Rating Bridges on Low-Volume Roads

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The rating of an existing bridge on a low-volume road can be a very labor-intensive assignment. Because most bridges on low-volume roads are located in local jurisdictions, resources for computers and bridge inspections and repairs are limited. Therefore, to increase the productivity and improve the rating procedure, a software system has been developed to run on microcomputers. This system is made up of two programs, KU-SBAR and KU-STAR, written to rate simple and continuous span girder-type and simple truss bridges. Both programs follow AASHTO rating procedures. Five standard AASHTO trucks and one user-defined truck are supported. A wide range of output options is provided to the user. These include a rating summary, moments, shears and reactions, member stresses, and nodal deflections. The system was run on microcomputers with two different microprocessors. One was found to run approximately 2.5 times faster than the other. It was demonstrated that analyzing and rating existing bridges on low-volume roads is feasible with the aid of a microcomputer. Although the analysis and rating phase is only a portion of the entire rating process, the use of the bridge rating system described is one means of improving productivity and rating options for transportation officials and engineers.

The Code of Federal Regulations *(1)* requires each bridge in the United States to be inspected and rated every 2 years. In this paper a bridge is defined as a structure that carries moving traffic and has an opening measured along the center of the roadway of more than 20 ft between undercopings of abutments, spring lines of arches, or extreme ends of openings for multiple pipes. There are approximately 586,000 bridges in the United States; nearly 270,000 are on the Interstate or state road systems. The remaining 317,000, or 56 percent, are city, county, or township bridges *(2)*. The majority of these bridges are located on low-volume roads, although many of them do have heavy volumes of traffic.

In rural areas, these bridges may not be subjected to any higher loads than a large pickup loaded with hay or feed. However, during harvest time, very large trucks with heavy loads travel to the area. These bridges must be properly rated and signed. Because most bridges on low-volume roads are located in local jurisdictions, resources for computers and bridge repairs are limited. With the high-technology products on the market today, the price of microcomputers is within the budgets of most organizations. The computing power of these machines, which are compact enough to sit on the desk of the user, is often as high as the mainframes of a few years ago. These microcomputers are relatively easy to use. What is required for these computers to be useful to transportation officials and engineers responsible for inspecting and rating low-volume bridges is well-designed software. This need was the motive for the development of the bridge analysis and rating system described in this paper.

This system was developed to aid local transportation officials and consulting engineers in rating single- and continuous-span girder-type and simple-truss bridges. Other objectives were to eliminate the tedious calculations required to rate an existing bridge and to provide for better estimates of the allowable rating for these bridges.

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RATING PROCEDURES

Throughout the development of this system, the analysis and rating procedures given by AASHTO *(3, 4)* have been followed as closely as possible. AASHTO permits each highway bridge to be rated at two levels. The lower level, inventory rating, is the load level that can safely use an existing structure for an indefinite period of time. The higher level, operating rating, is defined as the absolute maximum permissible load level that can be safely carried by an existing bridge. Bridges posted at the operating rating are safe to carry trucks at that weight level, but the life of these bridges could be reduced because of fatigue considerations. To estimate the reduction in useful life when increasing the allowable load, the existing fatigue design criteria found in the "Standard Specifications for Highway Bridges" *(4)* can be modified. For bridges on low-volume roads, the volume of traffic is often so low that fatigue is not a serious consideration in the rating decision.

AASHTO provides two methods for rating an existing bridge: the working stress method, in which the stresses induced in the bridge members should not exceed the allowable stress for that member, and the load factor method, in which the rating of a bridge is based on a strength criterion; that is, that the sum of the appropriate loads multiplied by load factors shall not exceed the strength of the bridge member. Both methods have their advantages and disadvantages. They also provide slightly different rating values. The system described in this paper is based on the working stress method. However, it would not be difficult to expand the system to allow the user to select either method for rating an existing bridge.

The primary loads considered when rating an existing bridge on a low-volume road are dead, live, and impact loads. These loads cause stresses in each bridge member. For each load type, the loads in an individual member can be expressed in the following general formula:

$$SF = DL + W \times LL \times RE \times DF \times (1 + I) \qquad (1)$$

where

SF = structural function for bending moment, shear, reaction, and axial forces;

DL = structural function due to dead loads;
W = truck weight;
LL = structural function due to a unit-live-load truck;
RE = reduction factor for multilane bridges;
DF = distribution factor; and
I = impact factor.

The reduction factor, RE, accounts for the fact that every lane of a multilane bridge is not loaded with trucks of maximum weight. Therefore, AASHTO permits a reduction in member live loads for these multilane bridges. The reduction factor is equal to 1 for one- or two-lane bridges. A 10 percent reduction is permitted for three-lane bridges and a 25 percent reduction is permitted for bridges with four or more lanes, that is, $RE = 0.90$ and 0.75, respectively. Most bridges on low-volume roads are rated for one or two lanes of traffic.

