Superstructure Envelope Generation with Conversation-Mode Software

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ABSTRACT

The versatile qualities associated with the IBM conversational monitor system (CMS) were used in the development of a computer program to generate shear and moment envelopes and maximum and minimum reactions for bridge superstructures. Carefully contrived questions throughout the envelope program, made possible through CMS, solicit a free-format user response that guides the direction of the program run. This conversation mode permits selected application of program segments, flexible input and output control, and repetition of analytical steps. A matrix-displacement approach is applied to the production of maximum positive and negative shear and moment values at every 20th point along a span for up to as many as 10 continuous spans. The program models the superstructure as a continuous beam with many user options governing the input of material and cross-sectional properties. The properties for nonprismatic spans may be input over user-designated length segments. An HS truck load, its corresponding lane, and, by request, the Interstate equivalent are positioned on the structure according to AASHTO specifications. The optimum magnitudes are found by way of analytically derived influence lines. Output may consist of shear, moment, and reaction influence lines, optimum magnitudes at selected points in the beam, and the shear and moment envelopes. A secondary program dead-load function may result in output that includes the reactions and shear and moment diagrams for both simple and continuous support conditions. The extent of the output is at the discretion of the user.

The New Mexico State Highway Department Bridge Design Bureau has an ongoing software development program to employ the latest in computer technology toward the solution of bridge problems. The goal of the bureau is to update existing software where feasible and, when necessary, to develop new material. Ultimately the bureau expects to have an interactive system that transfers information to and from a central core of data, uses direct input with immediate feedback, and may draw on the services of one or more programs, depending on the extent of the problem. The sequencing of the programs will offer a user the flexibility of moving forward to a next logical step or of digressing to a previous point in order to repeat a step or steps. The repetition of steps brings no loss in pertinant data because the data are stored in a central core for the user to modify or not, as desired.

Updating of existing programming has begun along with the establishment of a central data core or standard file. Software designed to generate the shear and moment envelopes and optimum reactions for bridge superstructures was considered an essential start in new program development. This new FORTRAN program, termed MAXMIN, was targeted to be diverse in its capacity and to lend itself for use in an existing beam design program. The many qualities associated with the IBM conversational monitor system (CMS) (1) were directed toward this goal. MAXMIN, the development and range of which are detailed in subsequent paragraphs, exceeded the objectives of the bridge design bureau.

CONVERSATIONAL MONITOR SYSTEM

The IBM CMS (1) may be incorporated into the larger IBM or Amdahl Corporation computers. When available, the interactive CMS editing, storage, and input capabilities give the programmer as well as the user a powerful tool. Simple edit commands allow the programmer to modify, add to, or take away from an existing program with relative ease. Although a MAXMIN user would not normally edit the program, an exception may be the occasional modifications to reflect future changes in AASHTO (2) specifications. Toward this end, the bridge design bureau has required the identification and extensive documentation of program segments dealing directly with AASHTO specifications.

CMS is divided into storage files; the first, or A, file is typically assigned as the primary work region. As such, main programs with their subroutines are often placed in file A in a packed form that reduces the amount of needed storage. Programs stored in a packed form must be unpacked before being compiled or executed. Main programs may also share subroutines, which eliminates duplication. CMS permits the use of EXEC programs to automatically control the extent of main programs. An EXEC program, for example, may compile a main program, identify and define the size of input and output files, and then direct execution of the program. Input data are not restricted to a file by CMS but may be read directly through a cathode-ray tube (CRT) terminal. In the current form, data are entered into MAXMIN through a CRT, whereas output is partly stored in a secondary file B and partly through a CRT. The user is given an opportunity to study the data in the file before he requests a hard copy.

