The following are examples of DVS road design project applications:

- Vehicle tracking characteristics through simple and compound curves to determine minimum required curve widening,
- Restricted operating and parking spaces for tractor-trailer units,
- Critical bridge approach designs,
- Minimum parking facility design required for large tour buses,
- Empty log truck turn-around designs,
- Waterfront log dump design,
- Analysis of log sweep of tree length logs on a log truck on curves and in intersections,
- Large log yarder wheel tracking and tower sweep to determine minimum road width and cut bank design, and
- Required curve widening for design of roadway retaining walls.

The procurement cost of the DVS was a prime consideration in its development and design. The cost of the entire unit, including the carrying case, was $495.00 in 1985.

The DVS has proved to be a cost-effective design aid in the analysis of vehicle tracking in low-volume roads. Its application covers a wide range of practical vehicle tracking design situations that other scale and computer models do not effectively address. The operating procedures of the DVS are easily learned and rapidly applied. A road design engineer can be taught to use the DVS in 1 hour. The application of this tool in road design yields considerable savings in road construction costs when compared to the traditional design analysis of horizontal road geometry.

Development of New Design and Construction Guidelines for Low-Volume Road Bridges

HOTA V. S. GANGARAO AND MICHAEL J. HEGARTY

Low-volume road bridges in the United States are currently designed with the aid of AASHTO Standard Specifications for Highway Bridges. These specifications were primarily developed for high-volume urban and interstate highways. The design and construction of low-volume road bridges is therefore expensive. It is obvious from the current design and funding pattern in the United States that available funds are not sufficient to rehabilitate or replace all the deficient low-volume road bridges. A systematic investigation is therefore being performed to study the cost-effective use of various super- and substructural systems and miscellaneous bridge components to better use available funds. The unique characteristics of a low-volume road bridge are defined in this paper as a function of speed limits, average daily traffic, gross vehicle weight, and bridge width. The standard highway bridge specifications of the United States and other countries are reviewed and modifications to certain specifications and elimination of others are proposed. Feasible low-volume bridge components can be selected by eliminating inappropriate alternates and comparing the advantages and disadvantages of the remaining super- and substructural bridge systems. Concrete, steel, and timber structural components are reviewed, and design and cost scenarios that were developed in this study are highlighted. In order to recommend the effective use of limited available funds for bridge replacement programs, a value engineering approach was adopted to research the cost-effectiveness of various bridge components; types of materials used in the construction of low-volume road bridges; and current specifications for design, construction, maintenance, and rehabilitation.

Over the past several decades, about a trillion dollars have been invested in the highway system of the United States. However, a massive infusion of additional funds is required to maintain, rehabilitate, and replace the rapidly deteriorating highway system. For example, it is estimated that $48.9 billion in 1982 dollars will be needed to repair or replace 253,196 of about 600,000 bridges that were classified as deficient at the end of

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1982 (*1*). It is obvious that available funds ($7.05 billion for 4 years through 1986, as authorized by the U.S. Congress) are insufficient to rehabilitate or replace all deficient bridges.

The major objective of this study is to evaluate the specifications and design criteria for bridges and determine if certain aspects of the existing criteria can be eliminated or modified to make low-volume road bridges more cost-effective. Low-volume roads are defined as those roads that have an average daily traffic (ADT) of less than 200 vehicles, and a posted speed less than 35 mph. Another objective is to systematically investigate the economics of various low-volume super- and substructural systems and miscellaneous bridge components, such as curbs, railings, and expansion joints. It is hoped that the potential savings derived through the proper selection of innovative bridge systems can lead to better use of available funds. This is particularly important in regard to badly deteriorated old bridges the life of which cannot be extended by maintenance alone.

The initial phase of the comprehensive work being conducted at West Virginia University is reported. In-depth investigations of the proposed modifications to develop new specifications for low-volume bridges will be reported as a sequel to this study. Because the current categories of bridges are wide and all-encompassing, only such items as material selection, design criteria, construction type, and maintenance and rehabilitation costs were carefully identified and evaluated before specifications were formulated to optimize the design of a low-volume bridge.

STATE OF THE ART

A comprehensive review of various technical articles on low-volume bridges and the associated topics was performed. It was found that the unique characteristics and problems of low-volume bridges were presented in specific, narrow subcategories (i.e., precast and prestressed, concrete low-volume bridges) and little comprehensive work was presented on the general topic of low-volume bridges.

Consequently, it is not surprising that the AASHTO design specifications do not differentiate between low-volume rural bridges and high-volume urban bridges (*2*). It is therefore highly unlikely that efficient and economical low-volume bridges can be designed using specifications that were compiled primarily for highway bridges. It should be noted that the only section of the AASHTO code that considers the ADT of a bridge is the section on allowable fatigue stresses. The Ontario Highway Bridge Design Code also does not distinguish between high- and low-volume bridges (*3*).

