Architectural Design of CONCRETE BRIDGES

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CONCRETE FOR PERMANENCE

Published by PORTLAND CEMENT ASSOCIATION, 33 West Grand Avenue, Chicago, Illinois

FOREWORD

Master builders of medieval bridges were artists trained in architecture, of which civil engineering was merely a branch, but two centuries ago the two professions—architects and civil engineers—began to follow different courses until they were ultimately severed in many fields, including that of bridge building.

While the architect designed for appearance, the engineer designed for structural safety but frequently neglected appearance. The *craft* of bridge building was transformed into a *science,* and the two professions no longer collaborated as in the past. Qualities that made bridges pleasing to view were overlooked in design.

It is only within the last decade or two that it has again become the rule rather than the exception to give serious thought to the appearance of bridges, and a strong current is now felt which takes us toward the point where "design by looks" will accompany "design by science." The increasing number of grade separation structures in the last few years has given added momentum to the trend toward architectural design of bridges.

Many bridge engineers are conscious of the lack of fundamental principles by reference to which they may judge architectural design of bridges. They have no tradition to fall back on, and there is but little training for engineers in appreciation of the visual arts. The literature on architectural design of bridges is meager and—with few exceptions —not sufficiently specific to be helpful.

The aim of this booklet is to make a contribution to the subject of architectural design of bridges, to present fundamental principles applying to the visual arts, to discuss the principles and their application to typical examples.

In following this program, specific rules will be mentioned, but these rules, it should be noted, are to be considered of an importance secondary to the fundamental principles on which they are based.

The bibliography appended contains part of the literature which has been published on the subject. Particular acknowledgment is due to Mr. Ian G. Macdonald whose prize-winning paper on "A Philosophy of Aesthetic Bridge Design"* marks a mile-stone in the literature. Mr. A. Reyner Eastman, Architect, Rockford, Illinois, has made the three renderings reproduced in this booklet.

*See Reference No. 16, page 36.

Architectural Design of Concrete Bridges

1. Introduction

BRIDGES built on railroads in the United States about the middle of the nineteenth century were generally fabricated in railroad shops and then transported to the bridge site. The requirement for speed and ease of erection prevailed, but little thought was given to appearance. The early highway bridges were built from designs inherited from railroad practice, and the popular bridge type was the one most easily designed and most quickly erected.

The crudity of early designs is striking when viewed on background of recent designs of large monumental bridges on which architects have collaborated closely with engineers. Sketches and studies of architectural designs for such structures have been given consideration commensurate with that of the structural studies and computations. Appearance and safety have gone hand in hand.

Most of the volume in bridge construction is in the type of bridges of intermediate size, such as simple and continuous deck girder bridges, rigid frames and arch bridges. A great many of the structures built are strictly utilitarian and lacking in architectural qualities. The last decade or two has fortunately shown a very great improvement in this field, and few bridges are now designed without at least some regard to architectural effect.

Architectural *design* will be distinguished in this text from architectural *treatment.* The concept of "treatment" infers that the bridge after having been designed for structural requirements is to be treated *afterward* for the purpose of remedying architectural ills. But bridges should be designed architecturally *before* they are designed structurally.

Double-span deck girder bridge in Adams County, Pa., designed by Pennsylvania Department of Highways. All lines in this structure are straight. The center pier is made large and conspicuous to divert attention from the duality of the openings. Photo courtesy of Pennsylvania Dept. of Highways.

Deck girder spans carry railroad over three streets in Dallas, Texas. The apparent height of the structure is increased by a distinct sense of verticality in the architectural design of the piers. A site of this type warrants giving more than usual consideration to the exterior of the structure. Designed by C. P. Howes, Bridge Engineer, Texas and Pacific Railway Co., Dallas, in collaboration with O. H. Koch, then Director of Public Works, City of Dallas, and George G. Wickline, then Bridge Engineer, Texas Highway Department.

There will then be no treatment to apply afterward and no cost for treatment to be added. The architecture becomes part of and one with the engineering.

The art of architectural bridge design cannot be acquired by adoption of a set of rules, but conspicuous errors can be avoided by adherence to certain fundamental principles. Certain rules for architectural design of bridges have been suggested. Some of these which are not considered of fundamental nature will be discussed first in the section entitled Function, Fitness and Truth. They will be followed by a presentation of principles that are considered fundamental for art in general. The so-called principles of Unity, Definition and Inflection will be discussed and their specific application to actual problems arising in bridge construction will be illustrated.

The plan is to present and discuss elements that make up the whole and to do it *not* from the viewpoint of "architectural treatment" but rather as artistic design of structural elements.

In connection with the many sketches included in this text, it should be noted that there is a considerable opportunity for individual preference as well as for opposite viewpoints. The sketches are presented not as inflexible designs but rather as illustrations of general rules, and the final choice is one for each individual to make.

The sketches contained in this text are confined to those designs which present the clearest illustration of fundamental principles. The possibility exists of extending the designs to include those which express "modern trends." But these are left out of consideration in this text because they belong in a field to be cultivated by the designer who has had intensive training and long-time experience in the medium of architectural composition.

2. Aim of Architectural Design

Architectural design has to do with appearance, and the end toward which it strives is beauty. A bridge possesses beauty when its appearance pleases—that is, when it gives delight to the mind on contemplation of its order and harmony. The visible properties of bridges include line, mass, color, texture, and those bridges are beautiful in which these properties are arranged in a harmonious whole.

It would be well if a set of definite rules existed which, when applied, would automatically create beauty. It is commonly stated in the technical literature on architectural bridge design that the qualities necessary to create beauty include Symmetry, Harmony, Proportion, Expressiveness, Simplicity, Honesty, Truth, Sincerity, Style, Feeling, Repose, Grace and Conformity with Environment. These esthetic conceptions express the *results* to be achieved, but they offer little assistance regarding the *methods* to be employed. A set of rules or fundamental principles must be more tangible and more susceptible to interpretation in the technical language of the bridge designer.

It is granted that a set of rules for architectural design would be useful, but it must be said at once that it is a delicate matter to attempt to confine architectural design within a hard and fast set of rules. Rules can be little more than sign-posts indicating the route along which one must travel toward the achievement of an appearance of order and harmony.

Whatever rules may be set forth must rest on a clear definition of what the *aim* is in architectural design of bridges. Mr. Ian Macdonald gives a full and complete definition when he states:* "The aim is the design of bridges which shall exhibit the characteristics of visible order and harmony in the relationship of their colors, textures, lines and masses, to each other and to their surroundings." He also adds the requirement that the sentimental or irrelevant be eliminated. This

*Reference No. 16, page 36.

Thirty-four 53-foot spans carry South Sixth St. over Springfield Lake in Springfield, Ill. The repetition of so many identical spans does not become monotonous, but rather lends a special interest to the appearance, a rhythmical note that pleases. Designed by Department of Public Works and Buildings, George F. Burch, Engineer of Bridges, Springfield, Ill.

Simply supported deck girder spans carry Chicago Avenue over Desplaines River in Cook County, Ill. Design by G. A. Quinlan, Superintendent of Highways, and H. C. Taylor, Bridge Engineer. The susceptibility of concrete to being molded in pleasing shape and form is interestingly illustrated. The verticality accentuated in this design makes the structure appear higher than if horizontality had been emphasized.

definition is a corner-stone upon which a set of rules can be built.

Much has been written about the principles of Function, Fitness and Truth. Beauty, it is said, depends upon the degree to which a bridge emphasizes its "function," to what extent the members show how they support and transmit loads and stresses. The principle of "fitness" is based on the assertion that any bridge that is built right looks right. "Truth" as a basis of beauty implies that the bridge as a whole and in every part must look what it really is. These three principles—Function, Fitness and Truth—are useful, but on closer study no positive assistance will be gained through a philosophy based upon them alone. Other more fundamental principles must be uncovered.

Writers on esthetic and architectural subjects have formulated principles of composition in the visual arts which Mr. Macdonald has summed up and given special application to bridge design in what he terms "a grammar of esthetic bridge design." In Mr. Macdonald's own words: "It is to be understood that a grammar of design is of no more assistance toward the production of structural beauty than is the grammar of language toward the production of literature. But it is no less essential in structural design than it is in literature that the body of correct form and usage, which is grammar, should be appreciated and respected."

The outstanding points of the "grammar" as applied to bridge design are Unity, Definition and Inflection. The idea of "unity" is suggested to the mind when it contemplates a bridge as one thing rather than a disorderly array of many elements. "Definition" means the setting of limits to an element—or to an entity—so that it may be recognized as such, to mark the beginning and the end of an element or a group of elements. "Inflection" involves modulation or variation as in the departure from the monotone, the change which elements undergo to mark their particular place in the whole.

The three fundamental principles have a significance which by no means is confined to "grammar" alone. Their sphere of influence includes creative composition in many media such as literature, music and the visual arts. They are not passing vogues but are instinctively—although often subconsciously—accepted and adopted by those who create, as well as by those who appreciate what others create. There is but little contention of the fundamental principles, and the matter of individual taste enters not into the discussion of them but into their interpretation.

3. Function, Fitness, Truth

An architect commissioned to design a building may find scope for exercise of his imagination in the endeavor to suggest in the appearance the particular function which the building is to fulfill. It seems obvious that no such scope exists for exercise of imagination in the design of bridges since these are all required to fulfill the *same* function. The function of a bridge, to carry traffic over an obstacle, must always be so obvious that it may really be said to express itself. This conception of "functionalism" does not appear to be of much positive assistance in evaluating the principles of beauty in bridge architecture.

Another conception of functionalism is that the bridge should show what load it is to carry, what forces it is to resist, and *how it does it.* Carrying this conception to its conclusion, it may be asserted that the bridge should possess no feature which has no structural function to perform—a negative philosophy which is of little constructive value.

It is true, however, that "functionalism" may be given an interpretation that is useful to the engineer. For illustration, refer to Fig. 1, which contains several incorrect design features, and compare it with the same general layout in Fig. 2, in which the undesirable features have been corrected. Spandrel columns should have a base to indicate proper transfer of load, and the arch must not be carried below the ground line without any visual sign of support. The *function* of the structural elements has been concealed in Fig. 1 but is clearly expressed in Fig. 2.

As far as it goes and properly interpreted, the expression of function is a useful principle but it is not of sufficient fundamental importance to say that beauty is achieved automatically in a properly and scientifically designed bridge. Neither can it be proved that when the economic proportions have been determined, the resulting designs must be pleasing and artistic. "Design by science"—after all—differs from "design by looks," and the design in Fig. 1 is not as pleasing as that in Fig. 2. Its simplicity has been exaggerated to the point of crudeness.