The bureau's standard file has preassigned regions to store relevant bridge data. CMS permits the selective retrieval of data from this file. A main program or subroutine read statement identifies the file line and, through format control, the line segment containing the desired information. A like process with write statements may be used to place information in the file. In this way, the data, such as span lengths or cross-sectional properties, may be withdrawn from the file before the operation of a program. An empty file at the relevant positions automatically sends the program to the CRT for the required data. However, a user may designate early in the process that the material be entered only through the CRT to avoid working with data in the file not applicable to the problem at hand. Similarly, CRT input or program output or both may

be sent to the file at the user's prerogative for use in subsequent program runs. MAXMIN is not operational through the standard file at this time even though the mechanism for doing so may be readily inserted into the program. This convenient process will not be made operational in MAXMIN until an interface with a pier analysis program, under development, is complete.

The CMS conversation-mode capability is of direct benefit to the MAXMIN user. Carefully contrived questions have been inserted into MAXMIN with formatted write statements at pivotal locations. The user response, through a CRT with a free format that uses commas to separate individual data terms, dictates the direction of the program. The anticipated response, in many cases, is either a yes or no. Instead of an alphanumeric answer, the bridge design bureau prefers the convenient 1 for yes and 0 for no. When data are requested, the bureau employs a subroutine that gives the user up to three chances to verify the data. Once this has been done, the program moves to the next step. The user may replace the previous data in any of the three chances. Failure to verify terminates the program run.

PROGRAM EXTENT

The program has as its principal objective the development of shear and moment envelopes and the maximum and minimum reactions for a bridge superstructure or individual girder modeled as a continuous beam. Loads consist of an AASHTO HS truck, the corresponding lane, and, when specifically requested, the military or Interstate equivalent. A truck load selection ranging from an HS15 through an HS30 designation is offered to the user. With the loads specified, the program is geared to produce the maximum positive and maximum negative (minimum) shear and moment at every 20th segment along each span for up to a 10-span beam. This process involves three steps. First a matrix-displacement continuous-beam analysis for unit loads at the 20th points precedes the development of influence lines. Simple statics is then applied, one point at a time, toward the resolution of the influence lines. Finally the loads are located over the influence lines in positions that create optimum values. The latter process follows AASHTO (2) guidelines with regard to truck-axle spacing and load placement.

A secondary program objective encompasses the reactions and shear and moment diagrams for dead load. The dead-load capacity was designed to handle three possible cases: simple span, continuous span with a noncomposite deck, and continuous span with a composite deck. The user may designate simple-span dead load for the girder weight and then follow through with a second continuous treatment involving the weight of the deck. The program permits, at the user's discretion, the addition of dead load beyond the weight of the deck and girder. Thus a user may incorporate random uniform or concentrated dead loads (e.g., signposts, road surface, and so on) into the analysis.

The question-and-answer format establishes the direction of the analysis, so the user may decline some of the dead-load portion and move directly to a live-load analysis. The user may also work with only the dead-load portion and skip the live-load portion. Normal application, however, would have the user build on the analysis, step by step, from dead-load to live-load analysis.

ANALYTICAL THEORY

The analytical choice was the matrix-displacement continuous-beam analysis detailed by Wang (3). Static equilibrium at the supports ties external generalized forces (P) to internal generalized forces (F) by a statics matrix ([A]). A conjugate beam establishes a member stiffness matrix ([S]) that bonds F to internal displacements (e). Manipulation of the statics and deformation-matrix equations with an application of the conservation of energy produces the two key equations:

$$\{F\} = [SA^T]\,\{X\} \tag{1}$$

$$\{P\} = [ASA^T]\,\{X\} \tag{2}$$

Once the load matrix ({P}) has been established, Equation 2 is solved simultaneously to obtain the external displacements ({X}). Insertion of {X} into Equation 1 leads to the internal forces ({F}) or span moments at the supports.

A span is subdivided into 20 equal segments for analytical purposes. A concentrated load multiplied by the influence line value directly beneath yields the associated quantity. Second-order interpolation is used to obtain the influence value when a load is not over a 20th point. A uniform load multiplied by the region beneath the influence line segment over which the load acts again yields the associated value. This region is derived by using Simpson's one-third rule.

