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Fundamental Considerations on the Aesthetics of Bridges

Considérations fondamentales sur l'esthétique des ponts

Grundlegendes zur Brückenästhetik

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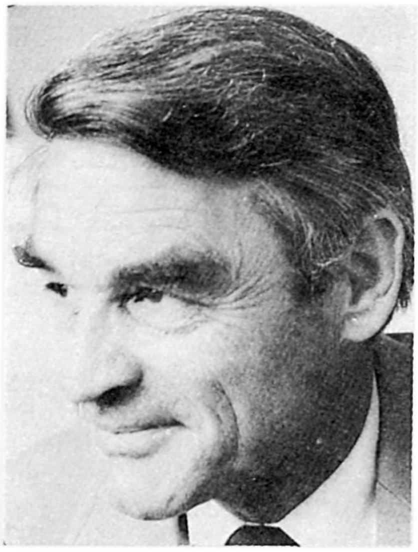

SUMMARY
Bridges are special among works of engineering in that their visual form is determined by a combination of technical and cultural considerations. This paper presents criteria, which reflect this fundamental characteristic of bridges, for assessing aesthetic impact. In addition, it proposes measures to improve the general standard of visual quality in bridges through reforms in education, design practice, and administration of projects.

RÉSUMÉ
Les ponts sont des ouvrages particuliers conçus par des ingénieurs et dont la forme reflète non seulement des aspects techniques mais encore culturels. Le présent article fournit quelques critères que l'ingénieur spécialiste des ponts devrait prendre en considération lors du projet, quant à l'aspect esthétique des ouvrages. Toutefois, outre une amélioration générale de la conception de ces constructions, cela exigerait égalemeent des modifications dans la formation, la pratique des projets et l'adjudication des marchés.

ZUSAMMENFASSUNG
Brücken sind besondere Ingenieurprodukte, bei denen die Form neben technischen auch kulturelle Aspekte wiederspiegelt. Im vorliegenden Beitrag werden einige Kriterien dargestellt, die der Brückeningenieur beim Entwurf im Hinblick auf das Erscheinungsbild des Bauwerkes beachten sollte. Darüber hinaus würde aber eine generelle Verbesserung der Brückengestalttung auch Änderungen in der Ausbildung, der Entwurfspraxis und der Auftragsvergabe erfordern.

Introduction

Works of civil engineering are, first and foremost, objects with clear practical purpose. They serve the needs of society by facilitating transportation, generation of energy, supply of clean water, and disposal of waste. To be effective, they must fulfill their specified functions and be safe and serviceable. Because the construction and operation of large civil works usually entail large expenditures of public funds, it is of primary importance to keep the ratio of costs to benefits as low as possible throughout the life of the project. This is achieved by civil engineers through consistent application of the most up-to-date technical knowledge in the design and construction of large projects.

As a result, the visual form of civil engineering structures follows directly from their function and the current state of technology. Purely visual criteria, if considered at all, are limited to the embellishment of minor details.

Works of architecture, on the other hand, must satisfy functional and cultural requirements. Because cultural costs and benefits cannot easily be expressed in monetary terms, it is rarely possible to establish an unequivocal ratio of costs to benefits for architectural projects. Cultural aspects are expressed through visual form, which is consciously and carefully designed. Technology is but one of many means at the disposal of the architect to create the desired visual effect. The costs of fulfilling cultural requirements through appearance are often substantial.

In the context of visual form, bridges occupy a special place between engineering and architecture. Bridges are undeniably practical structures, built to facilitate the movement of people and goods across obstacles. As with other public works, economy has dictated that bridges be designed and built using the most advanced technology available. This has resulted in an intimate link between technological developments and the appearance of bridges and clearly places bridges within the domain of engineers rather than architects.

Bridges are also objects of prominence in our environment. Their size and number have made them integral parts of most urban and many rural landscapes. Bridges thus hold great potential for enhancing quality of life through proper design of their visual form. and in the hands of gifted designers, they can even be vehicles for artistic expression. Aesthetically pleasing bridges do not follow automatically from technical considerations, however. Even when requirements regarding safety, function, and economy are satisfied, appearance may still be unsatisfactory. The raw form resulting from technical considerations can and must always be refined through conscious aesthetic choices.

The importance of aesthetics has always been recognized by great bridge designers, whose professional lives have been distinguished by ever-increasing concern for the appearance of their structures. This intimate relation between aesthetics and technology may be one reason for the fascination that bridges have always held for engineer and layman alike.

