AESTHETICS OF BRIDGE DESIGN

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There is an old Latin saying: "De gustibus non disputandum est—one cannot argue about taste." In fact, people's tastes can be very different, especially in aesthetics. Thus it appears as if there could not be any clear judgment, as far as aesthetics are concerned, whether a building or a structure can be considered beautiful or not. Views on beauty differ widely, especially in architecture. I think, however, that these differences in judgment are mainly because most people never spend much thought on why they consider one building beautiful and why they dislike another one. Few of us have been taught the laws of beauty and we have never trained ourselves to find out why we like to see one object while we dislike another.

In fact, it takes training to learn to see and to conceive and then explain impressions, which we perceive through our eyes. It requires a long training, which must also reach into history in order to find out why some of the old buildings, monuments or sculptures have been considered beautiful and great art through centuries, why they have been called classical art or classical beauty and have kept this designation though views and tastes were changing as the centuries passed. As to the masterpieces of modern art and architecture, we also speak of classical beauty, but this judgment will only be confirmed in the future, if and when these masterpieces do in fact satisfy the criteria of classical art.

Pieces of classical art move our soul when we see them, and we are touched if we are sensitive to beauty. They give us something that we feel enriches us. For this reason, so many people travel like pilgrims far and wide in order to see classical art and to gain those deep impressions. These facts are sufficient proof that beauty or, for the engineer, the aesthetic quality of design, of form and of shape can be defined and that there must be laws and rules for achieving beauty. If this is the case, then there must be both good and bad taste. It takes much learning to achieve the skill of really seeing and to develop good taste, but it is also a question of talent, which God may or may not have laid into our cradle.

Emphasized is the importance of artistic considerations, in addition to engineering design, to achieve beauty in bridges. Based on extensive experience, the author outlines his rules to achieve aesthetical structures, and shows by example how to blend aesthetics into bridge design.

RULES FOR AESTHETICS

Being the son of an architect, I have been trained almost from childhood to see and to analyze beauty. When I started to design bridges 35 years ago, I tried hard to design not only safe, but also aesthetically pleasing bridges. I was fortunate enough to belong to a group of engineers and architects which had the task of improving the aesthetical part of bridge design for the hundreds of Autobahn bridges that had to be built at that time. We traveled much in order to see and contemplate bridges, we had long discussions about the subject, and we gained more and more insight and knowledge that enabled us to develop tentative rules for good forms. Put into words, these rules might be valid for the design of any technical product which is fabricated to satisfy a certain purpose or need and which is not made only for art's sake, like sculptures.

1. There is the rule of good order —order of the systems and order of direction of lines and edges. For bridges, order of systems means to choose a beam, an arch, a suspension or a frame, but never to mix systems. Disorder cannot lead to beauty.
2. We have to observe the old laws of good proportions, of harmonic proportions between length and height, between span clearance and depth, between the supporting and the supported structures. Sometimes contrast leads to beauty, for instance the impression of slenderness of a beam bridge can be increased by the thickness of the piers.
3. We should aspire to simplicity and pureness of structure and restrict ourselves to few and simple elements. We should avoid all useless additives or ornaments. A design of a bridge is only perfect if nothing can be omitted.
4. Beauty of technical products will reach lasting value only if the product fulfills its purpose and gives good service. Technical products must be both serviceable and suitable.
5. The product, or the structure, must be shaped in a way to allow easy fabrication or construction. This means, that the material be-

ing used has an influence on the design. The final shape should also express special qualities of the material, for instance high strength should lead to slenderness or gracefulness.

6. The design must also consider economy as one of the main aims for technical products. Uneconomical shaping will not lead to lasting design value or classical appearance.

7. The presently available range of technical sciences and of methods of fabrication will always be of influence on the design. This means that with progress in science and technology, we will also have a steady development in the form and appearance of our structures. A well-designed bridge of the 1930's looks differently from a good, modern bridge.

8. One of the most valuable influences on design is creativity and intuition, which allows us to find and to develop new forms, which are more suitable, or improved fabrication and construction.

Excellent examples of perfect technical forms are modern airplanes like the Caravelle which comply perfectly with these rules and which are considered to be beautiful by everybody. They have reached classical beauty.

ENGINEER-ARTIST COOPERATION

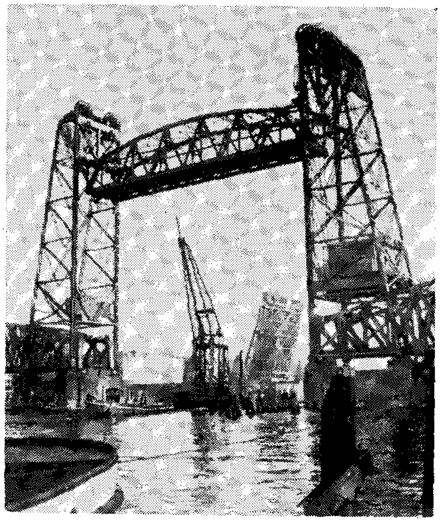
It is often said by engineers that sound engineering by itself must lead to beauty. This is not true at all. Sound engineering, of course, is a necessity for any good design of lasting value, but beyond the rational thinking of the engineer, there must be the aim and willingness to create beauty. This depends not simply on the application of rules and laws, but mainly upon the artistic talents of the designer, upon his sense of beauty, his intuition and his ability to judge and foresee the impression which his design will make.

Only a few men have the special gifts and talents for creating beauty of technical products, which primarily fulfill the purpose of serviceability. This kind of art demands sensitivity and sobriety simultaneously. Unfortunately, most engineers have no talent in this field, because the profession of engineering attracts persons who have a talent for rationalism and logical thinking, but not sensitive feeling. Therefore, there should be collaboration between engineers and artists. Both must cooperate in trying to find a solution which will satisfy both.

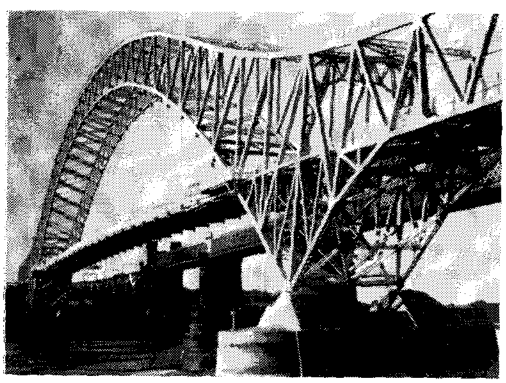
The artist should not dominate but serve, just as the engineer serves the purpose of his structures. The artist must refrain from forcing the products of his fantasy upon the engineer and he must refrain from insisting on fashionable extras and so-called styling. The collaboration of the two should be governed by a sense of serving with a willingness to understand each other; they must be master servants and not kings. It is seldom that we find such people.

