5TH INTERNATIONAL SYMPOSIUM ON STEEL BRIDGES BARCELONA 2003

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AESTHETICS VS ECONOMICS

or

MUST ECONOMICAL BRIDGES NECESSARILY BE UGLY?

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Abstract

It is often stated that German codes and over-emphasis on economic design hinder the procurement of aesthetically pleasing bridges.

This paper tries to demonstrate that, all to the contrary, economy and good design are not exclusive of each other and that economic bridges must not necessarily be ugly: an ingenious and effective load carrying structure is a prerequisite for cost efficiency and aesthetical design.

Nowadays, steel and steel composite bridges are economically competitive over a wide range of spans and designers are becoming increasingly aware of the varying possibilities they offer. Having dealt with the main topic – the relation between design and cost – the influence of the procurement procedure on both design and cost is considered.

1 INTRODUCTION

On the basis of a few adverse examples, the Section 'Baukultur' of the Berliner Academy of Art described current bridge construction as "gone to waste" as a cultural imprint, because the creativity of the engineer is constantly hemmed by new codes and requirements [1]. A suggested remedy is for large constructions such as bridges, railway stations, museums, banks and industrial buildings to be simultaneously brought about, through the vision of both architect and engineer, in which quality of design surpasses the functional form.

This accusation does not only concern bridge construction, but many important structures in our cities as well.

The standard of innovation is not only reflected by the problems faced by designer and client, but also their position and role in society. Countries such as France, Spain and Switzerland serve as a desirable model. Engineers are able to concentrate on their actual job in an entirely different manner than in Germany, where a large part of the working capacity is absorbed in settling public protests against proposed structures.

In contrast to other countries, almost all German bridges are designed and built for the public authorities; rather than being owned by the private sector they are financed with taxpayer's money. Money that is needlessly spent on new bridge projects can obviously not be spent elsewhere, e. g. for education and culture.

2 DEFINITIONS

2.1 Cost-Efficiency

"It is unwise to spend too much. However, it is even worse to spend too little. Hardly anything exists that can not be made a little worse or sold somewhat cheaper – and people who judge the price alone are at fault." Ruskin

"I will not sell the future for the momentary gain" Werner von Siemens

General

The cost of the transport infrastructure – especially in the case of bridge design – does not just concern the construction, but also the maintenance, renovation and eventual replacement of the structure (Lifecycle cost).

In connection with the cost of bridge design, the following are also to be taken into consideration:

Height and length of the embankments, subject to the construction height
Bearing capacity of piles and the design of foundations in poor soil conditions
Response to earthquakes
Duration of construction.

In connection with all of these points, steel and composite bridges can also be economical in cases where a pre-stressed concrete superstructure would be more cost-effective.

To determine the profitability for the general public, further points must be considered. For example, efficient connections with less interference in the surroundings causing an increase in the value of the location and savings due to the reduction of traffic congestion.

Thus, the following statements are just an indication.

Indicative Costs

The cost of bridges [DM/m²] is dependent on the following factors

Type of traffic
Span lengths, and structure
Height above the ground
Ground conditions
Market situation.

It is difficult to compare the costs of bridges – given in the literature - as they stem out of different time frames and it is generally not possible to differentiate between the costs of the superstructure and sub-structure. Considering the quantities also does not help since prices have declined over the past years.

The choice of structure as system in function of the span length, Figure 1, depends - amongst other things - on:

Ground conditions:

For poor foundation soils, a cable-stayed bridge is obviously more cost effective than a suspension bridge requiring expensive abutments.

Possible methods for construction:

Cable stayed bridges are stable in all the phases of construction, arch bridges are on the other hand only self-supporting when the system is fully complete. They are therefore only economical when the whole structure can be shipped into location.