Much of the pertinent material found under other subcategories includes material type, relative economic comparisons, systems construction approach, jointless bridges, and use of guardrails and curbing. The available literature under each subcategory was reviewed in regard to specifics concerning low-volume bridges.

Material Type

Many useful low-volume bridge applications were found in articles that discussed prestressed concrete, timber (glulam), or steel alternatives. Precast, prestressed concrete is applicable as a construction material in low-volume bridges because it can be prefabricated and is economical in many regions of the country. Tokerud considered a wide range of issues that affect precast and prestressed, low-volume concrete bridges, including planning, design considerations, abutments, bridge decks, and geometrics (*4*). A list of design and construction recommendations is also provided by Tokerud.

Precast concrete bridge decks are also a viable alternative to conventional bridge decks, especially for low-volume bridges (*5, 6*). Berger noted that modular precast decks have been successfully used since 1967 with excellent results (*7*). These deck modules are mass-produced because the same form work can be used repeatedly; quality control is improved because on-site pouring of concrete is eliminated. Other advantages include greater structural efficiency and a possible reduction in dead load. Construction cost data for four design examples were estimated and compared with conventional cast-in-place construction. Sprinkle stated that the use of these decks reduces the on-site construction time, which provides savings in labor costs (*8*).

Timber construction, especially glued-laminated (glulam) timber construction, lends itself well to low-volume bridge construction (*9, 10*). The fact that these components can be prefabricated means that savings similar to those derived from the use of precast concrete will result. Verna presented three case histories that outlined the rehabilitation of various components using glulam members (*11*). Verna stated that timber exhibits acceptable resistance to deicing agents and normal water exposure, and must be considered in the selection of bridge materials. Other authors expressed concern about such factors as installation problems with the alignment of deck panel dowels and cracking of any asphaltic overlay (*12, 13*). However, these problems are being resolved because of a greater understanding of their behavior (*14-16*).

Open-grid steel decks are not used on many large urban highways because of certain undesirable characteristics, including twisting and fracture of diagonals, weld failure, and corrosion problems. GangaRao noted that the underdesign of grid deck components because of a lack of understanding was the major cause of these failures (*17*). In addition, open-grid steel decks have been noted as having poor skid resistance, which makes them unacceptable for high-speed traffic. However, because of the low speed limits on low-volume bridges, skid resistance is not a major design or safety consideration. The most obvious advantage to the use of grid decks is that they are extremely light (15 psf).

Economic Considerations

A few studies attempted to compare the economics of one bridge system to another (*18*). Hill and Shirole presented a statistical breakdown of 3,700 bridge replacements for spans of less than 100 ft in the state of Minnesota (*19*). The 10-yr (1973 to 1983) test group was broken down into bridge type, number of each bridge type, and unit construction costs.

In a more recent report by Sprinkle, prefabricated bridge elements and systems were analyzed and current practices and problems were listed (*20*). In addition, a set of tables was presented and the costs of various alternatives were quoted according to several sources.

A complete methodology to determine whether a deteriorated bridge should be rehabilitated or replaced on a minimum life-cycle cost basis was developed by Weyers, Cady, and McClure

(*16*). Cash-flow diagrams were used to determine the equivalent uniform annual costs of alternatives. The effect of interest rates and inflation was then considered to obtain the most economical solution. Examples of the mathematical model and a microcomputer program were also presented.

Tokerud studied the potential economics of low-volume bridges (*4*). He discussed the most economical bridge alternatives considered in the northwestern United States under the three structural material groups of concrete, timber, and steel. Planning, design, contracting, and geometric considerations were also discussed. This study is based on a survey of state, county, and municipal agencies in that region.

It should be noted that economic information in regard to low-volume bridges in published technical literature is limited. This is especially true in regard to future costs, such as yearly maintenance and rehabilitation costs. Such information is necessary to establish the life-cycle costs of alternatives, which is the purpose of the value engineering approach. A sequel to this study is therefore being prepared at West Virginia University, with special emphasis on a value engineering approach to select a specific bridge system.

The Systems Approach

The systems approach to the construction of low-volume bridges is desirable for several reasons (*10*). More efficient use of materials through mass production coupled with the avoidance of costly and time-consuming conventional procedures are just two of the advantages of the systems approach.

GangaRao presented 10 different substructure systems and analyzed them in regard to economy, ease of erection, maintenance, and longevity (*21*). Hanson also presented prefabricated substructural units (*22*). Sprinkle discussed systems construction techniques for short-span concrete bridges and listed several uses of prefabricated components (*8*). GangaRao and Taly developed several innovative prefabricated, superstructural systems for spans of up to 100 ft (*23*). A numerical rating scheme was used to evaluate the alternatives in relation to one another.

Use of Jointless Bridges

Expansion devices and bearings are not used in jointless bridges because thermal expansion movements are transferred directly from the superstructure to integral or hinged abutments. Additional details are provided later. The costs of jointless bridges therefore do not include the initial cost of expansion joints and bearings and associated maintenance costs.

