ANALOG AND DIGITAL COMPUTERS IN CIVIL ENGINEERING

By Saul Namyet*

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Introduction

During the past 10 years there has been a rapid growth in the development of electronic computers, both digital and analog. The initial impetus to this growth was undoubtedly provided by the requirements of military research and development, and for that matter the continued rapid growth is currently being sustained by the same primary factor. Parallel with the developments in computer technology there has been an equally phenomenal growth in the use of electronic computers in research, engineering, business practices, process control, and data processing. The obvious reason for this is that we have been waiting for computers to come along and help us with our work. All of us, at one time or another, have faced problems that we would have liked to investigate, and solve if possible, which we have set aside because the methods available would require an impractical expenditure of time and money. Many of these problems can now be undertaken with the aid of computers.

The purpose of this discussion is to introduce you to analog and digital computers and to indicate some of the ways in which practicing civil engineers can make effective use of them. A few of your colleagues in each branch of Civil Engineering have begun to use computers; however, their use in Civil Engineering should be much more general.

Computers are now available in a variety of sizes, speeds, costs, and types. The two principal categories are called digital and analog (Figure 1). The digital computer deals with numbers and the analog computer is concerned with continuous variables. The output of a digital computer is generally a series of digits forming a number in some kind of arithmetic. In the analog computer the output is usu-

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*Professor, Massachusetts Institute of Technology Computer Laboratory, Cambridge, Mass.

ally a curve representing the variation of a physical quantity to some scale. The conventional speedometer produces analogic information, but the odometer which records the distance travelled has a digital output.

All other considerations aside, the accuracy of a digital computer solution is limited only by the approximations in the mathematical method of analysis and the amount of machine-time that is devoted to the solution. In the analog computer the accuracy is only limited by the agreement between the analog and the actual problem.

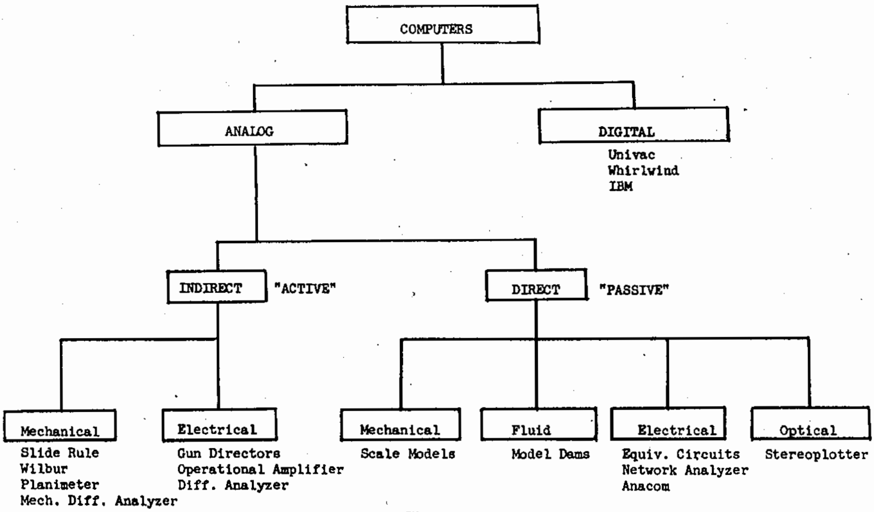

Fig. 1.

The precision of computers is a slightly different story. In a digital computer, increased precision is obtainable merely by increasing the number of digits that can be handled in one number. In general this results in a costlier machine. Precision in analog computation, on the other hand, is difficult to increase beyond about .01%. In general the cost increases rapidly for a small increase in precision.

What Is An Analog Computer?

Analog computers may be divided into two broad classifications, the direct and indirect analog. Both classifications may be subdivided further: direct analogs into mechanical and electronic; and indirect analogs into four categories, mechanical, electronic, hydraulic, and optical.

The direct analogy is characterized by those cases where problem variables and parameters are represented directly by corresponding units on the machine. The mechanical direct analog computers are generally scale models such as are used in wind tunnels or in structural analysis. The electrical direct analogs are instruments such as the network analyzers and equivalent circuits exemplified by the Anacom computer which has found considerable use for static and dynamic applications in the aircraft industry. The civil engineer is well acquainted with the fluid analog in the form of model dams, harbors, and stream beds which are found in hydraulic laboratories. The last category, optical analogs, are probably familiar to only a small group of highway engineers and photogrammetrists in the form of the stereoplotter which is capable of producing an optical 3-dimensional model of any object that has been photographed by stereoscopic methods. Of these different types of analog the electrical analogs are the only general purpose computers in that they may be used to solve a variety of problems by turning knobs or by varying the interconnection of the components.