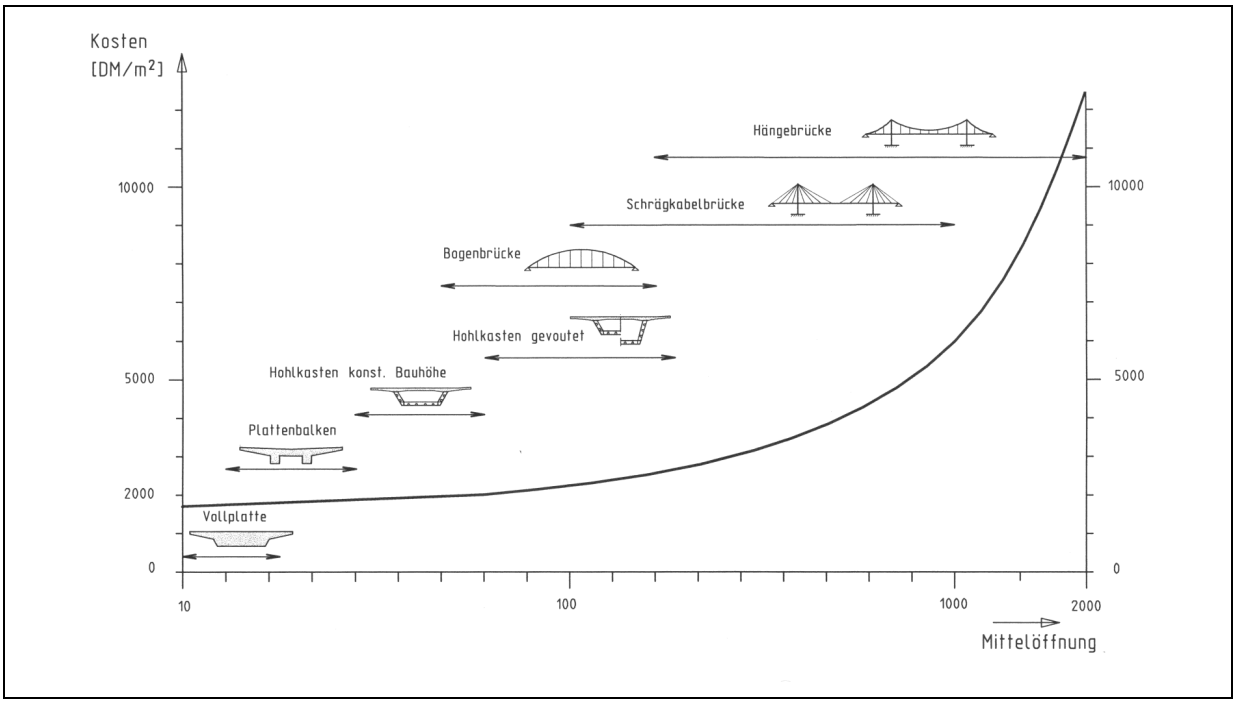


Figure 1 Guideline for structural forms and construction costs [DM/m²] of road and highway bridges

Overpriced solutions
Solutions become overpriced when too much emphasis is placed upon the design and statically effective solutions are consciously not chosen.

For example, if the design of a cable-stayed bridge is developed from the image of a flying goose – and therefore a back-stay cable is chosen - and the cross-section is derived from the front view of a bull – so that a small box section is selected with a spliced connection to the deck – it is no surprise that the construction costs greatly exceed that of a sensible static solution [2]. However, in support of the designer we shall consider the motto for the 97 m high Giralda (bell tower) of the Cathedral of Seville, a landmark for the city: *"We want to design a structure so audacious that future generations will still wonder how we could risk starting such a project."*

This attitude may be suitable for uncommon structures – for example garden or world exhibitions – but it cannot be a guideline for standard design bridges.

2.2 Ugly

"Everyone recognizes beauty, when he sees it, but hardly anyone can explain, what it is." Christoph Vitali, Director of Munich 'Haus der Kunst'.

General
We have seen that it is not easy to define cost efficiency. It is even more difficult to attain a definition for ugly or, what interests here: aesthetic.

Do we design bridges for them to appear in engineering magazines or architecture periodicals? Are they designed for engineers and architects or also for laymen, who partly have an entirely different concept of beauty? Surveys have shown engineers to favour established solutions whilst architects opt for high-tech, minimalist solutions that are almost impossible to construct. Laymen prefer designs typical of those they have previously encountered [3].

Is a bridge or structure only beautiful when the entire vision of architect and engineer is incorporated into the design? Or is the saying valid "The composition of a structure should be well-engineered so that if any detail is added or removed its overall harmony will be lost", [4].

Do we design bridges that are to reflect fashions, to have timeless beauty, to have creative aesthetic durability as well as structural capacity? This does not only encompass the overall appearance but also details, for example the surface.

Since it is almost impossible to reach an agreed definition of the notion of beauty, the path to attaining an aesthetically pleasing structure is less disputed. Worldwide, sustainability and durability are governed by numerous and detailed regulations, yet has recently become that the third issue – beauty - has been considered as a guideline in the appraisal of bridge designs, [5], [6]; tips and exemplary solutions can be found in the numerous literature [7].

