Modernizing Highway Engineering Practices

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We in the highway industry may be justified in taking our hats off to past accomplishments but we've got to take our coats off for the future. There is work ahead for all segments of the industry. One of the most important tasks is faced by those responsible for engineering the new highway program.

The time has come to re-evaluate highway practices objectively. It is necessary to gear these functions to the requirements of the new highway program. In other words, we must modernize. Modernize, the dictionary says, means to make conform to present usage or need.

Highway officials in this modernization process are beginning to find substantial solutions by the utilization of electronic devices, photogrammetry, and other methods and equipment. The application of electronics to highway work is as realistic as the Federal-Aid Highway Act of 1956. Passage of this Act started a chain of actions, not the least of which was the beginning of the emancipation of the highway engineers through electronics. As electronics become more thoroughly integrated into highway engineering and operation, the engineer and his profession will achieve new stature. This will come about because electronics in combination with other modern devices will perform for the engineer many of the tasks which now consume so much of his time.

State highway departments are re-evaluating basic engineering requirements and tolerable standards of accuracy that have been traditionally considered acceptable in data procurement, processing and presentation. With new electronic and other modern devices in mind, their search endeavors to answer three questions: First, which of our traditional engineering operations are needed; second, how can those which are not essential be eliminated; and third, how can we expedite those which must be continued? In answering the latter needs we will first discuss the electronic computer.
Electronic Computers

Electronic computers will be referred to several times and a brief description of the device may help to understand their potential in expediting highway engineering operations. As the name implies, these are high-speed calculators. They differ from the ordinary calculators not only in the speed of their output but also in the fact that they can store considerable quantities of data for later use. In addition, their operation is fully automatic from picking up data from cards or tape to entering the results on output cards or tape as the case may be. The operation of these machines is controlled by a predetermined program of instructions or actions which the machine is to take in arriving at the solution of a particular problem. When a program is placed into the machine and the computer is turned on, it will store data, add, subtract, multiply, divide, check and perform other operations in the proper sequence to give the desired result. There is already an impressive and factual record of accomplishment with the computer.

To illustrate, a program for earthwork calculations has been developed for use in Illinois. The following steps will be performed by an electronic computer:

1. Read and store the earthwork formula.
2. Read and store the cross-section templates.
3. Read and store the cross-section elevations and distances as determined by a field survey or by photogrammetry.
4. Read and store gradient data, including tangent grades, stations of P. L’s and length of vertical curves.
5. Calculate centerline elevation of each cross-section one at a time.
6. Select the applicable cross-section template.
7. Print out the location of slope stakes by distance and elevation.
8. Calculate end areas.
9. Apply shrinkage factor to fill end areas.
10. Pick up end area value for previous cross-section.
11. Compute volumes of cut and fill between successive cross-sections.
12. Print earthwork quantities.

Computer Use in Earthwork Calculations

At the present time, high-speed electronic computers are being used to calculate earthwork quantities by the State Highway Depart-
ments in Arizona, California, Nebraska, Texas, Washington and by the Bureau of Public Roads. A number of other State Highway Departments, including Louisiana, Massachusetts, Missouri, New Mexico, New York, and Ohio are in the process of developing electronic computer programs for obtaining earthwork quantities. The State of Washington completed 77.5 miles of earthwork computations in February 1957 and has standardized the method throughout the state.

The electronic computer gives the highway engineer a way to test alternate grade lines easily and quickly so that he can select the most efficient location, thereby effecting a still greater saving in construction costs. Data output from the computer furnish cross sections data in digital form ready for field staking. This raises the question of whether the bulk of cross-section sheets cannot be eliminated from the plans. It may be possible that 80 to 90 per cent of cross-section sheets can be omitted. Some highway departments indicate that only enough cross sections are needed to show the contractor what may be expected in side hill work, to show the adjacent landowner how the grade of a new road will affect his property and to show where and how crossroad culverts are located. Development work is in process to electronically produce cross sections when they are needed from digital computer output.