The indirect analog computers are capable of solving algebraic or differential equations. The most common example of a mechanical indirect analog computer is the slide rule. At the other end of the spectrum in size and complexity is the mechanical differential analyzer. The electronic indirect analog computer is probably the most popular analog computer today and one that the Civil Engineer should be acquainted with if he is to take maximum advantage of modern aids to computation.

ELECTRONIC INDIRECT ANALOG COMPUTERS

There are two categories of electronic indirect analog computers, real-time and suppressed-time. The difference between the two exists in the end results. The real-time computer produces solutions repetitively as fast as 1/3000th of real time. Thus it may handle problems which are being continuously modified to study the effect of a particular parameter.

The best known commercial example of a real-time computer is the REAC manufactured by the Reeves Instrument Company. Some representative repetitive computers are the BOEING by the Boeing Airplane Co., the GEDA by Goodyear Aircraft Co., the

GAP/R by Geo. Philbrick Researches, Inc. and the GPS computer by GPS Instrument Co., the latter two being Boston firms.

In the electronic indirect analog computer the voltage is considered to be the analog of the dependent variable with time as the independent variable. If we have a problem in which we wish to know the vibration of a mass on a spring, a curve of voltage vs. time would be obtained in which the voltage could be interpreted as displacement. In other types of problems, for which, for example, distance may be the independent variable, the time axis of the resulting voltage-time curve would represent distance.

The basic components of the computer which are of primary interest and utility are the Adder, the Coefficient Unit, and the Integrator. The Adder sums voltages algebraically (in some devices it is possible to introduce a finite gain to each input voltage before adding). The coefficient unit is capable of multiplying by an adjustable constant, usually between 0 and 1. The integrator is capable of integrating voltage with respect to time. The behavior of these units is illustrated in Figure 2. In its physical form each component is unidirectional, that is, information flows only from input to output; in addition, any component may instruct any number of others without correction. These three basic units are all that are required to simulate a linear system. However, there are available many types of non-linear components, and the computer manufacturers are always developing new special-purpose components. Some of the more common non-linear GAP/R components, for example, are known as bounding, backlash, inert zone, square root, squaring, and absolute value units. The behavior of each of these units may be derived from Figure 3 which shows the different output of each unit for a common input.

It is often necessary to represent functional relationships between two variables which exceed the capabilities of the basic components. For this purpose there are function fitters which can fit a curve by a linear segmented polygon with adjustable lengths and angles.

The most important non-linear component is the electronic multiplier which can multiply two varying voltage signals. A complete high speed analog computer includes auxiliary equipment such as a power supply, an initial condition signal generator, a timing signal to indicate the time scale of the output, a calibrating device to deter-

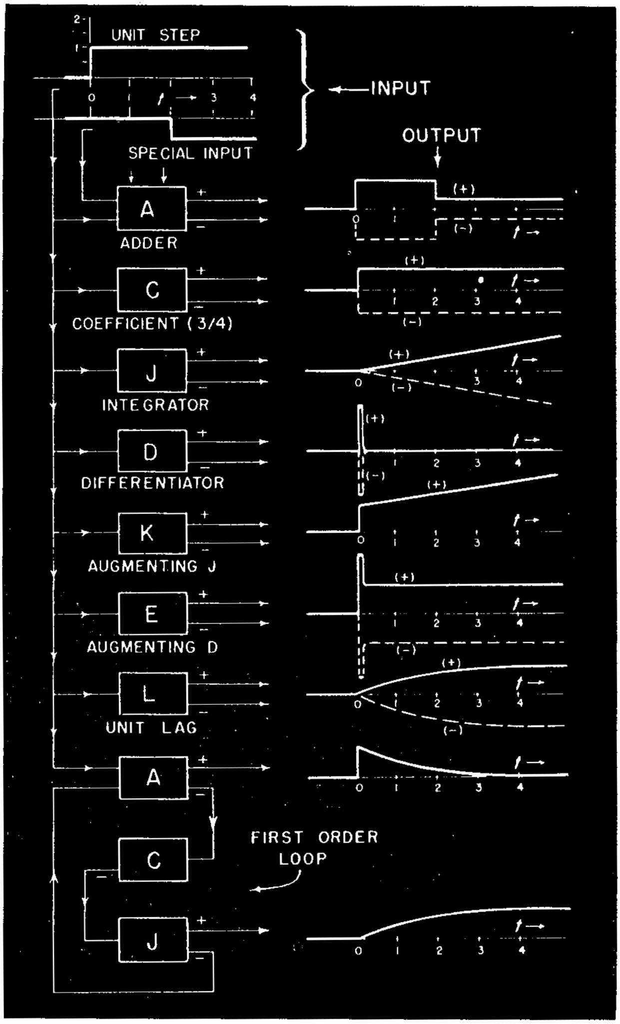

FIG. 2.—CHARACTERISTICS OF LINEAR ANALOG COMPUTER COMPONENTS.
(Courtesy of G. A. Philbrick Researches, Inc.)