What distinguishes beautiful from ugly bridges?
The necessary requirements for beautiful bridges are:

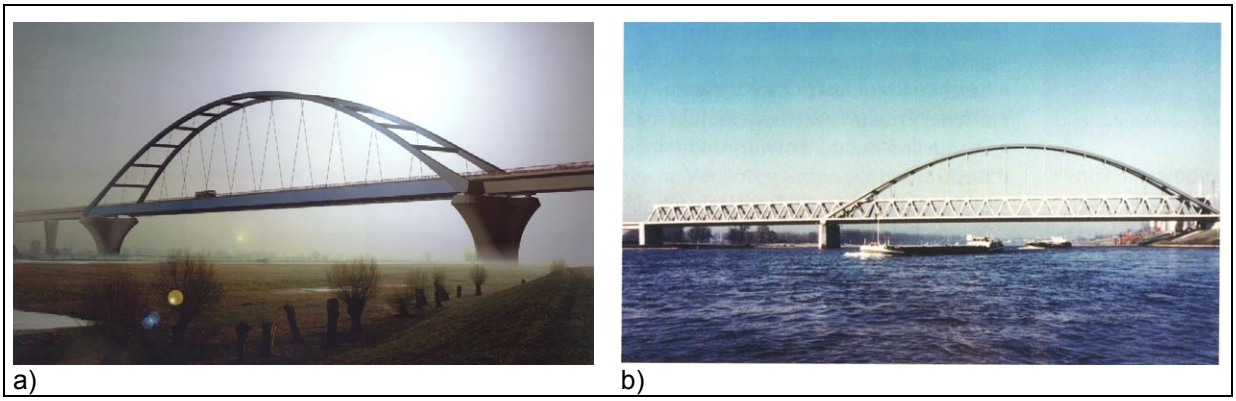
- Choice of a meaningful and clear design, well-defined load paths
  Well-proportioned in 3 dimensions
  Ordered arrangement of structural components
  Compatibility to the environment
- Diversity of materials used
  Colour
  Illumination
  Space above and below the bridge

Are German regulations and guidelines concerning aesthetic bridge design en route?
Regulations are what you make of them.

Engineers who have frequently worked in countries without codes and regulations will know how expensive it is to develop a design concept from the outset. A sound and definitive set of governing regulations are a distinct advantage – the modification of codes, e. g. in the conversion to Eurocodes, does not facilitate the design work.

Naturally, regulations can only be applicable for standard types of construction; uncommon structures, individual design details and materials are to be approved separately.

The scope for engineering creativity, permitted by the guidelines of the BMV and the DB AG are given in Figure 2.



a) b)

Figure 2 Bridges designed according to the codes and guide drawings of the Ministry of Traffic and German Railways: a) Elbebridge Tangermünde [8], b) Rheinbridge Düsseldorf-Neuss [9]

On the collaboration between architect and engineer during bridge design
There are two possible ways in which a bridge should not be designed:

First decide upon its appearance and then figure out how it can be brought into existence.

With particular regard to its construction and maintenance, choose a cost-effective solution and then decide how it can be made more aesthetically pleasing.

It is essential that the design, structural form and erection procedure be simultaneously taken into consideration as an integral part of bridge.

Not all civil engineers have enough sense of what beauty is in order to configure a bridge of a satisfactory aesthetical design. Similarly, not all architects have a clear conception that a well-formed pedestrian bridge can not necessarily serve as a model for a high speed railway line crossing To arrive at an appropriate solution it is therefore necessary to recognize ones own limits and be both modest and frank towards the ideas of others.

3 ECONOMICAL AND GOOD DESIGN – A CONTRADICTION?

3.1 General
The frequently listed statement that cost-effective bridges cannot be beautiful is, on closer inspection, incorrect. Structures can be both beautiful and cost-effective, as demonstrated by the following examples.

3.2 The Development of Cable Stayed Bridges
Until 1960 cable stayed bridges had very few cables only. The superstructure was stressed under bending and assembly was only possible with the use of temporary works, Figure 3.

In the middle of the 60s, in parallel with the advancements in computer technology, the multiple cable system, was realised. The superstructure in this system is primarily stressed by normal forces, can therefore be slender and is easy to erect.

This development simplified the anchorage and maintenance of the cables as well as the overall arrangement of the superstructure.

