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An Expert System for the Esthetic Rating of Bridges

Author(s)

Dr. William Zuk

Performing Organization Name and Address

Virginia Transportation Research Council
Box 3817, University Station
Charlottesville, Virginia 22903-0817

Sponsoring Agencies' Names and Addresses

Va. Dept. of Transportation
1221 E. Broad Street
Richmond, Virginia 23219

University of Virginia
Charlottesville
Virginia 22903

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FINAL REPORT

AN EXPERT SYSTEM FOR THE ESTHETIC RATING OF BRIDGES

William Zuk

Faculty Research Scientist
and
Professor of Architecture

(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

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The expert system presented should facilitate the in-depth analysis of bridge esthetics and encourage high standards for the appearance of bridges. The procedure described systematically evaluates features of a target bridge in relation to a similar comparator bridge, guided by a set of 177 rules established by experts. The rules, however, require some interpretation by the evaluator because of the subjective nature of the material. Nevertheless, the process leads to a numerical esthetic rating index for any type of highway girder bridge, with ratings falling between 0, the lowest, and 10, the highest.

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INTRODUCTION

Most bridges will be seen by millions of people and, therefore, should be designed as attractively as possible. Unfortunately, bridge engineers generally consider the esthetic evaluation of a bridge to be too subjective in nature. Such is not entirely true, for there are numerous frames of reference that may be considered objective. For centuries, authorities have spoken and written about the beauty of bridges, leaving a legacy of esthetic criteria. Martin P. Burke, Jr., in his recent "Bridge Aesthetic Bibliography," lists 280 books, articles, or reports on the subject published since 1883, and several more major works are currently known to be in preparation.

In the course of the project being described, a large percentage of the 280 publications were studied. From these writings, 177 statements, criteria, or rules were extracted that related specifically to the evaluation of girder bridges. For simplicity, statements, criteria, and rules will be referred to as "rules." Additional rules dealing with other bridge types, such as arches, trusses, and rigid frames, were found. However, the references to non-girder structures were much less complete than for girder structures. Since girder bridges represent the preponderance of all bridges, the study described is believed to be a good first step toward the development of a comprehensive expert system for the esthetic rating of bridges, despite its restriction to girder bridges. Rules concerning depths of girders and proportions of piers apply only to highway bridges, not railroad or pedestrian ones. Also, with respect to rules applying to details (as extensive as they are), it is probable that some gaps may exist for some situations. However, it is hoped that the more general rules presented will cover any possible specific omission.

DESIGN OF THE ESTHETIC RATING OF BRIDGES (EROB) EXPERT SYSTEM

Expert systems as they exist today generally deal with a set of definable rules incorporating a body of knowledge. Although it may be said that rules also govern esthetics, they are usually much less definable in nature because they involve both the attributes of an object and the subjective evaluation of the attributes. For example, a typical rule applied to bridges would read: "The overall form of a bridge should be simple." Most mature persons would know essentially what this statement means, but most computers would not because of the rule's vague definition. The only computers that would understand this rule are those that had learned its meaning by repeated exposure to numerous examples as directed by human operators--a very complex and laborious task. A newer "computer" that could deal with such a rule more effectively is based on neural networks, much as those in the living brain, but this device is still under development.

Since both of these advanced computer processes were impractical to consider for this current study, a modified type of expert system is proposed that is believed to be "do-able." The proposed expert system utilizes the idea of a knowledge base and an inference engine (as is usual in expert systems) but relies more heavily than most on the judgment of the user in certain phases of the process.

The objective of this expert system is to determine a numerical rating index concerning the esthetics of a given bridge, to be called the "target." The most easily applicable scale is that from 0 to 10. At the extremes, 0 would represent a structure with no esthetically pleasing qualities, and 10 would denote a bridge that is sublimely beautiful. In reality, ratings would fall between these two limits.

However, in rating a target, it is best to have something to compare it with, such as a comparative bridge, to be called the "comparator." The comparator would have a given rating index against which to judge the target--either higher or lower. To assist the evaluator, the many rules described, as offered by experts, will serve to guide the user through the rating process as well as ensure a certain degree of uniformity in rating an assortment of bridges.