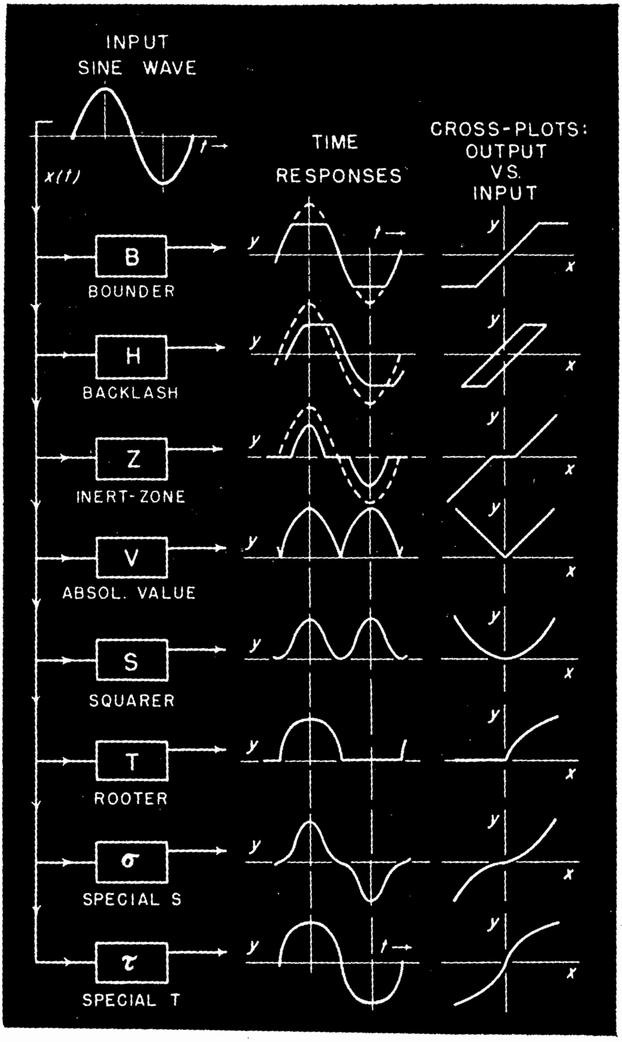

FIG. 3.—CHARACTERISTICS OF TYPICAL NON-LINEAR ANALOG COMPUTER COMPONENTS.
(Courtesy of G. A. Philbrick Researches, Inc.)

mine the output voltage scale, and finally, a display oscilloscope with the usual controls.

The description of the indirect electronic analog computer is best completed by a description of the method employed in setting up a simple problem involving a differential equation.

Consider the differential equation of motion for the system in Figure 4. The mass is subjected to a time-varying force f(t). The spring force varies directly with displacement so that the dynamic equations of motion may be expressed by

$$f(t) - kx = M\ddot{x}$$

The usual routine is to rewrite the equation so that the highest derivative is alone on the left so that

$$\ddot{x} = \frac{f(t)}{M} - \frac{kx}{M}$$

Then a block diagram is constructed by assuming that the voltage entering integrator A is $\ddot{x}$. The output must be $\pm\dot{x}$. If $+\dot{x}$ is introduced as input to another integrator B its output voltage will be $\pm x$. Putting the $-x$ voltage through the coefficient unit $\frac{k}{M}$ gives $\frac{-kx}{M}$. In the other circuit, a constant voltage is introduced as input to a function fitter which produces as output the function f(t). This is multiplied by the coefficient $\frac{1}{M}$ to give $\frac{f(t)}{M}$. The voltages $\frac{f(t)}{M}$ and $\frac{-kx}{M}$ are combined in adder C to give $\ddot{x} = \frac{f(t)}{M} - \frac{kx}{M}$ which is what is assumed as input to integrator A so the loop can be closed. To operate, the input voltage is introduced at the function fitter. Each of the functions can then be read on an oscilloscope. This completes the set-up of the computer except for scaling the voltage and time to the variables of the equation, a subject which is properly left for future detailed study.