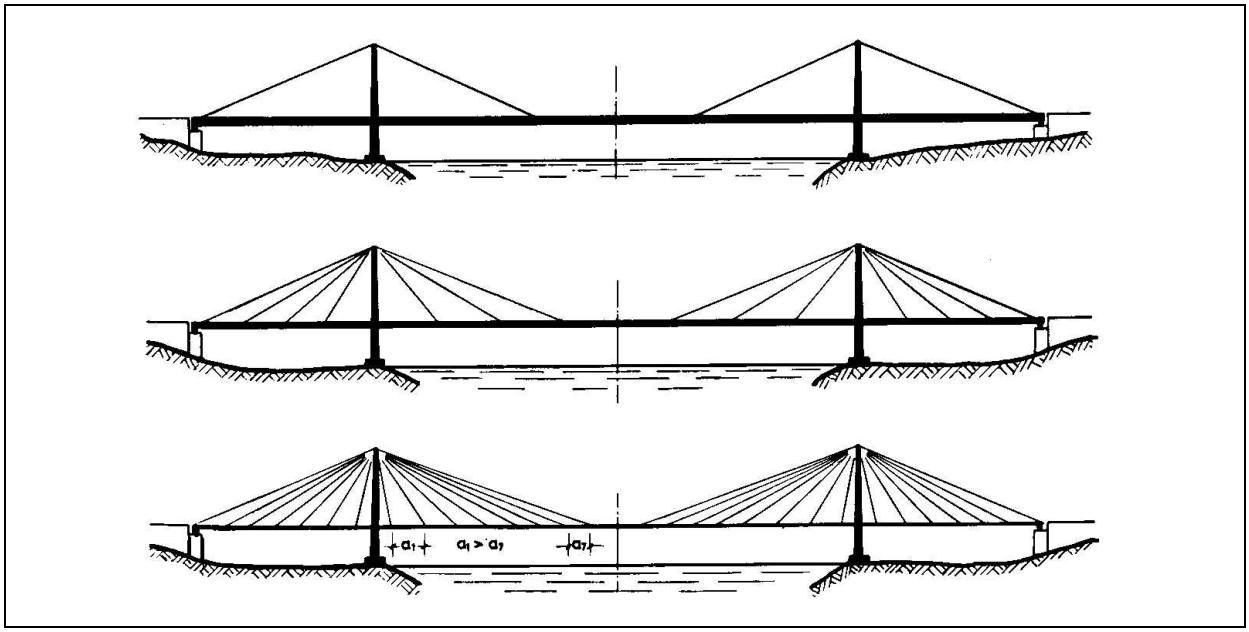


Figure 3 The development of cable-stayed bridges: a) Single cable, b) Few cables, c) Multi-cable system. According to [10]

3.3 Single or Continuous Beams – a nearly religious Matter

With regards to mechanised fabrication and the ease of replacement, many railway and motorway bridges abroad have a single beam structure. In comparison to continuous beams these look ungraceful, Figure 4, and need clearly more material.

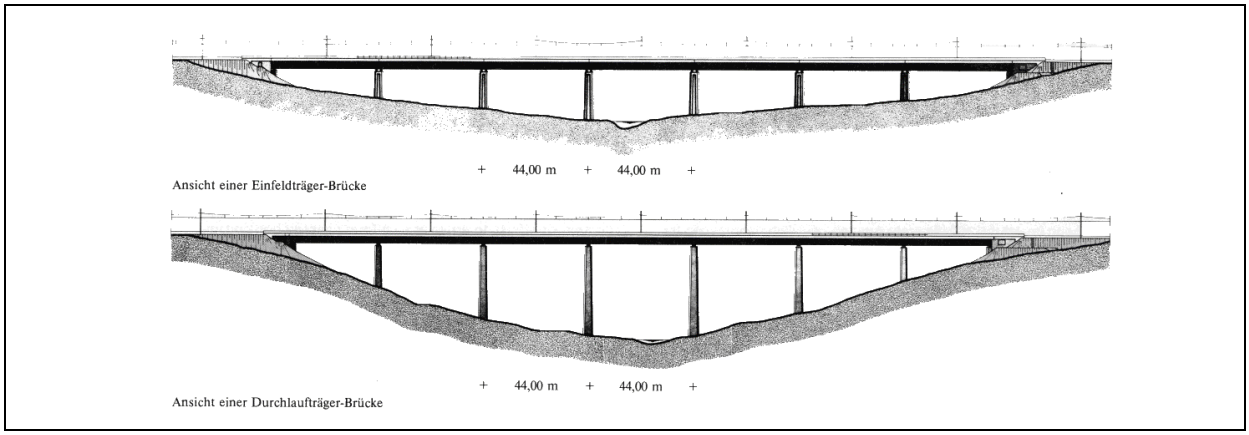


Figure 4 Comparison of single span and continuous beam railway bridges [11]: a) Design, b) Comparison of characteristic statical values

3.4 Aesthetics and the Honesty of a Structure

It is sometimes attempted to design against the load paths resulting from the system layout. These designs are not aesthetically convincing – particularly for the layman - and are also clearly more expensive than a construction that is 'true to itself', Figure 5.