In rare cases, both gifts—being a good engineer and a good artist—are combined in one person. This may lead to the best results. In my experience, however, the cooperation of several talented persons is more readily possible and, hence, is to be preferred.

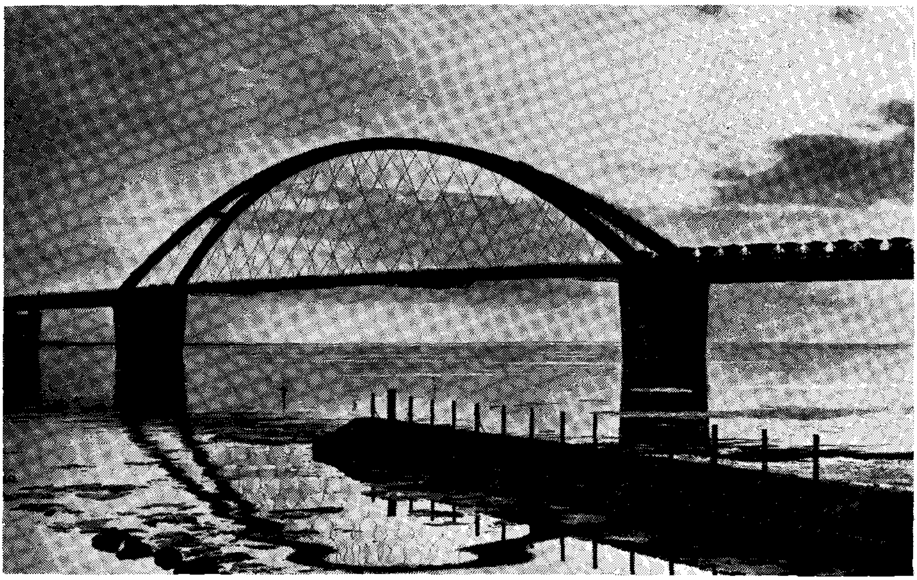
An example of *disorder* of a structure is this old lift bridge, where the members of the different trusses have all possible directions and sizes.



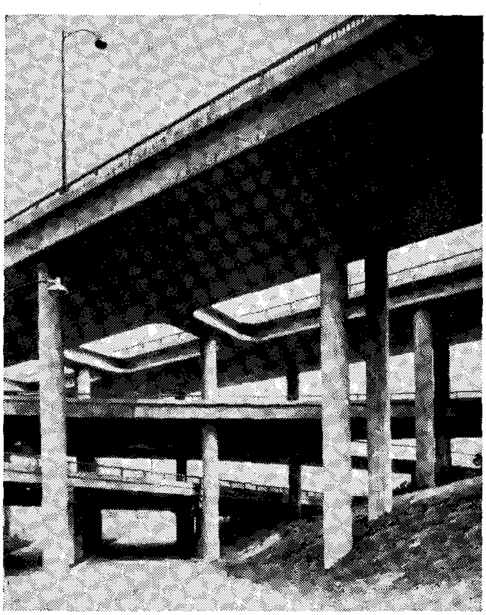
Trusses can be designed to give a *good* appearance if the chords are parallel and if the diagonal bars have only two directions, as this steel truss bridge may show. In addition to order of directions, there must be good proportions between the chord members and diagonal bars.



A second example of lack of order and of good proportions is this highway bridge with a span of about 1000 ft. The lattice work of this large arch, and especially the lateral bracing, do not show good order.

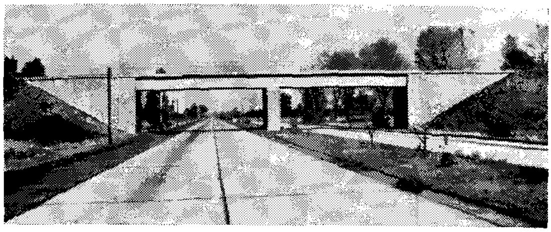


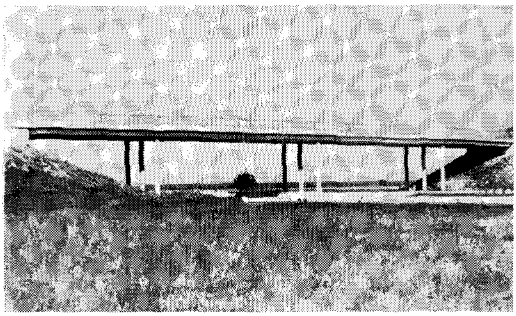
A steel arch-bridge with the same span, but which looks good, has been built by engineers who collaborated with a good architect. The rules of good order, simplicity and good proportions were observed in a perfect way.

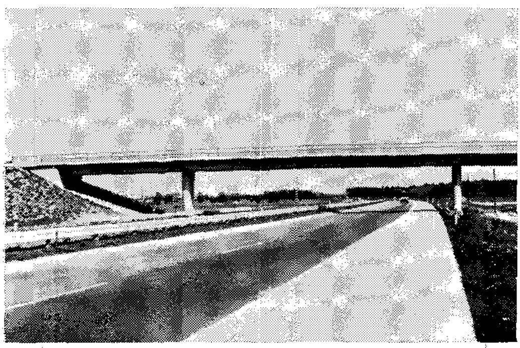


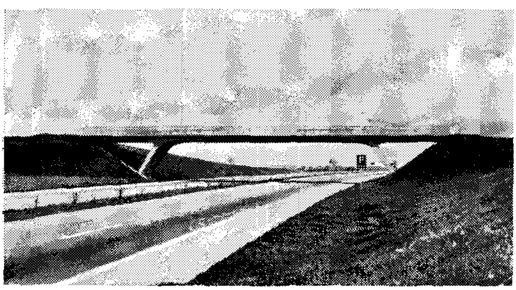
An excellent example of obtaining good order, by reducing the number of structural elements to a minimum, is the first four-level crossing in the world near Los Angeles. This difficult design was solved with two elements only—solid slabs and circular columns. This structure has high aesthetical value.

Beam bridges depend mainly upon their slenderness for good appearance. An overpass bridge of the early days of thruways has heavy reinforced concrete beams, heavy piers and abutments and large wing walls. The driver feels handicapped by the narrowness of the openings and the masses of the structure; his feeling of openness is disturbed. Such bridges no longer fulfill their purpose, looked at with our present perspective.