Functionalism is closely related to another principle which asserts that beauty is the direct result when a bridge is made *fit for its purpose,* that is, when the design is made with logical economic use of the material. This is the principle that guided American engineers during

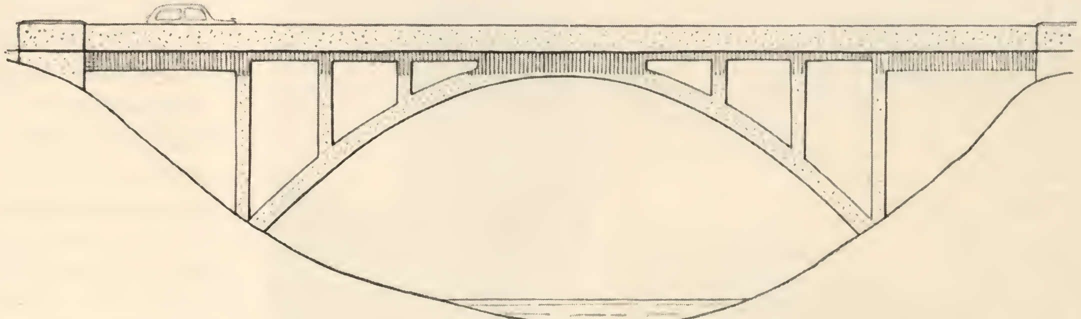


Figure 1

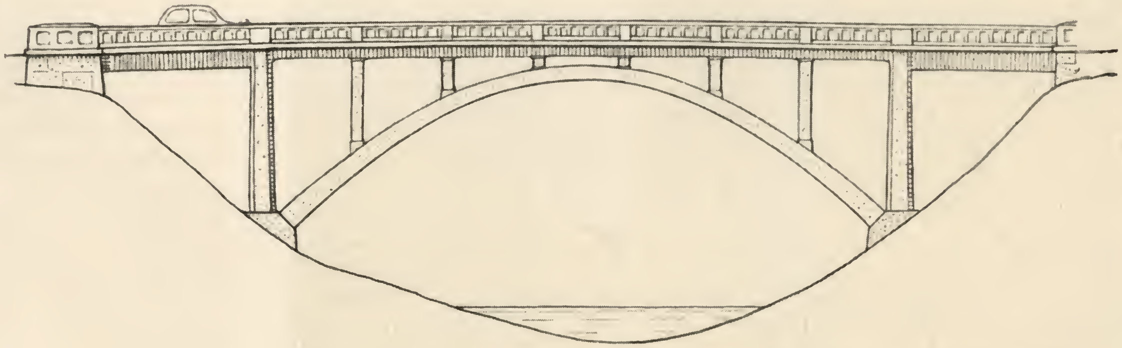


Figure 2

Nelson Bridge in Rockford, Ill., designed by George F. Burch, Engineer of Bridges, Springfield, Ill., in collaboration with A. Reyner Eastman, consulting architect, and Mogens Ipsen, consulting engineer, both of Rockford. A novel pier design is presented, and the details reveal excellent workmanship, a quality which is essential to beauty in bridge construction.

the latter part of the nineteenth century. They believed in "fitness for purpose" and "economy at any cost," and yet their structures were not, as a rule, beautiful. By strict attention to science, one may happen to produce beauty, but frequently one does not. If the assertion holds that a bridge if designed right looks right, then there is no difference between architectural design and structural design. Then the whole problem of designing to please the eye and to delight the mind would not exist.

As an example, the slender end columns in Fig. 1 may be strong enough and "fit" to carry their loads, but the architectural design is improved, nevertheless, when the size of the end columns is increased, because they then serve also to mark the vertical line which separates the different types of construction on approaches and above the arch.

A third theory has been advanced, in accordance with which it is claimed that in order to make a bridge beautiful it is necessary above all to be *truthful*, to shun the masking of truth and to avoid deceit. This theory has an air of august impregnability and, to be sure, is a theory not to be ignored. Upon closer examination, however, it becomes clear that there are circumstances in which the expression of truth is uncalled for—that truth and truth alone is not sufficient to create that which when seen pleases. In the arches in Figs. 1 and 2, for example, the stresses are minimum at the points which are level with the "elastic center." And yet, it is not conducive to beauty to vary the thickness of the arch so that it is a minimum somewhere between the crown and the springing.

The most disquieting thing about the theories of Function, Fitness and Truth is that they have given rise to no general guides or rules for good appearance, no tangible advice for the bridge engineer, and no opportunity for him to develop a philosophy on architectural design of bridges. The endeavor to make the bridge a "materialized stress diagram" may produce orderly design, but it is not apt to convey delight to the mind of the observer.

It will be discussed in subsequent sections how the achievement of visible order and harmony in bridge architecture may be reached through application of theories based upon the three principles of Unity, Definition and Inflection, terms which may be borrowed from the grammar of oral expression and applied to composition in the visual arts.

4. Unity

A bridge may appear to be a haphazard incongruous group of elements, each of which makes a separate appeal to the attention. If so, the structure lacks the quality of coherence, it lacks "unity." Unity denotes that all the elements together present themselves to the eye as a related group, as a structure which provides a central focus of interest.

Duality, which is a departure from unity, may be considered as a negative illustration. The human mind apparently resents the contemplation of two identical objects placed side by side. The eye wanders restlessly from one to the other and back again, comparing size, shape and texture, or searching in vain for possible dissimilarities. The central focus of interest is lacking, and there is no restful unity.

Duality in bridge design is undesirable and yet it cannot always be avoided. Two identical elements placed side by side are not to be confused with two elements that are complementary—that is, symmetrical but not identical. A duality such as the two arches in Fig. 3 can often be avoided by a change indicated not by structural but by architectural requirements and be resolved into two complementary elements, an example of which is presented in Fig. 4. The complementary arches in Fig. 4 do not exhibit the undesirable quality of the duality of the two identical arches sketched in Fig. 3.

At some bridge sites the general layout dictated by economy leaves no choice but to adopt a bridge type that exhibits duality in spans. The span is normally the most significant feature in the bridge and therefore tends to become the focus of interest. If duality in spans is unavoidable, it often is a successful solution of the problem to divert attention from the spans to some other structural feature and to accentuate the latter so that it dominates the group. In bridges with *two* spans, for example, there are *three* piers or supports, and these three supports may be

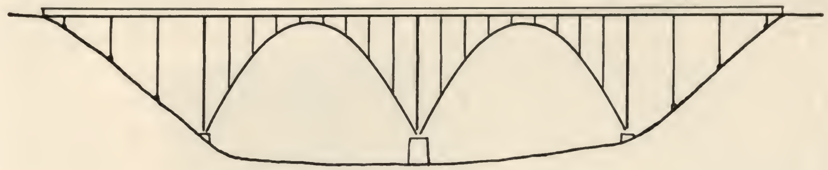


Figure 3

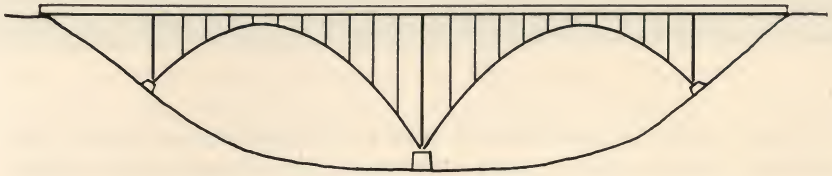


Figure 4

Bents made up of four large concrete piles support the Nanticoke River Bridge at Vienna on road from Cambridge to Salisbury, Md. Built in 1931 and designed by Maryland State Roads Commission, W. C. Hopkins, Bridge Engineer. The large concrete enclosures built to serve structural purposes are effective architecturally as well.

Rigid frame structure separates Plymouth Road and Middle Rouge Parkway in Wayne County, Mich. Design by Wayne County Road Commission, H. A. Shuptrine, Bridge Engineer. The pilasters are designed with a battered line on the side toward the span in order to mark the outline of the rigid frame, which is made the focus of interest.

laid out to attract the attention of the eye. As illustrated in Fig. 24 (see Section 12), the center pier in a two-span bridge may be made larger than required for utilitarian purposes. It may be built higher or wider than required for safety, and the exterior supports may also be accentuated. The dimensions of the center pier and the pilasters on the abutments in Fig. 24 may be contrary to the principles of function, fitness and truth, but these design elements are architecturally justifiable because they provide a dominant feature for the sake of unity.

Replacing an even number of spans by an odd number will not suffice to create unity. In a layout with, say, three spans, the center span tends to become the dominant feature. This tendency should not be weakened by making all three spans of the same length, as sketched in Fig. 5. The center span will appear even more inadequate in a foreshortened view of the structure, because foreshortening lends emphasis to the span nearest the observer. The principle of unity and its demand for a dominant feature require that the center span be made longer than the outer spans, as illustrated in Fig. 6.

As the number of spans increases beyond three, the difference in appearance between even and odd number of spans becomes less and less conspicuous and the choice of *number* of spans becomes correspondingly less important. There is still need for a dominant feature, however, and the choice of *length* of spans should be governed by this consideration.

The principle of unity extends its influence beyond the dominant features into the realm of the elements that make up the whole. Posts in parapets, brackets and lights that are placed on center lines of spans divide them into *two* halves and therefore are contrary to the desire for unity. Furthermore, conspicuous design elements placed at midspan give the appearance of concentrated loading placed at the point of critical stress and therefore tend to make the structure appear less strong and less fit for its purpose than if a similar element had been placed at, say, the third-points.

To attain the quality of unity in a bridge structure, the elements presenting themselves as a *related group* should provide a central focus of interest. Some illustrative examples may serve to explain what is meant by the conception of "related groups."

Figure 5

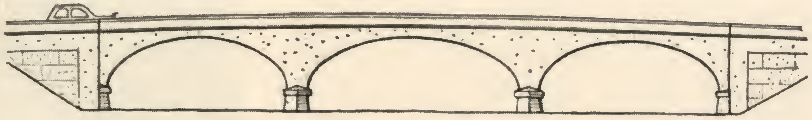


Figure 6

A single-span open-spandrel arch is sketched in Fig. 1 in which simplicity is the outstanding and also the discordant note. The parapet has been made solid and flush with the face of the water table, and the result is that the deck appears to be too substantial, out of proportion to the arch ring. The design looks top-heavy, or in other words, it appears as if the deck supported the arch. The trouble is that the wrong element is made dominant, the arch looks unfit for its purpose, and the structure lacks the quality of unity. In this design, the remedies are obviously to introduce a definite water table line and to change the parapet from solid to open construction. The alternate layout in Fig. 2 is viewed with pleasure because now the right element, the arch ring, has been restored to its proper importance as center of interest.