To rationalize the rating process further, a target bridge will be esthetically assessed with regard to four general aspects: (1) the bridge as a whole, (2) the details of the bridge, (3) the site and the relation of the bridge to the site, and (4) the special features of a bridge and/or its overall uniqueness. Rules specific to each of these four categories will be applied, and a separate subrating number will be determined for each of these aspects. Then, using appropriate weighting factors, an overall esthetic rating index can be determined for the target bridge.

Should it be desired, a more statistically refined rating index can be had by having several evaluators independently use the same expert system to determine their own personal index for a given target. The resulting average (or mean) rating index of all of the evaluators would serve to mitigate the possible bias of any one evaluator.

RULES

It was not the intent of this study to develop a fully programmed expert system on the subject, but a number of specifics can be offered. At the heart of the system are the rules applicable to the esthetics of girder highway bridges. These will be listed under the four categories previously mentioned, with those marked by an asterisk (*) as being the most important. However, several general statements to be kept in mind are noted first:

*1. The ability to evoke visual pleasure is the main desirable esthetic attribute of a bridge.
2. Standards of beauty change with time. (The rules presented in this report are those postulated for the later half of the 20th century.)
3. The arch is generally considered to be the most pleasing of all bridge forms.
4. The truss is generally considered to be the least pleasing of all bridge forms.
5. Men tend to like bridges with simple forms and slender members.
6. Women tend to like sturdy looking bridges with some ornamentation.
7. Older people tend to like traditional kinds of bridges and bridges of historical interest.
8. Familiarity with a bridge tends to make it appear more attractive.
9. For proper evaluation, a bridge should be viewed from several different angles and distances, with most attention given to the views generally seen.
10. A pleasing site improves the overall appearance of a bridge.

The rules pertaining to a bridge as a whole (exclusive of site) are as follows:

*1. The overall form of a bridge should be simple.
*2. A bridge form should clearly express its structural function.
*3. All elements of a bridge, particularly the girders and piers, should be harmoniously proportioned.
*4. All elements of a bridge should be visually unified.
*5. The girders, piers, and railings of a bridge should generally appear slender.
6. A bridge should have character.
7. A bridge form should appear dynamic.
8. The elements of a bridge should be ordered.
9. The relation of elements in a bridge should be simple.
10. Where there are several bridges close together, they should, in general, exhibit a common design theme.
11. Bridge girders should have simple unbroken lines.
12. The entire length of a girder bridge should be of the same material.
13. A bridge form should use as few geometrical elements as possible.
14. A bridge form should be symmetrical where possible.
15. Girders and piers should not be so slender as to appear unsafe.

16. On a multispan girder bridge, the girders should be relatively slender and the piers relatively heavy.
17. Bridge piers should be tapered where possible.
18. The abutment size of a bridge should be in proportion to the rest of the bridge.
19. Bridge abutments should be of moderate size.
20. An overpass bridge should admit as much natural light under it as possible.
21. A bridge form should have as few edge directions as possible.
22. In general, a bridge should have some repetition of elements.
23. Repeat elements in a bridge should display a clear rhythm.
24. The girders of a bridge should be haunched where possible.
25. Haunched bridge girders should not be used in connection with tall piers.
26. To appear slender, a bridge should be as high off the ground as practical.
27. On a bridge viaduct, the number of columns should be as few as practical.
28. In a long bridge viaduct, the supports should generally be evenly spaced.
29. For a bridge viaduct, the transverse distance between columns should be less than half the longitudinal distance.
30. A multispan bridge generally should have an odd number of spans.
31. A relatively short bridge should have either one or three spans.
32. Bridge piers should be unified where possible.
33. The supports for a haunched girder bridge should be relatively large.
34. There should be no abrupt changes in the depth of bridge girders.
35. The end spans of a continuous haunched girder bridge should be approximately 3/4 of the main span.
36. Except for a very long bridge, the curved portion of a bridge on a curve should be at least 1/2 of the total bridge length.
37. A girder bridge on a curve should have curved facia girders.
38. For a continuous span girder bridge, the facia girder should have a constant depth.
39. For a girder bridge, the depth of the girders should generally be less than 1/20 of the span length.
40. For a girder bridge with haunches, the depth of the girder at the haunch should be about 1/25 of the span length.
41. The depth of a girder on a single span overpass bridge with a 10-ft span with heavy wing walls or abutments should be approximately 1/5 of the span length.
42. The depth of a girder on a single span overpass bridge with a 25-ft span with heavy wing walls should be approximately 1/10 of the span length.
43. The depth of a girder on a single span overpass with a 40-ft span with moderate-sized wing walls or abutments should be approximately 1/20 of the span length.
44. The facia sides of box girders should slope or curve downward and inward.
45. Outrigger piers for a bridge should be avoided.

