PILOT STUDY OF THE BRIDGE ENGINEERING SUBSYSTEM OF TIES

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In May 1966 a work-study proposal, which outlined the objectives of the pilot study, was submitted to the Bureau of Public Roads by the New York State Department of Transportation. The primary objective was to develop and demonstrate a prototype integrated bridge design subsystem that included computer programs to solve computational problems and generate necessary parameters for plotting. These programs would apply to the major phases of highway bridge design and would be subject to decisions made by the engineer.

Work under this project was begun in January 1967 with a staff of engineers from the Bridge Design and Construction Subdivision and systems analysts and programmers assigned to the Bureau of Electronic Data Processing.

To accomplish the desired results within a reasonable length of time required that the scope of the pilot study be limited as follows:

1. Bridge over one or two roadways;
2. A maximum of 4 spans;
3. A maximum of 10 beams in cross section;
4. Bridge of constant width and tangent or circular curve alignment; and
5. Simple spans (composite rolled beams or welded plate girders).

From the standpoint of the TIES project, development of a prototype bridge design subsystem serves two major purposes: (a) It results in a workable system that can be expanded to accomplish the bridge design aims of TIES, and (b) it serves as a model for accomplishing the necessary functions in other subsystem areas and, ultimately, for developing the overall TIE system.

It was decided that a method should be adopted that would facilitate the accomplishment of the overall research goals and yet allow the earliest possible use of the programs developed. In effect, this plan allowed the results of the research to be implemented concurrently with its development.

Based on the premise that each independent program would be a unit in an integrated system, the following guidelines for the study were established:

1. Develop computer programs on an individual basis for each program area, condensing similar processes into a single program wherever possible;
2. Integrate these programs into a workable system that will automatically execute all phases of the design but, to avoid duplication, retain the option for independent program execution; and
3. Expand the system to include plot programs wherever practical.

As an initial step in the research process, letters requesting material for the project were sent to 17 highway departments throughout the country. Replies were received from all agencies contacted, and many agencies submitted source decks and program documentations.

These materials were reviewed by the engineering personnel assigned to the project to ascertain which of the many programs submitted would be most effective.

Recommendations concerning these programs were approved by the Bureau of Public Roads. Also, in line with the aforementioned guidelines, it was agreed that the program areas originally envisioned should be condensed into eight computer programs as follows:

Function	Program
Control geometry	B0500
Framing plan	B0600
Reinforced concrete slab design	B0800
Beam and girder design	B1500
Bridge bearing design	B3500
Abutment and retaining wall design	B5000
Pier design	B6000
Bridge quantities	B8500

The two geometry programs, one to produce control dimensions for a bridge and the other to produce a satisfactory framing plan, were developed by modifying and supplementing the recommended available programs.

Because programs were not available to serve this function, the reinforced concrete slab design program originated with the study. We have also developed a program that will detail slab reinforcement for straight bridges with the main reinforcement parallel or normal to the stringers. The beam and girder design program is based on logic contained in two available programs originally recommended but has been completely rewritten in its combined form. It also processes many designs in an attempt to select the most economical section within the specified depth range. A program for the design of bridge bearings was not available but was needed to prepare a complete design. This program was initiated in the project. In addition to its design function, this program also acts as a collector and provides the necessary input information for the substructure design programs.

The abutment and retaining wall design program is based on logic contained in three available programs originally recommended. Major modifications have been made in the combined program. The program will not design either abutments or retaining walls on spread footings or on piles. Rather, it processes a series of designs in an attempt to select the most economical section based on concrete volume and number of piles, if applicable.

The recommended pier design program has been modified to design the required steel reinforcement in the pier beam and columns. Logic has been added to design individual or multiple-column, spread or pile-supported footings. Subroutines have been added to the program to detail the reinforcing steel in the beam, columns, and footings. The originally proposed bridge quantities program will not be a part of the pilot study but will be developed in the future as time permits. It will be a collector type of program that will accumulate and combine quantities determined in other design or plot programs.