Another example of selecting the proper element for accentuation will be illustrated in Figs. 18 and 19. In Fig. 19, the abutments are laid out to a scale which dominates the design, with the result that the deck appears inadequate instead of occupying its rightful position of focus of interest. If the span is short compared with the height of the abutments, the relative shortness of the span often militates against its being made the dominant feature. Emphasis may then be transferred from the girder soffits to the top of the parapet and, if necessary, a simple design added on the face of the wing walls to emphasize horizontality as indicated in Fig. 18. These improvements represent some tangible rules derived from the principle of unity: (a) focus of interest should be attributed to the proper element; (b) the scale of related elements should be properly chosen; (c) horizontality of line is preferred in structures with short deck and high abutments. Further discussion of these points will be presented in Sections 10 to 16.

5. Definition

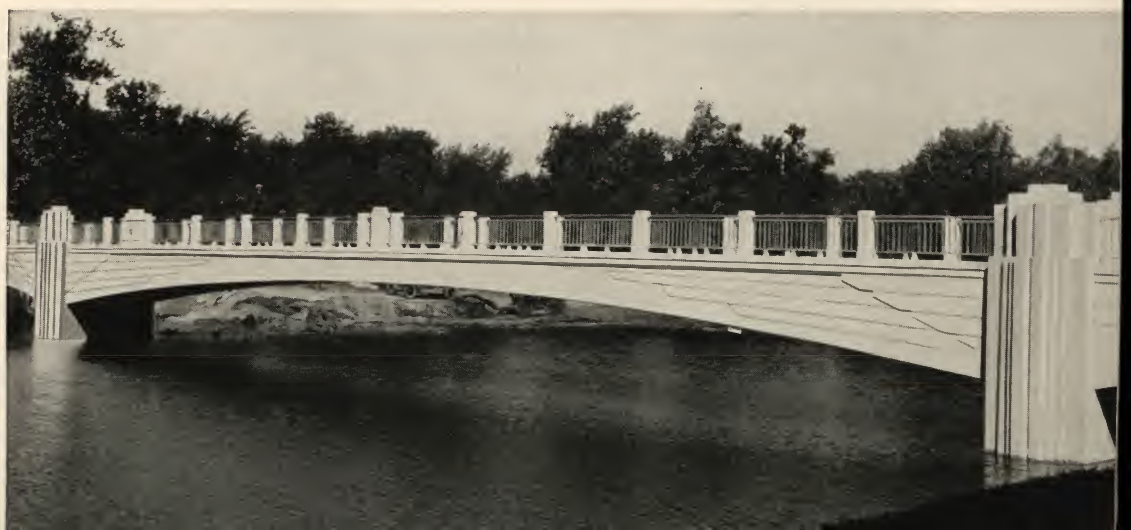
In bridge engineering, "definition" of an element means conveying the impression of what the element stands for, the setting of limits to the element so that it may be recognized as such. The beginning and the end of each element or group of elements must be shown in the design. If definition is neglected, crudeness may result.

A simple illustration of definition of an element is given in Figs. 1 and 2, which show spandrel columns designed to carry load from bottom of deck to top of arch ring. A plain prismatic column will perform its function properly, but it does not look well and gives an impression of crudeness. The addition of cap and base, even of the simplest kind, will please the eye and convey the impression that the column is securely and adequately placed in relation to adjacent elements. Splayed ends, as in Fig. 2, may suffice to give all the definition required. Other examples of definition are the abutments in Fig. 2 which indicate the beginning of the arch. In Fig. 6 the cutwater serves the same purpose.

Groups of elements as a whole should also be defined. Fig. 1 exhibits an example of lack of this type of definition. The lack of emphasis on the columns supported by the arch abutments is conspicuously a drawback in the composition. It has been corrected in Fig. 2 in which the longest spandrel columns have been enlarged to mark the ends of the arch span.

Compare the example of a spandrel column with that of a hanger, the function of which is to suspend a deck from an arch rib overhead. The definition involving cap and base is by tradition so intimately a

A 140-foot center span is the outstanding feature of the rigid frame bridge in Lincoln Park, Kenosha, Wis., designed by Hugo E. Bothe. The simply supported end spans are made deeper than needed for structural reasons in order to secure proper balance of mass in the architectural design. Built in 1936 by relief labor.



part of a column or post that it would be a mistake to "define" the hanger suspended from an overhead arch rib. Omitting cap and base on hangers is an exception to the principle of definition and is justified on the grounds that a vertical prismatic member may serve two functions, and a differentiation between them is desirable.

Definition of vertical members is also to be extended to piers, the regular parts of which are referred to as base, body and coping. When the visible part of an arch or a pier is designed as in Figs. 1 and 5 without being enlarged immediately above the ground or water level, the structure is apt to exhibit a distressing lack of definition and to give an impression of inadequacy. The eye searches in vain for some visual evidence as to the proper strength of the support for the pier. The pier design in Fig. 6 has a well defined base which makes the pier look substantial, stable, and is restful to behold, a quality which is lacking in Fig. 5.

The sketch of a pier with definition at top and bottom shown in Fig. 7 represents a design which is suitable for a high bridge but apt to look stubby for a low bridge. A type applicable to a low bridge, shown in Fig. 8, has no definition at the bottom except a band design which may be all that is needed. Extending the pier design as a pilaster up to the underside of the water table, as in Fig. 8, gives an appearance of slenderness desirable when the bridge is low. The band placed where the pier stops and the pilaster begins provides pleasing definition between pier and pilaster. The design in Fig. 9 represents a pier type suitable for multiple-span rigid frame bridges, the pier being defined by a flare at the bottom.

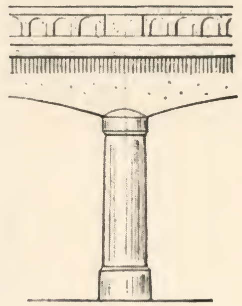


Figure 7

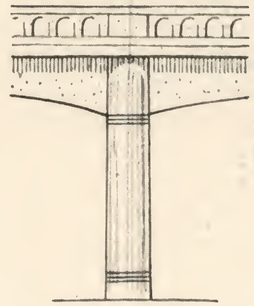


Figure 8

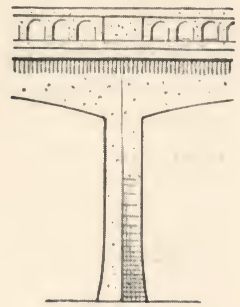


Figure 9

Parapets should be given three types of definition: (a) vertically as handrail, dado, base; (b) horizontally by use of enlarged end posts; (c) in plan by flaring or curving the parapet at the ends of the bridge. These and other examples of definition will be discussed in Sections 10 to 16.

Rigid frame bridge, designed by Carl Kuch, carries Findlay-Delphos Road over Cranberry Creek in Putnam County, Ohio. The segmental soffit curve is the center of interest and makes the structure appear higher than if the soffit had been made straight. The vertical design of pilasters and posts serves to accentuate height, an important consideration in a structure with long span but shallow headroom.

6. Inflection

Inflection in bridge architecture means modulation or variation as in the departure from the monotone, the variation of form which elements undergo to mark their relationship to one another as well as to the structure as a whole. In its purely grammatical sense, inflection of a word means a conjugation or modification of the main root to express the grammatical relationship of a word to others.

An illustration of inflection in one of its simplest aspects may be made in connection with design of a pilaster or a pier. If a pilaster is made symmetrical about a horizontal axis, as in Fig. 10, it is said

Without inflection

Figure 10

With inflection

Figure 11

to be without inflection, because the designer has failed to express the difference between top and bottom. The pilaster designed as in Fig. 11 has better appearance because it convinces the observer that an orderly arrangement prevails in which the top is up and the bottom is down.

The case of varying length of spans in bridges with three or more openings has been discussed under Unity but will be referred to again, briefly, from the viewpoint of inflection. The long span in Fig. 6, flanked by outer spans with decreasing length, naturally belongs in the middle. It is similar to the other spans, and yet it is not interchangeable with them. There is a relief from monotone, since each span has a length which clearly marks its proper position in the structure as a whole. The quality of inflection provides another good reason for introducing variation in span lengths.

Piers have two different inflections, as illustrated in the sketch of the unsymmetrical structure in Fig. 12. It is desirable first that the definition of top and bottom should be different and that the pier thickness should decrease from bottom to top. It must not appear as if the pier might be turned upside-down and still present the same appearance to the observer. His mind wants to be assured that the pier is intentionally designed and placed as it is. The second inflection has to do with the position of the pier in relation to other piers or to the entire structure. In Fig. 12, the two end piers or abutment piers are similar, and yet they cannot be interchanged. They belong just where they are placed, each pier being "in scale" with the nearest part of the adjacent structure. The inflection of both the piers and the spans in the unsymmetrical layout gives the composition as a whole a pleasing air of orderliness, and the absence of symmetry is not resented.

Where dissymmetry of bridge layout cannot be avoided, inflection

Close-up of grade separation structure in Salem, Ore., illustrates that beauty may be expressed by simple architectural design. Note offsets in soffit line over pedestrian tunnel, the same motif being used in the roadway span. The lack of symmetry does not disturb the effect of the design.

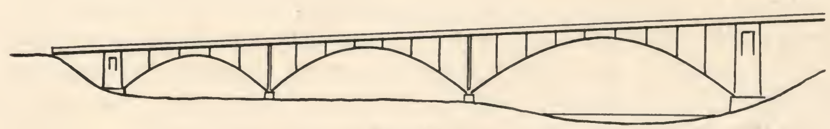


Figure 12

is the principal quality which, when properly expressed, may make the structure beautiful. Inflection must be imparted to spans, piers, abutments, parapets, and scale of detail as illustrated in part in Fig. 12. The lacking quality of symmetry may be replaced with the related conception of balance. Unsightliness may be avoided when it is remembered that "one symmetry in an unsymmetrical whole disturbs."

Arches may be inflected in two ways, the cross-sectional depth either being increased or decreased from crown to springing. Arches with constant depth, as that in Fig. 1, look clumsy and ill-contrived since the eye prefers a gradual change of depth from crown to springing.

In a single-span rigid frame bridge, as in Fig. 21, the depth of the deck is inflected from a minimum at crown to a maximum at face of support, and the vertical portion of the frame is also inflected. The pilasters in Fig. 19 are not inflected. In simply supported deck girders, as in Fig. 18, little opportunity exists for the application of inflection, and this is sometimes considered a drawback in the architectural composition of bridges with simply supported deck construction. The design and the handling of straight lines, however, may produce pleasing results and will be discussed in Sections 7 and 10.

Architectural design of parapets presents a wide scope for exercise of creative imagination on the part of the designer. Results, to be pleasing, depend upon the application of certain rules, of which those derived from "inflection" will be treated here. A typical parapet design has three parts—coping, dado and base; the base should be heavier than the coping, but neither of the two must be too deep compared with the dado. In addition, the parapet should be inflected horizontally. It is desirable to diminish the length of panels or interval between posts as the ends of the bridge are approached, an inflection similar to that discussed for length of spans. Introducing such details will create the impression that the parapet is arranged in an orderly manner, and the tendency to monotony due to repetition is pleasingly relieved.