EXAMPLES OF APPLICATIONS FOR ELECTRONIC ANALOG COMPUTERS

Without going into any details, it seems desirable to run through a few examples of the type of problem that can be handled with the analog computer. Back in 1947 the M.I.T. Hydrodynamics Laboratory with the aid of an analog computer initiated an investigation into the transient performance of power system prime movers. This led to a study of hydraulic surge and water hammer which is reported in two papers by Dr. H. M. Paynter (1, 2). A practical application by the hydraulic engineer involves the study of the dynamic routing of water flow in drainage basins. With an analog computer one can simulate a river system on a real-time or suppressed-time basis for purposes of flood prediction and water control. By varying the water storage conditions the most desirable operation can

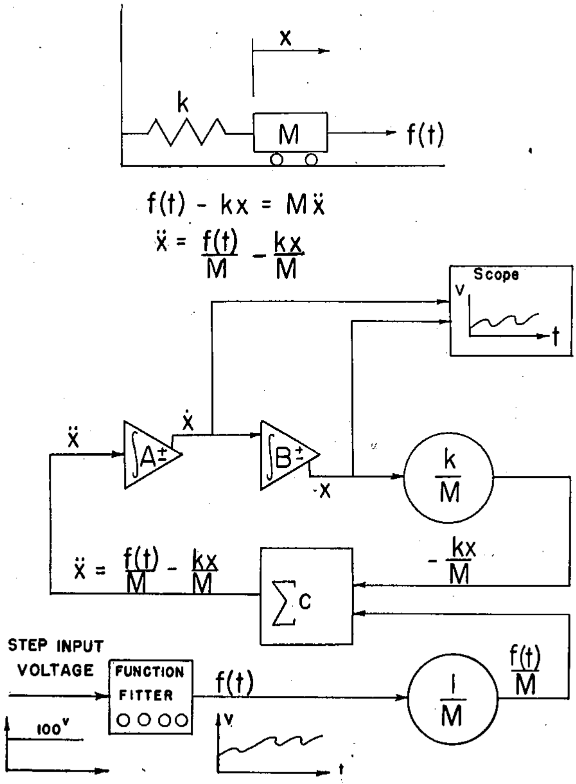

FIG. 4.

be devised. Dr. H. M. Paynter has reported on an investigation of this sort (2).

The sanitary engineer whose problem is designing complex sewage disposal systems should find that a similar approach to that used in water control studies will assist the design process immensely.

The transportation engineer trying to untangle the snarled traffic patterns of our cities should see many uses for analog computers and devices in design and control of traffic systems.

In the field of structures the analog computer finds a place in a long range investigation of bridge vibrations under the Joint Highway Research Program sponsored by M.I.T. and the Massachusetts Department of Public Works (3). The purpose of this investigation is to develop a method of predicting the magnitude and character of highway bridge vibration due to the passage of heavy vehicles. Field and model tests are run. The results of these tests are compared with a series of analog computer solutions. The problems performed on the analog computer are idealized and simplified mathematical representations of the complex system of moving load and bridge based partly on theory and partly on judgment. By varying the computer problem until the analog results agree with the test results a satisfactory mathematical relationship is obtained.

The soil mechanics engineer has used analog computers in problems involving consolidation, seepage, and thermal behavior (4). Professors Aldrich and Paynter of M.I.T. have recently devised an electronic computer incorporating commercially available components that is used to represent the behavior of a soil cross-section during freezing and thawing cycles. This computer is now in use at the Arctic Construction and Frost Effects Laboratory of the New England Division, Corps of Engineers, in Boston.

What Is a Digital Computer?

The modern automatic computer consists of four main elements and several possible subsidiary units depending on the size and complexity of the installation (Figure 5). The basic elements are the memory unit, control unit, arithmetic unit and input-output devices. These are the same as the basic elements of the conventional computation system utilizing desk calculators. The memory of the digital computer is analogous to the notebook of the numerical analyst, the arithmetic unit to his desk calculator. The control unit simulates the actions of the human as he manipulates the keys of the calculator and transfers data in and out of the calculator.

A memory unit consists of a large number of memory cells each identified by an address. Each of these in turn is subdivided into memory elements which are the smallest memory subdivision. In most machines information is stored in these elements in the form of binary digits, zero or one. The most popular memory devices are magnetic cores, drums, or tapes, with cores or drums for the primary or high-speed memory and drums or tapes for the secondary or slow-speed memory.

