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AESTHETICS IN BRIDGE DESIGN.

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(To be read before the General Section, 2nd February, 1911.)

Introduction.

Although the aesthetics of bridge design may appear at first thought a subject less suitable for consideration by this Society than by an organization devoted primarily to architectural interests, a little reflection will show that the solution of any problem in the subject is only possible by approaching it from two points of view: that of art and that of engineering science. It will be admitted as axiomatic that a basic essential of an artistic engineering work is the capacity to perform the service required of it in the simplest and most efficient manner possible with the chosen materials and in the light of present knowledge. No bridge, building, or other work which is manifestly deficient in strength, unnecessarily complicated, or structurally absurd can possibly be pleasing to the trained eye, nor can any amount of applied ornamentation or attempts at "aesthetic treatment" render it so. The artistic merit of a structure, therefore, primarily arising from its general lines and proportions, which are necessarily dictated by engineering considerations, the aesthetic design of bridges must to a large extent always be associated with mathematical analysis and a thorough knowledge of the properties of materials.

Since science and art must thus co-operate to produce an aesthetically correct result, the writer regards the field of bridge aesthetics as one into which the engineer may venture with propriety, but which he, unaided, can only partially explore. The discussion which follows does not, for this reason, purport to deal, except in the most cursory manner, with those phases of the subject having their basis largely in convention or in artistic intuitions, but only with the more rational aspects which frequently come up for consideration in the practice of a bridge engineer.

Present Disregard of the Aesthetic Element.

That there is very great need for increased attention to the aesthetic element in bridge design will not be questioned by anyone who has a fair acquaintance with existing highway or railway bridges in this country. Oftener than not they are nothing more than what the late George S. Morison called "tools of transportation." Nor does this apply exclusively to structures of one material, for very many of the present-day reinforced concrete bridges have little, if any, superiority aesthetically over the familiar and much-maligned structures of steel. This is particularly true of country highway bridges, where those responsible for the design and construction are often inefficient, careless, and utterly regardless of all save the requirements of strength and dimensions. In spite of the fact that the railways are regarded as exclusively money-making organizations, the general appearance and finish of steam railway bridge work at least is undoubtedly superior to that of most country highway bridges. The reason lies in the fact that all important railways are represented by expert bridge engineers, who give careful, painstaking attention not only to the original layout, design, and details, but to the constant maintenance as well.

The lack of good taste and conformity to aesthetic standards in bridge work is indicated in a variety of ways. Among general considerations may be mentioned the following: highly unsymmetrical layouts, often involving unsightly grades or skews; abrupt, irregular, or ungraceful structural outlines; false accentuation or misuse of ornamental features; badly proportioned piers and abutments, giving the impression of lateral instability or insufficient mass; incorrect layout of abutment wings or retaining walls, involving a waste of masonry or insufficient protection of the approach fill; deteriorating material or rough, discoloured, unsightly surface finish, and, not by any means the least, slovenly and unkempt condition of the approaches and surroundings.

Desirability of Artistic Bridges.

It is obviously unnecessary to point out at any length the desirability of artistic bridge structures. Because of enforced usage by the public and of its permanent character, a bridge, in a populous district particularly, presents an excellent opportunity for the expression of good taste in construction. Very many people, who, perhaps, would have no interest in the fine arts, either through incapacity of appreciation or lack of contact with works of that nature, would experience a genuine pleasure in simple, substantial, well-proportioned, and well-finished products of the constructor's art. Object lessons of this sort cannot fail to create a demand for constructional work of the best class for private as well as for public purposes, a development to be sincerely desired.

Causes of Inartistic Bridges.

Several considerations are responsible for the construction of inartistic bridges. They may be briefly summed up as (1) adverse local conditions, such as restricted waterway or headroom, unsuitable location or unsatisfactory building material; (2) parsimoniousness on the part of the purchasing municipality or company; and (3) the general lack of good taste in the people and also to some extent in engineers themselves.

The most adverse local condition is generally the necessity for preserving a minimum waterway or minimum clear headroom, the bad effect being sometimes seriously augmented by features and fixed arrangements incident to the location. Such an instance is afforded by the cantilever bridge over the Ohio River at Marietta, Ohio (Fig. 1 on plate), where it was necessary to maintain two navigable channels, and where the position of the three channel piers was fixed by the United States War Department. From the fact that the south approach is a viaduct with a sharp curve, but little room was afforded for the anchor span between the channel pier and the curve, and its length had to be made ridiculously small in comparison with the north anchor arm. The grade necessitated on this span was therefore very heavy—6 per cent.—while on the spans at the north approach it was correspondingly heavy and objectionable. Inability to alter existing railway tracks at anything short of prohibitive cost is also at times responsible for very pronounced skews, which are inherently defective from an aesthetic point of view.

In these days of cheap and excellent steel and concrete, little excuse can be offered for unsightly bridges on the ground of unsatisfactory building material. There is now little reason for the use of timber, except in remote parts of the country where inhabitants are few and timber is cheap and good. The rapid decay and accompanying distortion not only militate against whatever neatness of appearance may have initially existed, but so soon result in obvious impairment of the strength of the structure that timber no longer plays an important part in bridge construction. No consideration is therefore given to timber bridges in the following pages. As far as aesthetic proportions are concerned, all steels are equally good, but all stone or all concrete is not satisfactory. Any material which shows signs of rapid disintegration, in addition to presenting a rough and objectionable surface finish, creates a feeling of distrust in the mind of the observer concerning its powers of resistance, and the general effect of the structure on the mind is a bad one. Occasionally clay and pebbles of easily disintegrated shale in concrete aggregate gives rise to this by unsightly spalling on the face of the work.

The chief responsibility for the lack of aesthetic quality in our bridges rests with municipal councils or, in general, the elected representatives of the people. While railway directors and managers are not infrequently guilty of perpetrating a monstrosity in the form of a bridge, they are less culpable than those who, by accepting public office, place themselves under the obligation to conserve the higher interests of the community or state. The private corporation naturally directs its resources toward the increase of earning power, and it cannot be expected to give special consideration to matters beyond the field of economics unless forced to do so by outside influence. While the representatives of the people have little or no present control over the appearance of most of the bridges used exclusively for railway purposes, they are jointly responsible for bridges carrying both highway and railway traffic, and frequently in urban districts hold the power of accepting or rejecting designs for railway bridges within their boundaries. A case in point is the Wabash Railway bridge over the approach drive to Forest Park, St. Louis (Fig. 2). The city authorities made the replacement of the former bridge at the crossing of this roadway conditional upon the railway building a structure in every way suitable to its surroundings, and backed its request by agreeing to defray a part of the cost. Were public pressure brought to bear in all such instances where any check exists upon the railways, and were the people as ready to approve of a little additional expenditure on their own part as on the part of the corporations, a vast deal of improvement would soon be seen in the bridges in this country.

It is unfortunate that municipal councillors and bridge commissioners frequently regard it their duty to secure the lowest priced bridges to safely accommodate the traffic on their highways for a limited term of years. That all attention to the matter of appearance is foregone in such instances need scarcely be stated; indeed, there are few councils that will pay anything more than what is necessary to satisfy the bald structural requirements, and scarcely enough to satisfy these latter well. The desire for extreme present economy is so strongly seated in many municipal

Fig. 2—Railroad Bridge at Entrance to Forest Park, St. Louis, Mo.

Fig. 3—Alexander III. Bridge, Paris.

officers that where, in addition to the advantage of pleasing appearance, a practically permanent structure is offered, it will not be adopted on the ground that the municipality should not pay now for bridges which will be used by the next generation. In the effort to secure the cheapest possible bridges, the insidious system of competitive bidding, the bidder submitting his own design, is generally adopted. Since these designs are usually made according to specifications which impose no conditions as to appearance, it can confidently be assumed that all aesthetic considerations will be abandoned in the effort to secure the contract. As long as bridge contracts are let solely on the basis of structural sufficiency, there is little hope for improvement in highway bridges along aesthetic lines.

Means of Improvement.

Improvement in bridge design from the aesthetic point of view is slow in coming on account of the general lack of good taste among the people in these matters. Where the prevailing conception of an artistic bridge is a highly-ornamental one on which tons of cast-iron finials, rosettes, and stars have been lavished, little appreciation of a truly harmonious structure is to be expected. Many people have yet to learn that it is impossible to place one's finger on a few particular points which provide the "beauty" for the whole structure.