Another use of inflection has to do with the scale of detail on the surface of the bridge. Near the bottom, breadth of treatment is essential and may be achieved by leaving the surface roughly finished and of a dark shade. Rising from the bottom toward the top, the scale of detail should diminish, the surface should be more smoothly finished, and its shade should be made lighter. Examples illustrating this type of inflection will be discussed later in connection with Fig. 24.

7. Line

The eye is constantly occupied in following lines, in observing their length and direction, shape and curvature. Its sensitiveness is doubtlessly greater in regard to line than to the other elements in the visual aspect of bridges. The quality of "line" will, therefore, more than any other single thing contribute to the degree of pleasure with which a bridge is viewed.

The straight line is the least complex of curves, but its use has been said to be detrimental to beauty. Designs composed of straight lines—but no curves—may have a high quality of beauty, however, and the evidence from ancient Greek architecture is sufficient to show there is no basis for the assertion that "the straight line is inherently ugly."

The very simplicity of the straight line makes it necessary to give it more rather than less attention. Masses confined by straight lines, as well as structures exhibiting mainly straight lines, should be given the greatest care in regard to unity, definition and inflection.

The unity or oneness of the straight line leaves the designer no

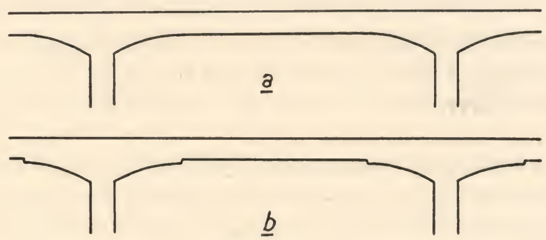


Figure 13

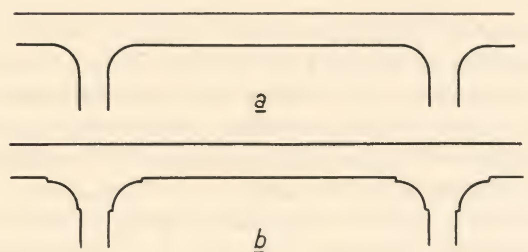


Figure 14

Triple-span rigid frame bridge with "hidden end bents" carries Rocky Pond Road over Soucook River near Loudon, N. H. Design by New Hampshire State Highway Commission, John W. Childs, Bridge Engineer, and Harold E. Langley, Assistant Bridge Engineer. Triple-span layouts as shown save abutment construction and provide maximum area of waterway.

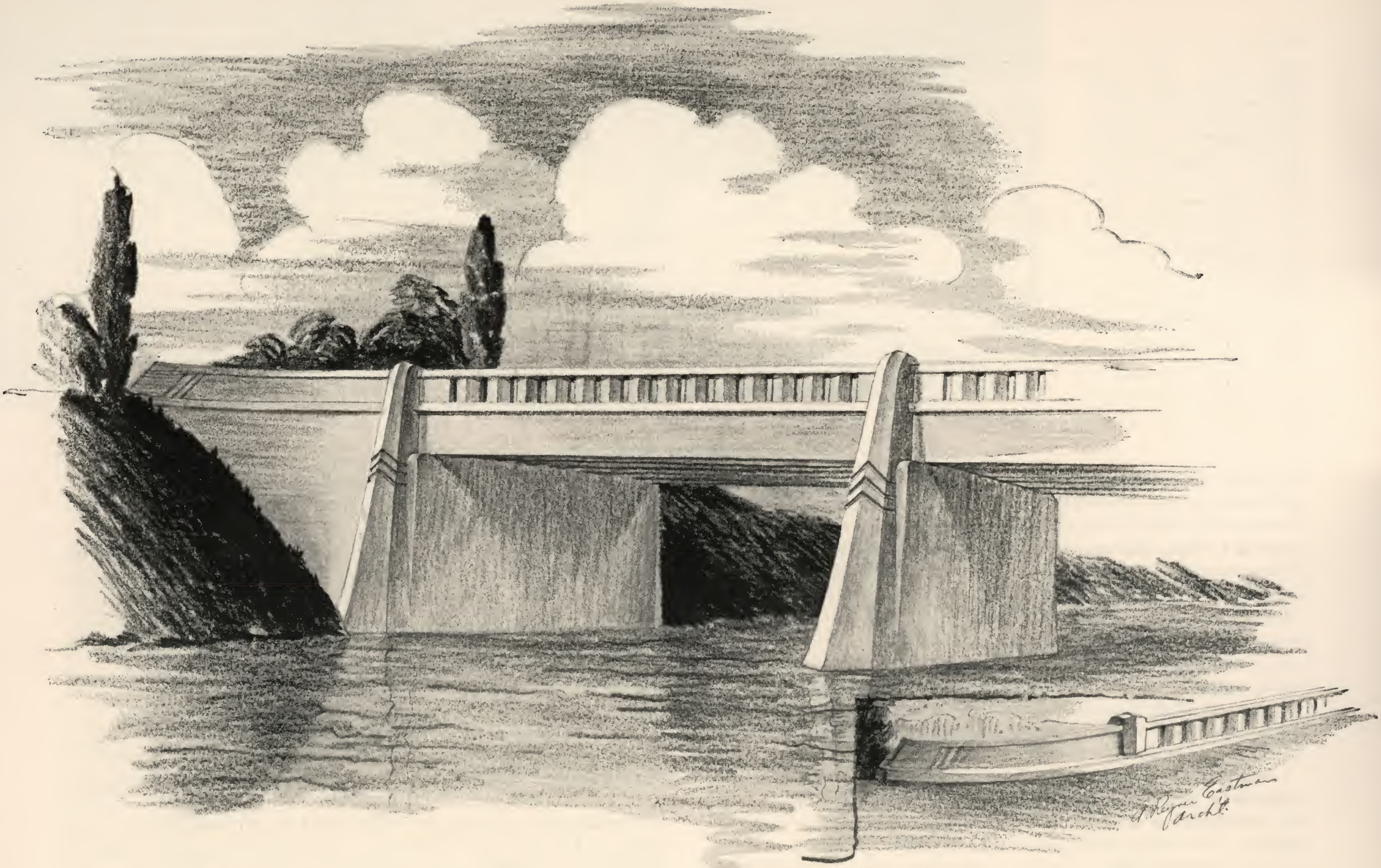
choice but to set definite limits to it and to show clearly where it begins and where it ends. A straight line should not, as a rule, be made continuous with a curve, and to make the straight line tangential to the curve as in Figs. 13*a* and 14*a* is especially undesirable. The combination is incongruous and violates the unity of the straight line. An angular "break" or offset gives good definition, and if a straight line is adjacent to a curve, the point where they join should be clearly defined in a manner such as illustrated in Figs. 13*b* and 14*b*.

A straight line may be inflected by giving it a camber which is barely perceptible. Too much camber will destroy the simplicity and the strength of the line. Inflection of the *masses* confined by the lines, already discussed to some extent, may replace inflection of the line itself, and examples of this will be discussed in subsequent sections.

Among the curved lines the three- and the five-centered arches have occupied a position of prominence in engineering layouts, but they do not present a satisfactory appearance, as illustrated in Figs. 15*a* and 16*a*. The eye following the outline of the composite curve in Fig. 15*a* gets accustomed to a certain rate of change in curvature in one segment and resents the sudden change to a much greater curvature in the adjacent segment. It demands either a transition curve between the two in order that they may appear as a unity, or a distinct limiting feature should be shown which will truthfully state where one segment stops and the other begins.

Arcs extending through a small angle, as illustrated in Fig. 15*b*, should be segmental rather than parabolic because the two curves are so nearly alike that the parabolic soffit line may convey the impression that a segmental soffit was planned but improperly constructed. Segmental soffit lines convey an impression of strength, and it has been asserted that their appeal to the eye is weakened by the addition of curved fillets, as in Fig. 15*a*. The handling of a segmental soffit curve should follow rules similar to those discussed for straight lines.

It often becomes necessary to lay out a soffit line in which the radius of curvature is much larger at the center than at the ends. In this case, the semi-ellipse as in Fig. 16*b* may present a good solution of the problem. The elliptical soffit illustrated in Fig. 6 has the qualities of unity and continuity, but the semi-ellipse must be given definition at the ends of its horizontal axis because, otherwise, the abrupt change in curvature at the ends of a flat ellipse may appear distressing. The illusion of weakness at the transition point as in Fig. 5 may be conspicuous, especially when the elevation is seen in foreshortened view.



The design by A. Reyner Eastman is particularly suited to a simply supported deck girder bridge with two openings. The prominence of three supports—only two of which are shown—diverts attention from the duality of two spans. The pier has a definite flare at the bottom for definition and the chevron design serves to describe "support" for the deck girders.

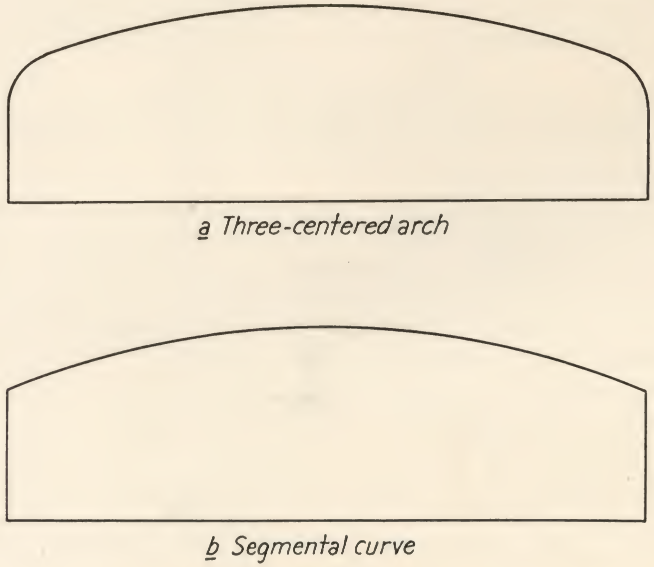


Figure 15

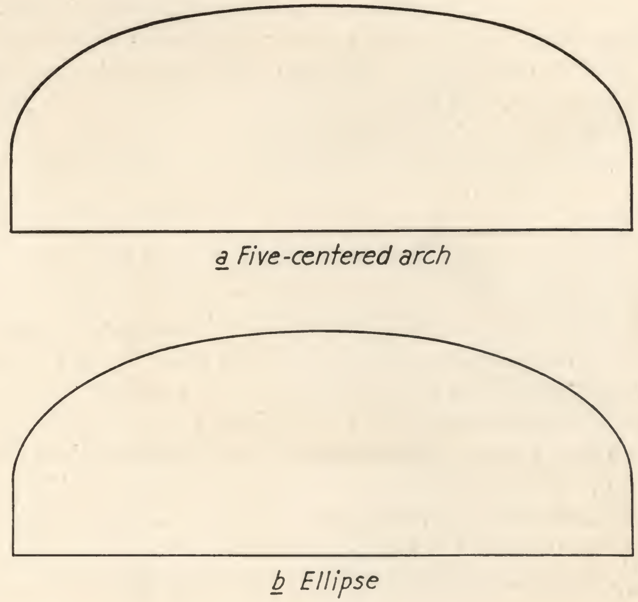


Figure 16

Introduction of a definition, as the coping on the pier in Fig. 6, restores proper appearance of strength and emphasizes the unity of the ellipse itself. A definition by means of an offset, as in Fig. 29, may also be suitable for a semi-ellipse at the ends of its horizontal axis.