To determine influence of a truck wheel on an individual member, AASHTO *(4)* developed a table of distribution factors. For girder bridges, the distribution factor is a function of the following bridge parameters: bridge girder material, deck material, number of traffic lanes, and girder spacing. AASHTO requires that different distribution factors be used for interior and exterior girders. For each condition, a formula is given to calculate the distribution factor. If the girder spacing is large, the distribution factor is calculated from simple statics.

In rating a bridge on a low-volume road, it is a matter of judgment whether the bridge should be rated for one or two lanes. For typical girder spacing, the distribution factor for bridges designed for one traffic lane is from 7 to 27 percent lower than the distribution factor for bridges designed for two or more lanes. Although these differences in distribution factors are small, they could have a significant impact on the resulting allowable truck rating weight.

AASHTO provides some guidance for determining if the bridge should be designed for one or two traffic lanes. For roadway widths less than 18 ft, the bridge will carry only one traffic lane. For roadway widths greater than 18 ft, the bridge should carry at least two traffic lanes. However, there is an exception that is applicable to low-volume roads. It states that when "conditions of traffic movement and volume would warrant it, fewer traffic lanes than specified by AASHTO may be considered" *(3)*. This exception allows the engineer to use some judgment with regard to the correct distribution factor. If the bridge is narrow and two trucks can pass, it is unlikely that they will be traveling at maximum legal speeds. Thus, the impact factor may be too high if a two-lane distribution factor is used. If the bridge is narrower than the roadway surface, one vehicle usually allows the other to cross the bridge before proceeding.

For truss bridges, the distribution factor is a function of centerline truss spacing, roadway width, and number of traffic lanes. A formula for this distribution factor can be found in the "Manual for Maintenance Inspection of Bridges" *(3)*. For both bridge types, the distribution factor defines the percentage of the wheel loads carried by an individual member or truss.

The last general parameter to be discussed is the impact factor. Because trucks move as they cross a bridge, a dynamic interaction between the truck and the bridge occurs. Because of this dynamic interaction, additional loads called "impact loads" are induced in bridge members. These impact loads are expressed as a percentage of the loads introduced by the truck weight. The primary bridge parameter needed to calculate the impact load is the bridge length. The impact factor is calculated from the AASHTO formula

$$I = \frac{50}{L + 125} \quad (I \leq 0.3) \tag{2}$$

where L is span length *(4)*.

The impact load does not need to be larger than 30 percent of the truck load. For all bridges, the impact factor is 0.30 if the bridge length is below 41.6 ft. Many low-volume bridges are shorter than 41.6 ft and, therefore, are rated with a 30 percent impact factor. When evaluating the negative moments over interior support of continuous bridges, the span length, L, is the average length of the two adjacent spans. Although not a part of the current system, the impact factor for timber bridges can be neglected.

SYSTEM CAPABILITY

The bridge rating system developed can evaluate two types of bridge structures. KU-SBAR, a program of the system, is designed to analyze and rate single and continuous, up to three-span, girder-type bridges. These bridges are typically found on low-volume roads. KU-SBAR can accommodate noncomposite steel girders, composite steel girders, and concrete T-beam bridges.

KU-STAR, the other program of the system, is designed to analyze and rate simple steel truss bridges. Although five-truss configurations are automatically supported, the program has the flexibility to support truss bridges with any generalized configuration.

Although these two programs support different types of bridges, they were developed with many common features. Both programs were written in BASIC. Although computer graphics was not a major factor in the development of this system, graphic displays are used to improve user understanding and efficiency.

One common feature of the programs is the way loads are handled. Because impact loads are developed from live loads, only dead and live loads must be determined to rate most low-volume bridges. Dead loads are those loads associated with the dead weight of the bridge and include the dead weight of the main structural members, floor beams, stringers, deck, guard rails, and overlays. If there is dirt or gravel on the bridge deck, an allowance for the dead weight of this material should be included.

Live loads are those loads associated with bridge use. These loads consist of one or possibly several trucks placed in each bridge lane. The second condition is called a lane load. In general, the single-truck condition is critical for shorter bridges and the lane load condition is critical for longer bridges.

Five standard AASHTO-defined truck configurations can be used to rate a bridge system. They are H, HS, 3, 3S2, and 3-3. Trucks H and HS are the primary trucks used in the design of new bridges. The distribution of the axle weights and spacing are important parameters that affect bridge member loads.

These parameters are shown in Figure 1 for the five standard AASHTO trucks.

