SMART BRIDGE: A Tool for Estimating the Military Load Classification of Bridges

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ABSTRACT
A major consideration in planning and executing military deployments is determining the routes available for moving troops and equipment. Part of this planning means ensuring that all of the bridges along the routes are able to support the specialized equipment needed. Because few trained and experienced bridge analysts are available, an automated tool is required to assist military engineers and planners in quickly and accurately determining the capacity or Military Load Classification of bridges. This tool must be flexible enough to handle various types of bridges, run on multiple platforms (Sun Unix and PC Windows), be usable by engineers with various levels of experience, and be able to utilize various analysis methods depending on the amount of information available.

Keywords
Bridges, military, transportation

INTRODUCTION
Military deployments require extensive planning and preparation. A major consideration in planning the ground portion of a deployment is determining the routes available for moving troops and equipment. Part of this planning means ensuring that all of the bridges along a route are capable of supporting the specialized military vehicles that must be transported. An automated tool is required so that military engineers and planners can quickly and accurately determine the Military Load Classification (MLC) of each bridge along a route. The MLC is a specialized measure of the carrying capacity of a bridge. A detailed evaluation requires extensive measurements and knowledge of the components of the bridge. Because the measurements and other attributes of a bridge are often unavailable, other less precise methods of classifying bridges have been developed. SMART BRIDGE captures and automates this range of methods in a single system.

SMART BRIDGE is designed to be used in a variety of roles within the military. First, engineers and reconnaissance personnel in the field can accurately enter information necessary to accurately analyze bridges.

Second, SMART BRIDGE can capture all the bridge characteristics and the analysis results in a database that can be used by planners in evaluating alternate deployment routes.

Third, military planners can use SMART BRIDGE to estimate the MLC of bridges when detailed, hands-on measurements of the bridges are not available. The system can estimate, with a lower level of confidence, the MLC of a bridge based on a few characteristics that might be available from other sources such as remote imagery and general knowledge of the region in which the bridge is located.

Finally, SMART BRIDGE is an ideal training tool for assisting new military engineers in learning and applying classification techniques and expertise.

The remainder of this paper is organized into several sections. The following section gives a short overview of the bridge and vehicle classification system used by the military. A overview of how SMART BRIDGE accepts, stores, and analyzes detailed bridge information is described in the next section. Finally, the last section summarizes the SMART BRIDGE efforts.

BRIDGE AND VEHICLE CLASSIFICATION
The U.S. military uses the bridge and vehicle classification system established by the nations of the North Atlantic Treaty Organization through international agreement. Within this system, vehicles are assigned MLC numbers that represent the size of the vehicle and the loading effects that it has on a bridge. The MLC of a vehicle depends on a combination of factors, including gross weight, number of axles, axle spacing, axle width, and weight distribution to the axles. Similarly, bridges are assigned MLC numbers that represent the largest vehicle classification that the bridge can safely support as part of an occasional convoy with the vehicles spaced 100 feet apart and traveling at a maximum speed of 25 miles per hour. The MLC of a bridge is the MLC of its weakest span and depends on such factors as the length of the span, the type of construction, the quantity and size of the structural members, the strength of the materials used, and the width of the roadway. In preparing for ground movements of troops and equipment, military planners must compare the MLCs of vehicles to be moved with the MLCs of bridges along potential transportation routes.

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The U.S. Army has developed a set of analytical procedures to assign MLC values to existing bridges [1]. The values may differ for wheeled versus tracked vehicles and for one-lane versus two-lane operation. Up to four MLC values can be assigned to a single bridge. In these analytical procedures, it is assumed that the bridge superstructure is the controlling or limiting feature in bridge classification. The substructure, which includes footings, abutments, piers, piles, posts, and other supports, is usually overdesigned to compensate for uncertainties in the underlying soil properties. The details for the analytical procedures depend on the type of construction used for the bridge (e.g., timber, steel, reinforced-concrete, or prestressed-concrete stringers; steel girders or trusses; steel, concrete, or masonry arches; or suspension systems). However, generally one or more of the following factors are examined, and the most restrictive one limits the MLC values assigned to the bridge:

- Bending stresses induced in structural members that exceed the allowable limits,

- Vertical deflections of structural members that may disrupt the bridge,

- Potential for the lateral buckling of structural members,

- Shear stresses induced in structural members that exceed the allowable limits,

- Bearing stresses induced in structural members or supporting members that exceed the allowable limits,

- Discrete loads that exceed the strength of the deck, and

- Required lane widths that exceed the roadway width over the bridge.