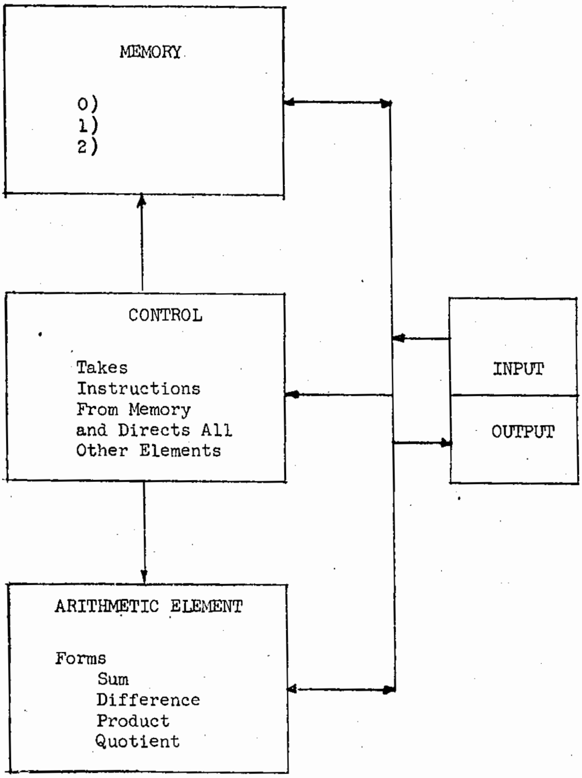

Figure 5 Automatic Digital Computation

The only important difference between the arithmetic unit of a digital computer and a conventional desk calculator is the extremely high speed of computation of the former. Otherwise a digital computer arithmetic unit operates on two numbers, adding, subtracting, multiplying, and dividing, just as in the desk calculator.

One of the more important aspects of large modern computers is that the control information is stored in the memory with the data that is being processed. The information for the control unit is stored in memory cells as instructions, consisting of two basic parts—one part indicating the operation desired, the other part indicating one or more addresses or memory locations involved in the operation. The control unit picks up the instructions according to a routine that is either automatic or programmed and interprets them by activating specific circuits, each instruction being a series of binary digits that determine the circuit to be selected.

The input-output system is comprised of devices which place numbers and instructions in the memory unit by punched tape, punched cards, or magnetic tape and obtains results from the memory for reproduction by automatic typewriter, punched tape, punched cards, or pictures of an oscilloscope screen. These devices convert from conventional language to machine language for input and back again from machine language to conventional forms for output.

It is almost universal practice to base the operation of digital computers on the binary system (base 2). This results from the fact that many electronic devices operate best when required to distinguish between the fewest possible number of different conditions, namely two. In the binary system each digit is either a zero or a one. Digits are coefficients of powers of 2 rather than powers of 10 as in the decimal system. Instead of a decimal point we speak of a binary point.

In decimal notation: 378.5 equals $3 \times 10^2 + 7 \times 10^1 + 8 \times 10^\circ + 5 \times 10^{-1}$. The binary number 101001 equals 41.0 decimal. This can be shown by the expansion: $1 \times 2^5 + 0 \times 2^4 + 1 \times 2^3 + 0 \times 2^2 + 0 \times 2^1 + 1 \times 2^\circ = 32 + 0 + 8 + 0 + 0 + 1 = 41.0$. Note that 6 binary places are approximately equal to only two decimal places.

The length of the binary numbers varies from machine to machine, anywhere from 16 to 50 *b*inary digi*ts* (bits) being used in contemporary machines. The position of the binary point may be "floating" or "fixed". In "floating-point" arithmetic the binary number consists of two parts, one indicating the position of the binary point and the other containing the significant digits. This arrangement permits storage of both very large and very small numbers. In "fixed-point" arithmetic the binary point is considered to be fixed between certain bits which results in a much smaller range of numbers that the machine can accept. Some computers can handle both "fixed-point" and "floating-point" arithmetic. To overcome the limitations on the size of numbers in a fixed point machine it is possible to introduce scale factors which adjust the numbers to fit within the machine limits.

When a human operator solves a problem with a desk calculator he must start out with a set of instructions which specify how the computations are to be performed. In like manner the digital computer needs a program. Preparation of a program consists of two steps:

1. Planning the sequence of elementary steps.
2. Coding the sequence of steps.

Planning a solution generally may be accomplished without special knowledge of the particular computer that will be used, although a given problem may be solved more efficiently if planned for a specific computer. On the other hand, coding of a program must be for a specific computer because ordinarily each machine has its own code and understands no other.