The California Division of Highways has integrated both earthwork and traverse computer service into the work flow pattern of engineering production at the field level. To do this required a field training program. Staff engineers from the central office visited each of the 11 field districts to hold group discussions, and talk individually to the engineers. Many followup visits were required as the engineers were generally reluctant to avail themselves of the new methods. They had to study the details of work flow, illustrate the points at which computer services would be beneficial, sell to the engineers the idea of giving up traditional processes and establish the method schedules and forms for the transmission of input data from the field divisions 200 to 300 miles to the computer center in Sacramento. This all had to be accomplished with the objective of expediting and not interfering with the field engineer's work flow pattern. The fact that cross-section sheets would not have to be plotted to a scale adequate for planimetering to determine end area for earthwork quantities helped to sell the program. California now processes 50,000 traverse courses and from 200 to 400 miles of earthwork per month at the computer center.
Computer Use in Bridge Design

The Bureau of Public Roads now has a program for the application of the electronic computer to bridge design. Initial effort was concentrated on the structural design of continuous beam bridges. The objective was (1) to determine the extent to which the use of the computer is feasible; and (2) to devise a usable program or programs. A computer program was completed after several months of work for the structural design of continuous steel beam bridges of three, four or five spans using AASHO bridge specifications. This program was furnished to all the computer manufacturers and demonstrated in operation at the Los Angeles conference in March 1957.

The computer program is divided into seven principal parts: (a) the computation of the maximum positive moment in each span and the maximum negative moment of each pier for an interior beam using a constant moment of inertia, and from these, the design positive moment and the design negative moment; (b) the determination of the size of beam needed for the design positive moment and the computation of the number, sizes and lengths of flange plates required for the additional moments at the piers; (c) the recomputation of the design constants taking into account the variation in moment of inertia due to the flange plates; (d) a repetition of Part A to determine new design moments; (e) a repetition of Part B to redetermine required beam and flange plate sizes; (f) checks against maximum allowable deflection and shear and the overload provision of the design specifications; and (g) a repetition of about three-fourths of the program to determine required beam flange plate sizes for the exterior beam.

An electronic computer was used by a consulting engineering firm in expediting the design of the Fort Pitt and the Fort Duquesne Bridges in Pittsburgh, Pennsylvania. Fifteen simultaneous equations were solved 14 times—one for each position of the unit—in order to obtain the influence lines of the hanger forces and the thrust. To set up the simultaneous equations, it was necessary to obtain through the use of the computer 225 deflection coefficients of the arch rib and 225 deflection coefficients of the stiffening truss.

The Washington Department of Highways is developing an electronic computer program for a reinforced concrete bridge. Their program will be used to compute end moments in structures with up to 15 continuous spans, final moments at any point along the structure due to loads at any point, and will include the effects of side-sway and other refinements. The Washington Department of
Highways has already completed an electronic computer program for determining slopes and deflections in finite beams on elastic foundations and a program for moment distribution in the design of bridges with continuous slabs or girders.

The Georgia Bridge Department has, through the Rich Computer Center, in Atlanta, Georgia, programed and successfully tested the use of an electronic computer in calculating the geometrics of a large bridge on curved alignment and with a skewed substructure. It is especially applicable to interchange structural design. The output of the computer consists of the following:

1. Stations of each bent.
2. Grade elevations at centerline for all points of intersections of concentric circles with centerlines of all bents.
3. Horizontal distances along centers of bents between concentric circles.
4. Chord lengths between intersections of concentric circles and centerlines of bents.
5. Angles between centerlines of bents and chords to concentric circles.
6. Middle ordinates for all chords between centers of bents.
7. Per cent slope on chords between centers of bents.

The Georgia Bridge Department is satisfied that solutions for bridges on curvatures of radii well in excess of 5,000 feet may be solved electronically with accuracy. Georgia reports that for a skewed bridge with 14 spans involving 11 concentric circles, the machine computations can be completed in less than 11 minutes. By the former manual method, 22 man-days would be required. The State is now planning to develop another program applicable to concrete superstructures of any type now in use, rolled beams, plate girders and composite concrete and steel structures.

Analysis of Traffic Data by Electronic Computer

Electronic computer programs were developed, tested, and used in the 1956 Washington, D. C., traffic origin and destination studies to reduce the time between the collection of data and the analysis of the data, to perform the summary extraction of results and to project the data to estimates of traffic for 1965 and 1980. The machine was used to sort, sequence-check, merge and edit the data.