Vocabulary and Criteria

Traditional vocabulary and criteria are often ill-suited for the discussion and evaluation of the aesthetics of bridges. For example, abstract concepts such as the golden section are of little value, since they do not account for the relation between technical and cultural aspects of design. It is preferable to develop a new vocabulary and new criteria based on observations of existing bridges.

As a first step, it is necessary to consider both the relation of bridges to their environment and bridges as independent entities. Bridges are not only elements of a larger landscape but are also artifacts of the historical era they were built in. Environment is thus considered here in a broader sense and can be broken down into two spatial components:

1. Natural landscape and topography

2. Man-made landscape, including existing structures

and two temporal components:

1. History and tradition
2. Contemporary intellectual climate and state of development of technology

Designers can integrate bridges into the environment by an appropriate choice of structural system and of scale (fig. 1). Careful consideration must be given to the relative importance of the previously mentioned components of environment. Although topography and state of development of technology normally govern, higher priority must often be given to existing structures and tradition, especially in urban areas. Structural dimensions–in particular length of spans and height of piers and towers–must be carefully chosen so as not to clash with topography and existing structures.

The design of bridges as independent entities can be characterized in terms of the following criteria:

1. Visual expression of efficiency
2. Order and unity
3. Artistic shaping

The purely technical concept of efficiency, i.e. maximum effect with minimum consumption of materials, is visually expressed through slenderness and transparency. Slenderness depends primarily on the form of the superstructure, in particular on the ratio of depth to visible length of the girder. Transparency is achieved through proper design of piers and arrangement of span lengths.

Order and unity are achieved through clear organization of the structural system and through coherent cross-sectional shapes (fig. 2). Discontinuities in form and in the principal dimensions (depth and width) should be avoided whenever possible. For example, precast girders should not be used in one portion of a bridge when cast-in-place box girders are used in another. The discontinuous cross-section of hammerhead piers can be particularly disturbing unless the transition from pier to head is carefully shaped.

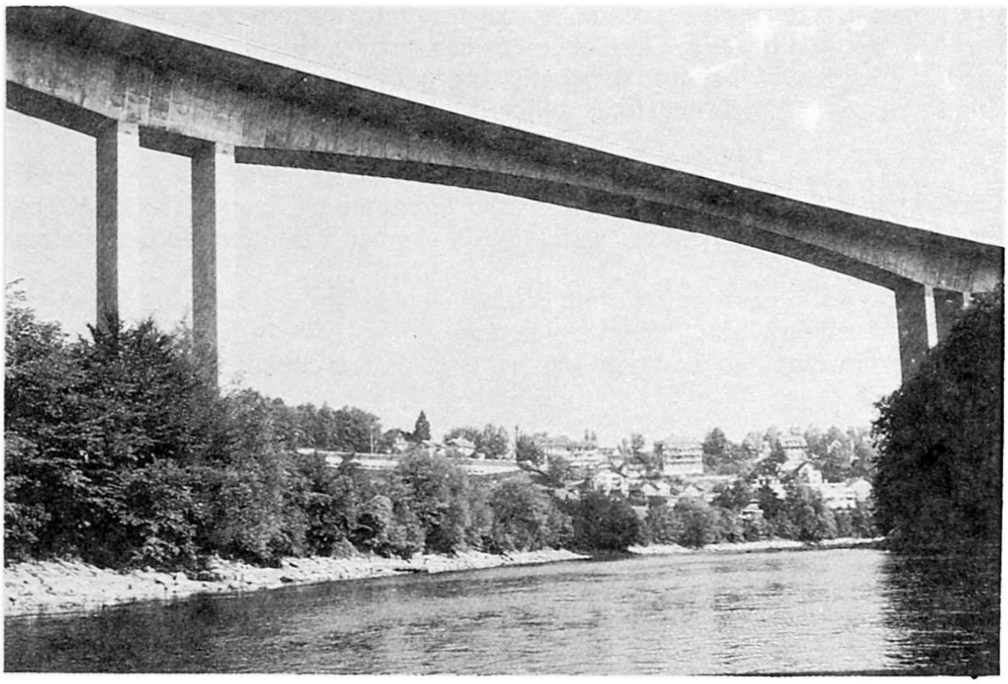

Figure 1
Suitably chosen bridge height and span lengths help to integrate bridges into their environment