MAXMIN determines optimum magnitudes by first identifying peak positive and negative influence values. Distances between peaks are found to correctly define trailer-axle spacing. The truck is passed over the influence peaks, both back to front and front to back, for up to five sections before and after a peak. The central axle is always positioned directly over a 20th section. A reaction, shear, or moment value is found for each truck placement and tested against the previous value to identify the larger. The maximum (or minimum) truck value is compared against the corresponding quantities derived from the Interstate and lane loads to obtain the optimum.

In some cases the truck and Interstate loads may be placed over the influence line so as to immediately create a maximum or minimum. The end reactions are an example. MAXMIN is designed to account for these special cases.

The 20-segment breakdown ensures a high degree of accuracy when nonprismatic sections are involved. The nonprismatic member stiffness coefficients and the fixed-end shears and moments are generated with a subroutine based on a flexibility approach outlined by Kardestuncer (4). Thus the force-deformation relationships are not predefined as they are for prismatic spans. The resultant fixed-end moments serve as an equivalent load in the matrix-displacement technique.

INPUT REQUIREMENTS

Three types of data are solicited by MAXMIN--the beam dimensions, properties, and load. The program requests data first for a dead-load analysis and at its conclusion proceeds to the live-load or principal analysis. Dimension and property data entered for the dead-load analysis are carried forward to the live-load analysis. However, a program inquiry to the user with regard to property changes allows the user to modify the material before the next step begins. As previously mentioned, the user is given the option to skip unwanted analytical segments.

The dead-load portion may involve only a few data requests or become quite extensive, at the user's discretion. The dead-load support conditions (simple or continuous), the number of spans, and the

span lengths are established first. Then the cross-sectional dimensions (or moment of inertia and area) and the material properties are entered one span at a time. MAXMIN calculates the moment of inertia and area given the cross-sectional dimensions and establishes the uniform dead weight of the span. Beyond this, the user may designate additional combinations of concentrated and uniform loads. The process concludes with a matrix-displacement dead-load analysis.

The case may arise in which additional dead load is placed on the structure after the simple spans have been made continuous. MAXMIN accounts for this possibility, permitting a second dead-load analysis with an equal capacity to enter an extensive array of uniform and concentrated loads. Again the user is queried as to changes in properties or cross-sectional dimensions.

Many options are possible with regard to the structural make-up. It is necessary to have a modulus of elasticity and moment of inertia to achieve a matrix-displacement solution. The dead-weight calculations require a cross-sectional area and specific weight. When the beam is composed of two different materials, MAXMIN carries out a section transformation by using a modular ratio. A moment of inertia and area may be input without definition of a specific cross section. However, a cross section may be constructed as shown in Figure 1. The height and width for each rectangular component of Figure 1 are input at the request of the program. A component that does not exist is given zero dimensions. The height and width of each rectangular component are assigned a number. On a cue from the program, a change is implemented by specifying the dimension number followed by the new magnitude. Thus, a change is quickly made without alteration of the other values. The user may make as many changes as desired. An empty record, as would occur when no data are entered, sends the program forward to the next series of statements. In this way the user concludes the changes by hitting the CRT return key without first entering data. MAXMIN continues to cue the user for new material until an empty record is encountered.