The Washington Department of Highways reports that the use of the electronic computer has doubled the output of traffic analysis work in their state and it is being performed without any increase in personnel. In addition, the use of the computer has
provided more detailed traffic analysis than would have been accomplished manually. The computer is being used on origin and destination studies, traffic surveys, and route analysis. Time and distance savings are converted to dollar value permitting the determination of benefit cost ratios for various alternate new routes to permit route decisions on a more factual basis. The State Highway Department is using the electronic computer on two shifts. The second shift runs from midnight to 6 a.m. The State Highway Department is buying a larger computer and when it is delivered it will also be used for earthwork computation service for the counties.

The California Division of Highways has the first four of the following electronic computer programs completed and in use in the state. The fifth program is being developed.

1. Traffic assignment to a proposed facility. The machine compares the time and distance on the freeway route against a basic route.
2. The preparation of Table W-6 for the loadometer study.
3. The preparation of a trip desire contour chart.
4. The determination of formulas for trends by the method of least squares.
5. Editing metropolitan origin and destination data.

These are some of the accomplishments in integrating the electronic computer into highway engineering to accelerate the work flow. The surface has just been scratched. When fully developed, it is anticipated that there will be at least 100 engineering operations programmed for electronic computation.

In order to accelerate this modernization process and to avoid duplication of effort among states in preparing computer programs, the Bureau of Public Roads is developing an electronic computer library for the benefit of all highway departments. Each State Highway Department was invited to furnish copies of their programs to the Bureau of Public Roads. These would be subjected to engineering analysis and correlation and then made available to any State Highway Department on request. A list would also be kept of the programs in the development stage but not yet ready for the library. Through such a correlation list highway departments initiating new electronic computer development would avoid duplications.

Many of you here are county and local officials. Most of you would not be justified in procuring an electronic computer. Nevertheless you may be able to take advantage of these high-speed machines at reasonable cost. Computer service centers have already been established in the major cities and they will be expanded to
other areas as needed. You can arrange to have your survey, earthwork, bridge design, traffic analysis and other calculations performed at these centers as your needs arise.

**Photogrammetric Equipment and Techniques**

Nor is this the only area where engineering processes are being modernized. Wider use of modern photogrammetric equipment and techniques is already showing substantial increases in engineering productivity.

The California Division of Highways, for example, makes maximum use of aerial photography and the minimum amount of topographic mapping in the early stage of location. Aerial photographs are used in the planning and reconnaissance stage of practically every project. Some districts have made all planning and reconnaissance studies from aerial photographs and existing maps. An aerial photograph can be obtained in a matter of a few weeks as compared to several months of photogrammetric mapping.

The State Highway Commission of Montana is using aerial photography to map the Interstate system. By this method, adopted in October 1956, the work is being accomplished at the rate of 100 miles a week. The photographic coverage is 9,000 feet wide. The data are being used to determine location and to estimate cost.

The Ohio Department of Highways uses aerial mapping to develop site plans for structures and also for highway location, design and plan preparation. While obtaining the planimetric information from aerial surveys, necessary data for cross-sections are taken from the Kelsh plotter. The state reports that the cross-sections taken by photogrammetric methods are of such accuracy that they are accepted for payment of earthwork quantities without additional ground surveys.

At this point it may be well to call attention to the fact that the engineering work flow consists largely in the collection and processing of data. It was only natural, therefore, for highway officials to begin to investigate the feasibility of a marriage of electronic computers and photogrammetry. For the latter is a high-speed data collector and the former a high-speed data processor. To synchronize and integrate these two into a continuous production line might eliminate many time-consuming manual operations.

Much has been accomplished and more will follow. The Ohio Department of Highways has developed a method whereby terrain cross-sections for earthwork computations are read directly from aerial photographs as elevation point readings and horizontal dis-
tances and not interpolated from a contour map. This is accomplished through a Kelsh plotter with a horizontal measuring device attached to it. The new device converts elevations and the distance from centerline into data on cards or tapes. These can be used directly as input for the electronic computer.

The Massachusetts Institute of Technology has made progress on the development of an integrated photogrammetry-electronic computer system for earthwork computations in cooperation with the Massachusetts Department of Public Works. For this purpose they are testing existing devices on the market that will convert analog movements into digital data. The final results when developed will be the direct reading of x, y, z coordinates from aerial photographs into input for the electronic computer. This is the same objective already achieved in Ohio except that MIT is using a different method—a skew coordinate system of cross sections with the hope that this system by allowing more latitude in line selection will prove more efficient.