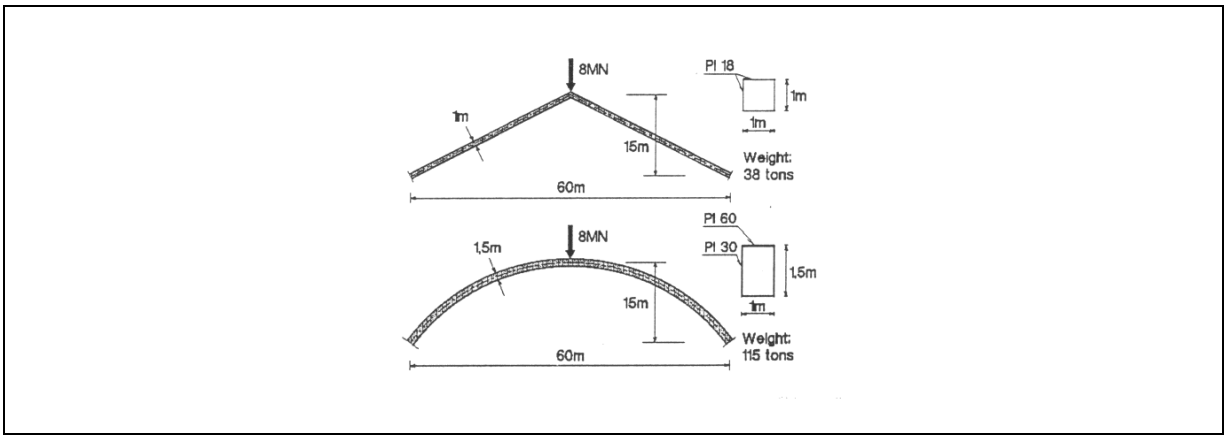


Figure 5 Honest and dishonest structures. According to [12]

4 BRIDGE FURNITURE AND COLOURS

4.1 General

The impact of a well-designed bridge can be improved and destroyed by its furniture – handrails, illumination, noise-barriers etc. Often, architects are involved in these design features and in deciding upon the colour scheme.

4.2 Noise barriers [13]

"At the beginning of the railway age its sound was perceived of as the sign of progress." H. Siebke

Whilst in the past one tried to allow the passenger to enjoy the landscape, nowadays - at least in Germany – sound barriers are a standard criterion. The soundproof barriers are often higher than the construction depth of the bridge itself and should , hence, be designed to be as discrete as possible. Glass barriers, desirable for aesthetical reasons, are frequently discounted due to their cost. In cases where noise barriers are installed afterwards, they often exceed the cost of the bridge structure.

4.3 Colour Scheme

Colour is an essential element of a beautiful overall design. The requirement that steel bridges are to be painted - as corrosion protection - is a clear aesthetical advantage, in comparison to concrete bridges.

It must be taken into consideration that colour is associated with emotions. Loud, glaring colours should therefore be avoided, as well as a non-expressive grey.

5 THE ROUTE TO ECONOMICAL AND WELL DESIGNED BRIDGES

5.1 General

The following procedures are customary in the realisation of bridge designs [14]:

- Direct assignment
- Restricted design competition

- Open design competition
- Design and Build
- BOT – Build, Operate, Transfer

The order reflects a decreasing possibility for the client to influence the design.

5.2 Direct Assignment

General

The direct commission of an engineering company by the client – eventually also with the involvement of an architect and landscape designer – has been a customary method of assignment for decades; the fee was determined according to HOAI (German Fee Regulation for Architects and Engineers).

Nowadays, bridge designs are awarded with consideration of VOF (European Procedures for Tendering Engineering Services). In many cases the client considers 3 to 5 designers - from a total of say 50 to100 applicants - suitable and in the final selection the fee plays a decisive role although the design and the accurate preparation of the tender documents are the most important phase for a cost-effective solution.