DATA ENTRY AND DETAILED ANALYSIS

To classify bridges accurately, military engineers must know what bridge attributes are important; how the attributes relate and interact with each other; how to measure or otherwise determine the bridge's attributes; how to calculate dead loads, bending stresses, and shear stresses; and, finally, how to assign MLC values on the basis of the calculations. SMART BRIDGE captures much of this expertise in a series of attribute input screens, automated attribute links, on-line help documents and diagrams, database tables, computational routines, and report generation facilities.

Entering Data for a Bridge

A bridge may consist of one or more spans. The spans that make up a bridge may be either of the same type or of a variety of types. Detailed information about each individual span is needed to assign MLC values to the span, and general information about the bridge as a whole is needed for transportation planning. The specific, detailed information needed about a span depends on the type of construction and includes the number and dimensions of the structural components, the strengths of the materials, and the weights of the components. The general information needed includes the location and name of the bridge, the highway or road carried by the bridge, the condition and nature of the approaches to the bridge, the feature crossed by the bridge, and the availability of nearby bypass routes.

When a SMART BRIDGE user wants to add a record for a new bridge to the database, a Create Bridge window is displayed (Figure 1). The user then enters basic information about the new bridge and its spans. Before the system actually creates the appropriate bridge and span entries in the database tables, certain consistency checks are performed on the entries. For example, a Bridge ID, a Creator, and a valid Country Code must be present and form a unique database record key. Also, span lengths must be greater than zero, and spans can only have a continuous boundary condition

Figure 1: Create Bridge Window

with adjacent spans of the same span type. As the basic bridge and span records are created, the system incorporates default values for those data fields where defaults are appropriate. If the information is available, the default values can depend on the particular country in which the bridge is located. This feature is particularly true of data fields that correspond to the strength of construction materials. Otherwise, general default values are provided.

Six different types of tables are used in the SMART BRIDGE database to store the detailed information about a bridge and its spans. The first five tables are the same for any bridge or span. However, the specific contents of the sixth type of table depend on the span construction type. The table types and their general contents are:

- BRMASTER - data items about a bridge that allow quick retrieval of the records for a specific bridge or set of bridges;
- BRCOMMON - data items that provide additional general information about the bridge;
- IMMASTER - file names of images (digitized photographs or sketches), if any, associated with a bridge;
- SPMASTER - data items that summarize a span, such as construction type, length, and MLC values;
- SPCOMMON - data items common to spans of all construction types such as deck and wearing surface type, width, and thickness and roadway width; and
- SPAN_SPECIFIC_TABLES - data items specific to spans of a particular construction type, such as the number and dimensions of structural components, the strength of materials, and the weights of components.

The user is guided through the data input process by a series of input screens, and the data are eventually stored in the database tables. When entering data about individual spans, the user is presented with input screens tailored to the type of construction assigned to the span from a predefined list. The list is based on the span construction types described in the U.S. Army's field manual on bridges [1]. About half of the types have been implemented (timber-stringer spans, two types of steel-stringer spans, four types of reinforced-concrete spans, and prestressed-concrete spans).

Once the logical bridge record is created, the user is presented with a series of bridge information windows for entering general information about the bridge as a whole. After this information has been entered, the user can enter detailed information about the individual spans. Upon specifying a particular span, the user can choose to be presented with a series of either span data forms or generic span diagrams. Either approach allows the user to enter values for all the detailed data items needed to fully describe the span. The user may select whichever approach is more convenient under the particular circumstances or, if preferred, a combination of the two approaches. A typical span data form is shown in Figure 2.