Among engineers there are few who are by training or special study of the subject fitted to be responsible for the aesthetic element in important bridges in populous districts. Lack of acquaintance with the principles of aesthetics leads the average engineer into adopting achitectural details and features which are entirely unsuited to the work in hand. Sometimes the attitude has been taken that aesthetic considerations are trifling in comparison with the structural and economic problems of the work and unworthy of consideration by the engineer. This position is fortunately not common, for there is a desire among most engineers to produce work in accordance with what they believe to be correct aesthetic principles.

It is apparent, therefore, that much educative work must be done before a general improvement in the appearance of our bridges can be expected. Such work must begin with the engineer. As the one ultimately responsible for the character of the design, he must lose no opportunity of familiarizing himself with the fundamental principles of aesthetics and putting them into practice on all his work. The presence of a few good examples of artistic structures in a community will soon create a general demand for work of that character elsewhere. Thus, by taking the initiative, the engineer will very soon have effected a marked improvement in public taste.

While most engineers may, unaided, be able to secure satisfactory aesthetic results on ordinary bridge work, for important bridges in populous districts or those of a monumental character, very few engineers are capable of relying exclusively upon their own aesthetic judgment. In such cases an architect of ability should be retained in consultation and the plans worked out in collaboration with him from the start. This custom is now very general in America as well as Europe. In the case of the famous Alexander III. Bridge at Paris (Fig. 3), some of the foremost architects and sculptors of France were engaged upon the work.

AESTHETIC STANDARDS.

In the consideration of the aesthetic features of a given bridge structure, the engineer must consciously or unconsciously adopt certain aesthetic standards as a basis of judgment. What these standards are will depend upon the degree of artistic perception which he has attained, and also upon the time and place, for there can be no absolute fixity in such a code. Thus, although the prevailing canons of artistic construction are based upon the use of stone, it is certain that ultimate approval will be obtained for materials which, for most effectual use, necessitate forms fundamentally different from those employed in stone construction. While the author is aware, therefore, that much diversity of opinion exists among architects and art critics of equal eminence upon aesthetic matters, an effort will be made to state a few fundamental aesthetic principles which should be observed by all who have to do with the design of bridges, and which are probably widely enough accepted to escape challenge by the reader. These are as follows:

(1) The structure must be in conformity with local physical conditions and entirely suitable for the work which it has to perform.

(2) General approval of a design will be most probable when the material and the type of construction are well known to the people at large.

(3) The simpler the lines of a structure and the more clearly the constructional principles involved are displayed, the more pleasing will be the result.

(4) Proper balance or relation of parts to each other and to the whole must be maintained.

(5) That design which is structurally the most efficient for the amount of material employed will at the same time be the most pleasing.

(6) There should be no attempt to conceal the true nature of the material of the bridge or the structural principles involved.

(7) The chief beauty of a structure arises from its general form.

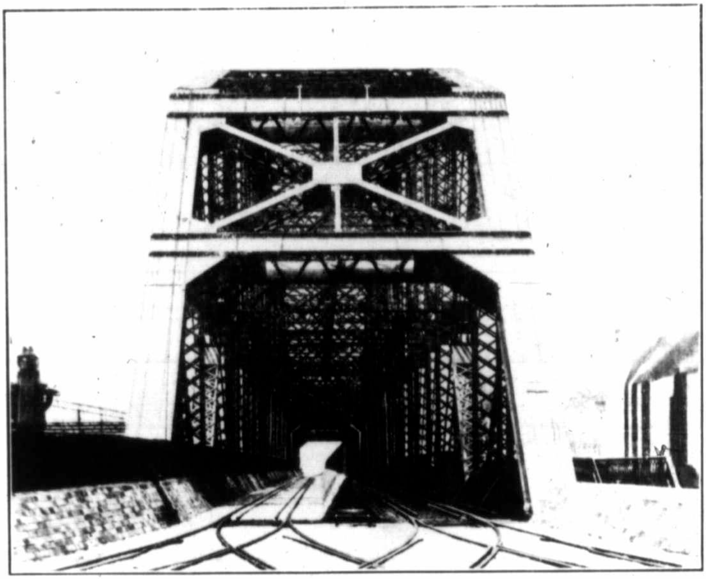

Fig. 4—Rankin Bridge, Pittsburg, Pa.

Fig. 5—Bridge in National Park, Washington, D.C.

(8) Ornamentation should be employed only as an aid to the display of general lines and proportions.

(9) Public appreciation of the work will be largely affected by the character of the surface finish.

(10) Neatness of the surroundings and approaches are indispensable to a pleasing appearance.

(1) Conformity with Physical Conditions and Suitability for the Work.

A more fundamental requisite for an artistic bridge cannot be stated than that it should be appropriate to its surroundings and exactly suitable for the service which it has to perform. Thus, to illustrate, while the beautiful Alexander III. Bridge already mentioned (Fig. 3), with its noticeable vertical curvature and elaborate decoration, is suitable for its setting and traffic, it would be altogether inappropriate for a railroad bridge in a dingy manufacturing town. For such a situation as the latter nothing could be more fitting than a structure of the type of the Rankin Bridge (Fig. 4), which carries a hot-metal route over the Monongahela River, Pittsburg, between Carrie Furnaces and the Homestead Iron Works. Every line of the great bridge suggests strength, simplicity, and capacity to perform enormous work with ease. The complete absence of everything which could be construed as ornamentation conveys the correct impression to the observer, that it is simply a magnificent device to facilitate the transportation of vast loads through an industrial centre.

In wild, rocky regions, with swiftly-flowing streams, bridges should be expressive of, and in harmony with, the rough, primitive conditions existing about them. Bold, powerful structures absolutely without ornamentation will alone do justice to such surroundings. Figure 5 illustrates a solution of a typical problem of this character. This span bridges Rock Creek, a rapid, stone-strewn stream in the National Park, Washington, D.C., and the existing local conditions were admirably expressed, as will be seen, by the use of a boulder-faced arch.

Where the landscape becomes thinly-wooded, more regular, and perhaps carefully kept, more graceful structures, with evidences of greater finish, should be adopted. Such a one, shown in Fig. 6, crosses Rock Creek in the National Park, Washington, D.C., already referred to, at a point where its usual wildness is succeeded by regular, grass-covered banks bordering a well-kept, gracefully-curving drive. The pebble-dash finish, with the cobble-stone belt course in the parapet, was adopted as suggestive of the gravelly bed of the stream at this point. Fig. 7 illustrates the manner in which similar results have been secured in steel in one of the Belle Isle Park bridges, Detroit.

In the closely-built-up sections of cities and towns, where clean, regular outlines characteristic of cut stone construction present themselves, bridges must bear evidence of greater finish than would be the case in rural or suburban districts. Cut stone or carefully finished concrete piers and abutments, with graceful superstructures exhibiting simple ornamentation of railings and portals, should characterize structures in such locations. The structure should be in conformity with the prevailing style of architecture in the vicinity, but need not be a reduced copy of any particular work near at hand.

Conformity with the physical features of the bridge site necessitates, for economic reasons, a general lay-out specially fitted to the profile of the crossing. Thus, in the case of the Garabit Viaduct over the River Truyère in Central France (Fig. 8 on plate), the presence of the deepest part of the ravine near the right bank clearly required that the longest span be placed at this point. Local irregularities and various special conditions may also necessitate the adoption of an unsymmetrical lay-out, but in general it may be said of such that they are pleasing only when the reasons involved are clearly apparent to the observer, as in the case of the Garabit Viaduct already mentioned.

In most cases the irregularities are not sufficiently pronounced to demand special adjustment to them in the number or length of spans. The crossing might thus be represented, as far as the general lay-out is concerned, closely enough by an ideal profile, or one in which the banks slope down along similar lines to a central point of maximum depth. Altogether apart from conventional aesthetic principles, for such a situation both economic considerations and the sense of orderliness and regularity necessitate a lay-out symmetrical about a centre line and involving spans of increasing length as the centre of the depression is approached, with the longest span at the centre of the bridge. Fig. 9, showing the Rocky River Bridge at Cleveland, O., as it will appear when completed, illustrates the pleasing effect of symmetrical arrangement of spans. The long span at the centre is suggestive of the ideal situation, where the stream flows under the bridge directly at its centre. It further marks the centre of the bridge, so that the eye may at once pick upon a point from which it may rapidly run in either direction and quickly appreciate the symmetrical arrangement. This is at times further facilitated by placing the summit of a grade at the centre of the bridge. The method of compensating for a slight lack of symmetry, adopted in the Rocky River Bridge by panelling the abutment wing walls at the end of the bridge, where only two approach spans occur, is evidence of excellent aesthetic designing.