In the HS truck, the distance between the second and third axles is permitted to vary. The location of the third axle used to rate an existing bridge is the position between the extreme values that causes the maximum structural function to occur. In KU-SBAR, this third axle is placed within the extreme values in 2-ft increments. In KU-STAR, this load is placed at every node along the roadway within its allowable spacing.

For H and HS trucks, lane loads must also be considered. These lane loads are approximated by a uniform load and a concentrated load. Both types of loads are placed on the bridge so that the extreme values of the structural function (plus and minus) occur.

For negative moments over an interior support of a continuous bridge, AASHTO *(4)* requires that a second concentrated load be placed on an adjacent span so that maximum negative bending moment occurs over the support. The magnitude of the concentrated loads are lower for moment calculations than for shear and reaction calculations.

To determine the maximum structural functions, each truck is moved across the bridge in steps. For girder-type bridges, the front axle is placed at 10 intermediate stations along each span. In addition, the truck is placed so that the front axle is off the bridge with only the back axles located on the bridge. This truck placement, which is important for short bridges on low-volume roads, is especially important if the weight on the back axles is large. For simple-truss bridges, the truck is placed so each axle is at every node along the roadway.

When the truck has moved across the bridge facing one direction, both programs automatically turn the truck around and move it in the opposite direction. For each member or

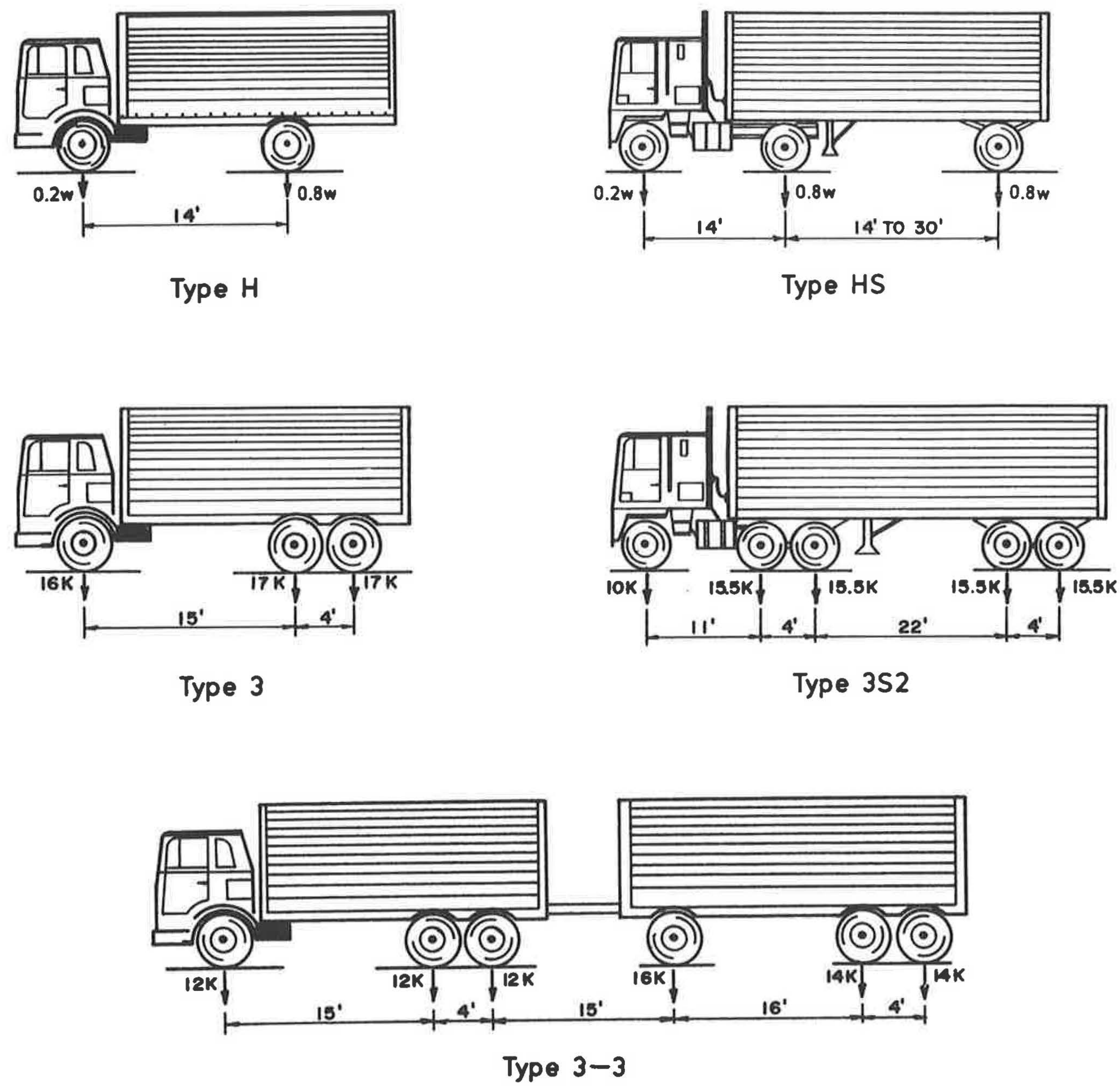

FIGURE 1 Standard AASHTO trucks.

station, the maximum and minimum structural functions are identified. These extreme member loads are important when the rating procedure is conducted.