We have tried to design all of these programs so that they may be executed both within the framework of the bridge engineering subsystem for TIES and on a stand-alone basis. In this way, it is hoped that users not yet possessing third-generation equipment may still be able to utilize the results of this research.

We have also written programs for the plotting phases of the pilot study. Subjects included in these plot programs include the following: general plan of bridge, framing plan, transverse section, beam and girder schedules, abutment details, pier details, and slab bar plan for straight bridges.

In addition to those various design and plot programs, we have also developed a master control program that allows the execution of the various programs within the system in a pre-established order. By using a system of interim disk storage, the control program will allow information to be passed from a given program to any other program in the system.

The first phase of the master control program edits the input data from cards and sets up the intermediate data file for a particular bridge design. The data for all programs can be input in random order. Tests are made on each record immediately after it is entered to determine the proper program location for the record, and a sequence check ensures the proper placing of the record in its program area. The data are arranged in blocks and in the same form as the input forms for individual execution so that additional data from other programs may be entered to update the file. Data from a project master file can be entered by the same process if the contents and order of the master file are pre-established.

The second phase of the master control program determines which programs are to be used and in what order they are to be run, initiates the execution, and automatically keeps track of the order of program execution. This second phase is entered from the first phase and from all the individual programs involved during any system execution.

The following is a description of the design of a bridge illustrating the use of the various programs in the bridge engineering subsystem (BEST). The bridge selected was designed in 1967 before any of the BEST development work, which allows a valid comparison to be made between the original design and a system design.

The bridge is a two-span crossing of two proposed roadways. The abutments have been placed 30 ft from the edge of the pavement, the minimum clearance under the Highway Safety Program. The structure has solid abutments on spread footings and a two-column pier on a combined spread footing. The superstructure is composed of steel-plate girders spaced 8 ft on centers. The bridge carries a straight roadway and is placed at the crest of a vertical curve. The structure was built near Syracuse, New York.

The first step in the system design is the preparation of the input to the control geometry program. The input consists of horizontal and vertical alignment and cross-sectional information about the upper and lower roads. Ultimately, it is planned that this information will be passed to the bridge design subsystem by the roadway design subsystem of TIES being developed by the Texas Highway Department.

In addition, horizontal and vertical clearances and design criteria such as footing elevations and steel type are input by the engineer. By varying these input criteria, the engineer is able to produce a variety of designs that he may use as a basis for comparative estimates.

The printed output from this program consists of the locations and azimuth of the substructure, placed in accordance with the input clearances and design criteria, and the depth available for the steel stringers to be included in the superstructure.

The program also writes information for subsequent programs on the subsystem working file, where it may be updated by other programs as additional information is required by them. The applicable information on the working file is written on prescribed locations and in the format as described in the format statements included in the appropriate read subroutines of the subsequent programs. Instructions are included in the beginning of each program to print or tabulate the contents of the program's input file. If a complete design is processed, some interim decisions must be made based on information generated since the beginning of the run. The engineer has ultimate responsibility for the design and should have complete control over it. In this program he can override any of the interim decisions by updating the input files and rerunning the programs affected by the change.

The structure laid out by the control geometry program is a two-span bridge. The dimensions in the plot, however, show that the system-designed bridge is 22 ft longer than the original design. The program determined that a span with an additional 11 ft could be used effectively without encroaching on the vertical clearance.

The next step in the system design process is the determination of the framing plan layout. These items are similar to the geometry program data items and consist of horizontal and vertical alignment and cross-sectional information about the bridge and the stations and azimuths of the piers and abutments. All of this information is obtained from the input disk file prepared by the control geometry program. The output from this program consists of stations for the beam end points, offset distances measured from the station line to the beam end points, finished slab elevations of the beam length, and azimuth or alignment of each beam. The plot of the framing plan was prepared by another process program in the automated design system. The framing is similar to the original design except for the span lengths. An additional bay of cross frames (determined by the computer to be needed to accommodate the longer spans) was added.