The rules relating to details of a bridge are as follows:

*1. Details of a steel bridge should be simple in appearance.
2. A bridge generally should not have any ornamentation.
3. The shapes of elements in a bridge should have meaning.
4. Details should be more carefully considered for a short bridge than for a long one.
5. If possible, a bridge should be well lit at night.
6. Girder bracing or diaphragms on a bridge should be visually as simple as possible.
7. For a girder bridge, a few large bracing members should be used rather than many small ones.
8. Where angled bracing members are used for girder bridges, all the angles with respect to the girders should be the same.
9. Repetitive elements in a bridge should be the same size or have the same proportions.
10. Straight haunches should be used only on a straight girder bridge.
11. The exterior face of a bridge parapet should have clean lines.
12. Large expanses of concrete surfaces on a bridge should be textured.
13. Nonstructural facing materials on a bridge should not be generally used.
14. Concrete texturing on a bridge should be sufficiently pronounced for it to be seen by passing vehicles.
15. Where texturing is used on concrete surfaces on or near a bridge, it should not be distracting to motorists.
16. Aggregates on textured concrete bridge surfaces should be exposed where possible.
17. Exposed aggregates on concrete bridge surfaces should be of colored variety where possible.
18. Color and/or texture should be used to highlight selected elements of a bridge.
19. The exterior face of bridge parapets should be textured.
20. A steel bridge (other than of weathering steel) should be painted colors such as light rust, light blue, or dark green.
21. The girders and railings of a bridge should be the same color.
22. A concrete bridge should be made of colored concrete in such hues as off-white, tan, reddish brown, or grey-green if possible.
23. Uncolored concrete bridges should be stained with a pigmented color where possible.
24. Stiffeners on a facia girder of a bridge should be on the inside face if possible.
25. Horizontal stiffeners on facia girders should run the full length of a bridge.
26. Long girders in a bridge should be slightly cambered.
27. A bridge should not have so much camber as to appear humped.
28. All drains in a bridge should be as concealed as possible.
29. The ends of pier caps of a bridge should be as inconspicuous as possible.
30. Pier caps of a bridge should be recessed where possible.
31. For full width piers, the outside edges should be flush with the facia girder.

32. For short transverse trapezoidally tapered piers, the base dimension should not be less than 2/3 of the top dimension.
33. For high tapered piers, the top tapered dimension should be less than the bottom.
34. Bridge piers should be so shaped as to have vertical shadow lines.
35. Octagonal or square columns with strong beveled corners should be used instead of round columns where possible.
36. A pedestal or footing of a pier should be concealed below ground.
37. Where battered bridge columns are used, they should not be mixed with vertical columns.
38. In a cluster of bridge columns, the overall transverse dimension of the cluster should be less than 1/3 of the longitudinal distance between clusters.
39. Where a pair of bridge piers is used, the transverse spacing should be about 1/4 of the span length.
40. For an overpass bridge with a solid parapet, the longitudinal widths of the piers should be between 1/4 and 1/2 of the total girder-parapet depth.
41. The inside face height of an abutment on a girder bridge should be between 1/2 the girder depth and 1/3 of the adjacent pier height.
42. On a skew bridge, the abutments and piers should be placed parallel with the roadway or river direction below.
43. On a curved bridge, the piers should be oriented toward the radial direction.
44. On a steel bridge, nuts and washers should not show on the exterior faces.
45. The transverse face of bridge abutments should slope upward and away from the main part of the abutment.
46. Bridge railings should appear as light as possible.
47. The underside of a bridge should be light in color.
48. Antimissile fencing should be used only where absolutely essential.
49. Antimissile fencing on a bridge should be integrated with the railing.
50. The exterior face of a bridge parapet should extend to the bottom of the deck slab.
51. Grooves or patterns on a bridge should be essentially horizontal.
52. The parapet height on a bridge should be between 1/4 and 1/2 of the girder depth where possible.
53. The parapet height on a bridge should be greater than 1/80 of the span length where possible.
54. Supports for lighting poles on bridges should be such that they do not interrupt the flow of lines of the bridge.
55. Light standards on bridges should line up with the piers.
56. Conduits for bridge lighting should be as concealed as possible.
57. All exit signs on a bridge should have the same width.
58. Signs close together on a bridge should be at the same height.
59. All signs on the side of a bridge should fall within the silhouette of the bridge.
60. The lighting of signs on a bridge should be done by lights on roadside locations if possible.