The next important features to be discussed are the properties of the bridge materials. Because the two bridge types handled by this bridge rating system are so different, each program is described separately. For specific information about the programs, the user is referred to the corresponding users' manuals *(5, 6)*.

KU-SBAR

Analysis and rating of simple and continuous girder bridges of up to three spans are carried out by KU-SBAR, which currently supports noncomposite steel girders, composite girders, and concrete T-beams. A typical cross section of each bridge type is shown in Figure 2. Because the cross-sectional properties may vary along a span, the program was written to accommodate prismatic and nonprismatic girder members.

If the member is prismatic, the member properties are requested only once for each span. If the member properties in a span vary, the user has several options for entering cross-sectional properties. First, the user may individually define the member properties at 10 different locations along the span. If the member has a prismatic section, KU-SBAR requires the input of member properties for that prismatic section only once. The program automatically generates the section properties for the other stations in the prismatic region. This approach significantly reduces the amount of work required by the user, and it provides flexibility for treating changes in cross section when determining bridge properties and internal loads.

The section modulus and moment of inertia of the steel girder are the only section property data required for the noncomposite steel girders. For composite steel girders, more data are required to describe the properties of the cross section. The moment of inertia, depth, and area of the steel girder alone are required. Haunch depth, deck thickness, and the area of the top and bottom coverplates, if present, are also requested from the user. If the section has coverplates, KU-SBAR will request the coverplate thickness. To calculate the modular ratio for the concrete deck, the ultimate strength, f_c' is also requested. From this information, the program automatically looks up the modular ratio given in the AASHTO manual *(4)*.

When evaluating a composite steel girder, the effects of creep must be considered for calculating the stresses due to that portion of dead loads that acts on the composite cross section. This is accommodated by calculating the moment of inertia and section moduli for two modular ratios, n and $3n$.

To calculate the moment of inertia of the composite sections, the effective width of the concrete deck is automatically determined using the AASHTO criteria *(4)*. When using these section moduli to calculate stresses, the procedure is to use the one that predicts the larger composite dead load stress. The section moduli are calculated for the steel girder alone. They are also calculated for the composite sections at the concrete, and top and bottom of the steel girder. The composite section properties are calculated for both modular ratios.

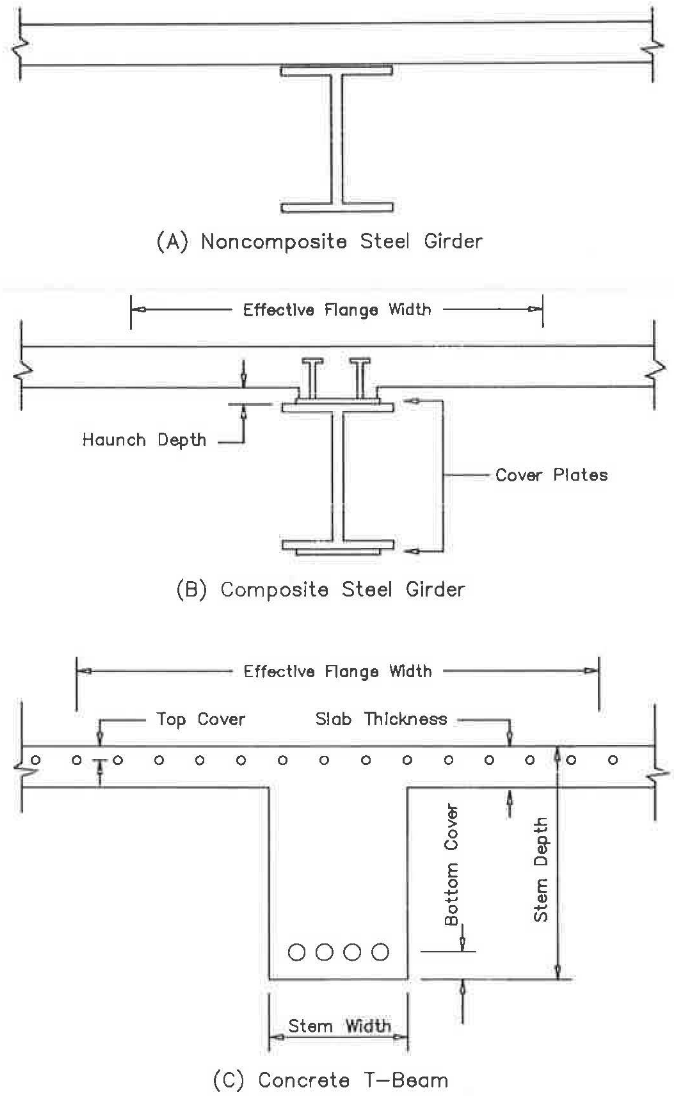

FIGURE 2 Cross sections for KU-SBAR bridges.