The jointless bridge also acts as a rigid frame because the superstructure is tied securely to the substructure, which substantially reduces the moments incurred by the superstructure and substructure (*24*). The state of Tennessee has constructed a 927-ft concrete bridge and a 416-ft steel bridge (*25*). Span length therefore is not a major consideration in the design and development of a jointless bridge.

Use of Guardrails

Bronstad and Michie investigated the applicability of guardrails on low-volume bridges (*26*). They proposed that guardrails are not warranted for bridges with an ADT of less than 50. Many government agencies, such as the U.S. Forest Service, use railings that do not meet AASHTO specifications. Preliminary discussions with state highway agency personnel revealed that guardrails do not appear to serve their purpose on low-volume bridges. The necessity of guardrails on low-volume bridges is evaluated in a later section of this paper.

ISSUES THAT AFFECT LOW-VOLUME BRIDGES

The use of various alternatives to maximize the economy of a low-volume bridge is considered. The following four topics are addressed: a review of existing codes and geometrics, minimization of components, material selection, and use of guardrails and curbs.

Review of Existing Codes

Low-volume bridges in the United States are currently designed according to the same criteria as urban and interstate highway bridges. It is obvious that the specifications for a bridge designed to safely carry high-volume HS-20 loads are overly conservative when applied to a low-volume bridge. Existing bridge design and specification codes are therefore reviewed in regard to fatigue, lane loading, and deflection to identify which standards are overly conservative or irrelevant.

Fatigue

Fatigue damage is a major consideration in the design of a bridge. The standard specifications for highway bridges adopted by AASHTO define allowable levels of stress that correspond to the number of fatigue cycles the bridge will experience in its lifetime (*2*). The lowest level of design stress corresponds to a maximum of 100,000 fatigue cycles.

The following three alternatives are available to minimize the significance of the fatigue factor in regard to low-volume bridges:

- Assume the current allowable fatigue stresses listed by AASHTO for 100,000 cycles;
- Expand the current AASHTO allowable fatigue stress criteria to include another category of cycles at a lower limit (i.e., less than 50,000 cycles); or
- Neglect fatigue effects in design.

If the second or third alternative is chosen, savings would be realized by using higher levels of stress, which would result in smaller size sections for stringers.

Vehicle Impact

No changes in vehicle impact for low-volume bridges are proposed. Many studies have concluded that the prediction of the dynamic loads as a result of vehicle impact are affected by a number of variables (*27*). The current practice of making the impact factor a function of span length with a maximum value of 30 percent is recommended to be retained for low-volume roads. It should be noted that Ontario Highway Bridge Design Code uses a maximum value of 40 percent, with various reductions of that percentage specified depending on the component type (*3*). An average increase of static live load ranges of 30 percent is therefore recommended for low-volume bridges.

Lane Loads

Lane loads were developed to provide a simpler method of calculating moments and shears than methods based on wheel loads (*2*). A truck train was modeled to attain the worst design criteria. This loading combination is irrelevant because the probability of a truck train being used on a low-volume bridge is essentially zero. It is therefore recommended that an analysis of lane loadings should be omitted in the case of low-volume bridges.

Deflections

Current AASHTO practice limits deflections by using specifications that are a function of span length, whereas a second type of specification involves the use of beam depth ratios in regard to span length for steel bridges. In both cases, AASHTO notes that these limits can be exceeded at the discretion of the designer. It is noted that these ratios are primarily serviceability considerations that account for user comfort and may not affect the structural integrity of a bridge.

Higher allowable levels of deflection can be used in a low-volume bridge because of its unique characteristics. The maximum acceptable deflection currently specified by AASHTO is L/800. It would be feasible to relax the deflection criteria to the levels prescribed for building floors (L/360) because only one vehicle would be on the span at a time. The proposed L/360 requirement would replace the other associated AASHTO criteria that limit deflection by controlling beam spacing, as is the case with concrete structures.

If deflection requirements were relaxed, savings would result in several areas. Deflection considerations are likely to control the design of girders in longer spans. If the requirements are relaxed, smaller or shallower members may be satisfactory. Wide flange sections might be able to satisfy the new design criteria in cases in which cover plates or built-up sections are required.

Geometrics

Items such as bridge width, posted speed, roadway approach curvature, and clearance heights must all be reviewed from the standpoint of their cost-effectiveness in terms of the present worth of a structure. The greatest cost reductions could be realized by reducing the bridge width. The possibility of two vehicles crossing a low-volume span simultaneously is remote. Therefore, serious consideration must be given to designing a one-lane bridge with a 12- to 15-ft clearance width.

Some low-volume bridges are definitely not suitable for one-lane configurations. Restricting variables include the following:

- The use of a bridge by oversized vehicles such as farm equipment;
- High roadway speeds or dangerous roadway alignments; and
- The prospect of future development.