61. On an overpass bridge, the wing walls on abutments should generally be parallel with the upper roadway direction.
62. For an overpass bridge on a grade, the abutment heights should be proportional to the respective vertical clearances at the roadway shoulders.
63. For a long span bridge, single massive piers should be generally replaced with lighter twin piers.
64. Heavy bridge piers should be dark in color.
65. A girder bridge should have a moderately high bearing between the girder and the pier.
66. The shape of the curve on the haunches of a haunched girder bridge should generally be parabolic.
67. The tangent angle at the lowest point of a haunch on a girder bridge should be between 70 and 80 degrees, measured from the vertical.
68. There should not be any haunches at the very ends of a continuous haunched girder bridge.
69. The connection of a curve to a straight edge on a bridge should be graceful.
70. On a haunched girder bridge, the length of the haunch should be about 1/4 of the span length.
71. For a girder bridge with haunches, the depth of the girder at the haunch should not be more than twice that of the depth at its shallowest.
72. Aluminum railings on a bridge should be anodized.
73. There should be no handrail on top of a concrete parapet, in general.
74. Fencing material on a bridge should be vinyl coated, if steel, or anodized, if aluminum.
75. For low bridges, the dimension of a pier on the longitudinal direction should be less than 1/2 the pier height.
76. A deck slab on a single span bridge should cantilever beyond the facia girder a distance about twice the girder depth.
77. A deck slab on a multispan bridge should cantilever beyond the facia girder a distance about 4 times the girder depth.
78. Rectangular elements in a bridge should have sides in the proportion of 1 to 1.73 if possible.
79. For bridge girder spans up to 150 feet, the depth of a cantilevered facia slab should be at least 1/100 of the span length.
80. For bridge girder spans greater than 150 feet, the depth of a cantilevered facia slab should be between 1/4 and 1/5 of the girder depth.

The rules concerning the site or relation of the bridge to the site are as follows:

*1. A bridge form should harmonize with the dominant features of its site.
2. Short and medium span bridges should not appear conspicuous in their surroundings.