The data required for concrete T-beams include deck thickness, stem width, stem depth, area of bottom and top reinforcement, and reinforcement cover. With these data, the moment of inertia of the bridge can be calculated for each station.

After all data have been entered for nonprismatic spans, KU-SBAR automatically generates inertial properties at intermediate stations located midway between the 10 stations. These properties are used to calculate the flexibility coefficients described in the analysis section of the paper.

KU-STAR

KU-STAR supports the following standard bridge trusses: Pratt, Warren, Parker, deck Warren, and K-truss (Figure 3). Once the user responds to the prompts for number of panels, panel width, and panel height for these standard trusses, KU-STAR automatically generates all joint coordinate and member incidences. This feature eliminates the tedium of setting up the structural definition of the truss to be rated.

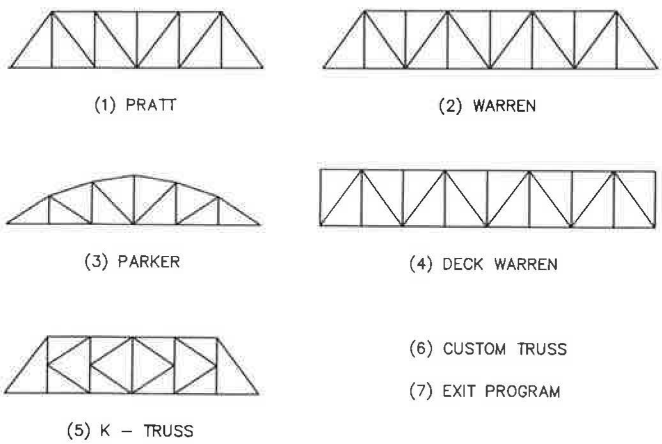

FIGURE 3 Standard KU-STAR-supported trusses.

KU-STAR also supports the nonstandard bridge truss, for which the program prompts the user for joint coordinates and member incidences for each node and member.

Each member of the truss has cross-sectional properties and allowable stresses. The original area of the member is required. To account for the deterioration of each member, a reduction in percent of original area is requested. For the rating section of the program, the allowable inventory stress in tension and compression is also required. The allowable operating stresses are automatically calculated from the inventory stresses.

To minimize user effort, only one set of member property data for each member type is required. The supported member types are top and bottom chords, verticals, and diagonals. If the members do not have similar properties, the same data are prompted for each member.

In addition, a sophisticated editing procedure is also supported by KU-STAR. This feature permits general data to be entered for each member type and then edited for those members that require modification.

METHODS OF ANALYSIS

Because the bridge types to be rated are significantly different, the system has two analysis methods. The more efficient method may be selected for each bridge type. This procedure minimizes the amount of computer time required to rate a bridge.

For truss bridges, the stiffness method was selected for analysis. Because of the wide range of configurations found in truss bridges, no generalized truss system can be defined in advance. Once the geometry and member properties are defined, the stiffness matrix can be easily generated. To improve the numerical efficiency of the solution process, symmetry of the stiffness matrix is considered. The memory requirements are minimized by storing the stiffness matrix as a banded matrix. Influence line coefficients are calculated for each member as a unit load goes to each node along the roadway. This analysis procedure can be found in most textbooks on matrix procedures of structural analysis *(7, 8)*.

For the continuous-span bridges, the flexibility method was selected for two reasons. First, the nonprismatic member capability of the program can be easily incorporated. It is easier and more efficient to calculate flexibility coefficients than stiffness coefficients for these members. They are calculated by breaking each span into 20 segments. Second, the number of unknowns for these bridge girders is always less than the number of unknowns for the stiffness method. For a three-span bridge, the number of redundants is only two.

Once these internal support moments are calculated, only simple equations of statics are required to determine influence line coefficients for the structural functions at 10 locations along the beam.

Influence line coefficients were calculated for a unit load at each node. The structural functions were calculated for each member or at 10th points along each span. For the girder bridges, an axle load placed between two adjacent nodes was distributed between the two nodes on a percentage basis.

After the influence line coefficients are calculated and the rating truck is defined, each program goes into a subroutine to march the truck across the bridge in both directions. While these trucks are moving across the bridge, the maximum and minimum values for the appropriate structural functions are retained. Lane loads are also evaluated for H and HS trucks.