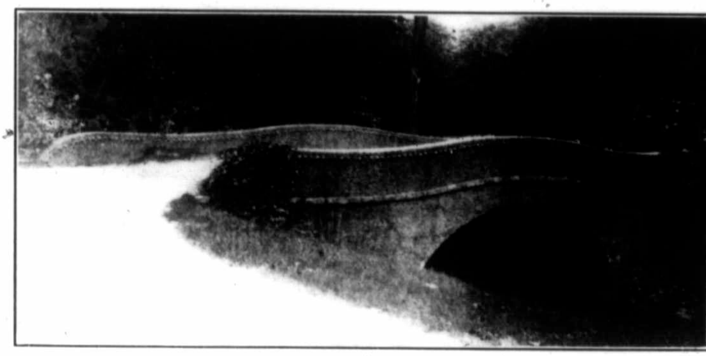

Fig. 6—Bridge in National Park, Washington, D.C.

Fig. 7—Bridge in Belle Isle Park, Detroit.

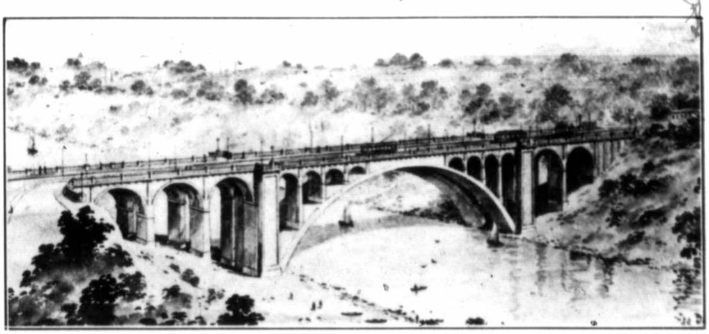

Fig. 9—Rocky River Bridge, Cleveland, Ohio.

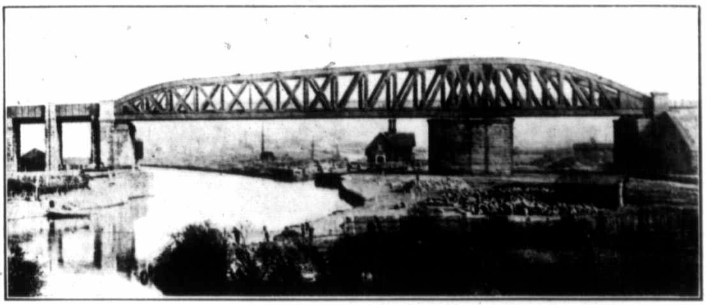

Fig. 10—Great Northern Railway Bridge, Leeds, Eng.

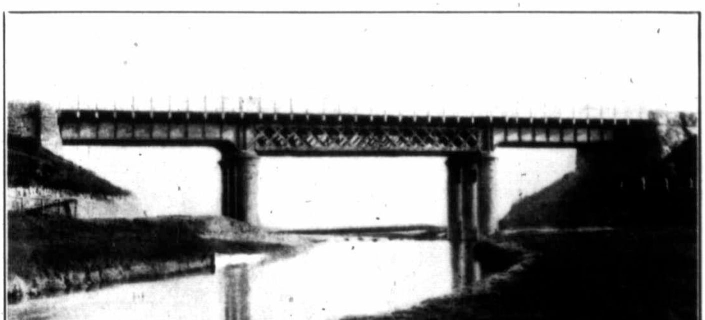

Fig. 11—Gormanstown Viaduct, Ireland.

As has been suggested, where the possibiltity of symmetrical arrangement exists and is readily apparent, it is a serious aesthetic error not to take advantage of it. In Fig. 10, illustrating the Great Northern Railway Bridge over the River Aire at Leeds, England, it would appear that the pivot pier might have been placed nearer the water and the unsymmetrical draw span avoided. The result is that an unfavourable aesthetic impression of the bridge is received by the observer. Further, if the reasons for an unsymmetrical or irregular layout are unknown to, or hidden from, the observer, such as the depth of the water or the nature of the bottom, and no adequate cause appears to exist for the lack of symmetry, the structure will not be pleasing. The Marietta cantilever bridge (Fig. 1 on plate) already mentioned is an example of this.

It also follows, from what has been said, that a pier at the centre of a bridge would be inconsistent with an ideal lay-out. The water being deepest at this point in the average case, and the maximum obstruction of the channel resulting by the introduction of a pier there, the most efficient arrangement would involve an odd number of spans, rather than an even number, the central span being longer than the adjacent ones. Fig. 11, showing the Gormanstown Viaduct on the Great Northern Railway, Ireland, exhibits the graceful effect of an odd-span structure. A bridge of two spans, or one in which the main spans are even in number, as in the Chestnut Street Bridge, Philadelphia, shown in Fig. 12, is undoubtedly inferior in appearance to the three-span structure, but this objection diminishes as the number of spans increases. Thus, in the case of four, five, and six-span bridges, while a five-span structure gives a somewhat more pleasing appearance than a four-span one, where the number of spans exceeds five the eye cannot readily appreciate the departure from ideal symmetry. The writer does not regard the introduction of an especially prominent pier at the centre of an even-span bridge as a remedy for this defect. Such a pier makes the lack of ideal symmetry much more apparent by making it possible to count the number of spans very quickly, and, further, it constitutes an obstruction to the stream.

(2) General Approval Based Upon Public Confidence.

Recognition of artistic merit in an engineering work is contingent to a large extent on our familiarity with the material and the type of construction employed. Thus, the long use of stone has given the race an accurate appreciation of its properties of resistance and the relation of strength to mass, so that incorrect or unscientific use of this material in a structure is readily detected by the observer. With new materials this is not generally possible, for the reason that their use has been of insufficient duration to create universal confidence. The reinforced concrete viaduct shown in Fig. 13, a structure recently built at Port Arthur, Ont., illustrates a too rapid adoption of unfamiliar construction, for to most people the viaduct posts will appear too slender and spindling in the light of past experience. There is no reason why this should always be the case, however, for if a material performs perfectly the service required of it, and is employed in a structure of scientifically correct lines and proportions, it undoubtedly satisfies one of the first and most important principles of artistic construction. The idea that structures of steel and reinforced concrete must forever be debarred from the realm of the aesthetically meritorious is fortunately being foregone very largely as the use of these materials becomes more general. As we become accustomed to a material, and come to realize its strength, safety, and permanence, we develop a liking for it, and according as certain constructional forms have exhibited its greatest possibilities and its more efficient employment, we formulate canons governing its artistic use. Already there is a concrete architecture growing up in which the suggestion of a poured material is conveyed by long curves and absence of joints, and the time does not appear far distant when a construction as artistic as that of stone may be secured by the use of materials quite different from it. Steel being more remote aesthetically from stone than concrete, is likely to be much slower than concrete in being recognized as possessing aesthetic value in construction. The establishment of standards depends to such a large extent upon environment and training that we cannot say how much of our disapproval of new materials such as steel, and to some extent concrete also, is due to the age-long association with stone as our chief material of construction in permanent works.

It might be urged that, in order to secure a structure which would be most generally approved by the people, new materials should not be employed. The mind regards as aesthetically defective any new departure or any new feature which does not correspond to accepted and time-honoured usage. New things are seldom regarded as beautiful, and, therefore, in order to build artistic bridges, dare we break away from past standards? The answer to this is that all progress would be arrested if no new materials and the peculiar features of construction attending their employment might be introduced. The period of disapproval is, however, fortunately limited. As soon as the people become accustomed to the new material and form of construction, and are satisfied that it possesses ample strength and fitness to discharge the duties required of it, it no longer appears ugly, but beautiful.

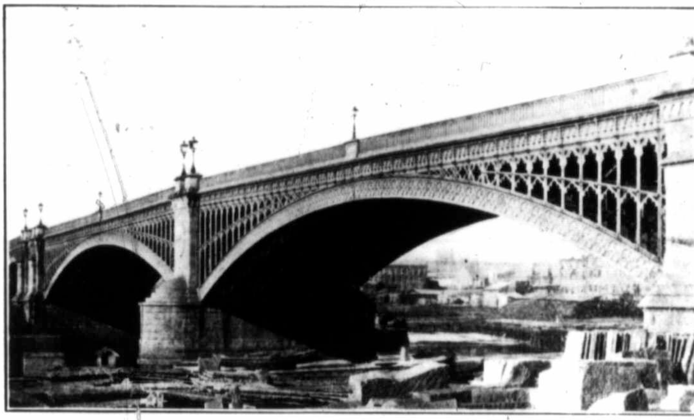

Fig. 12—Chestnut Street Bridge, Philadelphia, Pa.