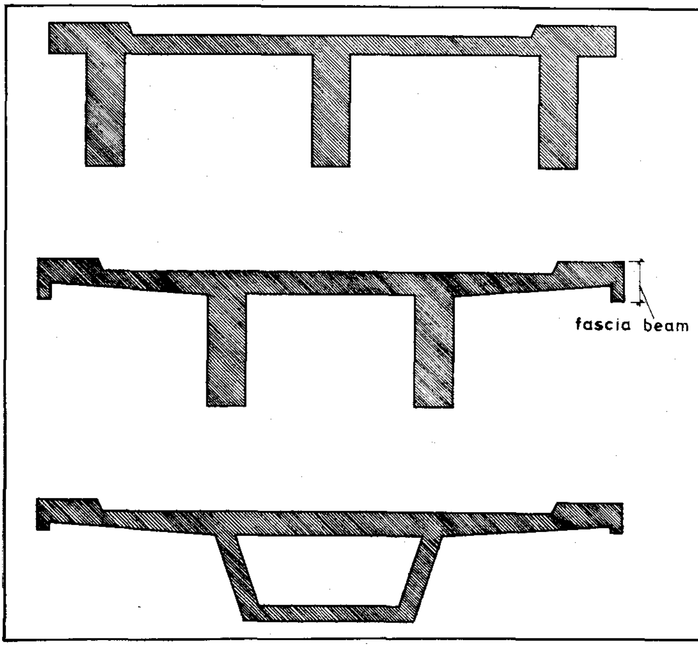






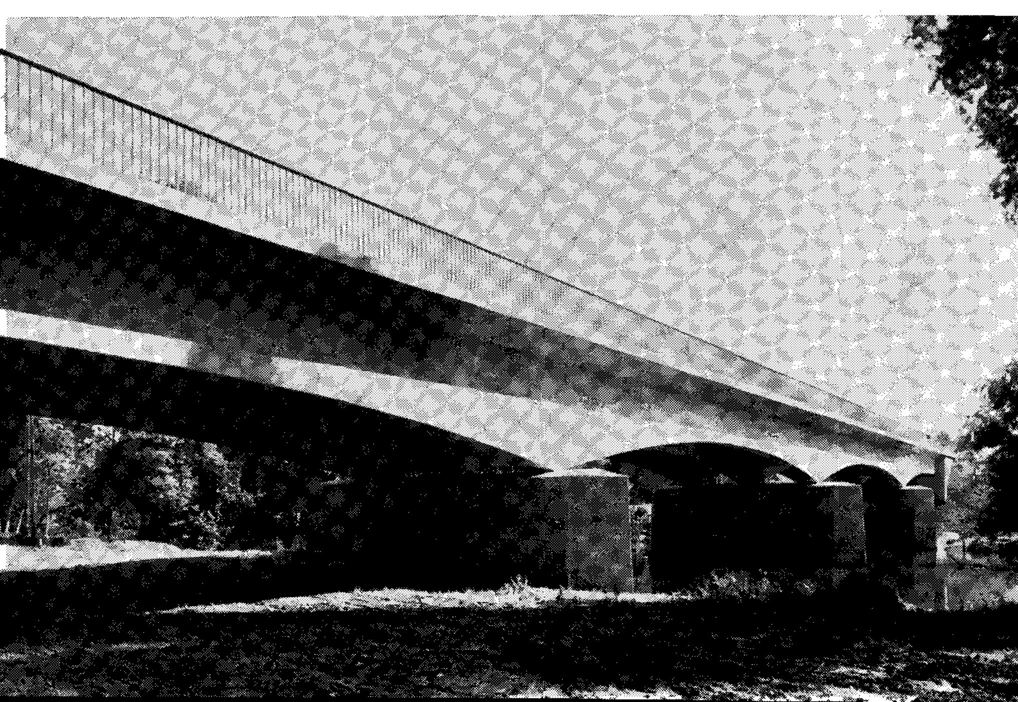


Progress in engineering, through the introduction of prestressed concrete, allowed us to build more slender beam bridges and enabled us to develop overpass bridges with a satisfactory appearance. The slender continuous beam rests on few columns; large wing walls are reduced to small abutments on top of the embankment. The first rule for good appearance, the rule of order, requires that all lines of the superstructure are to be parallel. All edges must follow the axis of the highway, no matter whether it is curved vertically or horizontally. The second rule requires good proportions between span lengths. In particular, end spans must be sufficiently long, so that a small slope for the end of the embankment can be used, preferably paved with dark stone.



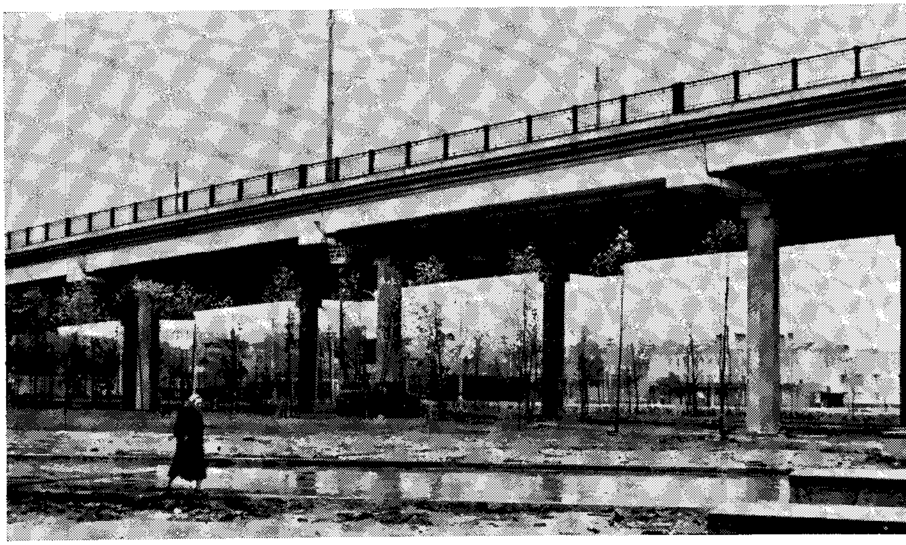
The impression of slenderness can be emphasized by increasing the cantilevered width of the deck slab and by good proportion between the depth of the fascia beam and the depth of the main girder. Fascia beam depth should also be in good proportion with the length of the main span—at least 1/100 of the span length for spans up to 150 ft. or 1/4 to 1/5 of the total depth for longer spans.

The type of railing, too, influences the look of the bridge. Light-looking steel railings, preferably with equal vertical bars, allow you, while driving over the bridge, to look through the railing just as if it did not exist. With a steel wire rope inside the hand rail, it gives excellent safety.