It would certainly be justifiable to place a one-lane bridge on a one-lane roadway, but it would be questionable to place a one-lane bridge on a lightly traveled two-lane road.

One approach would be to include additional safety provisions to compensate for the one-lane span. These provisions could include additional warning signs cautioning the motorist of the upcoming roadway change, speed bumps, and possibly the installation of guardrails. However, as will be explained later, guardrails are not economically justified on most low-volume bridges (*26*).

If the suggested safety provisions are enacted, the additional cost will be more than offset by the reduction in costs of the substructure and superstructure. A savings of almost 50 percent in materials costs could be realized if a one-lane span is chosen over a two-lane span. It is also reasonable to assume that construction costs could be decreased 30 to 40 percent by building a one-lane bridge instead of a two-lane bridge.

Clearance heights should also be reviewed. Both overhead and underpass clearances must be reviewed and revised to determine if savings in construction and maintenance costs can be realized.

Overhead clearance should generally not be a problem because it can safely be assumed that through truss or suspension bridge types would not be considered for low-volume bridges.

Bridge underpass clearance above a waterway must be determined by considering the hydraulics of a particular site. Conventional design practices are generally applicable, although low-water stream crossings that are designed to be over-topped by floods could be an economical alternative (*28*).

Minimizing Components

The careful selection of components and materials can help reduce the construction and maintenance costs of low-volume bridges. The use of monolithic, or tied-down, abutments is one major method of reducing costs. In this system, the superstructure is firmly secured to the abutments, which creates a rigid frame. A rigid frame has the following advantages:

- Lower design moments of up to 20 to 30 percent;
- Damping of dynamic (impact) forces that result from transmission through the frame and into the soil; and
- Reduction of moments at abutment base because the superstructure resists lateral earth pressures.

In addition to the use of monolithic abutments, the concept of a jointless bridge would be applicable to low-volume bridge construction. The construction of a jointless bridge could reduce several costs. The cost of expansion joints and their associated maintenance costs would be eliminated, and smaller bridge members could be used because of the rigid frame action.

Continually reinforced concrete highway pavements have been constructed for years (*29*). This concept has also been successfully applied to bridges in which the joint at which the bridge and roadway meet and all intermediate deck joints are eliminated. Thermally induced lateral loads and the vertical load are transferred directly to the integral abutment by use of monolithic construction.

Initial savings are derived by removing the joints from the bridge. However, more significant savings can be realized by the reduced maintenance cost associated with jointless superstructures. Expansion joints require periodic cleaning and inspection, and often do not function as they were intended to.

Material Selection

Careful selection and use of materials can reduce the construction and maintenance costs of a low-volume bridge. The unique characteristics of low-volume bridges must be considered when a selection is made.

As will be explained later, it is desirable to select a material with low maintenance costs even if the initial costs are higher. It is therefore beneficial to minimize, if not eliminate, the number of connectors on a bridge from both maintenance and inspection standpoints. The feasibility of a bridge with no connectors must be determined, but such new techniques as the use of epoxy glue as an adhesive must first be thoroughly investigated before they can be recommended for general use.

The use of lesser-grade materials (i.e., F_c = 3,000 psi concrete) generally does not result in appreciable net savings (*4*). However, because low-volume bridges are generally in remote regions, the lower costs of local materials could justify their use in terms of substantial savings.

Use of Guardrails and Curbs

The costs of installing bridge railings range from $10 to $80 per linear foot depending on the type of railing installed (*26*). The savings to be realized are easily in thousands of dollars if bridge railing costs could be minimized or even eliminated by considering the unique requirements of low-volume bridges. The following is a review of the issues relevant to this problem.

Only one level of bridge railing service is currently recognized by AASHTO (*2*). Although this level of service adequately provides a safe bridge railing design for large urban highway bridges, it is questionable whether or not this same level of service could produce cost-effective bridge railings for roads with an ADT of less than 10. A report published by the Transportation Research Board investigated this problem (*26*).

Comprehensive bridge accident data were analyzed in the report and the results were integrated in a cost-benefit model. It was found that railing was not economically justified for bridges with an ADT of less than 50. This conclusion was made by determining the probability of an accident occurring on a certain type of bridge and the material and human costs of that accident. This result was then correlated with the value of the estimated benefit of retaining the vehicle on the bridge deck. However, in the case of low-volume bridges, the impact probability is almost zero; therefore, bridge railing does not provide more benefits than costs on low-volume bridges.

Two low-cost railing alternatives are presented in the report, should a designer believe that specific site conditions warrant bridge railings. One is a steel post and the other is a timber post at 8-ft, 4-in centers with their beams. These alternatives were designed using a vehicle weight of 4,500 lbs, an impact speed of 60 mph, and an impact angle of 15°.

Although these criteria are less demanding than current AASHTO barrier criteria, it is proposed in this report that it is more realistic to use these criteria in the design of railings for low-volume bridges. The average cost of these alternatives is only $10 per linear foot.