With this procedure the client has the largest opportunity to influence the de
signer and to realise his vision of a suitable design. There are the following advantages:

- An early and ongoing agreement between all parties is possible
- Necessary allowances can be prepared in due time
- A basis for alternative proposals is established

The Nantenbach Bridge across the River Main [15]

The Nantenbach Bridge crosses the river Main with a main span of 208 m to join the newly constructed Hannover – Würzburg route with the trunk railway Würzburg – Aschaffenburg.

To attain an aesthetically pleasing bridge in the stunning Main valley countless possibilities were investigated and models were built of the four most promising solutions. The designs were compared in terms of complimenting the surrounding landscape, technical feasibility, economy and maintenance; a composite truss girder was selected and built accordingly.

Figure 6 Railway bridge across river Main at Nantenbach

By incorporating a tall, outward inclined cornice, long cantilevered sections, a clear composition of the truss elements, appealing paintwork etc., and with little consideration of modern attribute, a bridge was designed with timeless form and well-suited to the surroundings, Figure 6. The endeavour linked with this project was well rewarded in receiving the ‘Structural Engineering Prize 1994’ and the ‘Steel-Innovation Prize 1994’.

As a result of the extensive investigation, the following alternative proposals were discounted in the bidding phase:

- A continuous steel upper-chord due to the larger construction depth.
- A prestressed concrete framework due to the many required special allowances.

5.3 Restricted Design Competition (by invitation)

General

With the aim of realising the creative capacity of both engineers and architects, there are an increasing number of design competitions by invitation, whereby the client chooses a limited number of well-known companies, possibly some new names in addition, to participate. In such cases participants either receive a minor fee with a cash prize for the winner, or companies receive the same initial payment and the winner is assigned within the further work.

Hedemünden Bridge, crossing the Werratal [16]

The Hedemünden motorway bridge, crossing the Werratal with spans of 80 m–96 m-96 m-80 m = 416 m, was built 1935-37 and reconstructed following the war. In the 80s, the growing volume of traffic made it necessary to widen the bridge and the newly constructed Hannover – Würzburg railway required a further Werratal crossing to be built in an adjacent location.

Being a particularly complex design, the client opted to invite for a restricted design competition, in which two alternatives were allowed: design of two separate bridges for highway and railway or a solution with both, highway and railway, on a single superstructure.

Four out of the five teams of experts chose the common superstructure, Figure 7. Due to higher construction costs, doubts concerning the bearing capacity of the piers and the risk of damage from accidents, the dual bridge arrangement was constructed after all, each bridge being of a similar steel composite design.