Fig. 13—Concrete Viaduct at Port Arthur, Ont.

(3) Simplicity and Clearness of Principle.

In general, the simpler the lines of a structure and the more easily understood the basic principles involved, the more pleasing will it be to the average observer. Any design which mystifies or leaves the public in doubt as to the adequate support of superimposed loads, is an aesthetic transgression. Instances of such are afforded in many early bridges in which the suspension and cantilever or the truss and arch principles have been combined. Such arrangements are liable to create a lack of confidence in the structure and, consequently, aesthetic dissatisfaction through the natural inference that one system was introduced to bolster up one already overtaxed.

For all truss spans, except possibly those of short length, single intersection trusses are more pleasing than the more complicated ones with multiple systems of webbing. Short spans approaching the legitimate field of the girder and possessing only a small number of members of a considerable length in relation to the span, and having to perform the same work as the solid girder section, are liable to create the impression of insufficiency. This is particularly true of especially short through spans where the height is necessarily large in relation to the spans, and where, in addition, an appearance of "stubbiness" is unavoidable. For this reason the multiple intersection truss for short spans being in effect only a girder with a number of holes cut through it, is to be preferred. Pony or low trusses of simple single intersection types are superior to short through trusses, since in general proportions they are closer to the rudimentary beam or girder with which everyone is familiar.

Simplicity and directness being essentials of aesthetic excellence, it would be expected that the simple beam or girder with constant depth, the earliest form of structure with which we are acquainted, would be the most beautiful of all forms for a bridge. That it is not is generally contended by critics, but wherein does the reason lie? Surely not because of the predominance of straight lines, for this is a distinctive feature of one of the most beautiful of architectural styles—the Grecian. Indeed, so much was the appearance of straightness of outline valued that special efforts were made to secure it, for example, by cambering cornice lines or increasing the diameter of columns near their centres. It seems to the writer, therefore, that the lack of beauty in the girder is not a basic quality, but that it most frequently occurs under special conditions, for example, in connection with its employment for very long spans, or for lengths quite out of proportion to the beautiful girders or architraves of classic architecture. We have not, even yet, become inwardly convinced of the sufficiency of the slender proportions of long-span girders, and by reason of inherited bias, regard all such as aesthetically defective because they do not conform to the necessarily large relative depths of ancient girders of stone. Short-span girder bridges, such as the Wabash Railroad crossing of the entrance to Forest Park, St. Louis, Mo. (Fig. 2.), may be made singularly pleasing by proper treatment of the whole structure, for example, by employing unusual and graceful lines for the abutments and using lamp clusters, thus drawing attention away from the straight, rigid lines of the girders themselves.

The least pleasing of all plate girder bridges is that made up of a succession of spans of considerable length and of the same construction. The lack of contrast gives rise to pronounced monotony. A very good example of a girder bridge in which this difficulty has been overcome successfully is the Gormanstown Viaduct (Fig. 11). The use of the lattice girder for the central span breaks the monotony inseparable from a continuous line of plate girders, while the curved bracket plates at the pier ends of the approach girders, the handrailing, and the dentiled effect produced by the projecting ends of the long ties all conduce to the same end. These features, combined with the symmetry of an ideal arrangement of spans, produce an exceptionally pleasing structure.

In longer spans the most pleasing types are those simple structures which were first found to be adapted for bridging spaces beyond the capacity of the beam of wood or stone, viz., the suspension bridge and its inverse, the arch. From the days when the Peruvians, Thibetans, and Chinese first strung ropes of twisted wood-fibre or thongs across their mountain gorges and carried the traveller over on a platform safely to the opposite side, the race has been appreciative of the efficiency and singularly graceful lines of suspension cables. Following the lines dictated by natural law, the material is employed in the most advantageous way possible. Similarly, the inverted suspension bridge, or arch, in which the primary structural element, the arch rib, provides resistance by compression only, is ideal in efficiency, simplicity, and beauty of line for the material employed. Familiarity with the arch and its essential principle governs our judgments on all bridges to a remarkable degree. Thus, since stone is the material in which the great development of architecture has taken place, and since it is employed for bridges only in the arch, we have associated the highest aesthetic value with the arch. It is impossible to say how much liking for the material has coloured our judgment of the structural form, but undoubtedly it has done so to some extent. Proof of this need not be sought farther than in the fact that the steel arch is generally regarded as more beautiful than the suspension bridge, certainly not from superior grace of line, but simply because of the age-long association with stone.

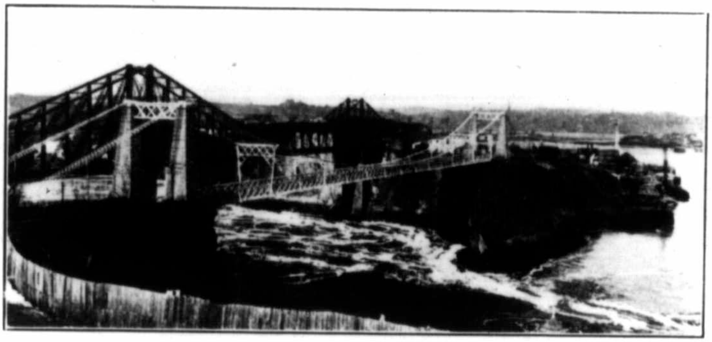

Fig. 14—Bridges at St. John, N.B.

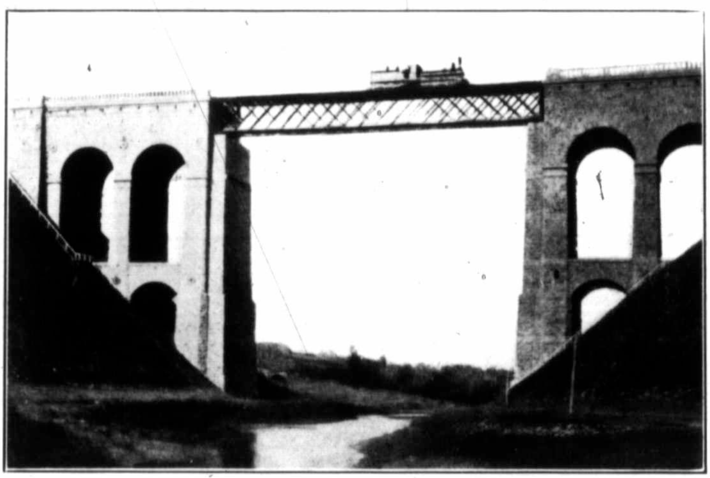

Fig. 15—Bridge over Ingool River, Russia.

Fig. 16—Washington Bridge, New York.

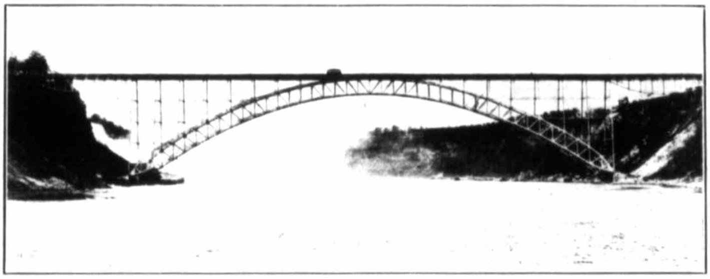

Fig. 17—Niagara Falls and Clifton Arch Bridge.

By reason of greater constructional complication the simple truss or cantilever span is in general less pleasing than a girder bridge. Articulation, which is the distinctive feature of the truss, conveys the impression of complication, and renders the layman less capable of appreciating the strength and sufficiency than in the case of a girder, arch, or suspension span, which, in addition, have many centuries of use behind them in which the race has grown familiar with these forms. The superior aesthetic value of the suspension bridge over the cantilever is well illustrated by the two adjacent bridges which span the St. John River at St. John, N.B. (Fig. 14). The graceful sweep of the cables and simplicity of the whole construction in the case of the suspension span is in striking contrast to the sharp angles in the upper chord of the cantilever and the complex web system.

(4) Proper Balance or Harmony of Parts.

Proper balance of parts in a structure requires that no part shall contain a suggestion of undue strength or undue weakness in comparison with any other part, but that all shall be equally efficient. Difficulty in producing proper balance is very often introduced by the choice of different materials for adjacent spans, but quite as frequently in the proportioning of the various structural elements of a single span, or in the relation of substructure to superstructure.