Figure 3 shows a typical generic span diagram. The components of the span are labeled, and individual parameters are designated by symbols inside of boxes either in the diagram or next to the diagram. Selecting a parameter brings up the Edit Item window (explained in the next paragraph) for that parameter. The color and thickness of the boxes are coded to indicate the source of the present value of the parameter and whether the parameter will be

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┌─────────────────────────────────────────────────────────────┐
│ [▼]          Smart Bridge(2.4): Steel Stringer: Span Data Form 1 │
│ ( Done )  ( Help )  ( More Data )                            │
│ Bridge ID: East Gate Span No.: 2                             │
│ ◡                           Span Length (L) *  93.5000   [▼] ft │
│ ◡ Boundary Condition (West): continuous                      │
│ ◡ Boundary Condition (East): continuous                      │
│ ◡     Dead-Load Continuity Coefficient (CDL) *  0.6000       │
│ ◡     Live-Load Continuity Coefficient (CLL) *  0.7000       │
│ ◡            Number of Stringers (Ns) *  4                    │
│ ◡            Stringer Spacing (Ss) *  8.2500   [▼] ft         │
│ ◡         Lateral Brace Spacing (Sb) *  13.4000   [▼] ft     │
│ ◡      Curb-to-Curb Roadway Width (bR) *  24.0000   [▼] ft   │
│ ◡ Type of Deck (Tdeck) *                  [▼] concrete       │
│ ◡         Thickness of the Deck (td) *  7.7500   [▼] in       │
│ ◡       Percentage of Lamination (flam) *  100.0000          │
└─────────────────────────────────────────────────────────────┘
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Figure 2: Span Data Form Window

used directly in the detailed analysis of the span. For example, a red box indicates that the parameter remains at its default value, a green box indicates that the user has specified a value for the parameter, and a blue box indicates that the system has automatically calculated a value for the parameter based on the values of other parameters.

Throughout SMART BRIDGE, each window has a Help button, which displays a textual description of the window, its contents, and its purpose. In addition, each data entry field in a window has a small button to its left that brings up an Edit Item window, as shown in Figure 4. This window provides a definition of the data item and a means of entering a value. Depending on the data item, the window may also explain how the item is to be measured or gathered, discuss typical or default values, and provide access to figures or diagrams that may help the user determine the value of the parameter. Data items that represent dimensional parameters have a choice of possible units associated with them, which gives the user the flexibility to use the most appropriate or convenient measurement system.

One or more buttons giving additional graphical descriptions may also be available for a data item. For example, when the user selects the button labeled Example Bottom View at the bottom of the window (Figure 4), a window like Figure 5 is displayed. Such windows show the user where specific measurements would be taken for specific example bridges or could display illustrations from the reference U.S. Army's field manual on bridges [1].

During data entry, the system makes and updates estimates of certain other parameter values based on the current values of parameters. For example, the calculation of the dead-load weight of the span superstructure is updated when the number and dimensions of the various components and typical material densities are loaded or modified. This update process ensures that each data entry item is internally consistent with other items. At any time, if the user can access more accurate values for any of these estimated parameters, the estimated values can be replaced.