One moment of inertia or set of cross-sectional dimensions is required for a prismatic span. A nonprismatic span, on the other hand, needs these values for 20 equally spaced intervals along the span. Although these values could be entered one interval at a time, this would be cumbersome in most instances. Thus, MAXMIN has a procedure for entering data in length segments. A set of values is input that defines the cross section at the beginning of the segment. These values are automatically assigned to the intervals within the length segment. The web depth for an established cross section may vary over the length according to linear or parabolic formulations shown in Figure 2. Additional
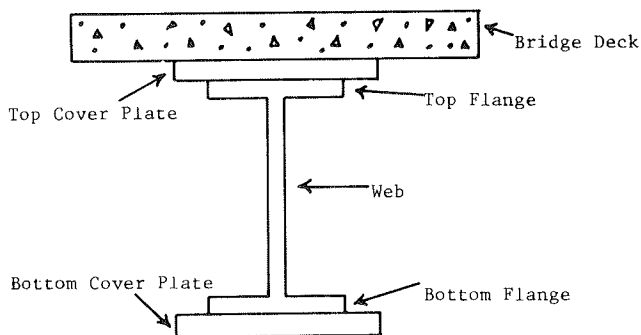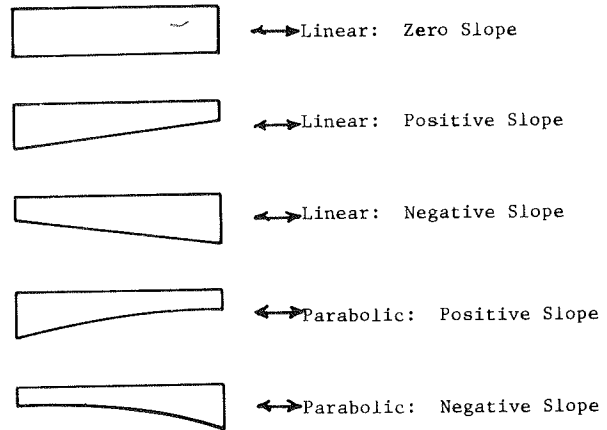

FIGURE 2 Web-depth variations.

web depth at the end of the segment is all that is required.

When a span is symmetric, the inertia or dimensions need only be input for the first half of the span. A change in section is accomplished as before, except that the user designates the beginning and end of the length segment for which the modifications are to be made.

The live-load portion typically needs the least amount of input data. Unit loads are automatically positioned at the 20th points to generate influence lines. The user is queried as to the truck load type and whether to include the Interstate equivalent. MAXMIN calculates the equivalent lane and Interstate load. No other data are required.

PROGRAM OUTPUT

The flexibility featured in the input requirements is carried forward to the output. For dead load the reactions are automatically printed, whereas the shear and moment diagrams are printed by user request only.

Shear and moment envelopes may not necessarily be the end result when live load is involved. The user may request a printout of influence lines for reactions or for shear and moment at selected points along the beam. In addition, the user may ask for maximum and minimum reactions or for maximum and minimum shear and moment at user-designated points along the beam. This process may be repeated again and again with either the same live load or a different load, as specified.

MAXMIN live-load output includes the optimum magnitudes, both positive and negative, and at the user's request, the load type and position over the beam that caused these values. If the truck load controls, the result is the location of the central axle from the left beam support and whether the truck is moving right to left or left to right. Similar treatment is given to the Interstate equivalent except that the location is to the front axle. Finally, if the lane load controls, the concentrated load (or loads in the case of negative moment) is again located relative to the left support whereas the uniform load is placed over the positive or negative influence region.

A shear or moment envelope is composed of a maximum positive and maximum negative value at every 20th span segment over the length of the beam. Although possible, a double listing of load type and position accompanying the optimum magnitudes is not generally requested. Instead a more reasonable approach is to generate the shear and moment envelope

FIGURE 1 Cross-sectional components.

followed by a selective request for additional data at selected points along the beam.

SAMPLE PROBLEM

The two-span nonprismatic beam in Figure 3 illustrates the kind of problem routinely handled by a MAXMIN analysis. The cross section is a cover-plated wide flange with a web depth of 40 in. at the supports, varying parabolically to a depth of 20 in. at the span centerlines.
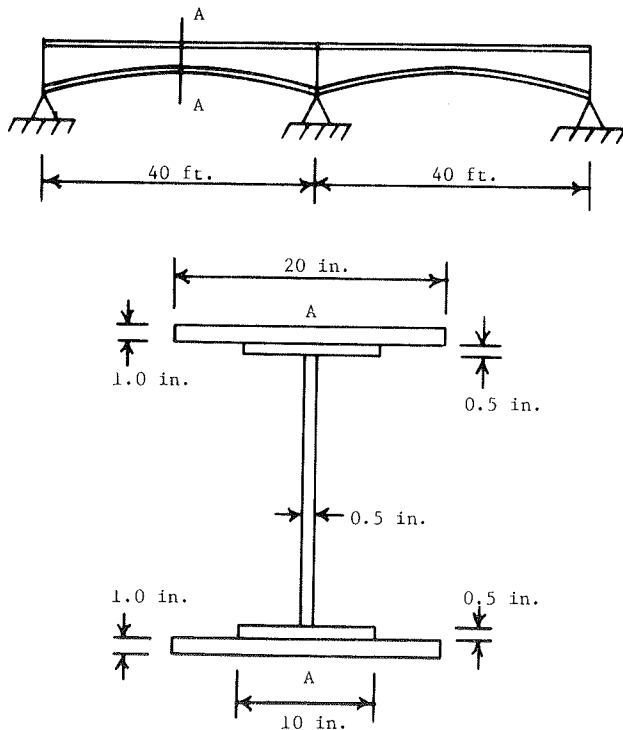
FIGURE 3 Sample problem: nonprismatic beam.