OUTPUT

The output is similar, for the two programs. When possible, the output format is compatible between the two programs. Each program provides the user with two different output options. If the user wants to display the data on the computer monitor, then no action is required. If a hard copy is desired, the user selects the print menu. which directs all output to the printer. The print menu and display menu are identical and have the following configuration for the two programs.

The output menu for KU-SBAR is

DISPLAY MENU

BRIDGE GEOMETRY SUMMARY
RATING SUMMARY
MOMENTS, SHEARS, & REACTIONS
MEMBER STRESSES
RETURN TO TRUCK SELECTION MENU
NEW BRIDGE

The output menu for KU-STAR is

DISPLAY MENU

TRUSS DATA SUMMARY
RATING SUMMARY
MEMBER STRESSES
NODAL DEFLECTIONS
RETURN TO TRUCK SELECTION MENU
NEW BRIDGE

The bridge geometry summary and truss data summary provide the user with a record of the input data. These options are useful for verifying input data and for making permanent records.

The rating summary option provides the user with the allowable inventory and operating rating for the truck configuration chosen. Based on the allowable inventory stress previously defined, the programs determine the allowable weight of the current configuration truck. For example, the Type 3-3 truck weighs 40 tons. If the dead load and the Type 3-3 truck induce stresses in the bridge that exceed the allowable inventory stress in any member, the weight of the truck is reduced until the total stresses just reach the allowable inventory stress. Although the allowable inventory truck may weigh 20 tons, the distribution of the 20-ton Type 3-3 truck is identical to the 40-ton Type 3-3 truck, except the axle loads are one-half the values given in Figure 2. For the concrete T-beam and composite steel girder bridges, the stresses in the steel and concrete are checked.

In addition to the inventory rating, the operating rating is also calculated. Although the operating stresses may be only 25 to 40 percent higher than the inventory stresses, the ratio of operating to inventory rating may be significantly higher. This phenomenon was observed because the dead load stresses are constant for the two rating procedures.

Because of the differences in the type of members and stresses in the bridge configurations, the member stresses are displayed or printed differently. Both programs request the user to specify the weight of the current truck. This approach provides the user greater flexibility to use the data for other applications.

KU-SBAR has similar stress formats for each of the three girder material types. The stresses are calculated at 10 locations along each span. The simplest format is for the noncomposite steel girders. Stresses caused by dead loads, truck loads, and lane loads are displayed. In addition, the maximum total stresses are displayed for the extremes of the moment envelope.

For composite steel girders, bending stresses are presented for the concrete for compression only, and at the top and bottom of the steel beam. Stresses are calculated for dead loads that act on the steel beam alone and on the composite section and for truck and lane loads. For dead load stresses acting on the composite cross section, the smallest section modulus at each location is used in the stress calculations. In addition, the maximum total stresses are calculated at each location for the moment envelope values.

For concrete T-beams, the bending stresses are presented for the reinforcement and concrete. They are calculated for dead, truck, and lane loads. Again, maximum and minimum total bending stresses are also presented.

In truss bridges, KU-STAR has a different format for output of axial stresses. As for KU-SBAR, the axial stresses are calculated from dead, truck, and lane loads. The total stresses are also presented based on the member load envelopes. For fatigue calculations, stress reversals for each member are calculated. Although fatigue is not an important rating criterion for low-volume roads, these values are useful when the effects of fatigue must be considered.

An output format similar to the member stress section was used for the moments, shears, and reactions option in KU-SBAR. The bending moments for dead, truck, and lane loads are presented for 10 stations along each span. The total moments required to draw a moment envelope are also presented. To improve the usability of this section, the user is requested to specify the weight of the truck before calculating the live-load structural functions.

The maximum positive and negative shears are presented for each end of all spans. In addition, the maximum reactions are also presented for all loading conditions.

EXAMPLES

The following examples are presented to illustrate the capability of the bridge rating system.

Example 1

A three-span concrete T-beam bridge (40 ft, 50 ft, 40 ft) with five concrete T-beams spaced at 7 ft 0 in. is to be rated for two lanes of traffic. An overhang of 1 ft 0 in. is found on both sides of the bridge. The width of the stem is 26 in. and it has a uniform depth of 50 in. The deck thickness is 7.5 in. The deck and T-beams are made from concrete with an ultimate strength of 4,000 psi, resulting in an inventory stress of 1,600 psi and an operating stress of 2,240 psi for the concrete. The inventory and operating stresses for the steel reinforcement are 20 and 28 ksi, respectively. To make the example as simple as possible, the steel reinforcement is assumed to have a constant area over the bridge length. The bottom steel area consists of eight no. 10 bars for a total area of 10.12 $in.^2$. The top steel consists of eleven no. 9 bars for a total area of 11 $in.^2$ The cover for the top and bottom reinforcement is 2 in. Determine the allowable ratings for all five standard AASHTO truck configurations based on an interior girder.