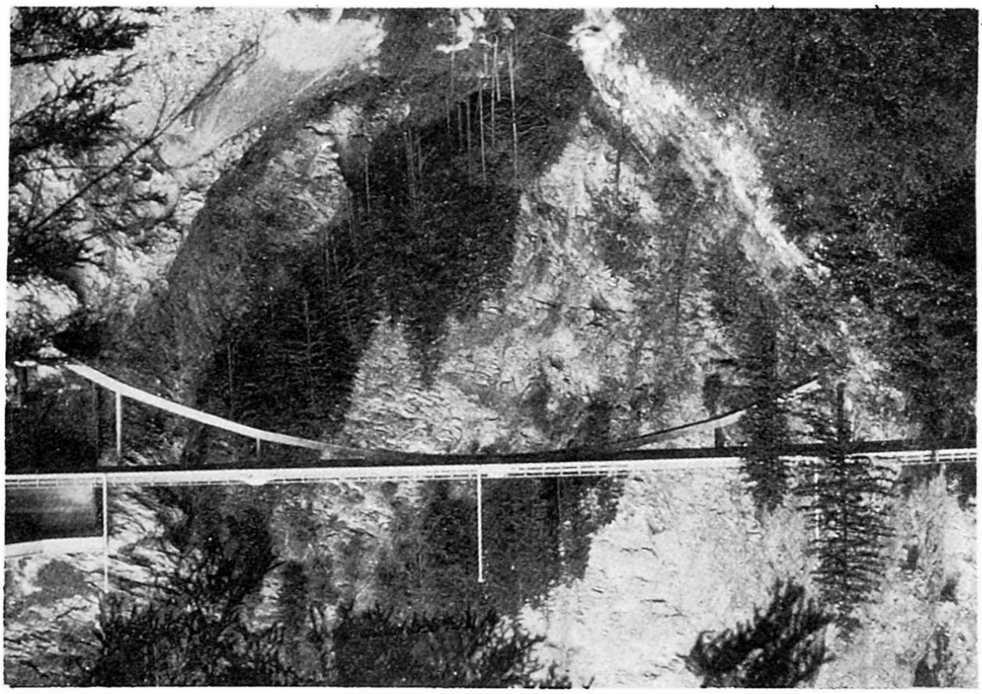

Figure 2
Mutually consistent cross-sections for arch, spandrel columns, and girder give this bridge a high degree of order and unity

Artistic shaping can be achieved through the following methods:

1. Visual expression of the flow of forces
2. Members and cross-sections that minimize stress
3. Light and shadow effects
4. Non-structural components and ornamentation

The flow of forces is often well expressed by the structural system itself. It is particularly evident in arch and cable-supported bridges. Flow of forces can also be articulated by proper three dimensional shaping, which is especially suitable for expressing stability transverse to the axis of the bridge, and by variation in cross-section dimensions, which can be used to emphasize the magnitude of stress in members.

Cross-sectional shapes and members that minimize stress are particularly suited for piers, towers, and arches. The resulting form often agrees well with the layman's intuitive notion of elegance.

Mechanized methods of construction often produce temporary states of stress that are different from those in the completed structure. The associated temporary flow of forces is best left unexpressed in the structure. It is preferable to deal with high stresses during construction using temporary measures (fig. 3).

Light and shadow effects, non-structural elements, and ornamentation have no direct relation to the technical aspects of bridges. These measures are best left to designers with well developed artistic ability.

The appearance of bridges can only be properly evaluated in three dimensions, using computer graphics or large-scale models. All possible points of view must be considered. Two-dimensional drawings are normally inadequate for this purpose, even for designers with good three-dimensional imagination (fig. 4).