Semi-ellipses with nearly equal axes are undesirable because they tend to look like semi-circles that are imperfectly constructed, in which case it is better to use a semi-circular soffit, which is also known as a "roman arch."

The outstanding character of the ellipse is grace, but the segmental curve has more decision and the choice between the two types of soffit line is often dictated by the nature of the bridge site. Both of these soffit lines are better curves for the spandrel-filled type of arch than is the parabola, which frequently appears to be too low near the quarter-points of the span.

In open-spandrel arches, the use of the parabola prevails. The interest is centered not in the mass of the spandrel surface but in the line of the arch rib, and for open-spandrel construction the parabola represents the apotheosis of fitness and strength combined with grace and the appearance of carrying the loads without undue stress and strain. Except in arches with relatively large rise ratio, the parabolic soffit curve may be modified to some extent by lowering or raising certain portions of the curve as dictated by the eye. This may be done without materially altering the stress conditions.

When the parapet of a bridge is clearly silhouetted against the sky, the top of parapet may assume an importance as center of interest which overshadows that of the soffit. For illustration, the parapet line is generally the dominant feature when the bridge is viewed from an underpassing roadway, in which case the parapet deserves attention even more than does the soffit.

The parapet line should be parallel with the roadway line, and the height of the parapet should vary but little in designs for ordinary highway bridges. The eye instinctively accustoms itself to the fact that parapets in general are approximately three feet high and that this height furnishes a convenient unit for "scaling" the dimensions of the bridge. If the parapet height indicated by the design is appreciably greater than three feet the supporting construction may appear to be dwarfed, and if the parapet appears to be appreciably smaller than three feet it may look inadequate and the bridge unsafe for traffic. In both cases the quality of scale is disregarded, the principle of inflection is violated, and an important element in the architectural design is improperly handled. If the parapet is not plainly discernible from a distance, as in the case of thin railing designs, its apparent absence will cause a feeling of distress, of lack of safety, or of inadequacy.

A line obviously should be introduced to define the lower limit of the parapet, and it is equally essential to have a line on the face of the bridge which delineates the outline of the roadway that is concealed behind the parapet. This line may be provided by the design of a water table which also serves to deflect water from the face of the deck construction. Further discussion of water table details will be presented in Section 9.

In discussing the lines of parapet and water table, mention should be made of certain rules that are considered essential in good practice. The bridge being a link in the general highway layout should convey an impression of unity in the handling of the roadway grade lines, as illustrated in Fig. 17. The main principle underlying all the cases in Fig. 17 is that transition curves must be provided and should be suitably chosen.

The line at top of the parapet should, in general, remain unbroken from abutment to abutment, but a slight increase in parapet height over the abutments is sometimes justifiable. The ends of parapet lines should be defined by a substantial end post, the top of which may be horizontal even if the rest of the parapet is cambered. In general, the top of parapet should not be broken over intermediate piers, but the water table may be interrupted at supports if necessary, and it is common practice to make parapets open over spans but solid over abutments. Recessed panels may be arranged in parapets that are solid.

Long bridges, except those with constant gradient, should have parapets built with a camber that is barely perceptible, in order to kill the appearance of sag in decks with soffit lines that are straight and horizontal. Slightly more camber may be required in bridges with arched soffit in order to avoid that illusion of sagging which is due to the convergence of the lines in roadway and arched soffit.

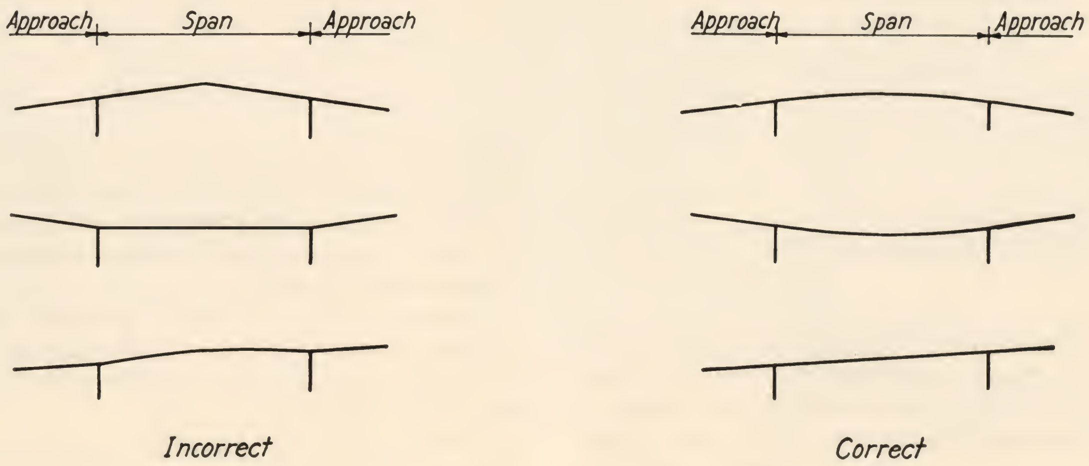


Figure 17

Multiple-span rigid frame bridge over Leaf River in Ogle County, Ill., built in 1937 and designed by Mogens Ipsen, Rockford, Ill. Horizontality is strongly emphasized by the parapet design which gives the structure a distinctive sense of unity and diverts attention from the dissymmetry of the abutments.

8. Mass

The distinction between "mass" and "line" is often vague, and some discussion relating to Mass has been presented in the section on Line. Other points regarding Mass have been treated elsewhere in this text, principally in the section on Inflection.

Masses must be of pleasing shape and agreeably related to each other. Many theories as to shape and its relation to beauty have been advanced, but the bridge engineer is generally wise in confining his appraisal of shape mainly to that point which has to do with stability and to those rules regarding stability which may be derived from the principle of inflection.

Shapes that are pretentious or represent "too much ado about nothing" are among those to be avoided. On very short bridges, for illustration, a parapet design divided into three distinguishable panels flanked by large end posts may represent a mass that seems too fussy and too substantial in relation to the shortness of the span. A better appearance may be gained by using an open parapet design with inconspicuous end posts.

The fact that "solid mass" gives the impression of more weight than does "open mass" leads to the rule that, generally, parapets should be open on decks but solid on abutments. A solid parapet looks wrong on a bowstring arch because the combination of solid mass of parapet and deck construction outweighs the rib. To emphasize the solidity of the mass in the rib, paneling on its face should be avoided.

The relation between pier width and spandrel depth deserves considerable attention. If girders are continuous over piers and rigidly connected with them, a very slender pier may be amply wide for

Small bridge structure built by Tennessee Valley Authority exhibits two decisive curves and no other lines in its elevation. The beauty of these curves and the interesting inflection imparted to the mass they encompass give the structure an arresting note of uniqueness.

strength but too slim for appearance. Piers that are too slim may be made to appear wider by inflection involving a base at bottom, a coping at top, and a body which is tapered from base to coping, as illustrated in Fig. 7. This design will serve to give the impression of greater mass in relation to deck construction.

The designer, in attempting to eliminate or circumvent those shapes which appear ugly, may make good use of the expedient of emphasizing either the horizontal or the vertical lines in his design in accordance with the dictates of his eyes. In subsequent sections, examples will be presented and discussed involving cases illustrating the advantages gained by giving the design a definite feeling of horizontality or of verticality. Every bridge, of course, presents both horizontal and vertical lines, but an effort should be made to accentuate one or the other, whichever seems more susceptible of successful architectural treatment. The result the designer strives for is to produce an effect of decision and definiteness, an effect which is simple and at the same time virile.

Horizontality in the design may be attained by accentuating the top of parapet and the water table, by introducing horizontal designs on the piers and abutments, and by stopping the piers at deck soffit or at water table. Verticality may be emphasized by vertical design of piers, by carrying pier and abutment lines unbroken up to the top of parapet, which may then be the only horizontal line to remain unbroken from end to end of bridge. Examples illustrating the application of such designs will be presented in Section 12.

Good balance of mass is difficult to attain when adjacent spans are of different type of construction or of different kind of material, because there may then be no agreement in sizes and shapes of members performing similar functions. For illustration, mass as well as line is unpleasing in case a center span of through type is flanked by spans of deck type construction. If it is necessary to combine different types of construction, considerable care is required to obtain shapes and masses that are of consistent scale throughout.

9. Ornament

Many designers have condemned indulgence in the use of ornament on bridges but, actually, there are two kinds of ornament, one of which has to do *not* with the physical nature of things but with their social or ceremonial significance. To express spiritual values through form and ornament is distinctly a matter for an architect who has received the proper training.

The engineer who has a feeling for and takes a pride in his works is entitled to the type of ornament which arises out of the work itself. His purpose in designing ornament is to accentuate structural parts, to describe their interdependence and to do it in an orderly harmonious manner. His aim is to construct ornamentation, not to ornament construction.

The modern bridge engineer possesses a viewpoint his predecessors did not have. Until recently, materials used for construction were thought of as being inert, without strain and without deflection. Ancient stone bridges clearly expressed the viewpoint of their designers that masses of inert material, massive in character, were ponderously compiled. But now, the bridge engineer works with material which he knows stretches, curves, deflects, and which has a quality of being peculiarly sensitive in its reaction to loads and forces. Materials of today are conceived as being—in a sense—alive, and the designer may aim to convey some of their sensitiveness to forces in the appearance of the structure.

Expression of sensitiveness to stress and strain may be particularly well achieved with a material such as concrete which has a quality of plasticity, a susceptibility to being molded and shaped. These qualities may, as Mr. Macdonald expresses it,* "become the keystones upon which further advance in modern bridge architecture will be based."

Examples illustrating the engineer's aim in "constructing ornament" may take various forms, as discussed in this text, but a brief summary here may be helpful. For illustration, piers may be projected past the parapets, their outlines may be battered and their faces may be made rounded, semi-circular, triangular or flat, and various lines may be designed on the surfaces as illustrated in some of the sketches. Such ornament, while not strictly necessary in a given structure, may have structural prototypes and bestow upon the bridge an appearance of desirable architectural qualities.