3. Greater attention should be paid to the harmony of a bridge with its site for a short span bridge than for a long span bridge.
4. Landscaping around a bridge generally should replicate the existing natural landscape in the area.
5. Vegetative landscaping around a bridge should not dominate the bridge.
6. Manmade landscaping around a bridge should have a sense of order.
7. The landscape around a bridge should have some visual complexity.
8. Except for congested urban areas and arid regions, there should be vegetation of some kind at the site of a bridge.
9. Large-scale vegetation should be confined to the ends of a bridge.
10. The vegetation at each end of a bridge should be in visual balance.
11. Vegetation close to a bridge should be neatly trimmed.
12. Slope protection at a bridge should relate to both the bridge and the surrounding landscape.
13. For a bridge crossing a relatively narrow valley with steep slopes, the spans should be proportional to the pier heights.
14. For a bridge with many spans crossing a valley, the higher piers should be associated with the larger spans.
15. A bridge crossing a relatively narrow valley with steep slopes should have relatively short spans.
16. For bridges crossing a deep valley, a pier should not be placed at the deepest part of the valley.
17. For a multispan bridge crossing a wide valley, the spans should be between 6 and 8 times the pier height.
18. For a bridge crossing a wide valley, the span lengths should be about 1.5 times the pier heights.
19. For a bridge crossing a valley, the longitudinal dimension of a pier should be less than 1/8 of the span length.
20. The end post of a bridge should blend with both the bridge and the site.
21. Guardrails and right-of-way fencing should not detract from a bridge's appearance.
22. Signs at the approach of a bridge should be as few as possible.
23. Signs at the approach of a bridge should be located in an ordered and harmonious way.
24. Supports for signs at the approach of a bridge should blend into the environment.
25. A girder bridge should generally be used in an urban area.
26. Where a bridge is located on a highway with a concave vertical curve, the bridge should follow the curve.
27. Where a bridge is located on a highway with a convex vertical curve, the bridge should be straight.
28. Where a bridge is located on a highway with a horizontal curve, the bridge should also curve.
29. Sloped embankments under a bridge should be surfaced with stone and/or concrete.
30. Sloped embankments under a bridge should be dark in color.
31. On retaining and noise walls leading up to a bridge, the edges of the walls should be continuous and smooth.

32. Large expanses of concrete retaining wall surfaces leading up to a bridge should be textured.
33. Texturing on concrete surfaces near a bridge should not be distracting to motorists.
34. Drain holes in a retaining wall should be organized in a consistent pattern.
35. A long expanse of retaining walls leading to a bridge should be broken up visually.
36. Any retaining walls along a roadway leading to a bridge should slope upward and outward toward the sky.
37. Fencing on or near a bridge should be framed in a series of panels.
38. Any water in the vicinity of a bridge should be kept clear, unpolluted, and unlittered.
39. Concrete piers set in a natural landscape should be dark in color.

The rules regarding the special features of a bridge or its general uniqueness are as follows:

*1. An otherwise simple bridge should have some variation from the normal, such as in its form or detail.
2. On some bridges, contrasting elements or proportions should be used within an overall bridge form.
3. At some locations, a bridge should boldly contrast with its environment.

EVALUATION PROCEDURE

Since esthetic evaluation is largely visual, a significant amount of graphic material must be introduced into a computer for the computer to function as an expert system. Information concerning the target need not be on the computer, although it may be; but visual images of the comparators must be, and in full color. The hardware and software to reproduce, store, and display a color photograph (as of a bridge) by means of a computer are currently available and are steadily being improved and made less expensive.

Because girder bridges can be of many types, it is desirable that a selection of comparative bridges be stored in the permanent memory of the computer. As a guide, there should be at least the following kinds of girder bridges represented:

1. steel stringer
2. steel box girder
3. concrete stringer
4. concrete box girder
5. single span
6. multispan

7. overpass
8. viaduct
9. rural
10. urban
11. valley crossing
12. water crossing.

As an example, consider a specific comparator bridge that is a three-span steel girder overpass bridge in a rural area. The two most commonly seen views of this structure are shown in Figures 1 and 2. The first is the bridge as seen when about to pass under it, and the second is as seen when about to pass over it. These two views would be stored in the computer's memory. This particular comparator would have a predetermined esthetic rating of (let us say) 5 for its overall appearance, 4 for the details, 6 for site conditions, and 1 for special features.

Assume that the target bridge is a four-span steel girder overpass bridge in a rural area. Further assume that of all the comparators in the computer, the three-span one shown is the closest in kind to the target and is thus selected for comparative rating of the target.

With views 1 and 2 of the comparator on the monitor screen, the evaluator would compare similar views of the target. At the same time, the rules for rating the bridge as a whole would consecutively and slowly appear on the screen as a guide. Keeping the rules designated with an asterisk foremost in mind, and noting that the rating of the comparator is 5, the evaluator would rate the target higher, lower, or even within the range from about 4 to 8. The reason for not using the full range from 0 to 10 is that at some future time other bridge forms, such as arches and trusses, may be subject to rule evaluation and that, in general, arches are considered more beautiful than girders and trusses less so. Thus it would be expected that arch bridges would generally rate higher than girder bridges, approximately in the range of 5 to 9. Truss bridges might range from 3 to 6 by comparison. For discussion, assume that the target evaluation is 6, considering the bridge as a whole.