An estimate of the dead load for this bridge was 3.0 kip per linear foot. This load was placed on each span. From KU-SBAR, the following inventory ratings were calculated for this bridge from the rating summary option: H16.2; HS16.2; Type 3, 31.2 tons; Type 3S2, 27.2 tons; and Type 3-3, 36.0 tons. The operating ratings for the five trucks were H42.2; HS42.2; Type 3, 81.0 tons; Type 3S2, 70.9 tons; and Type 3-3, 93.8 tons.

The behavior of this bridge under a variety of trucks can be understood from the output available from KU-SBAR. Because the concrete T-beams were underreinforced, the stresses in the steel reinforcement were critical for all loading conditions. In particular, the critical section for each truck was over the interior support. If the bridge has different span lengths, the location of this critical section may change.

Moment envelopes and bending stresses for concrete and steel reinforcement were available for each truck. Although the allowable operating stress for the steel reinforcement is only 40 percent higher than the allowable inventory stress, the operating rating for each truck is 2.6 times higher than the inventory rating. This discrepancy occurs because the dead-load moment over the interior support is approximately 57 percent of the total moment capacity of the cross section. This ratio of operating rating to inventory rating for an existing bridge is always higher for bridges with relatively high dead-load moments.

Although the rating for the H and HS trucks is identical, the total weight of an HS16.2 truck is approximately 29 tons. These ratings were identical because the lane load condition was the most severe loading condition for this bridge. In general, this condition does not occur.

Other interesting observations can be made from the rating summaries. The inventory and operating ratings increase as the length of the truck increases. The shortest trucks were the H and Type 3 trucks and the longest were the HS, Type 3S2, and Type 3-3. For many-simple span bridges, the Type 3 truck is critical. However, for this continuous bridge, the critical section was over the interior support. In addition, the back two wheels are heavily loaded and only 4 ft apart. Thus, the negative moment over the interior support is not as severe for this truck configuration as it is for some of the other truck configurations. This Type 3 truck configuration does cause a more severe positive moment condition at the midpoint of the longer center span.

After a review of the output, a better feel for the behavior of the bridge can be determined. For all bridges, the engineer must use good judgment to determine the allowable truck loads. Federal regulations require the bridge to be posted if the bridge operating rating is below the legal load limit for that jurisdiction *(1)*. During field inspections particular attention should be given to those stations where maximum stresses occur. If severe deterioration is found at these locations, a reduced truck load may be appropriate. A discussion of the times required to run these five cases is presented later.

Example 2

A four-panel Warren truss was selected for the second example. Each panel is 10 ft wide and 20 ft high. A sketch of the truss, with member numbers, is presented in Figure 4. Because the Warren truss is supported by KU-STAR, all joint coordinates and member incidences were automatically generated. The overall length of the bridge is 60 ft. Member properties, degree of deterioration, and allowable inventory stresses in tension and compression are given in Table 1. The width of the roadway is 20 ft, and the centerline distance between the two trusses is 22 ft. The weight of the deck, floor beams, stringers, and so forth, is 1 kip per linear foot. The dead weight of the truss, including a 10 percent allowance for connection weight, is automatically calculated by KU-STAR.

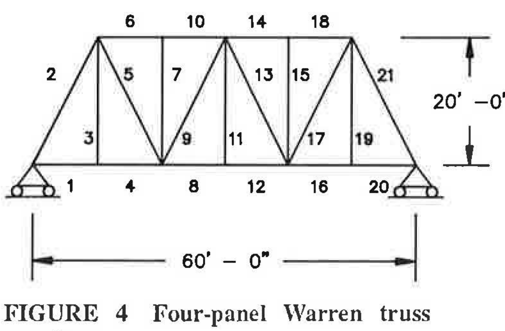

FIGURE 4 Four-panel Warren truss members.

The inventory ratings for the five standard-AASHTO defined trucks are H27.3; HS23.5; Type 3 38.5 tons; Type 3S2, 52.9 tons; and Type 3-3, 66.2 tons. The corresponding operating ratings for this bridge are H41.7; HS36.0; Type 3, 58.8 tons; Type 3S2, 80.9 tons and Type 3-3, 101.3 tons. The most critical members of the truss are Members 8 and 12. Because these members are tension members, they should receive extra attention during the field inspection. This is especially true if the members are not redundant. The connection between these two members also warrants additional attention during the field inspection.