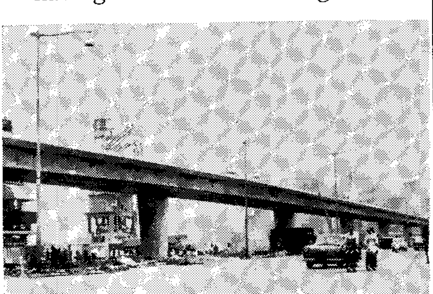
Many overpasses cross thruways at a skew angle. One of the difficult tasks is to develop good-looking bridges for such skew crossings. Some overpass bridges in California were the first to achieve this. Looking along the thruway the span length appears to be decreased, thus distracting from the impression of slenderness. Therefore, such bridges should be designed extremely slender. This can be achieved with hollow boxes, widely cantilevering deck slabs and rather deep fascia beams. The torsional stiffness of the hollow box beam permits such bridges to be supported with one column at the center line. Even hinged columns can be used for three or four spans, because torsional moments can be taken up at the abutments only or at some intermediate locations with double columns. This type of design has the great advantage of a bridge with normal rectangular superstructure.

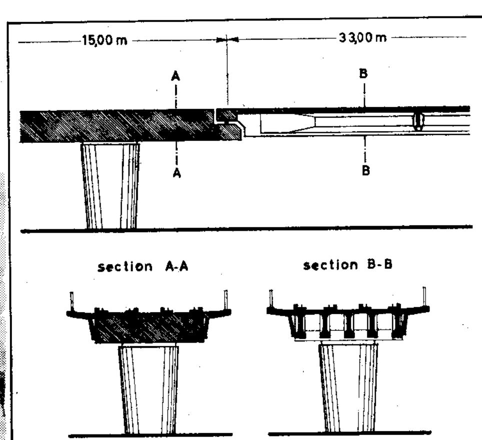
For long, multi-span bridges for elevated highways, the intermediate piers present the main aesthetic problem. The first example shows a continuous, hollow slab on transversal frames, with only a small additional depth for the frame beam. All edges of the superstructure follow the curve of the highway. Notice the good proportions between the spacing of the frames and the distance between frame legs.

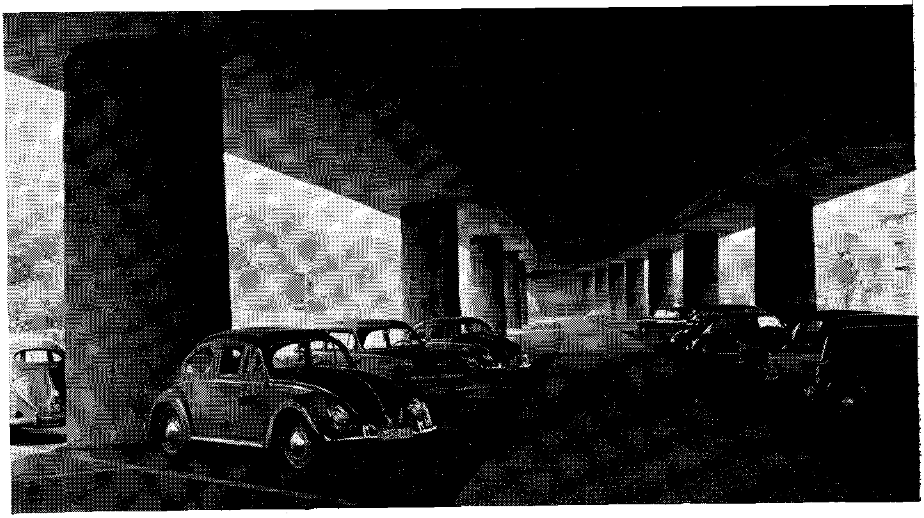


If prefabricated girders are used, quite often capping beams on the piers or columns are required. They tend to be heavy, because they have to carry heavy loads. This type of support does not look attractive but it can easily be improved by moving the capping beam upwards, so that its depth disappears fully or partially within the depth of the longitudinal girders. The Russians showed such a solution many years ago; girders rest on the bottom flanges of the transversal beams. Good solutions of this type have been proposed for the Crosstown Expressway in Chicago.

For an elevated railroad bridge in Rotterdam, the column carries a thick table plate on which the prefabricated girders are placed, with recesses for the bearings at half depth. With girders and table plate having the same depth, the bridge looks like having a continuous main girder.

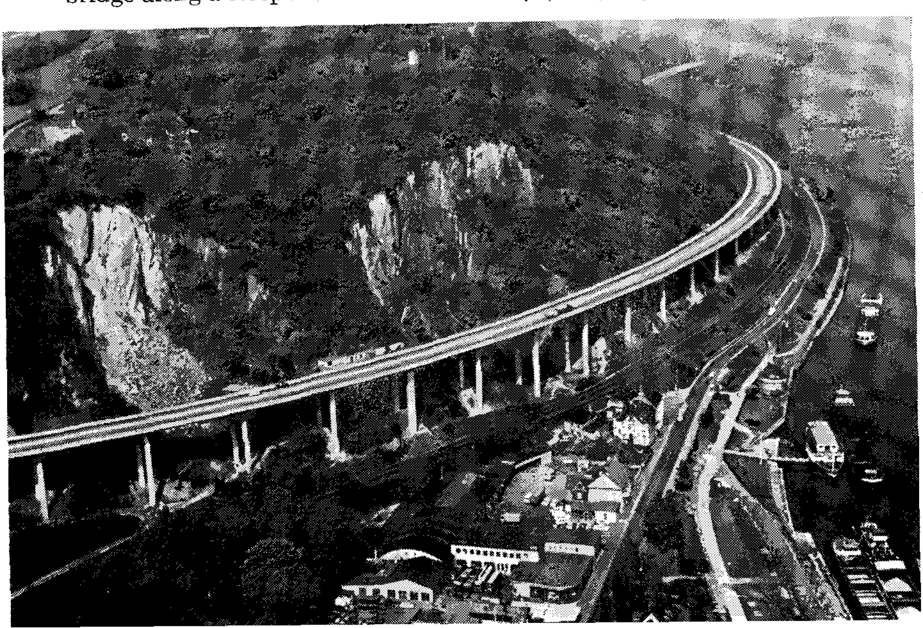


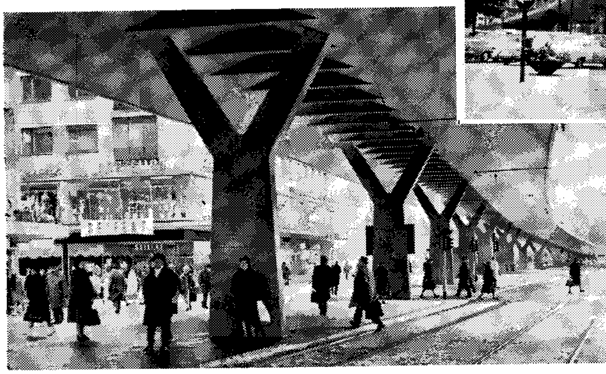




For a very wide bridge with six lanes, a good-looking solution consisted of two hollow box girders and two rows of columns, with cross girders between the two main girders of equal depth and equal spacing. This means good order. Good proportions for such a bridge are found in the longitudinal and transversal spacing of the columns. In such cases the transverse distance of the columns should be less than about half the longitudinal distance and the number of columns for each span should be small. If such rules are not observed, one gets a disorderly looking forest of columns.