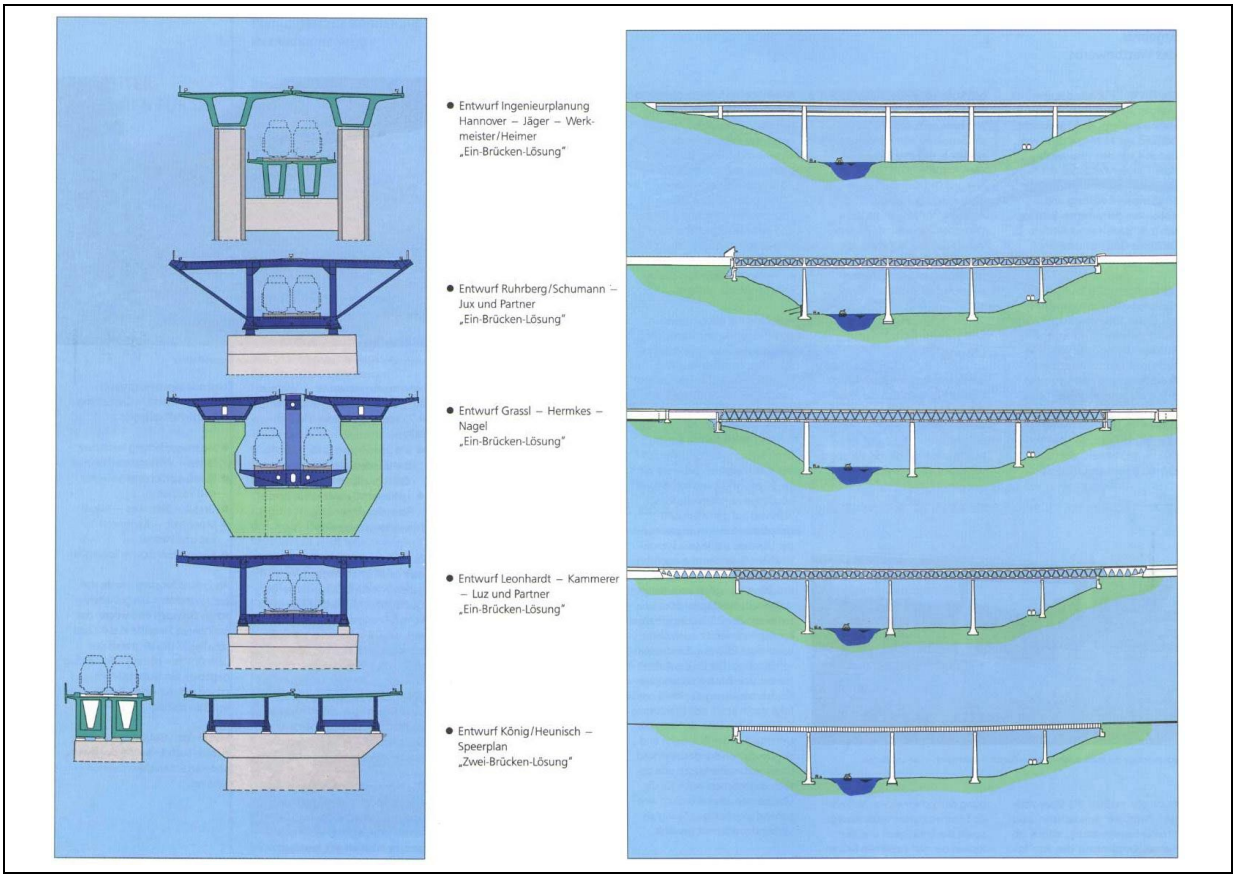


Figure 7 Werra valley bridge at Hedemünden: Designs prepared in the expert's competition

5.4 Open Competition

General

In an open competition – as usual in architectural competitions – participants are not pre-selected, but it is generally expected that both, engineer and architect and eventually a landscape architect, form a design joint venture. The award criteria are to comply with GRW 1977 [17].

Road Bridge across the Schornbach Valley [18]

During expansion of the B29 Stuttgart – Aalen, a bridge crossing the Schornbachtal was necessary, as part of the Schondorf bypass; 620 m in length and with a maximum height of 15 m above the ground. Following a press release, 53 interested parties asked for the design criteria, 25 of them submitted designs which varied from innovative to inappropriate, Figure 8.

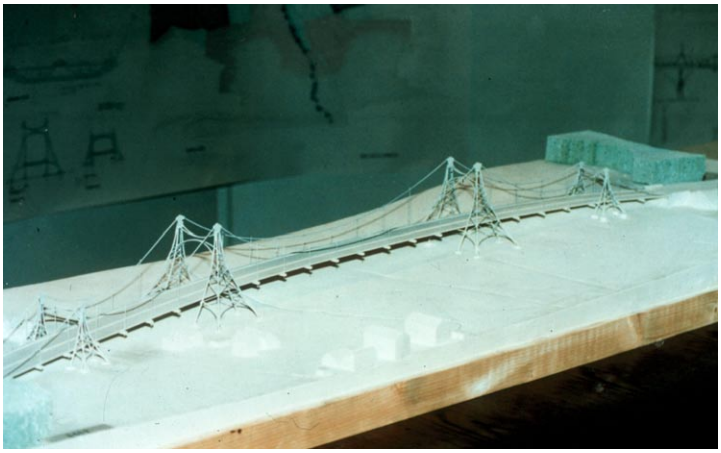


Figure 8 Road bridge across the Schornbach valley Design developed by an architect

5.5 Design and Build

General

In this procedure, the client provides the applicants with the alignment plans, load and design criteria and details concerning the soil conditions. The client has the advantage of cost guarantee, but the difficulty in establishing the correct balance between design and cost; it requires a lot of backbone to select a well designed but expensive proposal. The following examples demonstrate that aesthetically pleasing bridges can be realised via this method.

La Cartuja Bridge for Expo 92 in Seville [19]

Numerous bridges were planned for the development of the Expo 92 site, to be constructed by the Design & Build procedure.

The La Cartuja Bridge, stretching 170 m, links the old town of Seville to the world exhibition site. Due to the close proximity of the Santa Maria de las Carvas monastery and the La Cartuja pottery, any structure above the roadway had to be avoided.