The MAXMIN input sequence started with a request for the analysis type, which for this example was live load only. A series of requests followed to establish the number of spans, span lengths, and span type (prismatic or nonprismatic). Under the continued guidance of the program, a segment a half-span long was defined by entering the distance to and web depth at the beginning and end of the segment. A positive-slope parabolic web-depth variance was designated for the segment. MAXMIN calculated the intervening 20th-span property values after the flange and cover-plate dimensions had been entered. In response to the user-specified symmetry, MAXMIN assigned these properties to their counterpart on the other half of the span. An HS20 to 44 truck load (military) was specified to conclude the input.

For brevity the MAXMIN output was restricted to a few representative items. Table 1 presents the MAXMIN-generated influence coefficients for the first two reactions. The maximum and minimum reactions with the pertinent load data are contained in Table 2. MAXMIN was asked to produce maximum and minimum shear and moment values at user-selected points along the beam. These values are found in Table 3. ICES STRUDL II (5) supplemented with hand computations was used to verify the MAXMIN results.

TABLE 1 Reaction Influence Coefficients

Left Reaction		Central Reaction		Left Reaction		Central Reaction	
Span 1	Span 2	Span 1	Span 2	Span 1	Span 2	Span 1	Span 2
1.000	0.000	0.000	1.000	0.318	−0.125	0.814	0.701
0.934	−0.024	0.083	0.998	0.270	−0.117	0.860	0.634
0.867	−0.046	0.166	0.993	0.226	−0.107	0.898	0.563
0.801	−0.067	0.248	0.984	0.186	−0.094	0.929	0.488
0.735	−0.085	0.329	0.971	0.149	−0.080	0.953	0.410
0.670	−0.101	0.410	0.953	0.115	−0.065	0.971	0.329
0.606	−0.114	0.488	0.929	0.083	−0.049	0.984	0.248
0.544	−0.124	0.563	0.898	0.054	−0.033	0.993	0.166
0.483	−0.130	0.634	0.860	0.026	−0.016	0.998	0.083
0.425	−0.132	0.701	0.814	0.000	−0.000	1.000	0.000
0.370	−0.130	0.761	0.761				

TABLE 2 Maximum and Minimum Reactions

	Value	
Characteristic	Maximum	Minimum
Left reaction		
Load type	HS20-44	HS20-44
Movement	Left to right	Left to right
Back axle spacing (ft)	14	14
Central axle location (ft)	14 from left	64 from left
Reaction magnitude (kips)	50.88	−7.12
Central reaction		
Load type	HS20-40	—
Movement	Left to right	—
Back axle spacing (ft)	14	—
Central axle location (ft)	44 from left	—
Reaction magnitude (kips)	68.76	—