To simplify our introduction to digital computers we might consider a small fictitious computer based in part on M.I.T.'s Whirlwind. Provision is made for an accumulator register (AC) which is a special storage place for intermediate results in a sequence of arithmetic operations or a place where a number is held preliminary to further operations. For our purposes this machine can handle any number, large or small. The coded program may contain decimal numbers as well as the coded instructions, both of which are converted to the binary equivalents by the machine after "read-in". This is a single address computer which means that each instruction contains only one address, which is generally the location of the number to be operated on. The control system considers the instructions in sequence unless control is transferred to another address. When the instructions are "read-in" they are stored in sequence in the memory.

Some of the basic instructions for such a computer which help indicate the type of operations that can be performed are tabulated below. To simplify the explanation of the instructions use is made of the notation c(x) to represent the word contained in register x, reading it as the "contents of x" where x is the address of a memory cell. An understanding of the usefulness of these few instructions can only be obtained by some illustrative problems for which there is no time in this presentation, or by the reader attempting to solve some simple problems of his own invention. The large machines have many more instructions which can only be considered meaningfully in terms of the particular machine.

BASIC INSTRUCTIONS FOR A DIGITAL COMPUTER

Instruction	*Explanation*
CA x	*C*LEAR AC and *A*DD c(x) to AC
CS x	*C*LEAR AC and *S*UBRACT c(x) from AC
AU x	*A*DD c(x) to c(AC) and store sum in AC
SU x	*S*UBTRACT c(x) from c(AC) and store difference in AC
AO x	*A*DD *O*NE to c(x) and store in x and AC
TS x	*T*RANSFER c(AC) to STORAGE register x
TD x	*T*RANSFER address *D*IGITS of c(AC) to address portion of register x
SP x	*S*KI*P* control to register x. This is an *unconditional* transfer of control.
CP x	*C*ONDITIONAL *P*ROGRAM control. If c(AC) is negative take next instruction from register x; if c(AC) is positive go on in sequence.
MR x	*M*ULIPLY c(AC) by c(x) and *R*OUND-OFF the product in AC to fit one memory cell.
DV x	*D*IVIDE c(AC) by c(x) storing quotient in AC

We have made considerable use of digital computers in the Civil Engineering Department at M.I.T. in recent years and have been very pleased with the results especially since many of our problems could not have been undertaken without the aid of computers. However, this has not been without the usual—and some unusual, difficulties. Computers have not reached the stage at which they do any thinking, no matter what the newspapers are saying. In fact, today's computer as yet can only do what you tell it to do. Indeed you must be extremely careful, for example, that you punctuate your information exactly as specified for the particular machine. The human operator of a calculator has a good chance of detecting a misplaced decimal point but a machine cannot.

One of the fundamental characteristics of the digital computer, its ability to modify the instructions as the computation proceeds, is a major source of difficulty in obtaining completely satisfactory programs. The ability to change instructions results oftentimes in changing the wrong instructions. However, there is considerable effort being devoted to the development of procedures for detecting and preventing mistakes as well as for automatic programming, all of which should help the user of digital computers.

It should be emphasized that the digital computer is only another aid, although a very powerful one, for solving engineering problems. In this respect the engineer should list the digital computer with the slide rule and the desk calculator. In fact, for many problems in engineering the other two devices are better suited than the digital computer for obtaining solutions. The primary utility of the digital computer lies in its ability to repeat a series of simple operations at fantastic speed. Thus digital computers are best suited for problems that require numerous repetitive solutions of the same equations or relationships. Some problems can be solved once by the use of desk calculator (some many more times) for a given set of conditions much more rapidly than they can be programmed to the point where answers can be obtained. An obvious advantage of the digital computer is that once a program for a problem has been completed satisfactorily, in general it requires no more calendar days to obtain 100 answers than one answer. In production computations, that is computations using an established program, an engineering office can save considerable time or, what is oftentimes more desirable, make a more thorough analysis than is customary because of the time required to obtain a solution by conventional desk calculators. If a problem is solved by conventional procedures and a change in basic data is introduced near the end of the process, a revised set of computations will ordinarily require the expenditure again of a large percentage of the man hours and calendar days required for the original calculations. However, with the digital computer, although the original programming might require considerable time, new sets of answers can be obtained overnight.

EXAMPLES OF APPLICATIONS FOR DIGITAL COMPUTERS

What are some of the ways in which a Civil Engineer can use a digital computer? In general, the applications should have a repetitive nature, either considerable repetition of the same type of problem through the years, or repetition of a typical calculation within a particular problem. If a problem does not contain one or both elements of repetition it is probably not desirable to apply high speed digital computer techniques.

Two examples which embody both types of repetition come readily to mind from the newly adopted practice in a few state highway departments, notably California where all traverse and earthwork calculations are performed by digital computers.

