PRACTICAL OPTIMIZATION OF STEEL HIGHWAY BRIDGE BEAMS

R. H. Busek, N. H. Bettigole Company; and
J. T. Gaunt and A. D. M. Lewis, Purdue University

ABRIDGMENT

•THE objective of highway bridge design is to specify the most economical structure for a given situation. The loads that the structure must be capable of supporting, required clearances and other details, acceptable material stresses, and acceptable proportions are given in the AASHO specification (1). The engineer must select from available structural arrangements the arrangement that meets the design criteria and minimizes the function by which the cost of the structure is evaluated.

By using hand methods of calculation, the consideration of only a few structural configurations has been practical in attempting to design economical structures. With digital computers, the number of structural configurations that can be investigated has been greatly increased, and the development of optimum designs has become practical.

A computer program referred to as Girder Automated Design-I or GAD-I (4, 5) is available for the design of noncomposite welded plate girder bridges. There exists the possibility, particularly in the case of relatively short spans, that a more economical structure could be constructed by using rolled steel beams with cover plates, if required, in composite or noncomposite construction. The computer program described in this paper was developed for designing such rolled-beam bridges for required static and fatigue highway loads. The fatigue conditions are based on 500,000 cycles of stress. If the design is composite, ⅞-in. diameter shear connector studs are provided at proper spacing. Only W36 and W33 sections are investigated by this program because shallower sections are not likely to prove economical for these bridges.

The objective of the program is to produce the rolled-beam bridge design with minimum estimated cost. Wherever possible, cost estimation follows the pattern of GAD-I in order to facilitate comparison of costs of rolled-beam bridges with welded plate girder bridges.

GIRDER ANALYSIS

The program will handle either simple-span girders or continuous structures up to four spans. The analysis is carried out by calculating influence coefficients at a specified number of analysis points, equally spaced in each span. Initially, a constant moment of inertia throughout the length of the bridge is assumed. Loadings considered include AASHO truck and lane loadings, Interstate military load, pedestrian walkways if provided, and dead-load conditions. Dead loads include the weight of the steel beams, deck slab, bridge railings, and light fixtures. In the case of composite design, the dead loads are separated into two groups: one for the steel beam only and the other for the composite section. Influence coefficients are used for computing the shear and moment at each analysis point.

ROLLED-SECTION DESIGN

The shears and moments at the analysis points are used for determining the governing shear and moment for the elements of the member between each pair of adjacent analysis points. Initially, stresses are computed for each element by using the heaviest

Sponsored by Committee on Bridge Design.

available rolled section. If the stresses do not violate the AASHO specification, the next lighter rolled section is tried. If the stresses violate the AASHO specification, an attempt is made to eliminate these violations by the addition of cover plates.

In the addition of cover plates, requirements on extension beyond theoretical cutoff points and minimum cover-plate length requirements are considered. After cover-plate thicknesses required in different sections of the member have been determined, optimum locations for plate thickness changes are determined by dynamic programming using the procedures developed by Goble and DeSantis (3, 4, 5) and Razani (6, 7).

After final locations of cover-plate splices have been determined, details such as cover-plate welds, bearing stiffeners, and shear connectors for composite construction are designed.

COMPUTER PROGRAM

The computer program for the design of rolled-section beam bridges consists of a main program and 34 subroutines. The main program calls the subroutines in the correct sequence for reading data, performing an initial analysis, and selecting the most economical section.

Beam selection is started by checking the bending stress in the heaviest rolled section at the critical moment location and proceeds in descending weight order until the lightest acceptable rolled section without cover plates is determined. If the assumption is made that the cost of shear connectors and stiffeners is independent of the section used for beams without cover plates, all heavier sections can be eliminated from further consideration with a consequent reduction in computations. The design of this lightest acceptable section without cover plates is then completed, and the cost is estimated.

Cover-plate requirements for the lighter rolled sections are then determined, and cost estimates are made to see if a more economical structure is possible than the best determined previously. When cover plates are added, the girder is reanalyzed to consider the changes in moment of inertia along the length of the girder.

After the final design is obtained, deflections are calculated, and design details are printed along with the estimated cost. An option is available to design on the basis of either least cost or least weight. A complete listing of the program is available elsewhere (2).