A good example of a long bridge on pairs of slender columns is this bridge along a steep hill in the Rhine valley (design by Dr. Wittfoth).



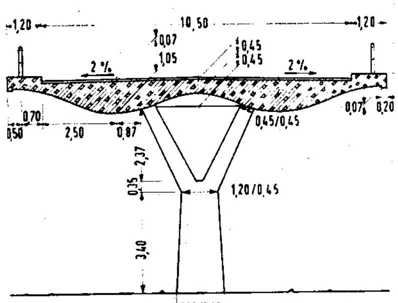


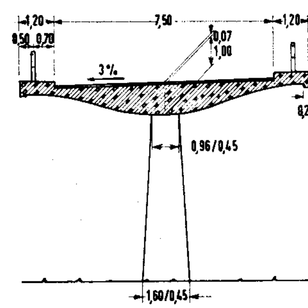
For bridges within cities, crossing squares, plazas or shopping streets with its many pedestrians, it is most important to dematerialize the supporting elements of the bridge, so that the bridge deck appears to be floating in air, thus disturbing the street life as little as possible. In Düsseldorf, such a bridge was built after long design studies. The columns for this bridge are very slender and widely spaced, the spans being between 100 and 130 ft.

For the four-lane portion of the bridge, the columns are shaped like a Y. In order to attain maximum slenderness of the columns, steel was used to support the prestressed concrete bridge.

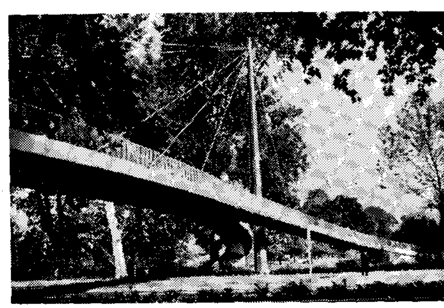
However, it is not only the columns but also the cross section of the superstructure which gives this light and floating impression. Cross sections show no distinction between main girder and deck slab. It was developed from a narrow, central hollow box and an extended, cantilevered deck slab, but all edges have been avoided by curving the bottom surface. This has the effect, more or less, that the depth of the structure can not be visualized. The deep portion of the main girder almost disappears behind the rather deep fascia beam and gives the impression of extreme slenderness. The relatively heavy prestressed concrete superstructure virtually eliminates traffic noise under the bridge, so that in fact the street life is not disturbed by this flyover bridge.

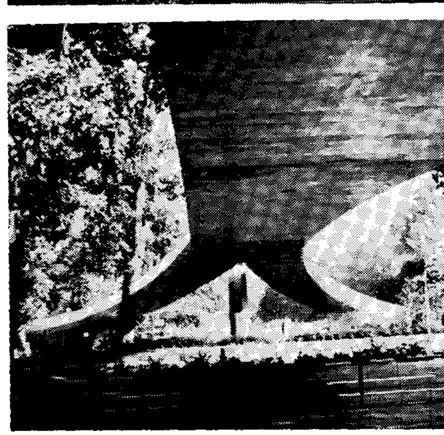
At the end of such a bridge, it is important to extend it until it almost touches street level, and to make the abutment as small as possible.



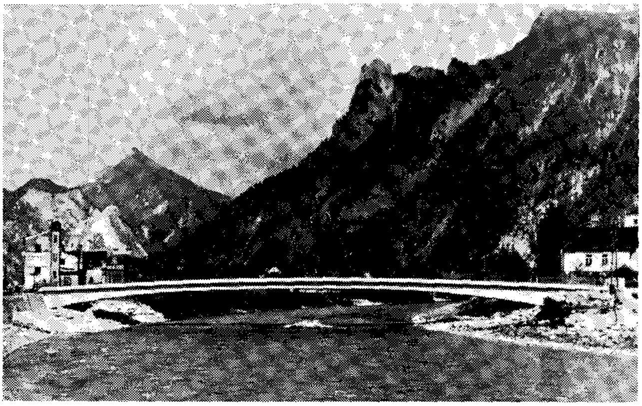


The above pedestrian bridge is a very slender, hollow-plate structure resting on two columns, strengthened at the top by means of a flat cone. Again, a rather deep fascia beam and different colors increase the appearance of slenderness. The structure ends at rather low points in order to reduce the size of the abutments.

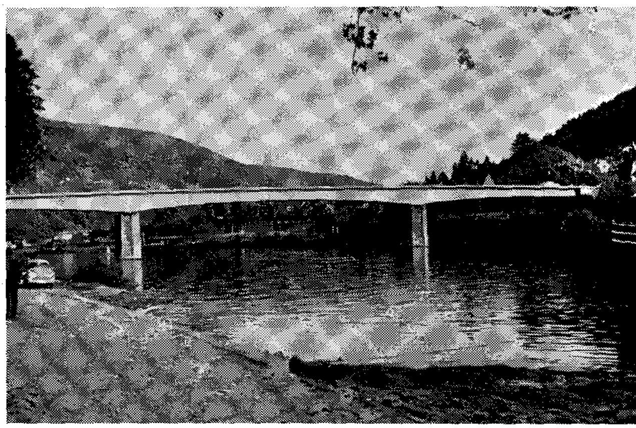




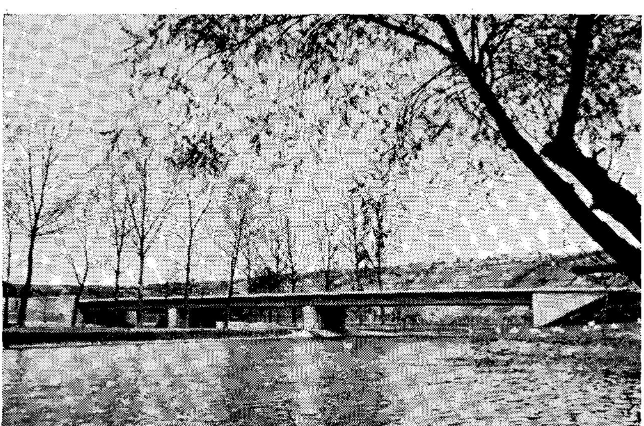
This pedestrian bridge is about 300 ft. long and forks into two different directions on one end. It is supported at several points with stay cables extending from a single tower at the beginning of the fork. Having no visible extra elements for anchoring the stay cables to the plate or to the top of the tower was important for the bridge's good appearance. The hollow plate is of constant depth and has a simple rectangular cross section. For aesthetics, it was most important to join the different curves—vertical and horizontal—with graceful transistions, avoiding any sudden change of curvature. This means that at no point should a circle meet a straight line without a parabola in between.