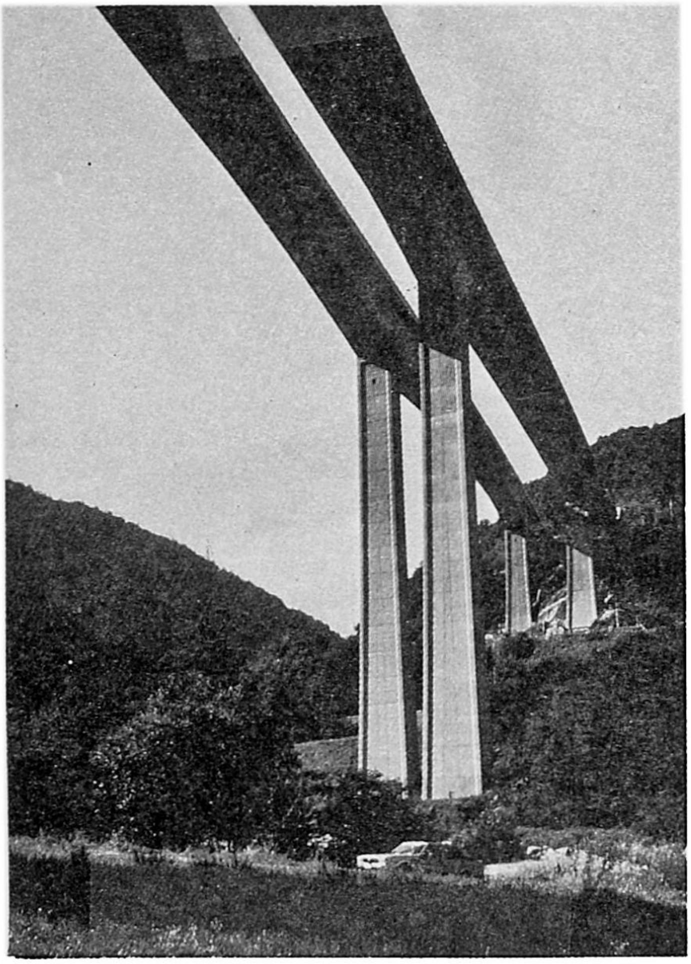

Figure 3
The cross-section and form of the piers are visual expressions of the flow of forces. The somewhat massive dimensions of the cross-section were required to resist critical loads occurring during construction.

Improving Bridge Aesthetics

The evolution of structural systems for bridges has, in recent decades, resulted in several commonly built types. In most parts of the world, one or more of these systems have been established as standards and far outnumber all other types. Unfortunately, the design of most of these standards has been limited to questions of safety, serviceability, and economy, with little or no attention given to aesthetics. This is above all due to the following reasons:

1. Neglect of the visual aspects of design in the education of engineers
2. Excessive emphasis on the analytical aspects of design in engineering practice
3. Insufficient support for aesthetic excellence from the owners of bridges

Structural engineering is based on the natural sciences. As a result, mathematics, mechanics, physics, and chemistry take up a large portion of the education of structural engineers. The actual specialist training normally consists of fundamental principles of technology and results of recent research. Little time is left for presenting a unified approach to design, in which both technology and aesthetics are considered. Unfortunately, there is a lack of motivation in academic circles to increase emphasis on design, possibly because few professors have any practical experience in this area.

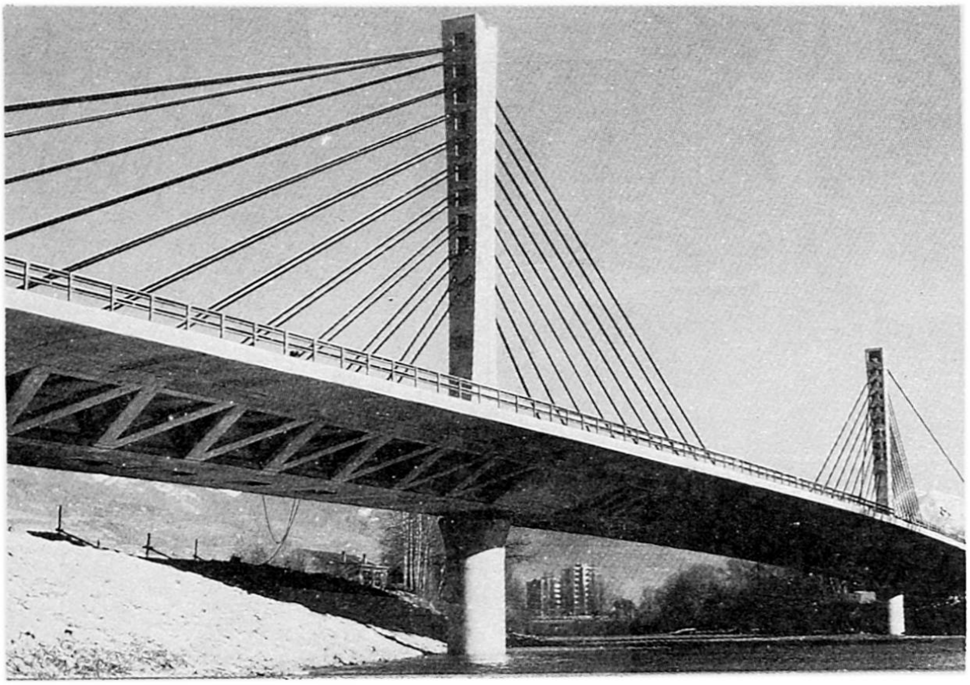

Figure 4
This otherwise elegant bridge has several small deficiencies: different shapes for pier and tower cross-sections, lack of visual order in the arrangement of cables, and a widening of the tower (in the longitudinal direction) that is unnecessary and complicated. Closer attention to the above-mentioned criteria would have helped to eliminate these defects.