Where two widely different materials are used in adjacent spans of the same bridge, the effect of equal strength throughout is not easy to produce, since the mind is compelled to suddenly change its standards for estimating the sufficiency of adjacent spans. For example, the massiveness of the approach spans of the Ingool River Bridge, Russia (Fig. 15), is in almost ridiculous contrast to the slender proportions of the superstructure. If the structure be an arch the effect is much better, as may be seen in the case of the Washington Bridge, New York (Fig. 16). This arises because of the greater massiveness of the main span or spans, and because the mind demands ample evidence of sufficient mass back of the springing to oppose the thrust of the arch rib. A notable example of an aesthetic defect arising from incorrect relative proportioning of structural elements is seen in the case of the Niagara Falls and Clifton arch (Fig. 17), where the light approach spans and the almost invisible abutments excite wonder as to the means by which the enormous rib thrust is resisted.

(5) Coincidence of Structural Efficiency and Aesthetic Excellence.

The principle that the most pleasing outlines or general form for a structure arise when the maximum economy of material is secured, does not require proof if we admit that Nature performs her work along the lines of least resistance. In fashioning a straw, reed, or stalk, Nature seeks only to obtain the greatest strength and rigidity with a minimum of weight, and by her own mathematics has arrived at the annular cross-section as the most efficient. She is not influenced by the objections of the bridge engineer that circular columns or compression members are difficult to splice and involve troublesome connections, for the element of cost does not enter into her calculations.

A type of structure which well illustrates the principle that economy of material and aesthetic quality go hand-in-hand is the simple truss span with curved top chord, which feature is now almost universally adopted for spans over 200 ft. in length, and sometimes even for much shorter ones. With any length of span, curving the top chord results in a saving of material and a great improvement in appearance. Thus, the attractive little highway span of Fig. 18, which is a standard structure of the American Bridge Co., is aesthetically decidedly superior to the familiar parallel-chord Warren truss spans built by hundreds in Canada. The superiority is to a large extent due to the curvature of the top chord of the former structure. For short spans this results in increased cost, the saving of material being more than offset by the additional expense of manufacture of the trusses, due to changing inclination of the chords. It, however, is never large in comparison with the total cost of the bridge or even of the superstructure, for the reason that only the top chords of the trusses are prejudicially affected, the verticals, diagonals, floor system, and bracing being as simple as for a parallel-chord structure. This small additional expenditure for curved chords is justifiable, and should certainly be made for all such bridges in populous districts.

The application of reinforced concrete to truss construction has made it possible to take advantage of the aesthetic properties of trusses with curved top chords at little expense over that involved for those with parallel chords, since shop costs do not enter into the problem and the form work is practically no more expensive. The bridge constructed by the writer's firm a year ago for the counties of York and Peel on the Middle Road crossing of the Etobicoke River (Fig. 19) is an example of this type.

For bridges over 200 ft. in span experience has shown that a net saving is effected by employing the curved top chord in addition to

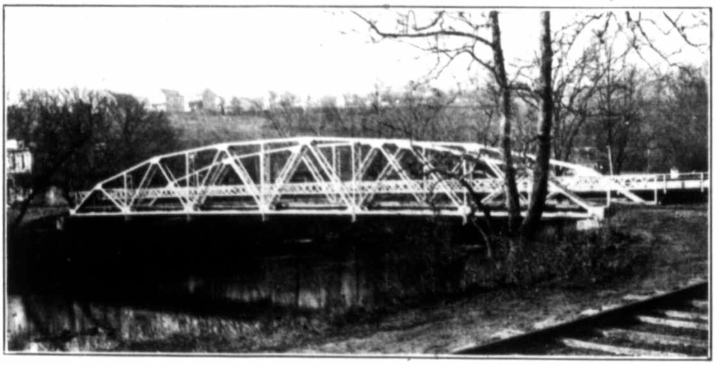

Fig. 18—Pony Highway Span, with curved top chord.

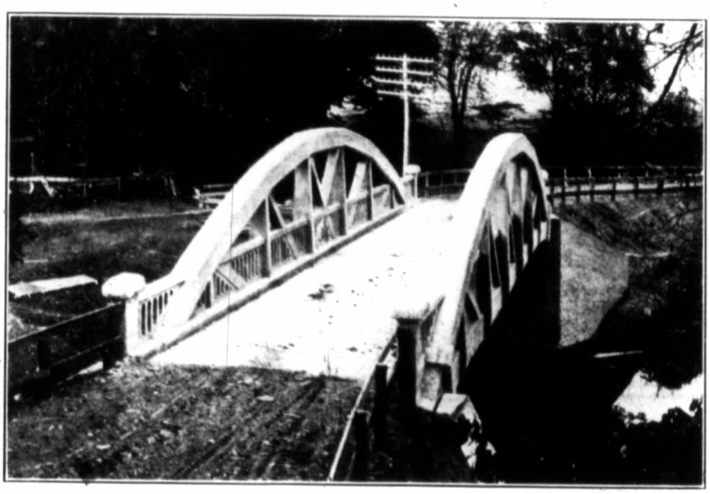

Fig. 19—Middle Road Bridge, Counties of York and Peel, Ont.

securing an improvement in outline. Still more significant is the fact that the saving is greatest when the curvature of the chords is most regular. Thus, Mr. Charles Macdonald, M. Am. Soc. C. E., points out* that investigations made in connection with the design of the Hawkesbury Bridge in New South Wales showed that a considerable saving would have been effected by the adoption of a regular curva-

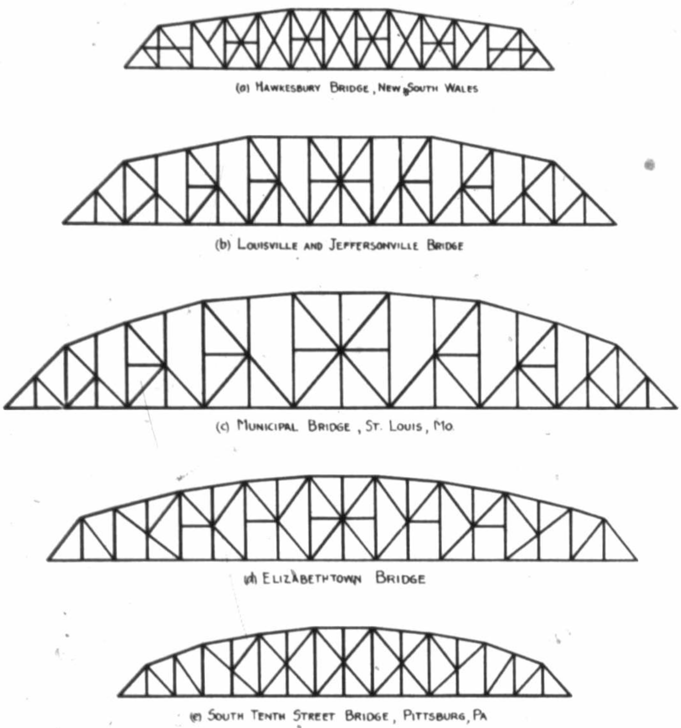

Fig. 20—Comparison of Trusses with Curved Top Chords.

ture for the top chords of the trusses instead of the broken outline as actually used (Fig. 20a). Certainly the appearance would have been greatly improved by a more regular curvature, and the same may be said of the trusses of the Louisville and Jeffersonville Bridge over the Ohio River, shown in Fig 20b, which are marred by the abrupt changes from the horizontal to the inclined sections of the

*Proc. Inst. C. E., Vol. CXLV, p. 235.

chord. Figures 20c, d, and e, illustrating respectively the trusses of the St. Louis Municipal Bridge, the Elizabethtown Bridge, and the South Tenth Street Bridge, Pittsburg, all show a pleasing curvature for the top chord.

Another evidence of the coincidence of aesthetic correctness with scientific efficiency is afforded in the relative slope of the diagonals of trusses with curved top chords. Examining Figures 20a to 20e, it is at once evident that a wide variation in the slope of these members is aesthetically objectionable, from the lack of satisfaction with the general outlines, probably, from a breach of orderliness. Figs. 20 (d) and (e) exhibit this defect particularly, but in the trusses of the Municipal Bridge, St. Louis, it has been obviated by varying the panel length, making it 30 ft. at the ends and 48 ft. adjacent to the centre. In Fig. 20 (e) the defect is enhanced by carrying the main diagonals over one panel only for the first three panels from the ends and then over two panels, producing further mystification in the mind of the observer. This dislike of large variation in the slope of diagonals has a scientific basis, when we learn that there is an economic inclination of diagonals—about 45 degrees—and that this inclination of such members is the one most pleasing to the eye.