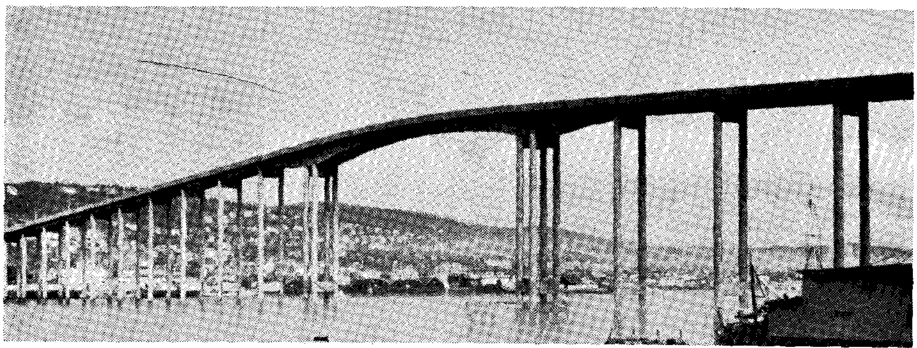
One of the best looking river crossings is this single-span beam bridge, encastered at both ends, over the River Traun in Austria. It is the slenderness and graceful curvature of all lines which makes it so attractive.



Quite frequently three-span continuous bridges have haunched girders on heavy piers. For good appearance with this type of bridge, much depends upon the curvature of the bottom edge related to the lines of the fascia beam. In my experience, there should be a rather long portion in the middle of the main span where the bottom and top lines are parallel or almost parallel. Further, there should be a good proportion between the visible depths at the pier and at mid-span. If the depth is changing too much, then the impression is less favorable. Similarly, the bottom and top edges should be parallel for some length at the ends of the side spans, especially if the bridge is joined to further spans.

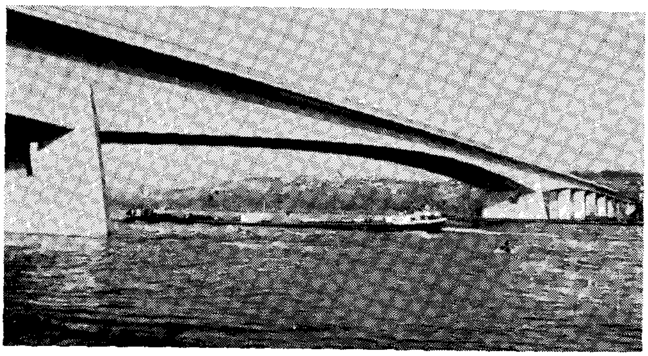


For multi-span river bridges with straight grade, it is preferable to have beams with parallel edges on heavy piers and abutments with parallel wing walls.

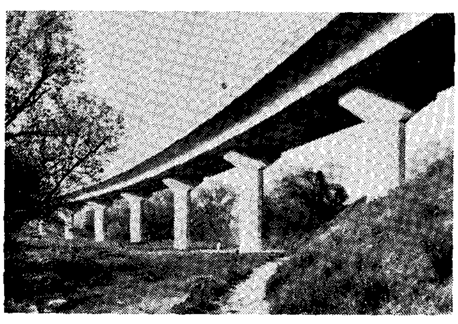


It is difficult to find good-looking solutions for haunched beams on high piers. Aas-Jacobson of Norway solved this problem with double columns in a satisfactory way.

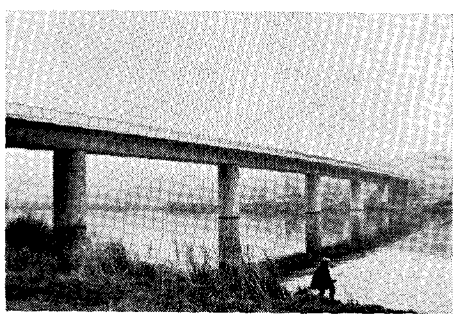
For Finsterwalder's bridge across the Rhine River in Bendorf, which has the longest span for prestressed concrete with almost 700 ft., an effort was made to suppress the very large depth of the superstructure at the main piers by extending the face profile of the pier into the beam.

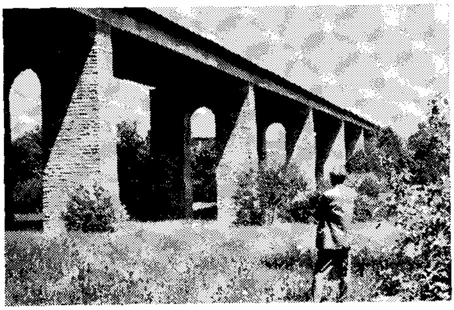


For multi-span bridges with parallel edges, single columns with a cap also give good appearance. The cap, however, must be limited to good proportions in relation to the width of the structure. Caps look bad if they are as wide or even wider than the hollow-box beam.



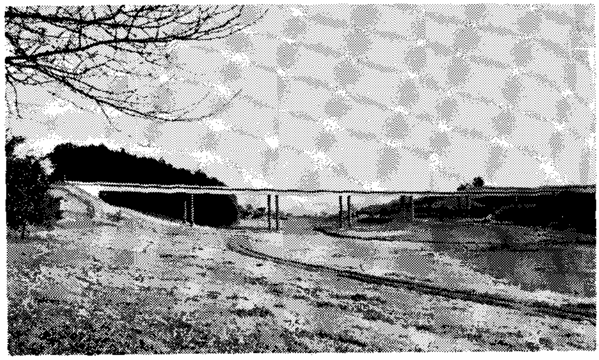
If circular or elliptical columns are sufficiently wide for placing two of the modern, rubber pot bearings, then we can eliminate the cap and support the whole superstructure, even for rather wide bridges, directly on the column. This can be seen on this bridge crossing the Mosel.