SELECTION OF FEASIBLE ALTERNATIVES

The cost of a new bridge on a low-volume road is broken down on the basis of the deck, superstructure, and substructure bridge components. The most cost-effective structure can be built by ranking and maximizing the use of each component, and determining their initial and future costs.

Based on a questionnaire, low-volume bridges were defined as those that have an ADT of less than 200. These bridges are often rural bridges that are located far from maintenance crews and materials. It is therefore logical to spend more money on the initial cost if it is spent on an alternative that requires minimum maintenance, both in terms of tasks to be performed and number of visits by maintenance personnel.

Bridge Decks

Recent trends in new bridge construction have shown a definite movement away from labor-intensive and time-consuming construction (*19*). Orthotropic decks that require a great amount of skilled labor therefore can be eliminated. Concrete-filled, steel-grid decks can also be eliminated because of the costs, labor intensity, and other maintenance problems.

Three types of prefabricated bridge deck systems are suggested: precast, prestressed concrete deck panels; open steel-grid deck panels; and glulam deck panels.

These prefabricated decking systems have advantages and disadvantages. However, the key factor in determining the most economical bridge deck alternative is the location of the site to the deck system producers. Although glulam is frequently used in the Northwest, concrete is by far the most common material for decks in the East (*4*).

This same principle governs the use of cast-in-place concrete on low-volume roads. If fresh concrete can be economically hauled to a certain site, it probably is the best choice. However, it is safe to say that most low-volume bridges also are many miles from a concrete plant. Cast-in-place construction is also labor-intensive. Cast-in-place bridge deck construction is therefore probably not one of the most economical methods.

Bridge Superstructures

As was the case with bridge decks, certain types of bridge superstructures are more suitable than others for low-volume bridge construction. Among the groups that should not be considered are steel build-up sections, trusses, and cable-stayed and suspension bridges. These types of construction are highly labor-intensive and would not be economical alternatives.

Prefabrication is suggested once again because of the high probability that these bridges are located in remote areas. Therefore, cast-in-place construction is generally not economically justifiable because of the high cost of transporting materials and labor to the job site. This may not be true in some situations, and cast-in-place concrete construction might be a viable alternative.

Another superstructure type that is not suggested is a precast, reinforced concrete system. This method of construction is generally used on short span lengths of less than 30 ft. Highway agencies may be able to make their own precast members by using idle construction workers in winter months. Because prestressed, precast members are structurally more efficient than their reinforced, precast counterparts, they only are considered in part of this study.

The three most promising types of bridge superstructures are precast, prestressed concrete stringers; steel stringers; and glulam stringers. In addition, a wide range of deck stringer systems has been analyzed from the standpoint of their applicability for low-volume bridges, including the following:

- Prestressed or nonprestressed plank timber or glulam decks with steel or glulam stringers (Figures 1 and 2);
- Voided slab (Figure 3);