Further indication of the truth of the fifth principle enunciated is afforded in a study of the form of arch rings.

It may be asserted that, in general, the most pleasing axial curve for an arch ring is the one which corresponds most nearly to the dead-load line of pressures. For spandrel-filled arches the structurally correct axial curve for low ratios of rise to span is not far from a parabola or the segment of a circle. As this ratio increases the curvature becomes sharper, particularly in the region between the haunches and the springings, until, for an arch having a rise of one-half of the span, the correct axial curve lies outside a semi-circle and is of the nature of an oval. In the case of open-spandrel arches the statical conditions necessitate an axial curve lying somewhere between a parabola and the segment of a circle.

It is therefore most significant when we note that arch rings which are noticeably out of conformity with the general lines mentioned are not pleasing to the eye. This condition arises most frequently from the employment of curves which are, or appear to be, too flat on the haunches, and which give the impression that settlement at these points is imminent, accompanied by tensional failure on the extrados near the springings. Such an effect is likely to follow the use of a ring for which the axial line lies on or approaches a semi-ellipse, or even where the intradosal curve is a semi-ellipse. The Brunswick steel arch bridge (Fig. 21 on plate) exhibits this defect, although the axial curve is only about midway between a segment of a circle and a semi-ellipse. The

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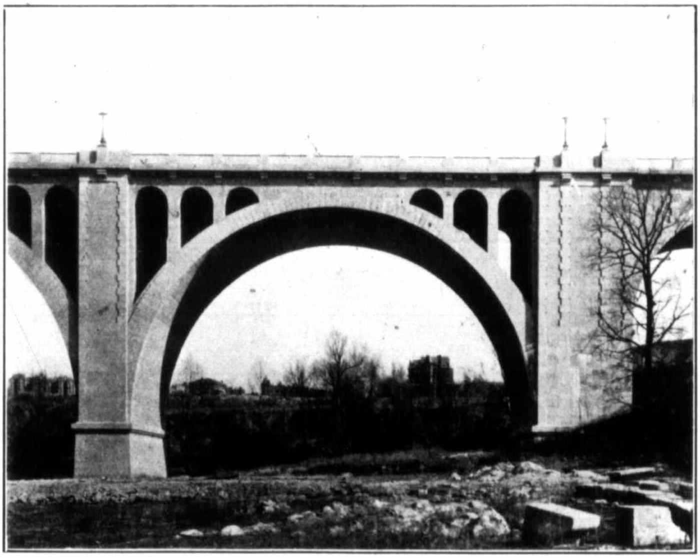


Fig. 22—One Span of Connecticut Avenue Bridge, Washington, D.C.

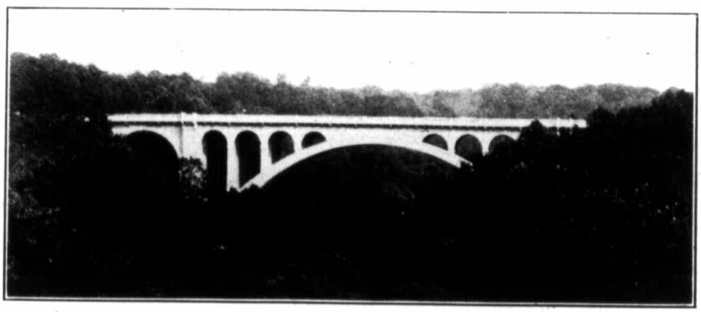


Fig. 23—Walnut Lane Bridge, Philadelphia, Pa.

form of ring adopted in the case cited is as objectionable as suspension bridge cables would be if forced by restraint to follow similar lines. A comparison of the lines of this arch ring with that of the Niagara Falls and Clifton arch (Fig. 17), in which the axial curve lies within the limits specified, will further illustrate the point.

The use of curves which are noticeably flat on the haunches is particularly objectionable for arches of low rise, the reason being that apparently full advantage has not been taken of the possible rise. The observer distrusts such a design as much too bold, and prefers a form of ring which appears to carry the superimposed loads much more directly to the abutments. It is not always due to the choice of a highly erroneous curve for the ring that the objectionable feature under discussion arises. A curve which is structurally correct for the greater part of its length may, for flat arches, be made to appear flat on the haunches through contrast by the introduction of a short, sharp curve joining up the ring with the face of the abutments. Local flatness may also be apparently introduced by a careless joining up of a number of circular arcs to produce the desired curve for the ring.

In the case of arches of such height that the rise may be made one-half of the span, the form of ring which best satisfies the eye depends upon the type of construction. Since time immemorial the race has been familiar with the spandrel-filled Roman arch with semi-circular intrados, and our judgments of artistic construction have no doubt been largely moulded by it. For this reason the oval-shaped intrados, which is the correct curve for such arches, will be slow in gaining favour, as are most improvements in construction. With open-spandrel masonry or concrete arches of rise equal to one-half of the span, the close spacing of the spandrel posts gives a pressure curve which permits of a full semi-circular arc for the intrados, at the same time giving an outline which is always satisfying. Fig. 22, showing one span of the beautiful Connecticut Avenue Bridge, Washington, D.C., is an illustration of this. The semi-circular arch, as it is called, is seen to best advantage in a structure involving a succession of arches on lofty piers, as the Romans so well demonstrated in their magnificent aqueducts of masonry.

Another illustration is afforded in this connection of the coincidence of maximum structural efficiency and greatest beauty, for the form of arch ring which involves the greatest security for the tall piers in case of the development of an unbalanced thrust is at the same time most pleasing to the eye.

The development and use of the open-spandrel masonry or concrete arch gives further basis for the generalization under consideration. Primarily, the object in view in leaving openings through the spandrels was to lighten the dead load over the haunches and thus extend the field of application of the masonry arch. No sooner was this done, however, than it was noticed that the new type was superior in appearance to the old from the relief of the large blank spaces in the spandrels. Fig. 23, showing the magnificent Walnut Lane arch at Philadelphia, and Fig. 22, already mentioned, are representative examples.

While the limits of this paper makes it possible to indicate the coincidence of aesthetics and mathematical science at only a few points, the author believes that many other points of agreement might be discovered. For this reason it would be profitable for the engineer to carefully examine the economic properties of designs which recommend themselves primarily to the aesthetic taste. An instance of the kind is afforded in the recent adoption by the Pennsylvania Railroad of masonry arches for short-span bridges. Since this policy was inaugurated chiefly on economic grounds, the incident is most significant.

(6) Truth as to Material and Structural Principles.

Not alone in the realm of ethics is deliberate deception and falsehood to be condemned, but also quite as promptly in art. Any structure in which the real nature of the material or the structural principles employed are purposely disguised is a sham, and, therefore, a failure aesthetically.

Attempts at veiling the real character of the material used are very common, but quite frequently they are far from successful. Fig. 24 is an illustration of a whole class of structures which are rendered aesthetically defective by the effort to make monolithic concrete look like masonry by employing joint lines. In the case of this particular bridge the lines of the structure at once give the lie to the surface treatment from the fact that the arch is much flatter than would be constructed of masonry. In many other cases rock-faced or cut-stone masonry has been employed for facing concrete arches in order to produce a pleasing surface finish where the rise is small enough to render the deception readily apparent.

What is to be said, however, of cases where the lines of the structure are consistent with stone masonry, but where the facing only is of this material, the load-bearing element being of steel or reinforced concrete? Is the deception any less objectionable because it is successful, or is it only to be deprecated where the designer has left the deceit open to detection by some inconsistency of the structural lines with the material? In answer to this it may be said that no deception is intended in the majority of cases, the sole object

Fig. 24—School Branch Bridge, Clermont, Ind.

Fig. 25—Bridge at Yorktown, Ind.

Fig. 26—Franklin Bridge, Forest Park, St. Louis, Mo.

being to secure a pleasing exterior finish, and no finer one could be obtained than by the use of cut or rough masonry. The custom is exactly parallel to the Roman practice of using masses of concrete for the backing of walls or for the unexposed portions of masonry work simply for reasons of economy and ease of construction; or, again, it is of the same order as the employment of cut stone or pressed brick for the exterior of walls in buildings with soft brick or terra cotta backing. If these modern constructional methods are aesthetically defensible, then should not the practice of facing a concrete arch with natural stone either cut, in the rough, or as boulders be equally admissible? The writer is of the opinion that, although it may not always have been, it is now, for the reason that the development of constructional methods and the introduction of new materials must necessitate a change or rather a broadening of aesthetic standards. It may be said, however, that some form of conventional surface treatment should be adopted which effects a distinction between solid masonry structures and those which are faced only with this material.