Performing the Analysis
Once the data concerning a bridge and its spans have been entered, the user can elect to analyze each span. Once the user selects the analysis option, SMART BRIDGE examines the data associated with the specified span to determine the span construction type and thus the appropriate detailed analytical procedure to use. Presently, analytical procedures for eight span construction types are implemented in SMART BRIDGE. The system has been designed so that additional procedures for other span types can be easily added. Next, a check is made to determine that values exist for all the attributes or parameters used by the selected analytical procedure. The parameter values can be (1) established by the system as default values, (2) entered directly by the user, or (3) calculated by the system from other parameter values.
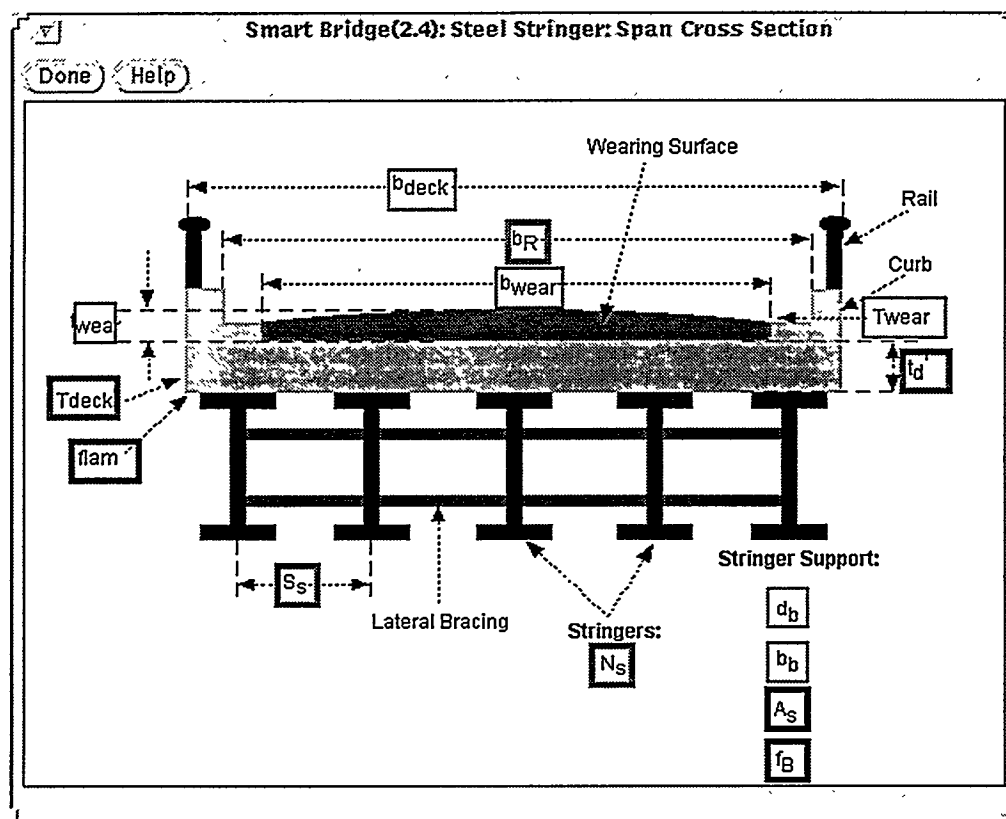

Figure 3: Span Cross Section Window

If values are not available for all the parameters required for a detailed analysis, the user is alerted to the missing values. The user can then opt to return to the data entry process described in the previous subsection or estimate temporary MLC values by using a less precise classification analysis that correlates military loadings with civilian loadings.

Once it has been determined that values exist for all the parameters used by either the analytical or the correlational procedure, calculations are made to establish MLC values on the basis of one or more of the potential limiting factors discussed earlier. The specific calculations carried out and the particular limiting factors considered depend on the span construction type and the analytical procedure being used. Upon completion of the span analysis, the MLC values for the span are presented to the user in a pop-up window, along with a brief notation as to what factor, if any, was the limiting factor. In situations where the MLC values are lower than expected, knowledge of the source of the limitation may direct the user to parameters that are in error or need to be evaluated more carefully. At the direction of the user, these MLC values and all the parameter values that describe the span just analyzed can be saved in the span database tables described in the previous subsection. In addition, the user can have the system generate printed reports that summarize the analysis and its results. These reports can include complete background information explaining the entire analysis procedure, or they can include just the data input values used, the calculations performed,

and the final results. With either option, all of the data items reported are tagged with source information, such as User, Default, Estimated, Calculated, Inferred, or the name of a table from which the item was selected. This information allows the user to assess the accuracy of the analysis.

After all the spans that make up a bridge have been analyzed, the user can direct the system to assign MLC values to the bridge as a whole by selecting the smallest values from among all the spans that make up the bridge. Again at the direction of the user, these bridge MLC values can be saved in the bridge database tables. In addition, the user can have the system generate a report that describes the bridge and summarizes the characteristics of each span.

SUMMARY AND CONCLUSIONS

SMART BRIDGE is a usable initial step in the process of developing a tool to assist (1) military engineers in classifying existing bridges in terms of their military capacity and (2) military transportation planners in identifying potential limitations to ground transportation routes because of bridges. The system captures the knowledge of what attributes of a bridge are important for classification and transportation planning. Input screens, on-line help documents and diagrams, and automated links among parameters help the user acquire the needed information about a bridge and establish reasonable values for parameters required for classification that cannot be directly measured. In addition, the system establishes a

Figure 4: Edit Item Window

database framework for collecting, storing, assembling, and retrieving detailed bridge information and analysis results.