SAMPLE PROBLEM

As an example of the application of the program, a structure for the problem originally presented elsewhere (8) has been designed. The problem is a two-span girder with span lengths of 70 ft. The design is based on a composite section having the following properties: (a) slab width, 84 in.; (b) slab thickness, 7 in; (c) f'_c, 3,000 psi; (d) modular ratio, 8; and (e) haunch, 1.875 in. The design loading is AASHO HS20. The unit costs used in design optimizations are as follows: (a) rolled section, \$0.15 per lb; (b) cover plates, \$0.12 per lb; (c) stiffeners, \$0.12 per lb; (d) connector installation, \$0.75 each; (e) fixed weld cost, \$20.00 each; and (f) weld material cost, \$2.00 per cu in. The final design is shown in Figure 1. The costs and weights of the computer program solution and the solution given in the manual are compared in Table 1. The design produced by the computer will be noted to be approximately 6.4 percent heavier than the published design, but the estimated cost is 4.3 percent less. The total cost of the plates, including both material and fabrication costs, for the computer design is \$238.48 compared with a cost of \$911.69 in the published solution. This cost difference offsets the increased cost of the rolled section.

The computer program is approximately 4,000 cards in length and was developed and executed on a CDC 6500 computer. The compilation time for the program was about 48 sec, and the execution time for the preceding sample problem was about 40 sec.

CONCLUSIONS

The computer program is another step in the automation of steel-beam bridge design. The previous sample problem shows that cost savings are possible by using the total-

Figure 1. Computer optimum design for sample problem.

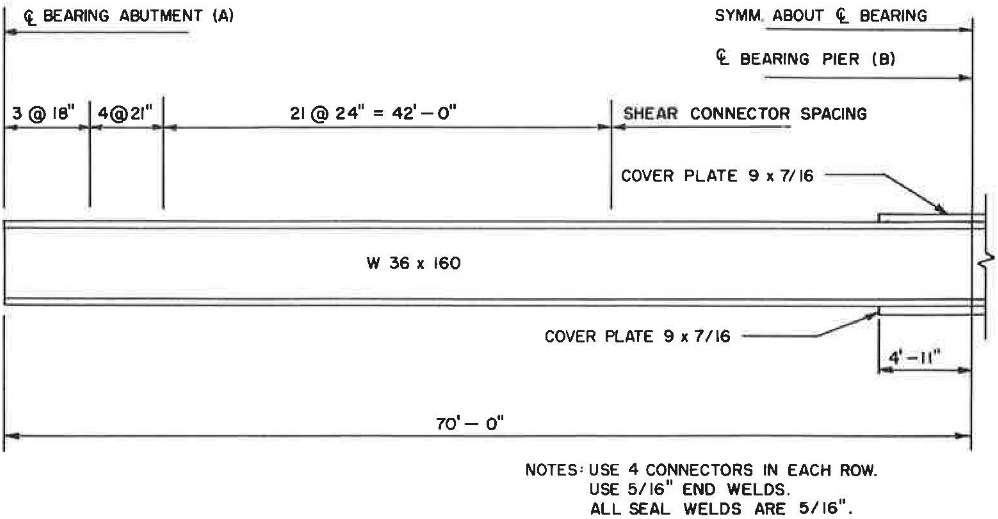

Table 1. Itemized costs and weights for two-span sample problem.

Item	U.S. Steel Manual Weight (lb)	U.S. Steel Manual Cost ($)	Computer Program Weight (lb)	Computer Program Cost ($)
Rolled section	18,900.0	2,835.00	22,400.0	3,360.00
Cover plates	2,361.6	283.40	360.1	31.22
Stiffeners	–	–	–	–
Connectors	202.2	193.50	179.8	174.00
Welds	–	628.29	–	207.26
Total	21,463.8	3,940.19	22,839.9	3,772.48

cost concept in design. The digital computer makes possible the use of optimum-seeking methods in practical problems such as highway bridge design. However, many problems remain to be solved before the optimization of an entire bridge design project will be possible.

ACKNOWLEDGMENTS

The authors wish to acknowledge the financial support of the Joint Highway Research Project. The guidance and help of Harold L. Michael, associate director of the project, is appreciated. The aid and support of the Indiana State Highway Commission is also appreciated.

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