As a result, high school graduates who are interested in construction can be divided into two groups: only those who have talent in the natural sciences choose civil engineering, while those who have creative and artistic talent usually choose architecture. This situation can only be changed by a thorough reorganization of the structural engineering curriculum, by which both natural sciences and design principles are firmly enshrined as equal partners.

After the Second World War, research in civil engineering increased dramatically and became more specialized. This development, in itself positive, led unfortunately to design standards and codes of increasing size and complexity, written by committees of specialists who would never themselves use these documents. As a result, many practising engineers find it difficult to assimilate new technical developments and can no longer distinguish between what is important and what is not. They therefore limit themselves to tried and true standard designs. Their entire attention is devoted to the prescribed treatment of specific technical problems, rather than the application of the practically unlimited technological possibilities to the creative design of innovative and elegant structures.

Roughly 90 percent of the practical problems confronting structural engineers can solved reliably and accurately with simple means. The scope of codes and standards should therefore be limited to fundamental principles and typical applications, so as not to constrain creativity and innovation by forcing engineers towards complex analyses. Proper preliminary design has proven to be far more important than exact calculations in achieving economy and elegance.

The owner and the engineers who represent him have a decisive influence on the appearance of structures. Many owners lack the necessary aesthetic sensibility and are often unwilling to provide the necessary political, administrative, or financial support for elegant projects. Faced with this situation, most engineers are reluctant to invest the additional time and money required to obtain a more aesthetically pleasing solution.

Design competitions hold promise for increasing the visual quality of bridges. They promote fruitful cooperation between owner, design engineer, and lay members of the community. The success of competitions depends primarily on the selection of a competent jury, whose members are committed to the ideal of quality in bridge design and who fully understand the interplay between technology and visual form. In addition, the owner must insist on the highest aesthetic standards and must be prepared, if necessary, to request major modifications of the winning project or to reject it altogether.

There is no lack of examples of elegant bridges designed by structural engineers without any assistance of architects. This does not imply, however, that architects may not participate in bridge design. Engineers should not ignore the special abilities of architects not only regarding proportion and form, but also in the area of urban design and planning. Fruitful cooperation, however, is only possible when both professions have a proper understanding of the fundamental principles underlying their counterparts' profession. Architects who have no experience with bridges and who do not understand structural systems, flow of forces, methods of construction, and costs are of little help to engineers. They cannot contribute much more than insignificant cosmetic embellishment.

Aesthetics and Economy

Aesthetics and economy are not mutually independent. It is false to infer, however, that the most economical bridge is necessarily the most elegant one. This proposition is nothing more than a cheap excuse for engineers who would rather save the effort required for visual design and for owners who put little value on the appearance of their structures.

Since cost constraints are usually severe, economy must normally be given primary consideration. Economy may be subordinated to elegance only in exceptional cases, for instance bridges that have special symbolic roles in cities or primarily cultural significance. Genuine bridges are neither works of sculpture nor of architecture that by happy coincidence can also be used to carry traffic.

Elegant structures have their price. Impressive results can be obtained, however, with increases in construction costs of only 10 percent beyond the least expensive solution. Increases of more than 10 percent are therefore rarely necessary. Many of the previously mentioned aesthetic criteria can be achieved at little or no additional cost. Structures that are in scale with their surrounding topography, for example, are always economical. Slenderness, transparency, order, and unity also enhance economy. Added costs can result, however, for bridges that must be integrated into the human components of environment or when extensive artistic shaping is desired. The additional costs associated with artistic shaping are only due to the added complexity of formwork, which amounts to at most 2 percent of total construction cost. As a general rule, simpler and more economical forms for structural components work out better than complicated and expensive ones.

Concluding Remarks

Elegance must be allowed to take its rightful place alongside safety, serviceability, and economy as legitimate objectives of bridge design. A single elegant bridge creates more sensation than a dozen technically correct bridges. For this reason, every major structural engineering congress has rightfully dedicated important sessions to aesthetics in bridge design. Lectures alone, however, are not enough. Changes must be made in engineering education and practice, in codes and standards, and in the attitudes of owners of bridges. Elegant bridges need not be much more expensive than conventional structures. Structural engineering art can be regarded as a search for the best combination of economy and elegance.

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