Another class of structures which have been subjected to much criticism in the past are those in which the loads are carried by a steel skeleton covered by a shell of masonry or concrete. A noted example of this is the famous Tower Bridge, London, which has perhaps been the object of more criticism on the ground of aesthetic transgressions than any other notable bridge. A more recent example of the type of construction under consideration is the Strauss bascule bridge at Camden, N.J., in which the towers are of steel with a reinforced concrete casing.

The adverse criticism of such structures cannot be fully disposed of, since, in the present state of our knowledge and experience, we have not yet attained full understanding and confidence in this class of construction. When it has become thoroughly familiar, and when we rid ourselves of the idea of premeditated deception, work of this class will be regarded as quite as legitimate and aesthetically correct as work of stone masonry. Comparing the two bridges mentioned, the latter is open to the lesser criticism, since the general proportions of the towers are comparable with those which would have held for solid reinforced concrete construction, while in the case of the Tower Bridge it is obvious that masonry towers of the proportions employed would be entirely inadequate.

(7) The Chief Beauty in the General Form.

It requires but little examination of representative structures to establish the conclusion that the chief beauty of a bridge arises from its general form. Consider, for example, the concrete arch bridge at Yorktown, Ind. (Fig. 25), and the Franklin Bridge in Forest Park, St. Louis, shown in Fig. 26. The former, while not beyond criticism, appeals to most observers as a beautiful structure, and yet it is almost totally devoid of ornamentation. On the other hand, while some people find the Franklin Bridge pleasing, the majority would prefer the former structure. The preference can only be based upon the admirable general form of the simpler bridge, which is undoubtedly superior to that of the Franklin Bridge with its sharp break in grade at the crown. This structure is an illustration of the inability of decoration to compensate for lack of beauty in the general form. The Park Bridge at Medford, Mass., shown in Fig. 27, is also an excellent illustration of the results which may be obtained from proper lines and proportions alone.

(8) Legitimate Ornamentation.

While the beauty of a structure arises principally from its general form, ornamentation as an auxiliary may by skilful employment be made to contribute much to the aesthetic excellence of the result. Thus, it may be legitimately and properly used to (a) accentuate or contrast the structural functions and characteristics of the parts, (b) emphasize the magnitude or strength of the structure, or (c) afford relief to long, unbroken, straight lines or large blank spaces. It should never be applied thoughtlessly to the first clear space which occurs to the designer as in need of beautification, but only where it can serve as handmaiden to the chief element of beauty, the general form.

Instances of the misuse of ornamental features are sufficiently numerous to convince most engineers of the extreme difficulty of attempting anything at all extensive in this line without the collaboration of an expert architect. As a single instance of this the use of columns over the piers of the Waterloo Bridge, London, may be cited. The column is a member the function of which is to support vertical loads, and the insertion of them over the piers of a bridge suggests the existence of a considerable weight from above which must be carried down to the piers. As a matter of fact, but a trifling load can ever come on them, carrying as they do only a short entablature. The correct treatment above these piers would have been in the form of a counterfort, conveying the impression of lateral stability, as in the bridge over the intake of the Canadian Niagara Power Co., Niagara Falls, Ont., shown in Fig. 28.

To render the principal structural elements outstanding and their functions easy of appreciation by the observer, many artifices may be successfully employed. Reference to only the most self-evident of these will be made in the present paper.

Reasoning alone, apart from the actual observation of existing structures, would be sufficient to establish the principle that decora-

Fig. 27—Auburn Street Bridge, Medford, Mass.

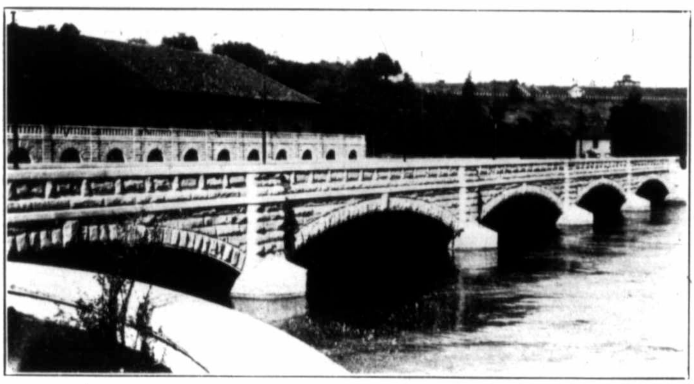


Fig. 28—Bridge at Niagara Falls, Ont.

Fig. 29—Friedrichsbruecke, Berlin.

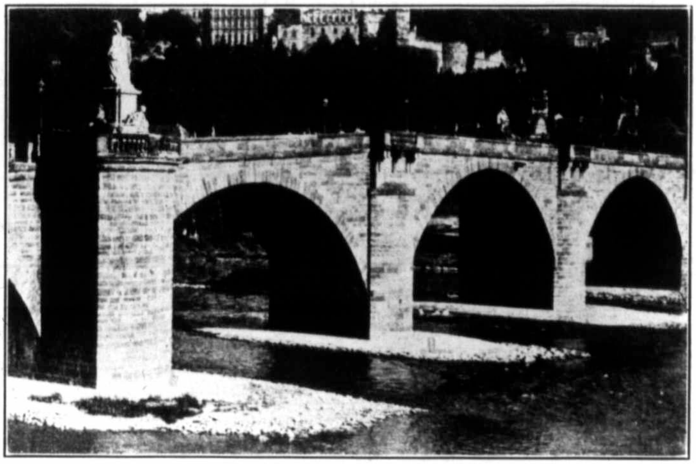


Fig. 30—Heidelberg Bridge.

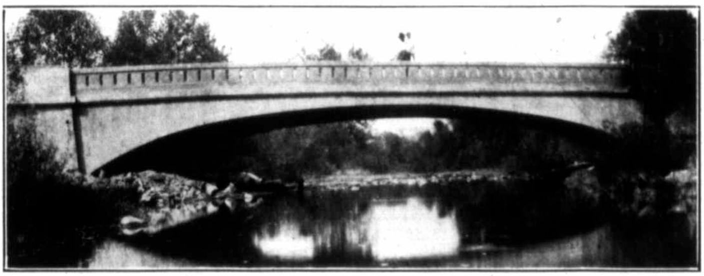


Fig. 31—Kemp Bridge, Wabash, Ind.

tion should be applied to the lighter and frailer portions of a structure rather than to massive load-bearing parts. We do not ordinarily find great strength and great delicacy as co-existent attributes of the same being or object. The application of ornament in the form of cast or wrought-metal designs to the chord or end post of a truss is therefore incompatible with the character of these members. Accentuation of the structural characteristics of a steel span by contrasting the heavy stress-resisting members with those performing a less serious and vital duty is admirably afforded by the use of a light latticed steel or ornamental iron handrailing, as in Fig. 18, to which reference has already been made. An excellent example of a similar effect in masonry is to be seen in the parapet of the bridge shown in Fig. 28. In order to convey the impression of lightness in this member, alternate stones have been set on edge, a proceeding which would never be followed in masonry carrying heavy loads where the stratification planes would be placed at right angles to the pressure.

The careful delineation of the ring of masonry or concrete arches facilitates general understanding of the principle involved. In masonry the necessity of radial arrangement of the voussoirs involves the desired accentuation of the ring, as in the Niagara Falls arch (Fig. 28). No such condition existing in concrete construction, special means must be adopted in all full spandrel structures, such as allowing the ring to project two or three inches from the face of the spandrel walls or giving it a different finish from the spandrels, as in the Medford Bridge (Fig. 27). The true structural dimensions of the ring should be preserved in so doing, since noticeable deviation from them is highly objectionable. An instance of this latter is afforded in some arch bridges, where the faulty panelling of spandrels suggests a constant thickness of arch ring throughout its length.

Full appreciation of the structural characteristics of an arch is aided by clear definition of the springings, with the abutting of the ring accentuated. Such a result is secured by providing a seat for the arch ring at right angles to it at the point of springing, as shown in the Friedrichsbruecke, Berlin (Fig. 29). Where this is not done, as in the Heidelberg Bridge (Fig. 30), the arch ring appears without visible support, and conveys the impression of tending to slip vertically downward between the abutments.