If panels are to be added anywhere on the face of a bridge, on piers, abutments, or spandrel walls, they should be recessed and not raised, as they then tend to become ornament that is applied. On wing walls, depressed panels should not be triangular, as in Fig. 5, and should be designed only in case the eye demands that large areas be subdivided and that either horizontality or verticality be accentuated.

Ornament on the water table should never be elaborate. Square, quarter-round or cove moldings may be used to good effect, and the overhang of the water table should be studied carefully to obtain the proper effect of shadows on the face of the deck construction below. A common mistake is to give the water table or deck slab too much overhang, often to the extent that part of the structure is in deep shadow, giving the impression that "something is left out." For an example, refer to the arch bridge in Fig. 1 in which the width of the

*Reference No. 16, page 36.

Westons Mills Bridge near New Brunswick, N. J., designed by New Jersey State Highway Department, Morris Goodkind, Bridge Engineer. Solid wing walls and pleasing pylon design mark the ends of the arch structure and provide a contrast which accentuates the graceful lines of the arches.

Bixby Creek Bridge on Carmel-San Simeon Highway, Calif., has 320-foot span and 240-foot height over stream bed. Designed by California State Highway Commission under direction of C. H. Purcell, now State Highway Engineer. A good example illustrating a beautiful arch line, large piers defining the ends of arch span, piers as well as spandrel columns showing proper inflection by means of tapered and offset lines.

deck greatly exceeds the width of the arch structure, with the result that the shadow tends to conceal from the observer the part of the arch near the crown. Overhangs and recesses should not be too small either, for then the shadow effect may become inadequate for the purpose intended.

It is only in the design of the parapet that the engineer is justified in giving so much attention to detail that it approaches ornament in the architectural sense of the word, but even here simplicity is preferable. First of all, the parapet should not only *be* but should *seem* strong enough to serve as protection for traffic, and this should be the cornerstone of all parapet design. The handrail, or coping, on the parapet should be smooth, slightly gabled, and with a true line at the peak. Its underside may have one or two right-angle beads, but the handrail should not appear to be as deep as the parapet base. The dado, or body of parapet, may receive decorative treatment if desired. It may be solid with recessed panels, perhaps with different color or texture. In open construction, the balusters may be made quite ornamental. Posts in parapets, the use of which has been discussed elsewhere, should be most conspicuous at the ends of bridges, less conspicuous at ends of openings and over piers, but they may be left out in parapets on relatively short bridges.

Nothing so dates a bridge as applied ornament, and passing styles in decorative design leave a bridge behind more than does progress in structural design. But the type of ornament which expresses the principles of Unity, Definition and Inflection has no date and remains a lasting tribute to the designer's skill and understanding.

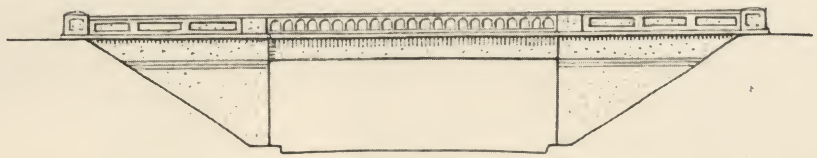


Figure 18

10. Single-span deck girder bridge over road

The two layouts in Figs. 18 and 19 are design sketches for a simply supported deck girder bridge spanning a four-lane highway. The approximate lengths are 44 feet from face to face of abutments and 107 feet from end to end of wing walls.

The two designs shown illustrate how the structure will appear when horizontality is emphasized (Fig. 18), and when verticality is emphasized (Fig. 19). An important problem to be studied at this bridge site is the one pertaining to the relative merits of horizontality and verticality.

The bridge will be viewed most frequently from the underpass, and from this place the top of the parapet will be clearly outlined against the sky and therefore becomes the main focus of interest. The soffit of the deck also commands attention but less so than does the parapet, and the faces of the abutments come last in regard to attracting attention. Good design makes it desirable to accentuate the quality of unity in the parapet, to make it appear as the dominant element with a breadth and definiteness of line extending from end to end of the structure, and the parapet lines should therefore be carried through unbroken. Large end posts set a distinct limit to the unity of the parapet, and less conspicuous intermediate posts serve to define the points where the parapet is changed from open to solid construction. Solid parapet is used over wing walls to give more "weight" to the abutment and thereby convey to the eye the appearance of stability and fitness.

A horizontal "band" is designed on the wing walls in Fig. 18,

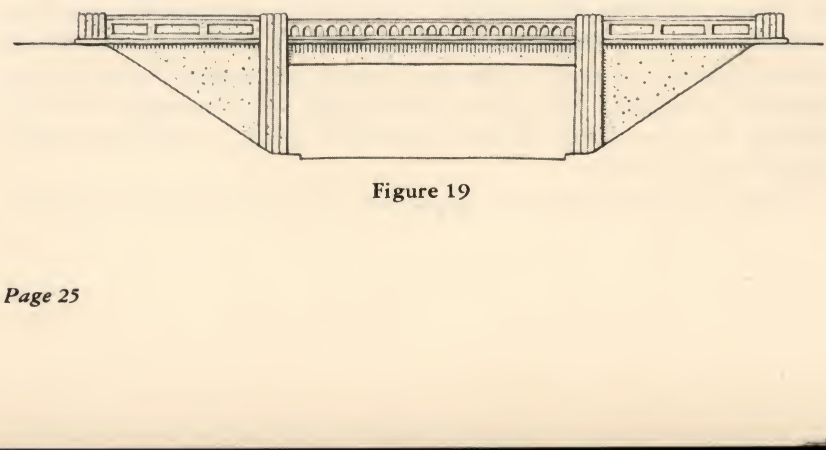


Figure 19

Cortright Creek Arch just outside Mount Rainier National Park, Wash., has 200-foot span. Built in 1935 and designed by U. S. Bureau of Public Roads, Regional Office at San Francisco. The bridge presents a well-designed layout in which simplicity prevails.

Close-up of Coos Bay Bridge in Coos County, Ore., illustrates an interesting view of beautiful details designed in this monumental structure. Design by Oregon State Highway Commission under the direction of C. B. McCullough, now Assistant State Highway Engineer. Note the use of different surface textures on pedestal and on superstructure.

and the purpose of the band is three-fold. Its presence accentuates the horizontality of the design, and it may also serve to conceal a horizontal construction joint. But its most important function is to provide a visual support for the deck which takes the place of the structural support that is concealed behind the wing wall. As an ornament, the band is justifiable on the ground that it expresses definite functions and reveals the fact that the abutment is built according to an orderly and harmonious pattern which pleases.

The band design may also be justified from the viewpoint that it imparts the quality of inflection to the wing wall. It subdivides a large area which might otherwise appear monotonous and separates it into a larger part—belonging below—and a smaller part that properly belongs near the top. Additional inflection may be introduced by giving the inside abutment face a batter, and—in plan—by curving the wing walls slightly outward.

In the design in Fig. 19 an attempt has been made to accentuate verticality in design. All horizontal lines have been broken at ends of the span, and a conspicuous vertical design has been introduced on the pilasters confining the opening. It appears, however, as if the deck might be raised or might be lowered, as in a lift span, and the mind becomes involved in the searching for a reason why the deck was placed at the elevation where it is.

One drawback in the design in Fig. 19 is that unity has been destroyed because the deck is isolated and made a separate unit. Even worse, the unity that should be the outstanding quality of the structure has been replaced by a duality, by two equal and symmetrical designs, the pilasters. Dualities are instinctively contemplated by the eye with resentment, and it is never wise in a single-span structure to overemphasize the two points of support. The design in Fig. 19 is weakened still more by the lack of inflection in the pilasters, which are symmetrical with respect to their horizontal axes.

The masses in Fig. 19 are unpleasing principally because the pilaster design gives the impression of "fussiness," an appearance of too much effort for too little reason. The mass of the wing walls as a whole is too large for the scale of the deck design and makes the deck look cramped. Verticality may give good designs for the bridge site considered, but the design chosen illustrates some of the undesirable points to be avoided.

The desirable quality of unity in the top of the parapet would be

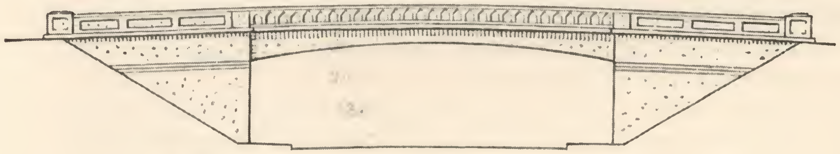


Figure 20

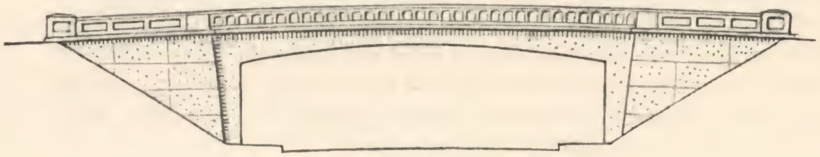


Figure 21

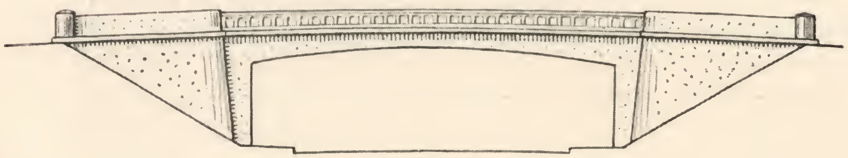


Figure 22

destroyed completely in both Figs. 18 and 19 if the mistake were made of using a parapet design on the deck so light and inconspicuous that it would not be clearly discernible from a distance. The structure would then appear as a group of three distinctively separate entities, of which the two heavy-looking abutments flanking the deck would make the latter look skimpy, inadequate, and perhaps even unfit for its purpose. It is a cardinal rule that the "scale" of the parapet design must be adequate in proportion to that of the rest of the structure.

11. Single-span rigid frame bridge over road

The three layouts in Figs. 20, 21 and 22 are design sketches for a rigid frame bridge spanning a four-lane highway with sidewalks. The approximate lengths are 55 feet from face to face of abutments and 115 feet from end to end of wing walls. The roadway on the bridge is assumed to be cambered, and a minimum vertical clearance of 14 feet is maintained at the gutters of the underpass.

Horizontality is accentuated in the layout in Fig. 20, which is similar to the design for a simply supported deck shown in Fig. 18 in Section 10, to which reference is made for discussion of architectural details. An important difference between Figs. 18 and 20 is that the arched soffit in Fig. 20 appears to be less pleasing than the straight soffit in Fig. 18. The eye following the straight lines in the band design on the wing walls is arrested by the abrupt change to the decisive curved line of the soffit in Fig. 20. The three line elements are definitely separate units and the single vertical line at face of the abutments seems insufficient to punctuate the limit between the elements. Objection may also be raised on the ground that only part of the frame—the deck—is shown, and that the structure does not express the truth that the stability of the deck depends upon its continuity with the vertical legs of the frame. The sketch does show a strong horizontality with the parapet design as a dominant focus of interest imparting a pleasing quality of unity to the appearance of the structure.