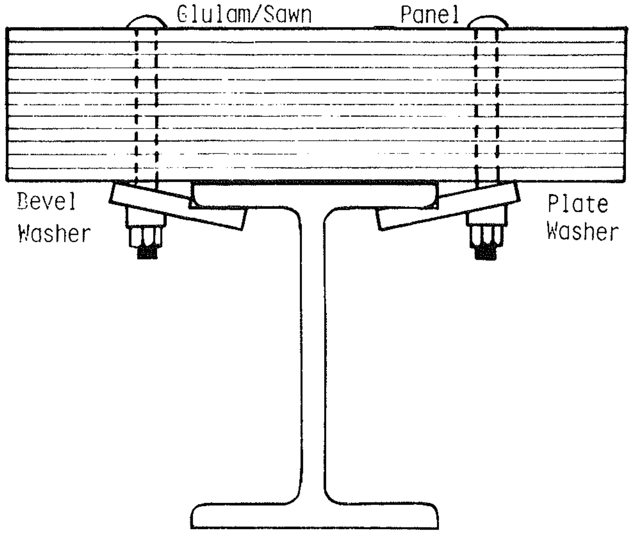

FIGURE 1 **Glulam/sawn panel with steel stringer.**

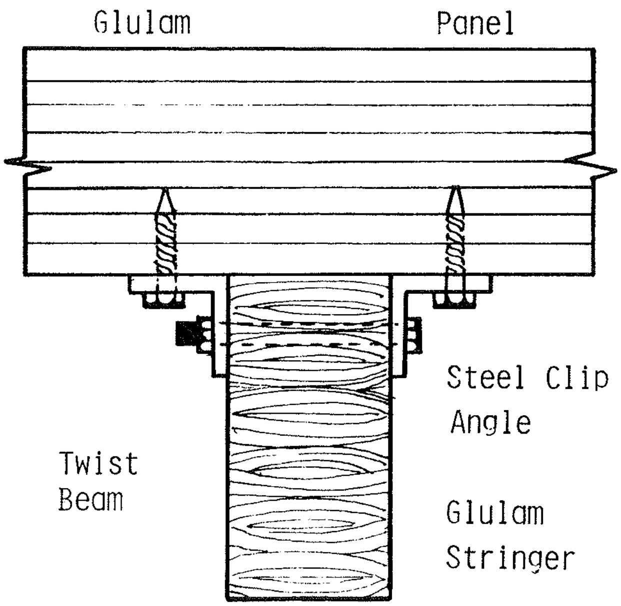

FIGURE 2 **Glulam stringer and panel system.**

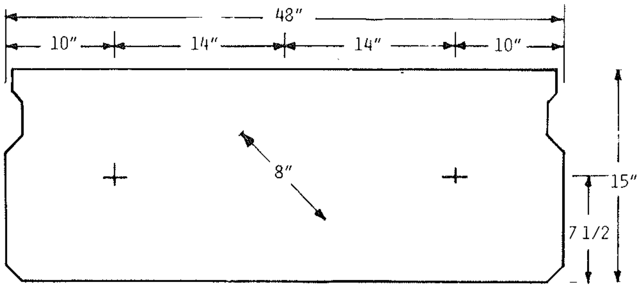

FIGURE 3 **Voided slabs for a 30-ft span.**

- Cast-in-place concrete or glulam decks with steel or glulam stringers (Figure 4);
- Prestressed or steel-grid deck panels with steel stringers (Figures 5 and 6);
- Cast-in-place deck with precast, prestressed I-beams (Figure 7);
- Precast decked bulb T-beams (Figure 8); and
- Box beams (Figure 9).

The first two items in the list are commonly considered for span ranges of 30 ft and less, whereas the rest of the items are considered for spans ranging from 60 to 100 ft. A few cross-sectional details of these bridge systems are given in Figures 1 through 10.

Other ways to minimize cost of the superstructure include avoiding the use of diaphragms and other projections, limiting skews to less than 30°, using welded wire fabric and elastomeric bearing pads when possible, and repeating a great number of identical spans when possible.

Bridge Substructures

Finally, potential savings can be derived from the choice of abutment type. The use of either a full or stub abutment can significantly affect the final cost of a bridge. The use of full abutments involves the construction of vertical abutment walls that are backfilled to create a level subbase. The use of this

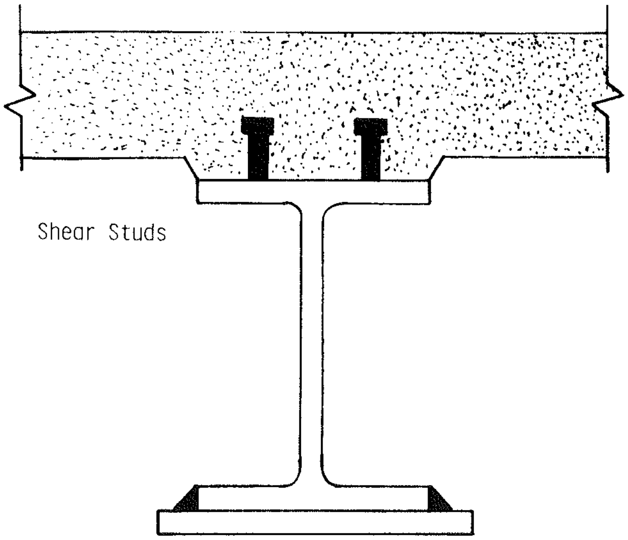

FIGURE 4 **Composite WF-section with cover plate.**

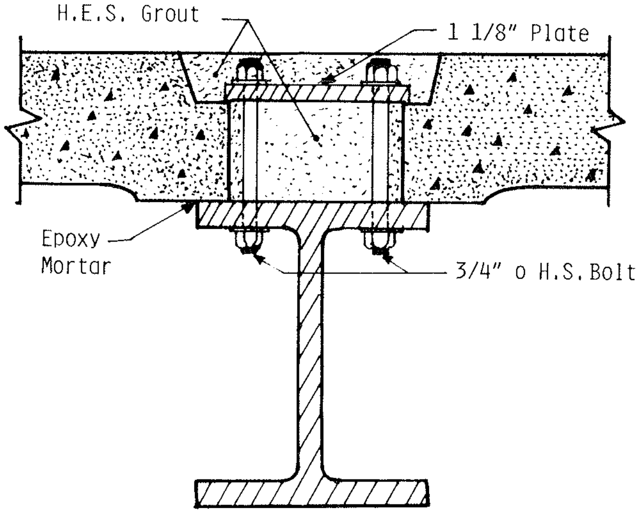

FIGURE 5 Precast deck panel steel stringer system (grouted connection).