The structural designer who handles rigid frames by approximate methods such as moment distribution, can use digital computers to obtain "exact" solutions by solving the simultaneous equations that result from writing the slope-deflection relationships. This is very simple to do; but more can be done by giving the machine a procedure for selecting member sizes. To further complicate things, the machine may be given a procedure for varying the properties of the elements of the frame so as to permit it to search for the most economical design.

It should be evident that any procedure that an engineering group can systematize for its own use is amenable to digital computer methods. In this regard it seems reasonable to expect that someone will soon have a program for determining all of the data that is required to prepare the construction drawings of a highway bridge. This of course would require a separate program for each type of bridge. On a steel stringer bridge, for example, some of the factors that the program would account for are: span, skew angle, width of roadway, width of walks, profile of road over, clearance requirements, profile of road under, spacing of strangers, load specifications, etc.

Highway structural engineers are designing rigid frame piers ad infinitum using routine tabulated procedures which the digital computer can follow. The machine procedure would have to be more complex than the office routine because the designer uses his judgment as a basis for neglecting certain design load conditions. Although some of these judgment factors can be provided in the program, one would expect the machine to produce a more complete design pob than the design engineer would if he had to make all the computations himself.

The traffic engineer needs the help of a digital computer to handle the vast amount of statistical information that he collects in highway use studies and accident records, to mention a few instances.

There is a whole class of problems which are best described as transportation problems. These problems are handled most efficiently by a mathematical procedure called linear programming. The practical transportation problem will generally benefit by the use of digital computers. An example of such a problem that might interest a traffic engineer would be to determine how to obtain the maximum flow of traffic through a given complex network of one-way and two-way streets.

In general, any of the problems which are amenable to analog computer solution can be handled by the digital computer. The essential difference is that the suppressed-time electronic analog permits rapid survey of the various parameters involved in a problem. On the other hand, the digital, like the real-time analog can only yield one answer at a time for a given set of data. In many instances it is good practice to use both analog and digital devices.

In the highway bridge vibration study (3) mentioned earlier we have an example of such effective utilization. The analog computer with its ability to quickly survey an extended range of the various parameters but with its relatively moderate accuracy was used to define the significant limits of the critical parameters. The digital computer was then used to determine the maximum bridge deflection for various combinations of the parameters within the critical range.

Before closing it is appropriate to consider briefly a current research activity which is tied directly to digital computers in the Photogrammetry Laboratory of M.I.T.

LOCATION AND DESIGN OF HIGHWAYS BY MACHINES

a. *General*

Digital computers have recently been introduced into the list of engineering devices and aids that find use in the highway engineer's domain. In more than a dozen state highway departments, the earthwork calculation problem has been attacked in various ways on several different computers. In most instances, excepting a few, however, the computers have been solving conventional problems using conventional techniques, with the sole difference that the high speed computer replaces either the planimeter or the desk calculator.

The outstanding exception is a procedure recently announced by the Ohio Department of Highways in which it is proposed that topographic data be collected from a Kelsh plotter for use in a digital computer.

It is our feeling that the full potential of computers will not be achieved except by approaches that depart from conventional procedures for data procurement and data utilization in favor of all-inclusive procedures which eliminate as many conventional steps in the engineering process as possible and obtain all the useful design data in one continuous automatic or semi-automatic operation. With this as a guiding principle the Photogrammetry Laboratory at M.I.T. is developing a system for locating and designing highways by the use of stereoplotters linked with electronic computers.

If we consider the over-all process of location and design of highways to consist of three steps, namely:

(1) Preliminary location using 5′ contour maps,

(2) Design location using 2′ contour maps, and

(3) Construction drawing preparation, the proposed system is expected to make step 2 a machine operation insofar as possible.

This step begins with aerial photography of ground strips approximately 2,000 feet in width along the tentative route. From these aerial photographs the usual photogrammetric maps may be prepared in stereoplotters. At this point however, the automatic system of obtaining data is introduced so that full advantage may be taken of the stereoplotter. From this point on the design and location calculations are expected to be performed entirely by a digital computer.

b. *Description of the Basic System*

The proposed system may be divided into two principal parts: first, the method of data procurement and second, the method of data processing. The first part is basically concerned with the photogrammetric plotter and the second part is essentially a digital computer programming problem.

The basic idea of the system which determines almost the entire process involves the establishment of a rectangular grid system relative to which the coordinate axes of the photogrammetric model can be located. From the photogrammetric model, at the nodes of the grid system, in a predetermined sequence the elevations of the existing terrain are automatically recorded onto a tape or punched card to form a digitalized model of the terrain. The tape may be punched paper or magnetic.