Radio Communication

The wider use of radio communication in highway operations is another demonstration of the effort to modernize engineering practices. I am sure that all of you are familiar with the value of radio communication in conserving the productive time of highway engineers.

There are, however, some recent new applications of radio which may be of interest to you. For example, the city of Chicago has developed a radio system for the remote control of traffic signals at intersections.

In the radio system, a program is developed to control the desired traffic signal functions. Information from the program is automatically transformed into code tones which are sent over the air. Radio receivers at the signalized intersections receive the code tones and transform them into functions within the local traffic signal controller. It is also possible to use the same radio frequency for voice communication with the field maintenance crews working on the traffic light system. The same radio tone signal can also be used to vary no-left-turn and speed signals, lane assignment signs and informational signs. When a highway is overloaded or an urban freeway is blocked by an accident or snow removal equipment this radio control system can be used to divert traffic over the nearest ramp or around the congested section. Expansion in the use of electronics in this area seems limited only by the ability of
the engineer to establish the fundamental requirements and to assure the manufacturers of a market. An effort is being made to secure adequate radio frequencies for this service by the American Association of State Highway Officials’ Committee on Radio.

Other Means of Speeding Up the Program

The electronic computer is also being integrated into traffic control systems. In Baltimore, a new traffic system is being installed where the traffic counts on major through streets are fed continuously into an electronic computer at the central office. Then when the computations of this data indicate that a traffic jam is imminent, a signal is given by the computer to the master traffic program selector. This automatically changes the timing of the signal lights on the through streets and on the side streets to ease the flow of traffic.

Closed circuit television equipment is also coming into use as a traffic control device. Installations on bridges, in tunnels and on critical sections of highway enable observers at a central point to watch the movement of traffic. They have demonstrated the value of television in preventing congestion, in getting assistance to the scene of an accident and in notifying maintenance forces when they are needed.

In this re-evaluation of engineering practices, no area is being overlooked where present methods could be modernized. The effort to simplify plans has already brought beneficial results. Highway departments in increasing numbers have developed standard plans for such features as cross-sections, culverts, bridges, etc. Such standard detail sheets, reproduced in quantity, are incorporated with the contract drawings. A standard bridge plans library is being established in the Bureau of Public Roads to utilize existing plans where possible. Considerable progress is being made in accumulating plans for this library.

Highway departments are using photography and multilith process to reproduce drawings rather than tracing and blueprint methods. Hand lettering of drawings is being replaced in many instances by Vari-typing. Plans are being reproduced photographically from penciled drawings, eliminating the necessity for inking. Repetitious details are being eliminated wherever possible to do so.

Specifications are also being revised to take advantage of new and improved equipment now available. Specifications where they describe methods in detail which limit the introduction of new equipment models are being changed where possible to specify results. The following new types of equipment have been recently intro-
duced: the slip-form paver, higher-speed asphalt pavers, self-contained pile driver, compaction units and a variety of others. By specifying results rather than methods and equipment wherever possible, highway departments are getting quality work and at the same time benefiting more fully from the contractor's experience and ingenuity in getting these jobs done quickly and at the least cost.

Construction procedures are also being modernized. Advance notice of work that a highway department intends to let to contract gives the contractor a better opportunity to look over the site, prepare better bids on the work he is interested in and to select the work for which his equipment fleet is best fitted. Earlier letting of contracts gives him a better chance to order materials, secure employees, organize his equipment, move onto the site and to take advantage of favorable weather so that delays in completing the construction are less likely.

Contractors and highway engineers are studying the possibility of accepting final quantities obtained from aerial photographs as a means of expediting final payments for completed work. This would also eliminate considerable field and office work required by present methods.

These then are some of the ways that highway officials are integrating new methods and techniques into their operations to modernize highway engineering practices so that the needs of the expanded highway program can be met. Many of you have very likely accomplished similar improvements in your own operations and we are confident that this effort will be continued by all of us.

In order to assure a continuity of modernizing highway practices a new Division of Development was established last week in the Bureau of Public Roads. This Division will initiate and execute development work, studies and other operations for the purpose of finding ways in which the results of research (by our own Office of Research as well as other government agencies and private industry) can be applied or adapted to the highway programs of the Bureau, the states, and other Federal agencies.

This effort to modernize highway engineering practices will require the joint cooperation of all in the industry. We can be encouraged by the progress made in the last few years. But, as I said in the beginning, we must take our coats off for the future.