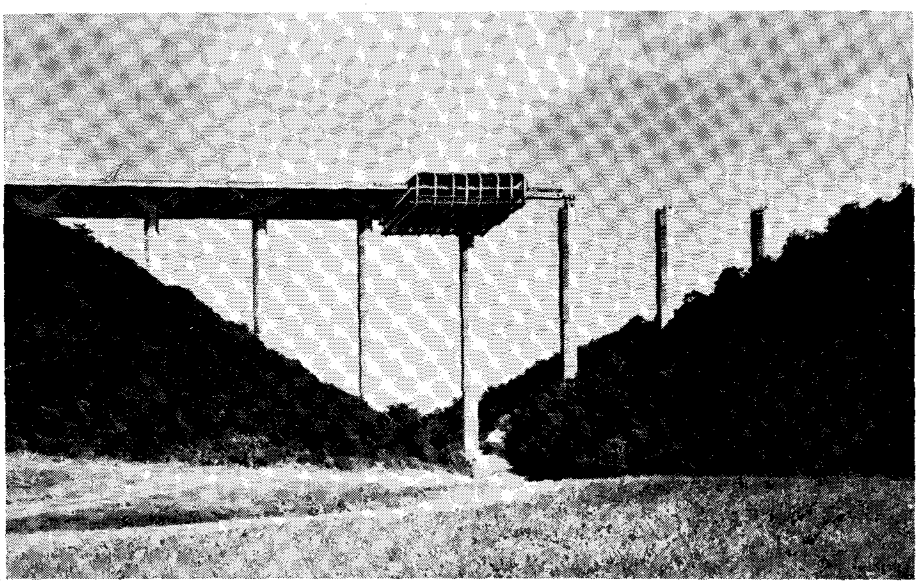


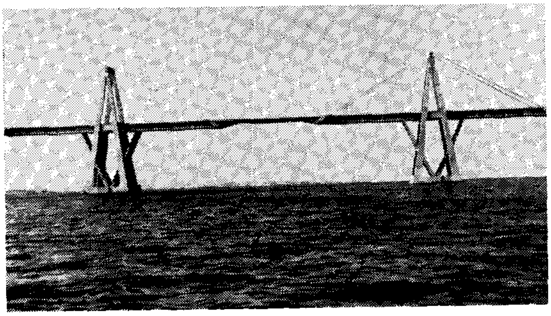
In the design of valley bridges, the development was from heavy and wide masonry piers to slender columns. An old bridge on the Autobahn shows masonry piers fitting well into the free landscape, but almost closing the view into the valley.

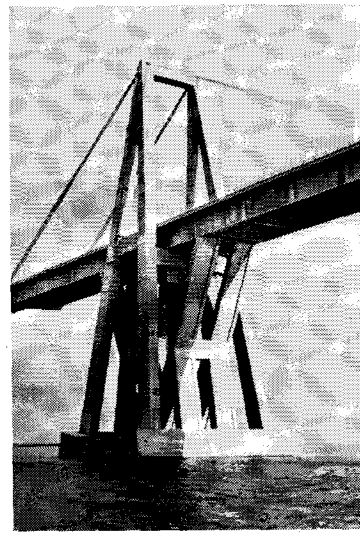
Today, slender double columns, or even slender single columns, are more often considered to be the best solution. Single columns can support straight and wide bridges only if the superstructure is of great torsional rigidity.



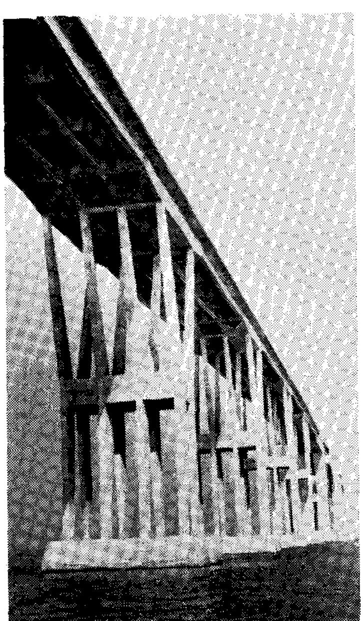
The best looking bridge on such slender single columns was designed by Finsterwalder for the Elztal viaduct, with spans of about 120 ft. The shallow slab is thickened by a flat, mushroom cap to get the necessary fixity with the columns, which are as high as 320 ft.! Many examples already prove that continuous beams on rather high, slender piers least disturb the beauty of the landscape.



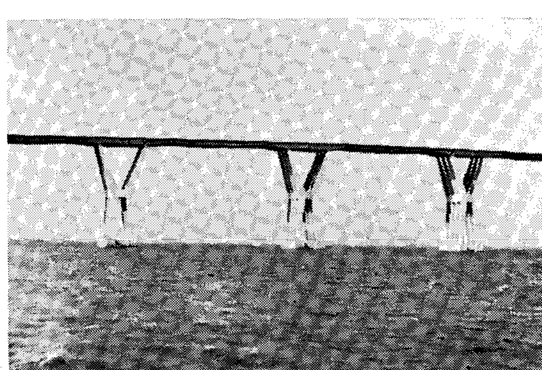


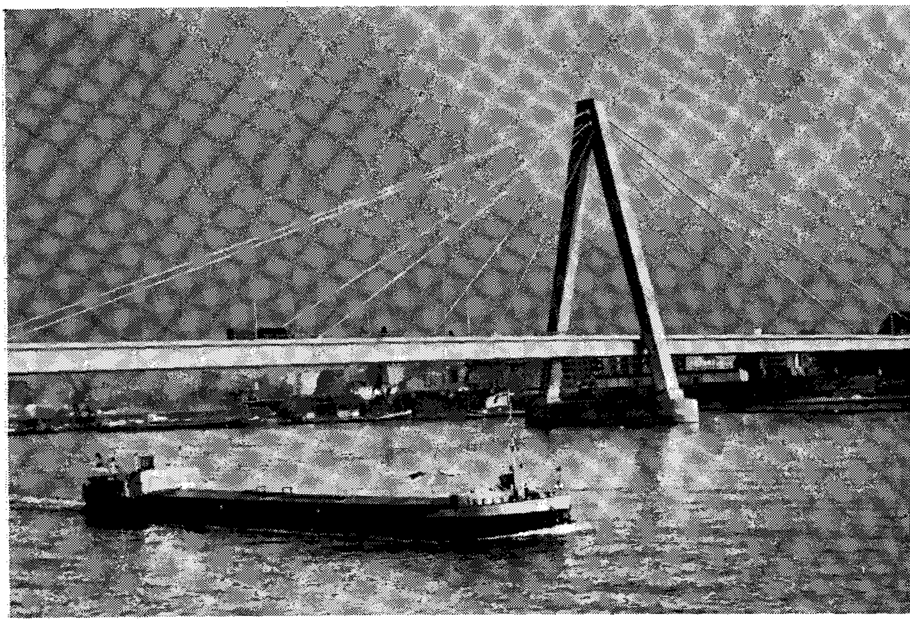


The longest span achieved thus far with prestressed concrete is in the Maracaibo Bridge, designed by Professor Morandi. Looking at this bridge from an architectural point of view, there is no doubt that there are good proportions and good order of lines, providing the bridge is considered at right angles to its longitudinal axis. However, if the towers are viewed at a skew angle, less favorable impression results. There are too many elements in different directions, with dimensions not in proportion to the tasks. This example shows that designs should be studied not only from drawings, but also from small-scale models which can be regarded with a critical eye from all possible directions.