TABLE 3 Select Shear and Moment Envelope Values

	Value	
Characteristic	Maximum	Minimum
First span, midpoint		
Shear		
Load type	Military	Military
Back axle location (ft)	16 from left	20 from left
Magnitude (kips)	15.36	−27.54
Moment		
Load type	HS20-44	HS20-44
Movement	Left to right	Left to right
Back axle spacing (ft)	14	14
Central axle location (ft)	20 from left	64 from left
Magnitude (ft-kips)	314.58	−142.48
First span, intermediate support		
Shear		
Load type	—	HS20-44
Movement	—	Right to left
Back axle spacing (ft)	—	14
Central axle location (ft)	—	26 from left
Magnitude (kips)	—	−59.92
Moment		
Load type	—	HS20-44 lane
Magnitude (ft-kips)	—	−358.12

COMPARISON WITH GEORGIA BEAM

The MAXMIN program solves problems by user interaction that are currently handled by noninteractive programs of which GEORGIA BEAM (6) is typical. The two programs carry out many of the same functions. GEORGIA BEAM is more thorough in that it can develop optimum displacements and stresses. However, GEORGIA BEAM is goal oriented toward beam design. MAXMIN, on the other hand, is directed toward load

distribution with a supplement to beam design as a secondary consideration.

A further comparison with GEORGIA BEAM reveals other differences. MAXMIN uses an exact matrix-method solution whereas GEORGIA BEAM uses one-step moment distribution. MAXMIN also derives intermediate influence magnitudes with a higher-order interpolation and generates shear and moment envelope values for twice the number of points along the beam. Finally, MAXMIN calculates uplift reactions at intermediate supports.

Differences in the computational time are difficult to access. Attempts at such a comparison have led to no definite conclusions except that the differences appear to be negligible. A choice, then, as to whether to use one or the other of the two programs comes down to an assessment of the problem objective and the individual's preference for interactive input.

CONCLUSION

CMS provides a diverse yet comprehensive tool to the programmer and program user. Valuable CMS options include storage manipulation, flexible input and output features, straightforward program modification procedures, and support program features. The CMS interactive mode gives the user a sense of being in control in that not only the end result but the process of obtaining it is in the hands of the user. This freedom quickly overcomes the resistance to CMS often exhibited by the novice.

Many of the CMS user qualities have been incorporated into MAXMIN. The user-initiated question-and-answer free format, repetition of steps with accompanying data changes, file storage, and the omission of analytical segments is the result. The accuracy was_ verified by numerous comparisons against American Institute of Steel Construction tables (7) of moments, shears, and reactions for continuous highway bridges. Further confirmation of the MAXMIN results were provided by a series of ICES STRUDL II (5) analyses.

An extensive number of potential analytical directions or choices have been built into the MAXMIN

program. Thus, the total operational time may also vary extensively. The principal goal, shear and moment envelopes, normally involves the most computational time. Toward this end, a four-span beam operates on a time scale of approximately 2 min once the required data have been entered.

MAXMIN has two major deficiencies. The program does not as yet have a graphics capability and so the output is restricted to tabular form. As a result, the visual impact of the output is not realized. MAXMIN was designed as an Interstate program or for bridges subjected to an HS truck loading. Other categories of truck load were not considered.

The MAXMIN program is of immediate benefit in the application of the beam-design program of a bridge design bureau. The goal in the near future is an extension of MAXMIN to include a lateral distribution of the load culminating in a pier analysis and design.

REFERENCES

1. CMS for Programmers: A Primer. IBM Corporation, Poughkeepsie, N.Y., 1978.
2. Standard Specifications for Highway Bridges, 12th ed. AASHTO, Washington, D.C., 1977.
3. C.K. Wang. Matrix Methods of Structural Analysis, 2nd ed. International Textbook Co., Scranton, Pa., 1966.
4. H. Kardestuncer. Elementary Matrix Analysis of Structures. McGraw-Hill, New York, 1974.
5. ICES STRUDL II, the Structural Design Language, Vol. 1. Massachusetts Institute of Technology, Cambridge, 1971.
6. J.M. Nieves-Olmo. The Analysis of Continuous Beams for Highway Bridges, Volume 1: GEORGIA BEAM. State Highway Department of Georgia, Atlanta, 1962.
7. Moments, Shears, and Reactions for Continuous Highway Bridges. American Institute of Steel Construction, New York, 1966.