A similar procedure would be followed with regard to the details of a bridge. Illustrations such as in Figures 3 through 7 of a comparator would appear on the monitor screen, along with the rules applying to bridge details. As the rules scroll, the evaluator would compare the details of the target with those of the comparator. With a rating of 4 for the comparator details, a relative rating for the target details would be made, within the full range of 0 to 10. Assume here that the target rating is 5.

Once again, a similar procedure should be followed with respect to the site and the relation of the bridge to the site. Figures 8 and 9 show the two views of the comparative bridge and its site as seen by most people. These views would appear on the monitor screen as the associated rules slowly scrolled across the monitor. At the same time, the evaluator would view the target bridge and its site. If the comparator is rated as 6, assume that the target is rated as a 7. The full range from 0 to 10 is applicable here.

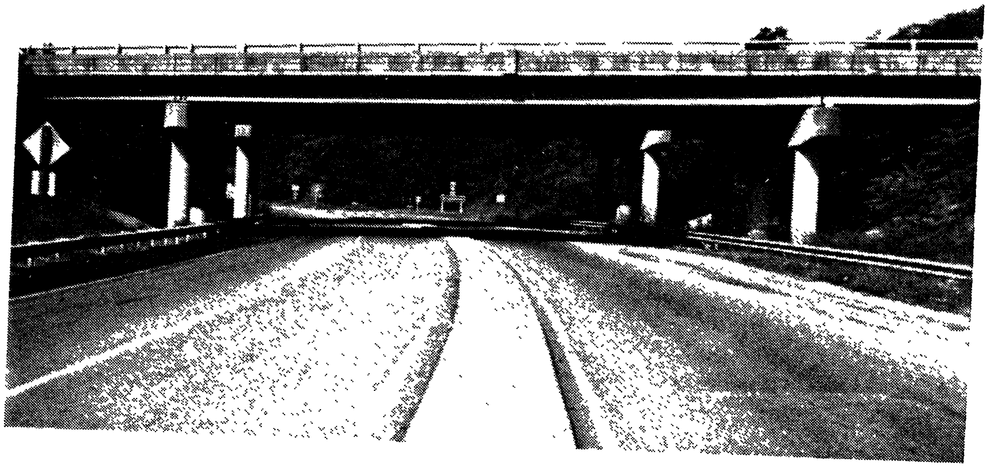

Figure 1. Overview A

Figure 2. Overview B

Figure 3. Detail View A

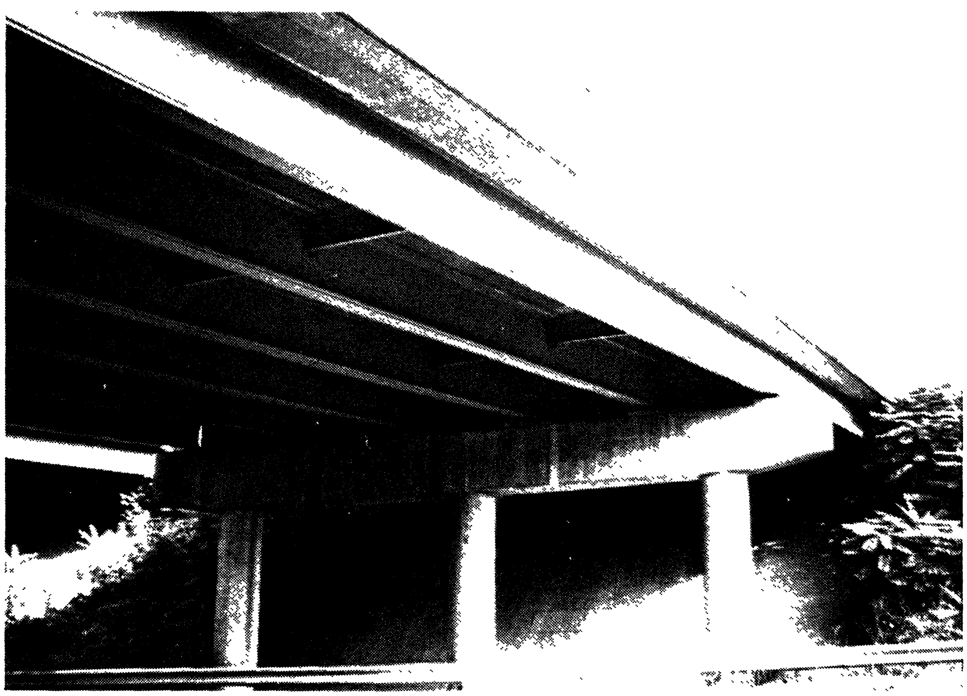

Figure 4. Detail View B

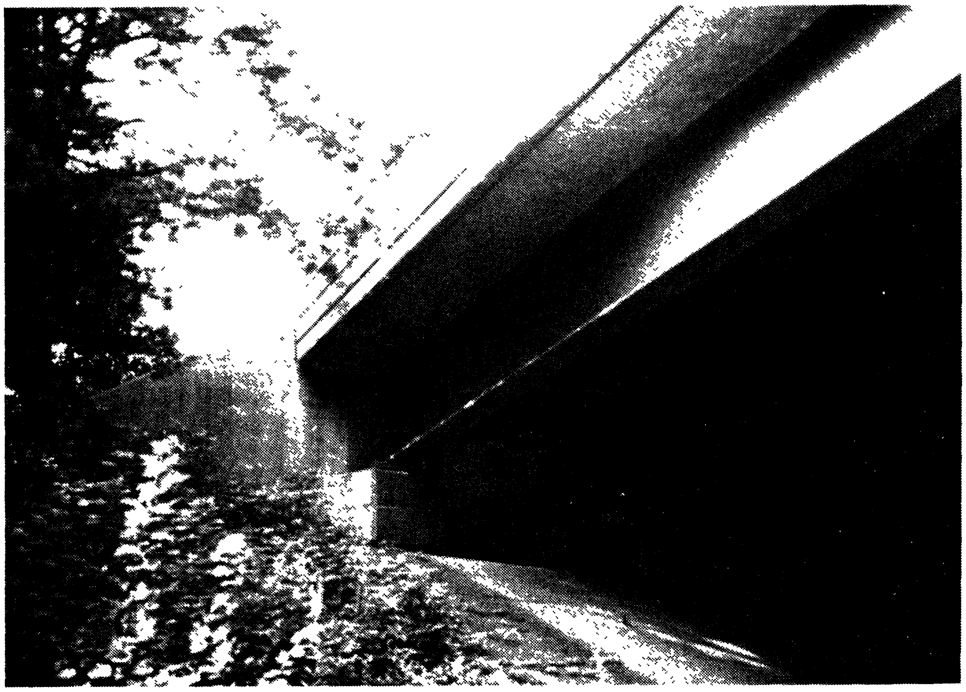

Figure 5. Detail View C

Figure 6. Detail View D

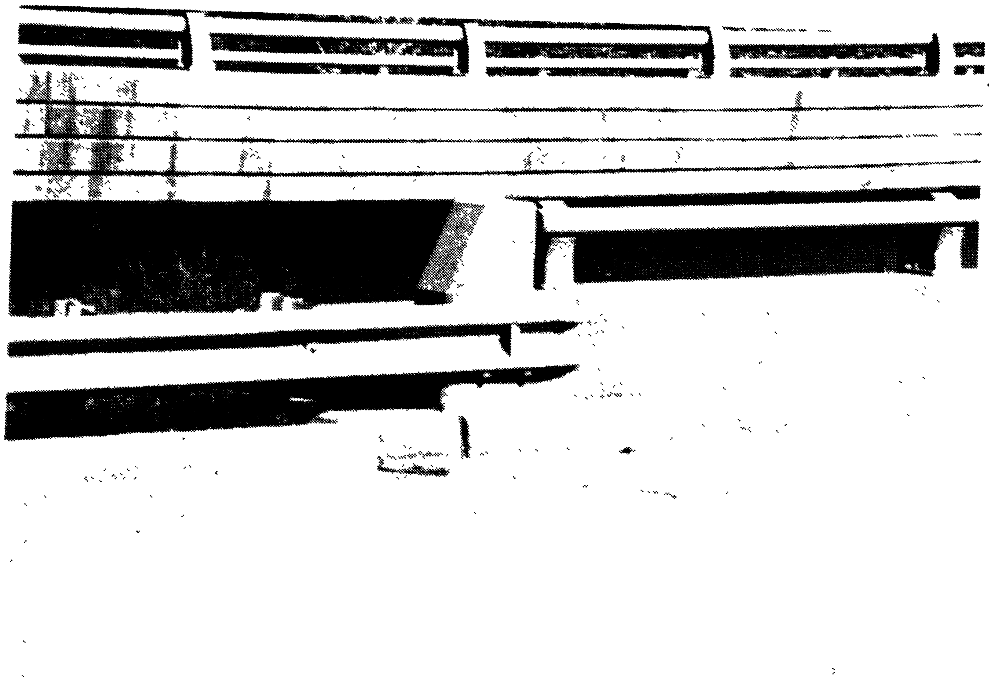

Figure 7. Detail View E

Figure 8. Site View A

Figure 9. Site View B