Emphasis of the lateral stability of piers and abutments adds to our appreciation of the functions of these parts of the bridge, with a corresponding heightening of the aesthetic value. Counterforts running from the tops of the piers to the top of the coping of the parapet wall, as in Fig. 28, give the effect of security against sidewise displacement of the structure, as they do to a wall, and at the same time break the monotony which would result from perfectly plain spandrel walls above the piers. In abutments a noticeable batter of the face, as employed in the Kemp Bridge, Wabash, Ind. (Fig. 31), is essential to obviate the appearance of tending to tip forward.

The use of copings for piers involves the accentuation of the structural functions of these portions of the bridge, and adds to the clearness of the whole design. Besides providing a necessary covering for the body of the pier, in the case of stone masonry construction, it, in any case, emphasizes the point of support of the superstructure and obviously distributes its weight over the support. An excellent example of the proper use of such a feature is seen in Fig. 22, already described. The Heidelberg Bridge (Fig. 30) illustrates the defect of its omission.

Skilful contrasts in colour are at times employed to accentuate the main structural lines. For example, in the case of the Connecticut Avenue Bridge, Washington (Fig. 22), the arch rings, coins of piers and abutments, copings, and cornices are of light gray artificial stone blocks, while the spandrel walls and faces of piers and abutments are of a light buff shade. It is therefore comparatively easy to instantaneously trace the structural outlines of the whole bridge and form an estimate of their correctness.

Special treatment of a structure may advantageously be employed at times to emphasize its magnitude. Thus, the emphasis of the ring stones or voussoirs of an arch enhances its size. This impression is a result of the observer's realization that a great number of large stones are required to make the circuit of the ring. On the other hand, the use of moulded rings, while permissible for small arches comparable in size with those employed in building construction, effectually dwarfs the span when used for large arches. The use of spandrel panelling of a type familiar in domestic architecture, or the provision of niches for heroic statuary, also have a reducing effect and should be avoided for large spans.

Emphasis of strength, either directly or by withholding any decorative feature which gives the impression of reducing the capacity of the structure for traffic, are important aesthetic details. The placing of large retreats or other heavy features over the crown of an arch is objectionable, since it creates a feeling that the arch is being burdened with a considerable load which might have been placed where it would tax the structure less severely—for example, over the springings. The Franklin Bridge (Fig. 26) contains this objectionable feature. Lamp clusters should not be placed over the crown, for the same reasons. They should be placed over the piers, as shown in Fig. 29.

The relief of the monotony of large blank spaces or the breaking of the extensive repetition of a detail are among the legitimate functions of ornamental features. It has already been shown that the piercing of spandrel walls by secondary arches (Figs. 22 and 23) constitute a great improvement in the general appearance. Panelling the spandrels of small arches may be used for the same object. Such treatment should not be extended to large arches, for the reason already given. A happy interruption of the monotonous repetition of spindles in a railing is afforded by the insertion of an especially heavy post in the railing, as shown in Fig. 26.

(9) Surface Finish.

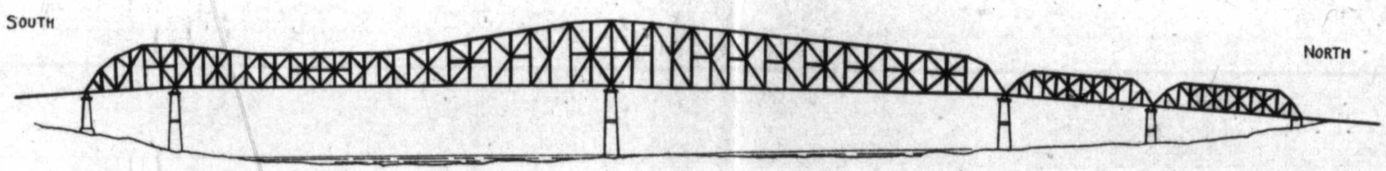
Unfortunately, many bridges of excellent design and construction present a most unattractive appearance due to a rough, discoloured, or patched surface finish. So pronounced is the effect of such that the work of the designer is lost sight of, no matter how excellent it may be, and a highly unfavourable impression of the entire work is formed. This is particularly true of concrete structures, where the discolouration of the surface film of cement, accompanied by prominent form-marks and patches, often offset the general excellence of this class of construction. Fortunately, much is being done to remedy the evil, and engineers are now generally specifying some form of surface treatment. Whether the surface be scrubbed or etched with acid, bush-hammered or ground down and washed with a thin mortar, will depend upon the judgment of the engineer and the character of the particular work in hand, but undoubtedly something of this nature must be done on concrete bridges if they are to be classed as artistic structures.

(10) Neatness of Surroundings.

No matter how well designed or well executed a structure may be, if the surroundings and approaches are left in a slovenly, untidy condition much of the good effect will be lost. This is particularly likely to be the case with country highway bridges, where the work in the field is often in charge of an incompetent inspector, appointed by the municipality for other reasons than experience or good taste in the work. Even the storage of building material around a bridge mars to a great extent an otherwise pleasing effect, as in the case of the Chestnut Street Bridge, Philadelphia (Fig. 12). In pleasant contrast to this are the surroundings of the bridges shown in Figs. 2, 5, and 16.

In conclusion, the writer wishes to acknowledge indebtedness to Mr. Charles Evan Fowler for permission to reproduce Fig. 15 from his "Engineering Studies," and to the University of Toronto for the use of many photographs from its collection.

Fig. 1—Cantilever Bridge, Ohio River, Marietta, O.



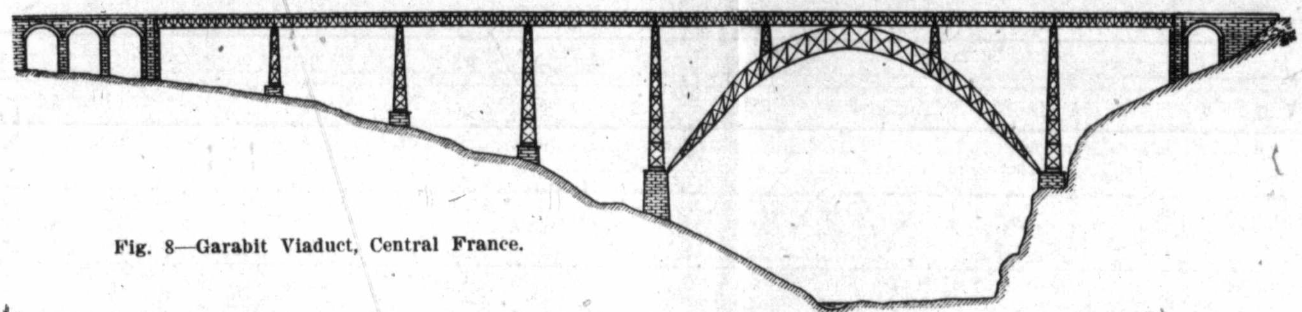


Fig. 8—Garabit Viaduct, Central France.

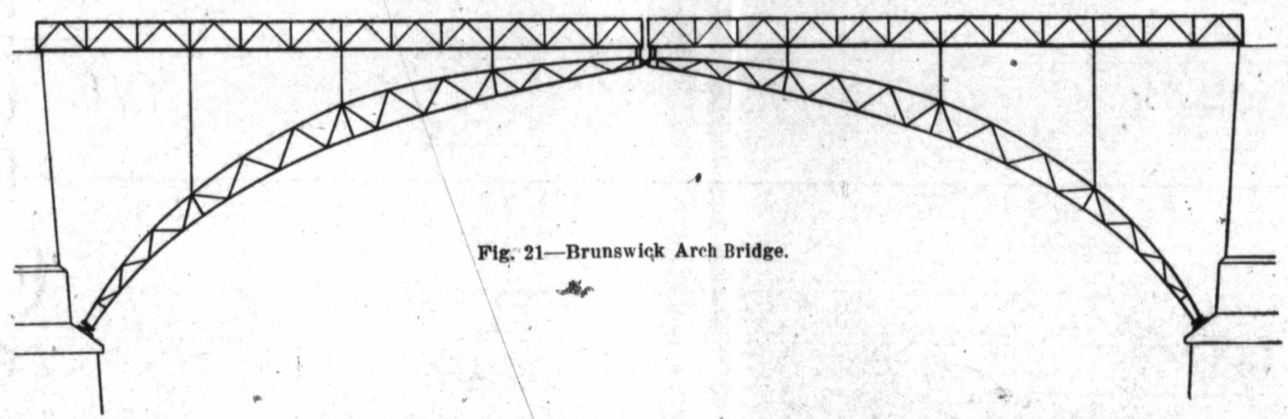


Fig. 21—Brunswick Arch Bridge.