The detailed analytical procedures for classifying about half of the bridge construction types considered in the U.S. Army's field manual [1] on bridges have been incorporated into SMART BRIDGE, along with all supporting tabular data and ancillary calculations needed to apply them. These bridge types represent most of the common bridges that would be encountered by engineers in most deployment analyses. Automation of the process eliminates the tedium involved in applying the procedures, provides the user with printed documentation of the calculations made, and reduces the likelihood of arithmetic and other human errors.

The inclusion of classification by correlational procedures for bridges designed or rated according to the civilian standards of certain countries allows users to obtain reasonable estimates of capacities for all bridges (of any type) on the basis of very little detailed information. Built-in rules for inferring design standards of a bridge from the characteristics of the roadway carried by the bridge allow transportation planners to estimate capacities for preliminary planning.

ACKNOWLEDGMENT

REFERENCE
1. *Military Nonstandard Fixed Bridging*, FM 4-446, Headquarters, Department of the Army, Washington, DC, June 3, 1991.

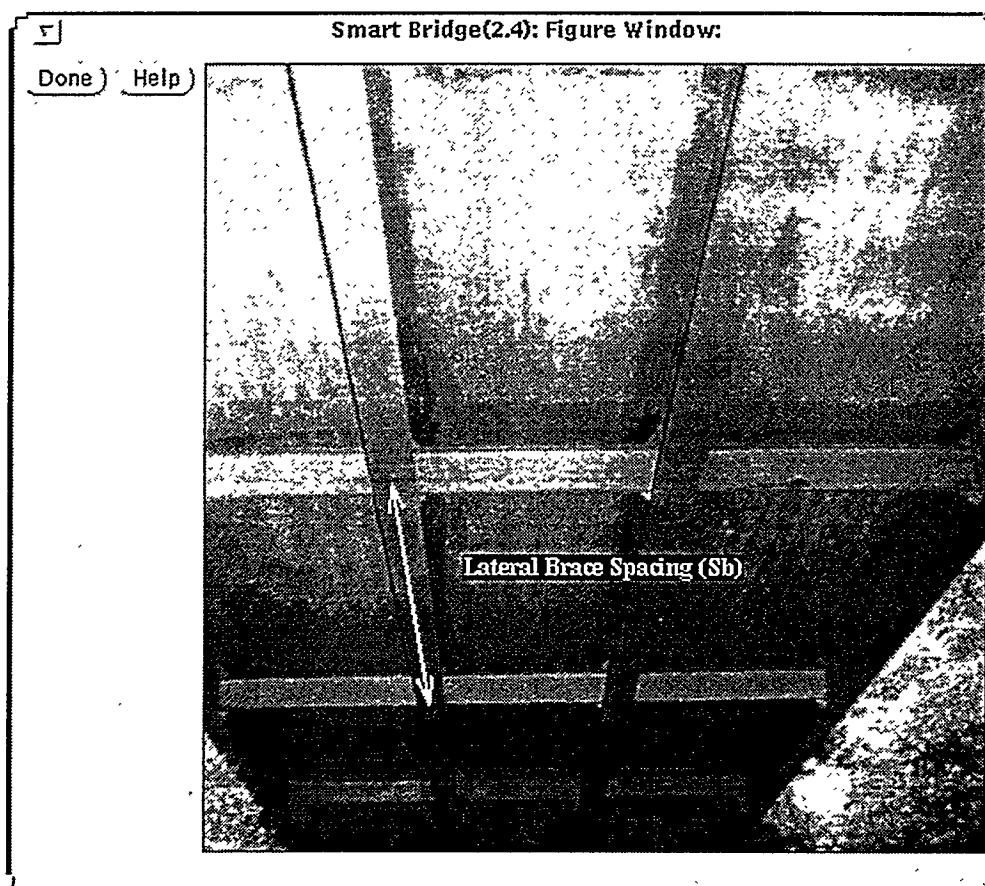Figure 5: Figure Window