Finally, an evaluation has to be made with regard to the target's special features and/or overall uniqueness. For that, all nine previous views of the comparator can be recalled, noting that it has a rating of only 1 in this category. Such a low number indicates that the comparator is a rather common type of structure with very few special features. Once again, the target would be judged against the comparator and given a rating as the related rules are displayed on the screen. Let us say the target is thus rated as a 3, within the full range of 0 to 10.

At this point, the evaluator's task is essentially done. However, either at this stage of the evaluation procedure or at any prior stage, the evaluator can backup the procedure and review the rules and/or change the assigned rating for a target.

FINAL ESTHETIC RATING INDEX

The final esthetic rating index (ERI) is determined by a simple formula based on a predetermined set of weighting factors of the four subratings. That formula is as follows:

$$ERI = 0.5R_a + 0.2R_b + 0.2R_c + 0.1R_d$$

where R_a is the rating for the bridge as a whole;
R_b is the rating for the details of the bridge;
R_c is the rating for the site and the relation of the bridge to the site;
R_d is the rating for the special features of the bridge and/or its overall uniqueness; and
0.5, 0.2, 0.2, and 0.1 are the respective weighting factors.

For the comparator bridge used as an example, the ERI is 4.6. The imaginary example target would have an ERI of 5.7.

Conceptually, an ERI of about 5 denotes a bridge rather average in appearance. Values much below 5 suggest a structure somewhat ugly, and values much above 5 reflect an especially beautiful bridge. It is not likely that any bridge would rate a perfect 10 or an absolute 0, however.

CONCLUSIONS

The EROB expert system described provides a needed underpinning to the way bridge engineers judge the esthetics of a bridge. Using an extensive set of rules as set forth by experts, the system serves to establish a common documental basis for esthetic evaluation. Although the proposed system by no means represents the ultimate in the use of artificial intelligence in such a subjective area as esthetics, it is surely better than judgment based on indefinable personal likes and dislikes, as is too often currently the case.

The actual operational time to determine the ERI of a given bridge by EROB is a matter of a few hours at most. In comparison to the many days it takes to stress analyze a bridge, the time devoted to ascertaining the esthetic worth of a bridge is rather minimal. In doing so, it is hoped that a higher consciousness will be developed with regard to beauty in the bridge design process, perhaps leading to a policy establishing a required minimum ERI for all new bridges.

It is recommended that the basic expert system proposed should continue to be developed and refined. An actual computer program must be written, and additional rules must be promulgated for bridge types other than girder bridges. Notwithstanding, even before all this is done, the many rules along with many of the procedures described for EROB can be utilized as guides for immediate application in evaluating the esthetics of bridges.

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