A minor change in Fig. 20 leads to the design in Fig. 21. The difference is merely the change from a horizontal to a vertical line on the wing walls, but this minor change in design produces a considerable change in appearance. There is good justification for drawing the battered line on the wing wall in Fig. 21, because this line describes the function of the frame, establishes a limit between frame and wing wall construction, imparts a pleasing quality of inflection, and adds to the appearance of stability of the abutment.

If the portion of the wing wall outside the battered line appears too small in proportion to the frame and the opening, it may be given more weight by the expedient of making a change in texture and shade. If the surface of the frame itself has a rubbed surface finish, the abutment may be given a darker shade and a coarser texture by leaving the concrete as it comes from the forms. This is in accordance with the rule discussed in Section 6 that the "scale of detail" should become increasingly finer from the ground up to the top of the structure.

Fig. 21 illustrates appearance of a structure which has two foci of interest, the parapet and the frame, but the principle of unity calls for just one dominant feature. The two-dimensional layout in Fig. 21 does not fully illustrate the actual conditions, however, and the finished structure may when viewed from different points lend emphasis either to the parapet or to the frame. If the bridge is viewed from a point from which the parapet blends into the background, the frame will attract the attention; when viewed from below the parapet may predominate.

In order to circumvent the possibility of having *two* dominant features, some designers may attempt to lessen the emphasis on the parapet as done in Fig. 22. Breaking some of the parapet lines will make the frame structure stand out with even more accentuation than in Fig. 21. This effect is heightened by making the abutments in Fig. 22 look more substantial than in Fig. 21.

It will be observed that a definite horizontality was expressed in Fig. 20, and that the designs in Figs. 21 and 22 represent consecutive steps leading away from it. Horizontality in itself, however, is a virtue mainly on account of the decisiveness it imparts to the design, and the layout in Fig. 22 appears to have sufficient horizontality blended with a proper amount of verticality for contrast. As a whole, the layout presents lines and masses which show order, strength, decision, and these are among the outstanding virtues in design.

The rather large surfaces of the wing walls in Fig. 22 are broken only by the water table. It will often give attractive variation and relief from monotony to curve the wing walls slightly outward. The curvature will tend to give inflection to the texture, since curved surfaces reflect light with varying degree of intensity.

12. Double-span deck girder bridge over road

The two layouts in Figs. 23 and 24 illustrate designs of simply supported deck girders over two openings, each of which is wide enough to accommodate three traffic lanes and one sidewalk. The approximate lengths are 83 ft. from face to face of abutments and 145 ft. from end to end of wing walls.

The design in Fig. 23 has the same general characteristics as that in Fig. 18 for a single-span layout to which reference is made for discussion of details. The most prominent difference is that Fig. 23 presents a case of duality in design, since it has two identical shapes—the openings—placed side by side. The eye moves restlessly from one to the other shape, and a central focus of interest is lacking. The result is not considered esthetically pleasing as discussed in the section on Unity, although some relief from the duality is obtained in this case due to the strong sense of unity expressed in the parapet.

The horizontal design, which was pleasing in a bridge length of 107 feet (see Fig. 18), appears less attractive in the design in Fig. 23, in which the length is 145 feet from end to end of wing walls. There is too much horizontality with too little verticality for contrast, which may result in making the structure look squatty. An alternate layout will be discussed in connection with Fig. 24.

Since two spans have three supports, attention may be diverted from the duality of the spans by lending particular emphasis to the supports, as in Fig. 24. The architectural design in Fig. 24, in which the supports are made conspicuous, possesses the additional advantage of exhibiting good balance between horizontal and vertical lines. Some of the horizontal lines are made less decisive by being interrupted, although the handrail is kept continuous in order to maintain its character of unity. The emphasis on verticality in Fig. 24 serves to make the design appear higher, and the structure as a whole gives the impression of better balance in design than does the layout in Fig. 23.

Architectural detailing of the piers may be varied, but the design shown is chosen to illustrate the principle of inflection as applied to design of piers. Vertically, the pier design is modulated in such a manner that its orderly and logical arrangement is apparent. The top of the pier must be up, the bottom down, and the two cannot be interchanged. Horizontally, the pier design is inflected so that the abutment pilasters are similar yet dissimilar to the center pier, and the eye readily

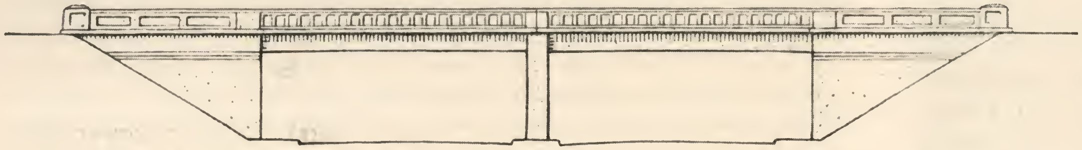


Figure 23

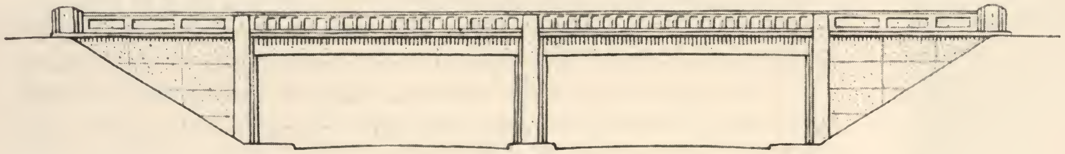


Figure 24

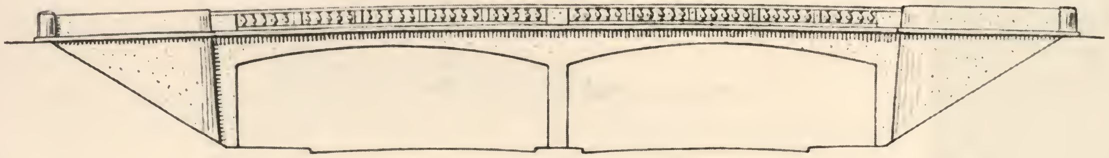


Figure 25

perceives the justification for the dissimilarity. The orderly harmonious arrangement serves not merely to divert attention from the duality in spans, but also to accentuate strongly one element—the center pier—which assumes the position of central focus of interest. The entire design gives as much quality of unity as can generally be obtained in a double-span layout at the bridge site considered.

The center pier in Fig. 24 presents visual sign of support for the deck which takes the place of the structural support that is concealed. The pilasters on the abutments serve to express the same function of support for the deck and at the same time clearly define the limit between deck and abutment, a definition which is not emphasized with sufficient strength in the design in Fig. 23. If it appears desirable to make the wing walls look more substantial, they may be given the same kind of texture as discussed in connection with Fig. 21, that is, the natural texture of the concrete may remain as it comes from the forms as indicated in Fig. 24. All other surfaces may have rubbed finish except the recessed panels of the parapet on the wing walls.

13. Double-span rigid frame bridge over road

The layout in Fig. 25 illustrates a design for a rigid frame structure spanning two separate roadways, each accommodating three traffic lanes and one sidewalk. The approximate lengths are 96 feet from face to face of abutments and 155 feet from end to end of wing walls.

For the bridge site considered, designs similar to those sketched for simply supported deck girders in Figs. 23 and 24 might be adopted, the only difference being that the deck soffits

Robert E. Lee Bridge carries Second Avenue over James River in Richmond, Va. Viewed from various angles, the structure presents interestingly different aspects. In this view, the skyline of the parapet dominates. Design by Allen J. Saville, Chief Engineer, and A. C. Janni, Consulting Engineer.

would be curved instead of straight lines. Referring to Fig. 23, it will be observed that the change to arched soffits involves a drawback, since the single vertical line at the face of abutment appears to be of insufficient weight to provide proper definition between the straight band design and a curved soffit line.

A double-span layout, as in Fig. 24, but with arched soffits, presents a more pleasing solution of the problem, but objection to it may be raised on the ground that the width and the mass of the center pier would be out of proportion to the slenderness of the deck construction near mid-span of the rigid frames. Other objections are that the type of pier support in Fig. 24 conceals the true nature of the structural action of the frames, and that it destroys the continuity which rigid frame structures should express in their appearance.

The design in Fig. 25 reveals the characteristic features of rigid frame structures and is unique in the sense that it cannot be used adequately for any other type of structure. At the same time, the continuity of the double-frame is accentuated to such a degree that it expresses oneness and unity. The eye is not preoccupied with the duality of the *openings,* but perceives these as part of the surrounding *double-frame.*

The unity of the double-frame is given still more emphasis by the use of two different types of parapet and by the massiveness of the wing walls which set a definite limit to the extent of the double-frame. The strong definition expressed through the wing wall design may be accentuated to good effect by introducing quarter-round corners, as indicated along the battered lines, and by curving the wing walls outward. The result is a pleasing modulation of the large surfaces, and the impression of strength and stability of the abutments is enhanced. Other features of the architectural design in Fig. 25 are discussed previously in connection with Figs. 21 and 22.

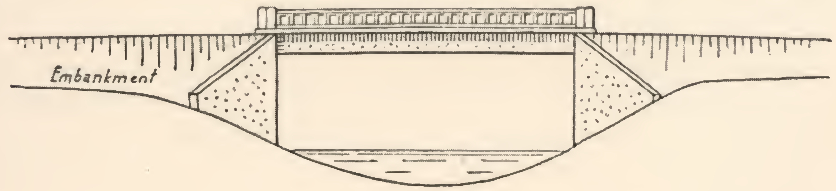


Figure 26

14. Single-span deck girder bridge over stream

The two designs in Figs. 26 and 27 are laid out for a deck-girder construction spanning a stream, the distance from face to face of abutments being approximately 45 feet.

If the wing walls may be made parallel with the axis of the roadway, the layouts and the discussion of them presented in Section 10 apply not only to grade separations but also to stream crossings. The discussion that follows is given with special reference to those bridge sites where flared wing wall construction is required.

The common type of layout for this site sketched in Fig. 26 presents an unsatisfactory appearance. The most conspicuous drawback is that the structure appears to be a separate entity which is set apart from the highway as a whole. There is an impression of abruptness in the change from approach embankment to structure, and a lack of unity prevails because the eye perceives the two approaches and the structure as *three* elements. The parapet looks too short, it seems inadequate because it does not provide for safety of traffic on the embankments, and the structure gives the impression that the design is skimped. Another undesirable feature in the design involves the top of the wing walls which, tapering up to a point, creates the distressing feeling that the support for the ends of the deck is weak and inadequate. The point of visual support is at the water table instead of at the girder soffit where it belongs. The provisions for strength and safety appear to be inadequate, and the design as a whole looks crude. Certain features incorporated in Fig. 27 to improve the appearance will now be discussed.