Next, we proceed to the beam or girder design. Input is read from the subsystem working file. This information consists of bridge dimensions, sidewalk width, curb height, number of lanes of traffic and number of beams, allowable steel depth, span length, beam spacing, and an overhang dimension for fascia beams. The program initially designs an economical beam or girder for the longest span in the bridge. It establishes this depth as the minimum depth for fascia beams to provide a pleasing appearance, and then it proceeds to design each individual beam or girder. Printed output from this program consists of a detailed description of all the components of each beam or girder, together with stresses, reactions, and deflections. Again, information is written on the working file for use by subsequent programs. The beam and girder tabulation and the transverse section plot programs then draw on information from the input disk files to make the necessary computations to prepare the appropriate plots.

The next step in the process is the deck slab design. Information is read off the subsystem working file and consists of the stringer spacing, flange width, and assumed slab thickness. The program designs the transverse reinforcement in the interior spans and the fascia overhangs and the longitudinal distribution steel. Printed output consists of the size and spacing of the reinforcing bars. The deck slab plot program then reads information from the file and prints out a detailed reinforcing bar list for the slab and makes the necessary computations for the deck slab plot.

The bearing design program retrieves the necessary information, such as stringer reactions and span lengths, from the working file and designs the bearings for each beam. Printed output consists of a detailed description of the component parts of each bearing and beam seat elevations that are based on the dimensions of the previously designed components of the superstructure. By using parameters determined in this and the previous programs, the program arranges appropriate data for the substructure design and plot programs.

The abutment and retaining wall design program uses the data from the working file and designs two abutments and up to four wing walls depending on the differences in height. Printed output from this program consists of complete cross-sectional dimensions, necessary reinforcement, and piles, if required, for each of these structures. It then prepares data for the abutment plot program and places those data on the working file. The abutment plot program, using those data from the working file, performs the necessary computations to prepare a plot of the abutment plan, elevation, and appropriate cross sections. Because of the increase in spans previously mentioned, the abutments were not nearly as high as those in the original design. The footings of the abutments were approximately the same length, but, because of the lower height of the system design, the width of the footings was approximately 4 ft narrower. The lengths of the wing walls were also about 7 ft smaller, and the height of the abutment was 4 ft lower.

The pier design program uses information placed in the working file by the bearing design program to analyze the pier based on assumed concrete dimensions of cap beam and column and to design the foundations and all necessary reinforcement. Printed output from this program consists of a detailed description of the reinforcement and, if necessary, the pile pattern for the foundations. It next completes the input data for the pier plot program, which in turn performs the necessary computations to prepare the plot of the pier plan, elevation, and sections. As might be expected, the pier is similar to that in the original design. Differences are due primarily to the additional length of the supported spans.

The time for this layout, analysis, and design was 35 minutes. Plots were processed off-line on a Calcomp plotter using magnetic tape. Plotter time for the drawings was approximately 3 hours. The cost of this complete design was approximately $120 based on estimated computer and plotter usage.

Comparison of the BEST design with the original design indicates one major difference. The design using BEST resulted in spans approximately 11 ft longer than those used in the original design, with a resultant reduction in abutment height.

Although the original design satisfied the minimum lateral clearance required under the Highway Safety Program, the system design has the somewhat intangible advantage of providing an additional 10 ft of lateral clearance. At the same time, a comparative estimate using actual bid prices for the construction of this structure indicates that it would have achieved this advantage at a lower cost than the original design.

This structure was built, under contract, at a cost of approximately $212,000. The increased superstructure costs of approximately $20,000 from the system design would have been more than offset by the reduction of abutment and approach costs amounting to approximately $45,000. The net cost reduction of $25,000 would result in a cost of $187,000 for the structure designed by using the system.

This random comparison, as well as the many others we have made during the development stage, has indicated great potential advantages with the systems approach to bridge design. Although this system was developed as a prototype and is, therefore, limited in scope, we feel that it would be of advantage to extend this approach to include a much greater percentage of our work load. Including other types of construction, such as continuous steel and prestressed concrete members, would make the systems approach much more versatile and could provide additional economic benefits in permitting comparative designs to be quickly and easily made.