TABLE 1 MEMBER PROPERTIES AND ALLOWABLE STRESSES FOR WARREN TRUSS

Truss Member Group	Original Area (in.^{2})	Area Reduction (%)	Allowable Inventory Stress: Tension (ksi)	Allowable Inventory Stress: Compression (ksi)
Top chord	12	0	18	14
Bottom chord	5	5	18	3
Diagonal	10	2	18	12
Vertical	6	5	18	3

For truss bridges on low-volume roads, fatigue of the bridge members is not usually a significant consideration. However, if heavy-truck traffic is critical, then the stress reversals from KU-STAR are useful for evaluating the fatigue characteristics of each member.

If desired, maximum nodal deflections are available. Dead-and-live load deflections can be obtained.

COMPUTER EFFICIENCY

As previously stated, the method of analysis varied between the two bridge types supported by the bridge rating system. Both examples were run on HP Vectra and Zenith 158 microcomputers operating at an 8-MHz clock speed. The HP Vectra had a 80286 processor, and the Zenith a 8088 processor. Both machines operated under MS-DOS version 3.10. The two programs were run in interpretive mode. The total run time for the five trucks on the three-span bridge (Example 1) was approximately 19 min with the HP Vectra. The fastest run time, 2:27 min, was for the H truck. The longest run time was 5:41 min for the Type 3-3 truck. When the number of numerical calculations required is considered, the improved efficiency of engineers and transportation officials due to the microcomputers is significant. In addition, a better idea of the behavior of this bridge is obtained.

For the simple-span, four-panel Warren truss bridge, the total run time for the five truck configurations was approximately 13 min on the HP Vectra. Again, the shortest run time of 0:41 min was found for the H truck. The longest run time was for the HS truck. Because the location of the third axle is permitted to vary, additional time was required. For the Type 3-3 truck, the run time was only 2:10 min.

The run time for the 8088-based Zenith 158 microcomputer was approximately 2.5 times longer than for the 80286-based HP Vectra microcomputer. Although slight variations in run times have been observed for different microcomputer manufacturers, the biggest factor is the type of processor. The 80286 processor is even faster than the 8088 processor. The use of the microcomputers will improve the efficiency and productivity of the engineers responsible for rating bridge structures.

CONCLUSIONS

The productivity and capability of transportation officials and engineers responsible for rating the 586,000 bridges in this country may increase with the development of the bridge rating system described in this paper. This system was designed to assist in the rating and evaluation of girder and truss bridges. The system, written in BASIC, was developed to operate on microcomputers. Computer graphics were used on a limited basis to improve user understanding of input data.

The system prompts the user for all information required to define the bridge. The manner of inputting data was chosen to minimize user effort. When appropriate, the user is given the opportunity to edit the data after they are entered.

Noncomposite and composite steel girders and concrete T-beams are supported for simple and continuous girder bridges. Simple-truss bridges are also supported. Both programs support the five standard AASHTO trucks and one user-defined truck. A wide range of output options is provided for the user. This output can be displayed on the monitor or printed on a printer for a permanent record.

An efficient software package has been developed for microcomputers. With the capabilities provided in this system, transportation officials and engineers are no longer required to simplify actual conditions to fit the conditions available for tables found in the literature. With this system, better estimates of bridge ratings are obtainable, especially for low-volume roads, where these bridges are loaded at their maximum weights only a few times per year. In addition, a better environment and credibility should result when a bridge must be posted.

The 80286-processor-based microcomputers were approximately 2.5 times faster than the 8088-processor-based microcomputers. For the three-span bridge, the five standard trucks took approximately 19 min on the 80286-based microcom puter. For the four-panel Warren truss bridge, the run time for the five standard trucks was approximately 13 min.

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REFERENCES

1. *Code of Federal Regulations.* Title 23—Highways, Part 650.300, Subpart C.
2. Better Roads 1985 Bridge Inventory. *Better Roads,* Vol. 55, No. 11, Nov. 1985, p. 23.
3. *Manual for Maintenance Inspection of Bridges.* American Association of State Highway and Transportation Officials, Washington, D.C., 1983.
4. *Standard Specifications for Highway Bridges.* 13th ed. American Association of State Highway and Transportation Officials, Washington, D.C., 1983.
5. K. V. Boldt and C. E. Kurt. *Kansas University—Simplified Truss Analysis and Rating—User's Manual.* Department of Civil Engineering, University of Kansas, Lawrence, 1985.
6. C. E. Kurt. *Kansas University—Simplified Bridge Analysis and Rating—User's Manual.* Department of Civil Engineering, University of Kansas, Lawrence, 1986.
7. R. B. Cook. *Concepts and Applications of Finite Element Analysis.* 2nd ed., John Wiley and Sons, New York, 1981.
8. C. K. Wang. *Intermediate Structural Analysis.* McGraw-Hill, New York, 1983.

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