Settlement of embankment fill behind abutments is frequently responsible for maintenance costs which may be so high that many bridge engineers prefer to construct a reinforced concrete approach slab over the fill adjacent to the abutment. The approach slab is then designed to be strong enough to span a distance of up to 20 feet without any intermediate support from the fill. An extra depth of concrete is required for strength at the edges of this slab and may be added above the surface of the roadway. The edge construction may then serve not only for strength but also as a curb similar to the curb on the bridge deck. A parapet constructed on top of this curb, as illustrated in Fig. 27, will provide a much desired quality of safety on the embankment and will also improve the general appearance of the bridge.

The layout illustrates that the structure has been developed from a separate entity into an integral part of the highway, a pleasing quality of unity is expressed and an effective link has been established between highway and structure. The unity of the parapet requires that the handrail be carried through unbroken from end post to end post, and definition in form of posts is shown at the ends of the span. If a solid

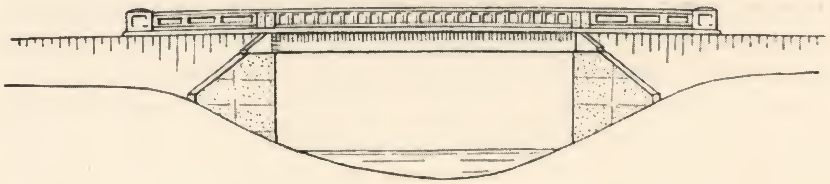


Figure 27

Vachel Lindsay Memorial Bridge at Springfield, Ill., crosses an area that was later to be inundated. Semi-elliptical soffit curves are accentuated by a design cast in plaster waste molds. Design by Burns and McDonnell, Kansas City, Mo.

Blaine Viaduct at St. Clairsville, Ohio, is also referred to as "Arches of Memory." Built in 1933 and designed by Ohio State Department of Highways and Public Works, J. R. Burkey, Chief Engineer of Bridges. The roadway grade dictated a design with arch spans varying from 103 to 146 feet, and the gradual increase in size of the arches lends interests to this unsymmetrical layout.

parapet design looks too heavy on the approaches because of the lack of visual structural support, an open parapet design may be adopted throughout the entire length.

The design of wing walls in Fig. 27 expresses several structural functions. The offset at the soffit line supplies visual support for the deck girders, serves to conceal a construction joint, and imparts an appearance of solidity and stability to the abutments. The strength of the abutment is accentuated even more if its surface is not rubbed, but left a darker shade, as in concrete having its natural form texture.

The sketch in Fig. 27 illustrates how design of a few architectural features, all of which are structurally justifiable, may change a bare and crude-looking structure into one which presents an orderly and harmonious pattern possessing unity, definition and inflection.

15. Single-span rigid frame bridge over stream

Fig. 28 shows a design for a rigid frame construction spanning a stream. The approximate lengths are 58 feet from center to center of piers and 114 feet from end to end of deck.

The design in Fig. 28 consists of a single-span rigid frame structure with deck cantilevered beyond the supporting piers. Structurally, this construction has the advantage that both moments in the piers and horizontal thrusts on the foundations may be reduced to a minimum. Further substantial economy may be obtained in this layout because the cantilever construction replaces not only the heavy approach slab mentioned in Section 14, but it also eliminates the ordinary wing wall construction. The structure provides more waterway area for flood

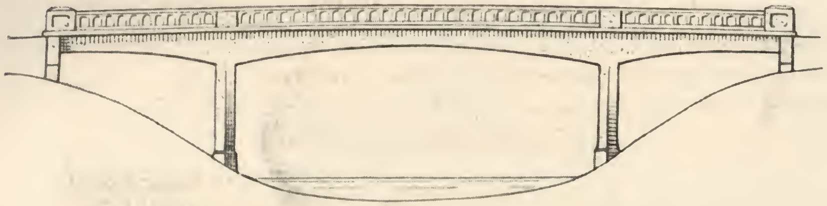


Figure 28

conditions, a feature which may be used to economical advantage.

The appearance of the structure in Fig. 28 is of particular interest because it is typical of the kind of design discussed in Section 9, in which the material in the bridge structure is conceived as essentially alive rather than inert. The contemplation of a structure as in Fig. 28 creates a distinct feeling of the strength and the sensitiveness with which the structure resists stresses and strains.

Two of the details in Fig. 28 which have not been discussed in connection with designs already presented are the piers and the cantilevers. The face of the piers has a cutwater design of triangular shape, the angle at the apex increasing gradually from, say, 90 degrees at the base to 180 degrees at the deck soffit. The design serves as cutwater, imparts inflection to the texture of the pier face and adds stability to the pier design. The small retaining walls at ends of the cantilevers are suspended from the deck, and no support is relied upon from the ground below.

The design represents "functionalism" as it is conceived by the engineer, since nothing is shown except that which has a structural function to perform. The structure also expresses the "truth" because the supporting structure is revealed in its entirety and its true shape. It has simplicity but not to the point of crudeness; and it expresses both life and beauty.

16. Triple-span rigid frame bridge over railway

Examples and accompanying discussion of designs for specific bridge sites have been presented in Sections 10 to 15, the aim being to illustrate application of the design principles treated in Sections 3 to 9. The designs presented are not the only ones suitable for the sites considered, nor do they include all the sites commonly encountered in a bridge engineer's practice. The opportunity to create new designs is ever present and constitutes a fertile field for development of beauty in bridge construction.

Designs for *double-span* bridges over streams may be developed from architectural elements already discussed in Sections 10 to 15, but for stream crossings such designs have shortcomings from both architectural and structural viewpoints and are therefore avoided wherever possible. The *triple-span* layout, on the other hand, possesses considerable structural adaptability, and one type of design will be discussed in connection with Fig. 29.

The triple-span layout which is shown in Fig. 29 has "hidden end bents," a term that owes its use to the fact that only the intermediate bents are visible, whereas the major portion of the end bents is concealed in the embankment on the approaches. This layout is—in a sense—an extension of the type of structure presented in Fig. 28, and reference is made to the discussion accompanying that figure. One of the outstanding advantages of the layout considered is that expensive abutment construction is eliminated, and since the resulting reduction

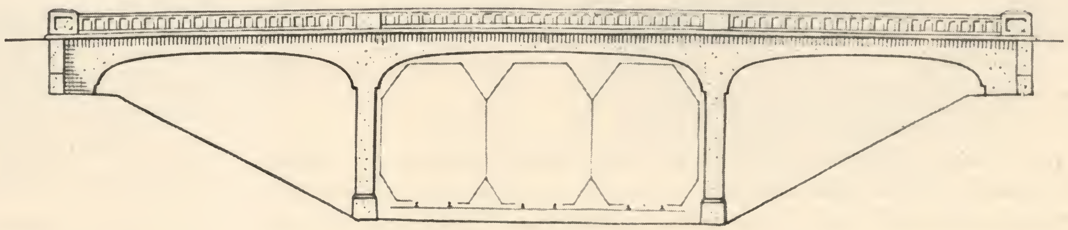


Figure 29

in cost is greatest where abutments are highest, the layout is particularly adaptable for use over railroads, in which case the vertical clearance generally required is 22 feet.

The triple-span rigid frame design in Fig. 29 has a center span of approximately 52 feet, center to center of piers, spanning three railroad tracks. The approximate length from end to end of bridge is 150 feet.

It is seen from Fig. 29 that the general outline of the soffit in the center span fulfills two structural requirements, since it is drawn with due regard both to clearance diagram and to magnitude of moment. Architecturally, the increased depth of the deck at supports is of pleasing effect because it reduces the apparent height of the pier. If a single segmental curve of the type in Fig. 28 had been adopted, the piers would have looked too high and too slender. The appearance of height is reduced further by introducing the bases on the piers. The result is that the masses represented by the pier and deck surfaces are well balanced, every element in the design expresses fitness and strength, continuity and resilience.

In the design in Fig. 29, the soffits might have been made semi-elliptical curves, as in Figs. 5 and 6, but ellipses that are very flat exhibit certain drawbacks. The elliptical lines in Fig. 29 have been modified to please the eye and to fit the clearance diagram. If the offsets at the ends of the modified ellipse were omitted, the top of the pier would look inadequate and relatively thin at the point where the ellipse merges into the pier line, and the pier would appear too tall and too slim. The offsets at the junction of the straight and the curved lines in Fig. 29 are therefore considered a good architectural detail.

The soffits in the outer spans must remain visible in their entirety, and for this reason a "berm" as shown is required at the top of the embankment.

17. Conclusion

As administrator of public funds, the bridge engineer is vitally interested in cost, and cost considerations cannot be treated too seriously. While this text is not a treatise on cost, a few points on this subject deserve to be mentioned.

A clear distinction should be made between "architectural treatment" and "artistic design of structural elements." The former implies that something is added *after* the structural design is made, the latter means that architectural design *precedes* structural design, or that architecture and engineering are essentially one. Artistic design of structural elements as discussed in this text should give rise to little, if any, added expenditure. It might even cause a reduction in costs of construction, because the sketching of *several* preliminary architectural layouts will tend to clarify the designer's judgment as to which type is the most suitable for a certain bridge site.

It is fully realized that the construction of a bridge may affect adjacent property values, that it may be either an asset or a liability to the community. This fact is recognized generally and given expression by C. B. McCullough* who inserts in his "cost equation" on bridge construction a term which includes gain or loss in value of adjacent property due to beauty or ugliness of a structure. It is true that no way is known of measuring pleasure imparted through the contemplation of beauty, but it is no less true that such pleasure is both tangible and valuable. Beauty in bridges carries down to posterity an expression of the spirit of the community and is a tribute to the skill and understanding of the engineer.

Bridge design is considered both an art and a science. It has been said that art without science is apt to be inefficient, but science without art is unattractive. Architects frequently collaborate with engineers on large monumental bridges, but when the engineer is solely responsible for both architectural and structural design, which is customary for medium-sized structures, there is no escape from the necessity that he be well versed not only in science but also in the principles of artistic design of structural elements.

Architectural design in bridge engineering belongs in the general layout. The time to determine the structural safety comes afterward. The science of bridge construction should aid the art in bridge design, dominate it perhaps, but never be allowed to overpower it.

**Economics of Highway Bridge Types*, published 1929 by Gillette Publishing Co.

The spandrel-filled arch bridge, drawn by A. Reyner Eastman, has a segmental soffit curve of decisive quality. The water table line expresses unity in the structure itself as well as unity with the highway grade line as a whole. Slightly increased height of parapet on wing walls with solid and flared construction imparts inflection, strength and stability to the appearance of abutments.

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