optimal technology of performance and maintenance, but above all the highest level of design.

The importance and role of the *right proportions and attractive form* are beyond dispute.

Acceptance of the future is not always taken seriously enough in relation to its weight. It is often difficult to avoid some embellishments typical of the prevailing fashion, perceived as a kind of oddities of the designer. Bridge structures belong to structures with long-life service. They are designed for several generations – sometimes they serve several hundred or even several thousand years. Some of them we admire for an exceptionally proportionate, understandable, beautiful form – they please our eyes with their attractiveness, winning praise for many generations.

However, compatibility is the most important canon for shaping bridges. The bridge in every environment affects the observer with some power, although in the vast majority of cases its beauty was not the primary goal of the engineer's work. Although, even a single bridge can significantly increase the aesthetic value of the area in which it is located, it should nevertheless harmoniously blend in with the surroundings. Sometimes contrast can have a positive effect, but operating it requires a unique sense, great imagination and experience of the designer.

The construction of the bridge must be in line with social expectations. The designer should not suggest something that will not be generally accepted. Public opinion, supported by mass media, is a great force to be reckoned with.

The principle of compliance also applies to the very important relationship between the form and function of an object. It is extremely important that this relationship is legible, even to an outside observer. The arrangement of structural elements should clearly indicate the magnitude and directions of the flow of internal forces. Knowledge of the function is necessary to understand the form.³

To sum up, all constructions in which string structures are used should be shaped in such a way that the structural system and the course of forces are simple and legible in the expression of the architectural form, eliminating all imitations, decorations in particular.

³ Constructivism followed specific principles, which included:

- strict compliance with the form and function of the structure;
- treating the expression of gravity as the primary means of artistic expression;
- using innovative achievements of construction techniques.



Ill. 1. Renault Centre in Swindon, arch. Norman Foster, www.fosterandpartners.com



Ill. 2. Golden Gate Bridge in San Francisco, www.budowle.pl

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