The 12 bidding teams submitted a total of 21 proposals. The client decided to opt for a haunched continuous steel girder with extreme slenderness of ratio L/57 in the span and L/28 in the support above the haunch, Figure 9, although this was 70% more expensive than the cheapest solution.

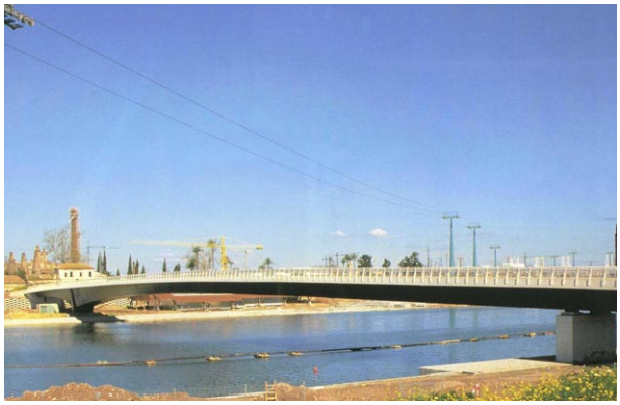


Figure 9 The La Cartuja Bridge at Sevilla

Kap Shui Mun Bridge in Hong Kong [20]
The Kap Shui Mun Bridge is part of the development of a new airport and was the first to be built in Hong Kong according to the Design & Build method. In the design criteria the following was specified:

- Alignment, gradient and arrangement of traffic routes.
- A 120 years lifetime in accordance to BS 5400.

Following their own soil investigation, the bidders themselves had to determin the design criteria for the foundations.

The most economical proposal was a cable-stayed bridge with a main span of 430 m and approach spans of 2 x 80 m. The vehicle traffic is on the upper deck, the Airport railway as well as emergency lanes are on the lower deck. The central 387 m of superstructure is a steel composite structure, the rest is of prestressed concrete.

Figure 10 The Kap Shui Mun Bridge at Hong Kong

Despite a large construction depth of 7.5 m it was possible to reach a pleasing design by including a cornice – which also serves as easy access to the cable anchorages – and by inclining the main girders, Figure 10.

5.6 BOT

General

In this design procedure a consortium of construction firms, banks and exploiters offer to the client the design, construction and operation of the traffic infrastructure. One must not only take into account, hence, the construction costs, but the source of funding and costs of maintenance must also be considered. It is standard for a bridge constructed by this method to be financed through the payment of toll or an allowance from the client. Whilst the pros and cons of BOT in Germany are still debated, [21], it has led to an improvement in transport infrastructures abroad, which were not accomplished by customary methods.

An advantage of this process is that a source of capital exists – from toll – which specifically pays for the extension of the infrastructure and that not an increase of the petrol tax disappears in the overall national budget. Short construction duration is another distinct advantage in keeping expenses low. A disadvantage is that, in general, cost is the decision-making criteria; yet the following example demonstrates that despite this one can still arrive at a good design, if the designer concentrates into the essentials.

The Rosario-Victoria Connection, Argentina [22]

The towns Rosario and Victoria are situated on either side of the Parana River, 50 km apart as the bird flies, but 500 km by road.

The 60 km connection between the two towns consists of:

- A 4 km long bridge crossing the Paraná, with a cable stayed bridge at its core.
- 12 bridges spanning tributaries of the Paraná river, totalling a length of 8 km.
- 48 km of dams.

Due to foreseen difficulties in widening the bridge if required and in consideration of ship collision protection, the Paraná Bridge has four traffic lanes; in order to reduce the initial expenses the remaining bridges and dams have just two lanes.

Figure 11 Cable-stayed bridge across the Paraná River between Rosario and Victoria, Argentina

6 FINAL REMARKS

Bridges of good design and economical investment in the transport infrastructure appear to contradict one another; yet they are not an unsolvable conflict. Bridges, which are cheap with respect to their construction, are neither price worthy nor beautiful. On the other hand, bridges which are over priced due to a disregard for cost-effective structural form, are not necessarily considered to be beautiful.

Currently, steel and composite bridges are often the only solution in achieving a good and cost-effective design. This is the case for large span and extremely slender, movable or arch bridges as well as for the reconstruction and widening of existing bridges.

A large part of the overall expenditure is involved in the early design phases of a project. It is therefore preferable that, even in our increasingly hectic and cost conscious world, enough time and resources are made available for these decision-making stages; to save money here means to save at the wrong place.

In the new century this problem will still be a struggle that bridge engineers and architects must overcome. Be happy; it would be tiresome if everything was so very straightforward!

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