Having the digitalized model of the terrain, the second part of the system comes into play. A computer program is necessary that will perform the following tasks:

(1) Accept and respond to any legitimately defined highway alignment equation.
(2) Accept and respond to any definition of profile grade, or compute the profile grade according to specifications and terrain.
(3) Select the appropriate cross-section templet at any station from a review of the model and profile data, and the highway design specifications.
(4) Compute the limits of slopes that are required.
(5) Compute the amount of cut and fill between stations and cumulative cut and fill.

c. *Unconventionalities of the System*

It should be emphasized at the outset that the highway centerline is expected to be skewed to the coordinate axes of the model grid system and as a consequence of this it is expected that preliminary data will be obtained for skew cross-sections. This means that slope stake data obtained directly from the computer would be on skew sections.

Another important change in conventional practice that results from adhering rigidly to the basic concept of a rectangular grid system is the general use of plus stations instead of full stations. This is necessary if the centerline of the highway is skewed to the grid and only one set-up of the photogrammetric model is to be used.

These two deviations from conventional design data presentation practices, it is expected, would meet with great objections from the constructor, although plus stations are necessary to some degree in current practice and "skewed slope stakes" once installed should not look much different to the construction engineer or equipment operator than "square slope stakes", except that the spacing would not be at 100 feet. However, these unconventional procedures can be avoided by making the procedure slightly less automatic and producing "square slope stake" data from "skew slope stake" data by graphical methods. The final profile station and elevation data can be obtained by the computer in a separate run for full stations once the final line has been selected.

It is also conventional design practice to consider the three cross-sections at plus stations where the existing ground line intersects the proposed subgrade elevation at the outside of the base and the centerline. In the proposed system, to consider these sections would greatly complicate the procedure. The possible adverse effect of omitting these conventional cross-sections can be minimized by use of a smaller grid length than the conventional spacing of cross-sections.

d. *Advantages of This System*

There are more or less advantages inherent in such a system relative to conventional methods of location and design of highways, depending on whether photogrammetry is currently being used in any form. Assuming the best current practice, however, the proposed system is expected to have the following characteristics to recommend it:

Rapid Multiple Trial Alignment and Profile:

With the complete grid system model available on punched cards or tape the location engineer may try various alignments and profiles in sequence by changing the short alignment profile tape or the small deck of alignment profile punched cards. A group of trials may be planned in advance and handled continuously or alternatively; successive trials may be based on a study of the results of the previous runs. In the latter case the problem would probably be removed from the computer pending a decision on the next trial alignment profile in which case there would be a certain amount of lost time in getting "on" and "off" the computer. However multiple trial alignments are obtained at a minimum of personnel effort and time because the entire model is available at the press of a button and the relatively slow and expensive stereoplotter set-up need not be repeated.

Flexibility:

In the location stage it is reasonable and customary to base decisions on cross-section data obtained at 200 to 500 feet rather than 50 or 100 feet as needed for design purposes. It is a simple operation to vary the size of the rectangles of the grid system that are to be used in the computations. To have a simple operation the grid system will always be an integral number of basic grid units.

Thus, in the location problem a large grid may be used and when designing from the same model, the smaller grid may be used.

There are other reasons for varying the grid size so that the decision will probably be left to the engineer in each particular case.

It is only necessary that the basic grid on which the digitalized model is recorded be at the minimum size that may be used in the design phase.

e. *Concluding Remarks*

The preceding description of some of the basic elements of a semi-automatic procedure for performing the data collection and processing of a highway location and design system only touches the surface of the potential system that should include consideration of all the operations involved in the design and construction of highways, including land-taking. The purpose of discussing this research program in its very preliminary stages is to call your attention to the potential developments in this area of interest and perhaps lead you to propose innovations in the methods of obtaining, processing, and presenting engineering information for all kinds of projects.

One hesitates to conjecture about the general acceptance and use of computers by Civil Engineers. However, a short word on the subject is probably necessary to round out this presentation. There are many problems which cannot be solved properly without computers. These computer applications, we can be certain, will take place. But what about the type of problem that is being handled well enough by conventional methods? Why change accepted techniques for new and untried techniques? There are probably many engineering offices and many problems for which computers hold little promise. However, there is no question that for many other engineering groups, computers promise the ability to provide faster engineering service, more thorough engineering, more economical engineering, more accurate engineering, as well as a better environment for engineers who will then have an opportunity to THINK a little more about some of the problems they face instead of spending so much tedious time grinding out computations.

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