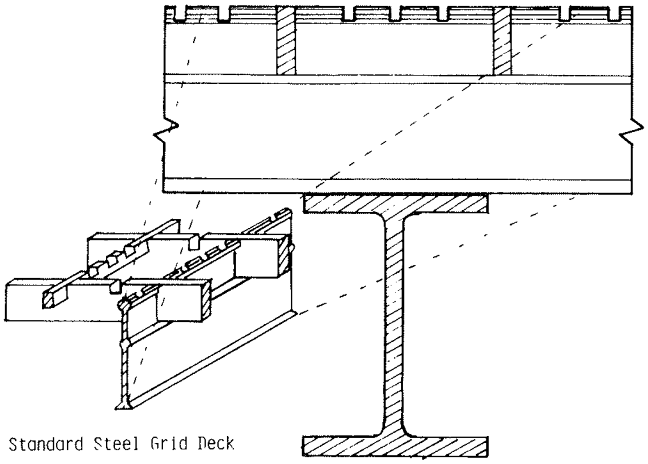

FIGURE 6 Open steel-grid stringer bridge system.

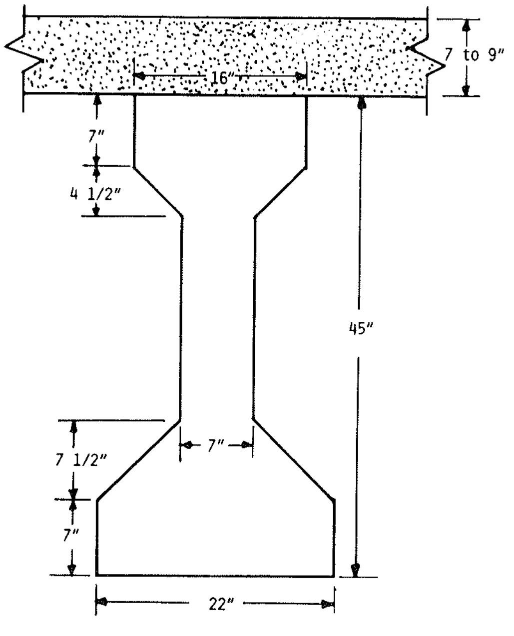

FIGURE 7 Type III girder section.

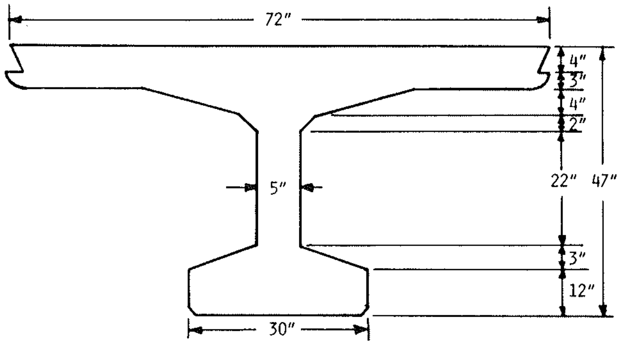

FIGURE 8 Decked bulb T-beam for 100-ft span.

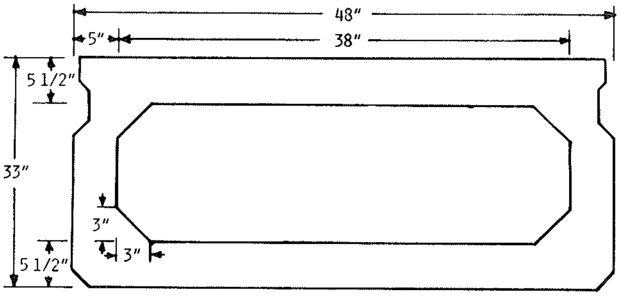

FIGURE 9 Box beam for 60-ft span.

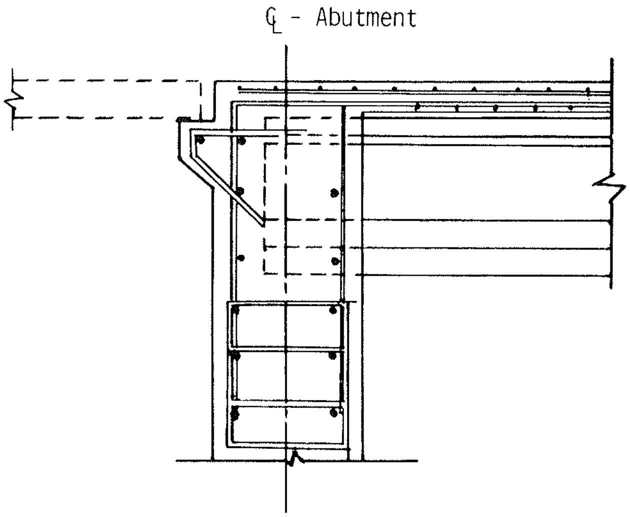

FIGURE 10 Integral abutment.

method results in shorter span lengths but requires the construction of abutments and wingwalls. A piling cap is used in stub abutments to support the girders. This piling cap is much smaller in size than the total abutment, but the span length is increased because a fill-slope is incorporated instead of a vertical wall (*4*).