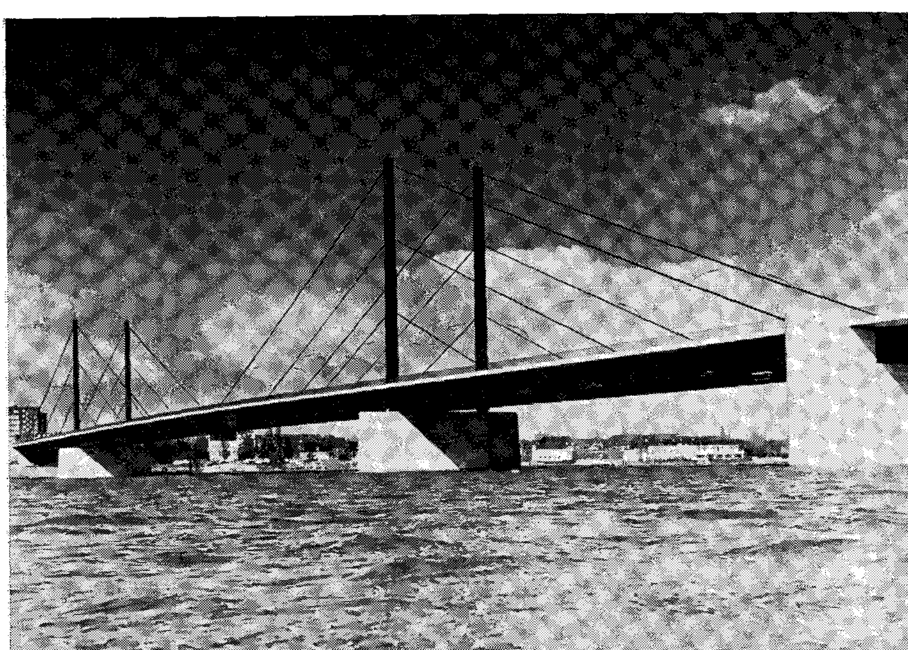
The same can be said of the approach bridges over Lake Maracaibo. Here, too, the silhouette shows a very good appearance, but the interesting piers have too many legs and too heavy horizontal bracing beams, when viewed at a skew angle.

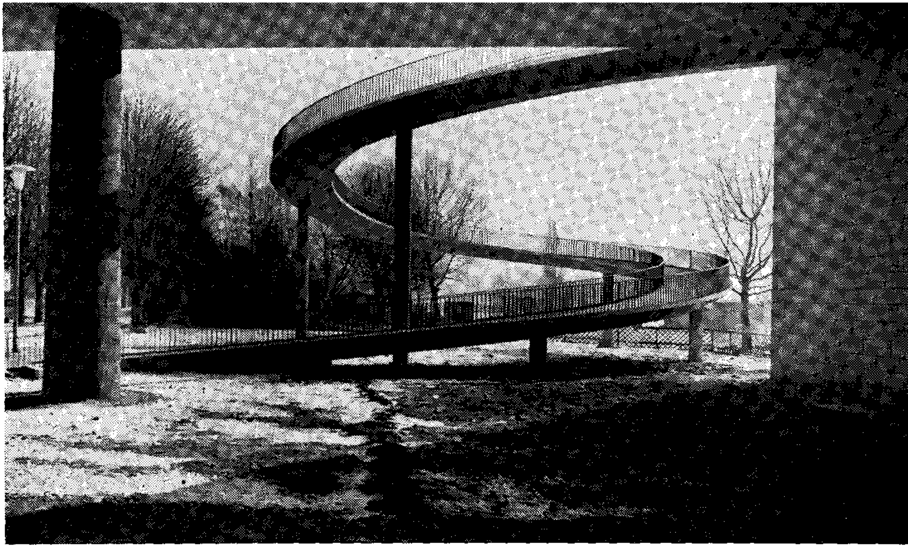




During the last 15 years, bridges have been developed in Germany with different types of stay cables, suspending continuous beams, So far mostly steel bridges have been built, like this bridge crossing the Rhine in Cologne.

To show what can be done with stay cables, and how long-span bridges look when the stay cables are parallel, a bridge crossing the Rhine in Düsseldorf is shown below. The impression of slenderness of the beam has been intensified by using near white for the fascia beam and a very dark gray for the web of the main beam. In the near future, there will be more prestressed concrete bridges with multiple stay cables for longer and longer spans.





From an architectural point of view, the access bridges for pedestrians to the previous Rhine River bridge are interesting. The usual stairs were avoided by designing curved and slender ramp bridges, which have been very well received by the citizens of Düsseldorf.

CONCLUSION

If we consider the development of bridge design from an aesthetical point of view, or the development of taste concerning beauty of bridges, we find a preference for very slender structures supported by slender piers or columns. We prefer simplicity and restriction to a minimum of elements. We prefer continuous and steady long lines, either straight or in smooth curves, which correspond to fast-moving traffic. We avoid heavy, clumsy structures with large abutments.

The reduction of structures to minimum sizes, or dematerialization, corresponds to the general aim of engineering to fulfill the purpose of structures with a minimum of material, effort and cost. This is also a sound principle of nature for whatever nature develops.

Bridge designs must be governed by valid rules for simple order and good proportions. Aesthetics for bridge design is a necessity for the future as it is for architecture, or for anything that we build. Unattractive buildings or structures not only devaluate real estate, but cause sickness of man's soul. We must recognize these facts in order to be convinced of the high responsibility which engineers also have towards beauty in their structures.

Discussion of this paper is invited. Please forward your discussion to PCI Headquarters before May 1 to permit publication in the August 1968 issue of the PCI JOURNAL.