Tokerud reported that the stub abutment is generally the most economical abutment unless, for example, the use of two spans is required instead of a single span (*4*). Therefore, it should be noted that the savings in girder size will not generally offset the increased substructure cost.

As was previously stated, the concept of prefabrication is applicable to substructures of low-volume bridges. GangaRao proposed 10 prefabricated substructural systems; however, their use has been limited to date primarily because of the unique site variables, such as soil bearing values and depth or location of bedrock (*21*).

Perhaps the most critical question to be answered involves the connection between a prefabricated superstructure and a prefabricated substructure. Because monolithic (rigid-frame) construction is encouraged when it is feasible, this connection (Figure 10) must provide either full moment transfer or at least prevent the translation of the girders over the abutment.

Deep foundations such as piles were not considered because they are probably uneconomical for low-volume bridges. It would be more effective to use a larger, shallow foundation than to use a deep foundation in the remote regions in which low-volume bridges are typically found.

Economic Survey

Several factors affect the determination of the initial cost, including availability of materials, availability of forms and equipment to fabricate and handle one type of element, the qualifications and experience of the available labor force, and the characteristics desired in the finished bridge. Therefore, stock items should be used whenever possible and construction techniques should be employed that are within the capability of locally available equipment and labor crews. Some of these aspects have been described by Sprinkle (*20*).

COST-REDUCTION SCENARIO

A cost-reducing design scenario has been developed, the purpose of which is to outline a series of design decisions that will illustrate the potential savings to be realized if the proposed recommendations are enacted.

For this particular scenario, a traditional 60-ft, simple span, two-lane (34-ft) bridge has been designed with four steel stringers spaced at 8 ft, 4 in centers, and overhangs of 4 ft, 6 in and a 7-in-thick concrete deck. In addition to the traditional design (according to AASHTO specifications), two other alternatives are considered for the sake of comparison: construction of a one-lane bridge and rigid-frame construction. The weight reductions of girders are given in Table 1. Percentage reductions in components are given in Table 2.

CONCLUSIONS AND RECOMMENDATIONS

Two crucial points have been made in this study thus far. First, only limited work has been performed that relates specifically to low-volume bridge design, construction, maintenance, and rehabilitation. Second, potential savings can be realized through reduction in bridge parts, design modification, and effective rehabilitation schemes. The following areas of research may lead to potential savings.

Considering the problems that bridges currently develop as a result of fatigue cracking, it is essential that the unique characteristics of low-volume bridges in regard to fatigue be understood before current AASHTO specifications are changed (*2*).

Many dynamic loading tests have shown that an impact load of 30 percent can be reached at speeds as low as 15 mph. Therefore, it appears that no reduction of the current AASHTO specifications if justified. The type of construction material used should be investigated. For example, timber is less susceptible to impact than other materials because of its excellent energy-absorbing characteristics under dynamic loading situations. Special consideration must also be given to relaxing the deflection requirements.

TABLE 1 WEIGHT REDUCTION OF GIRDERS

Alternative	Girder Size (in)	Weight (lb/ft)	Percentage of Reduction in Weight From AASHTO
AASHTO	36 × 194	194	0
One-lane	36 × 170	170	12.4
Rigid frame	33 × 130	130	33.0

TABLE 2 REDUCTION IN COMPONENTS

Component	Two-Lane Quantity	One-Lane Quantity	Percentage of Reduction of Two-Lane Bridge
Slab	60 ft long × 32 ft wide = 1,920 ft^2	60 ft long × 16 ft wide = 960 ft^2	50
Steel stringers	194 lbs. ft × 60 ft × 4 girders = 46.56 kips	170 lbs ft × 60 ft × 2 girders = 20.40 kips	44
Abutments	32 ft wide	16 ft wide	50
Railings	60 ft × 2 = 120 ft	No guardrails	0

Preliminary investigations revealed that many government agencies have used guardrails that are below AASHTO standards on their low-volume bridges. The issue that needs to be resolved is whether or not guardrails are necessary on low-volume bridges; if so, the most economical systems should be designed. Legal aspects such as liability must be considered. Case histories should be studied to establish proper precedents.

A more detailed investigation of the cost of constructing jointless, rigid-frame bridges in remote locations is needed. The ratio of additional costs, such as tying the superstructure down to the substructure, to the realized savings, such as eliminating joints, bearings, and smaller stringers, needs to be defined.

The availability of accurate cost data is essential to evaluate various alternatives with a value engineering approach. This is being performed as a continuation of this study.

An expanded list of design scenarios should be developed with span lengths that range from 50 to 100 ft, abutment heights from 8 to 20 ft, and a soil bearing capacity from 1 to 5 ksf.

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The contents of this paper reflect the views of the authors based on their interpretation of the research data. The conclusions of this study should not be regarded as specifications or standards for the design of low-volume road bridges.