

INTERACTIVE GRAPHICS IN HIGHWAY ENGINEERING

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In September 1970, an NCHRP project was initiated that had as its overall objective the development of an interactive computer graphics software system capable of being used by highway engineers in the design of highways. The first phase of the project was completed in August 1971 and consisted of the following major activities: review and definition of interactive design and roadway perspective system applicable to highway engineering; development of specifications for interactive graphics software, user action requirements, and modifications to current system and programs; review and delineation of interactive graphics terminal hardware specifications; and consolidation of findings and determination of the feasibility of interactive graphics to the highway design process. The end result of the project will be a new method of computer-aided roadway design.

•THE HIGHWAY engineering community was one of the earliest users of, and has continued to be a leader in, the application of computers in engineering work. There has been a continued growth in the sophistication of the computer techniques employed. Even with this continued growth, the engineer, in general, has still not been able to realize the full potential of the computer because of restrictions placed on his ability to communicate with the machine and guide its decision-making process. These restrictions are a direct result of the manner in which information is transferred between man and machine by computer hardware and software. It has been widely acknowledged that benefits to be realized from the computer will be significantly increased when the user can gain more control over the programmed decision process through improved communication techniques.

Most recently, the thoughts of highway engineers are turning to the use of interactive graphics as a means to overcome these communication restrictions. One such thought, toward which briefly positive steps have been taken, resulted in a project to study the feasibility and development of system design specifications for using interactive graphics in roadway design. This project was sponsored by the American Association of State Highway Officials under the auspices of the National Cooperative Highway Research Program. This paper will discuss the way in which this NCHRP project planned to apply interactive graphics to a specific task of highway engineering, final roadway design.

In September 1970, NCHRP contracted with Control Data Corporation to perform phase I of an intended two-phase research project to result in a functioning interactive graphic roadway design system (IGRDS). As of this date, the phase I effort has been successfully completed and the design accepted, but all further funding of this and other similar projects through the NCHRP was terminated by AASHO.

To elaborate a bit more on this work so that the nature of the system can be more readily assessed, I would like to highlight a few key points of this project. The key objectives of the project were

1. To study existing applicable hardware as well as procedures and techniques developed in other interactive graphic applications and
2. To design engineering procedures and software to create a system for interactive graphic roadway design.

The project effort was to emphasize the engineering procedures to be part of such a system. The role of roadway design programs in the system, insofar as the project was concerned, was to be that of a data generator.

The Texas Roadway Design System (RDS) was selected to be used as part of the interactive graphic system to be designed by this project. Selection was based primarily on the broad capabilities of RDS, its modularity, clarity of file design, and the fact that Federal Highway Administration support of RDS would probably make it one that would be much used in the future. The system was not to be machine dependent; it was to be a useful and economically justifiable tool.

Two complete papers would be required to cover both the interactive graphics roadway design procedures and the design recommendations for the specialized interactive graphics software. This paper will be restricted solely to the former concepts and leave the latter for another forum.

IGRDS was to be a research tool that would permit the practical in-service study of interactive graphic techniques by highway engineers. The results of this research study were to provide a practical base for future interactive graphics development in other areas of highway engineering.

The project was made up of work of two different, but related, kinds:

1. Development of procedures for a roadway designer's use of a computer interactive medium and
2. Design and preparation of specifications for computer programs that will allow RDS to work in conjunction with interactive hardware and software in a manner that will permit the performance of the prescribed procedures.

The former category of work consisted primarily of creating new procedural concepts. It involved analyzing each step of the roadway design process and determining what the designer needs and desires to do at each step. As each need was identified, it was necessary to determine of what assistance RDS could be to the engineer at that design step and what interactive graphic techniques could effectively be utilized to provide these design capabilities. The resulting procedures were then recorded in documentary form.

The second type of work included the study of existing interactive graphic hardware and software and the selected RDS to determine what additional interactive graphic program functions were necessary to create a combined system that would effect the desired procedures. This work type also includes determination of whether the proposed interactive engineering procedures were possible. Whenever it was found that the system could not perform in accordance with the procedures first proposed, another approach that was more compatible with the interactive graphic capabilities was sought.

IGRDS DESIGN CAPABILITIES

RDS capabilities are almost exclusively pointed at pure roadway design functions, i.e., design related to horizontal and vertical alignments, earthwork, and geometrics. It is a final design system with limited capabilities for preliminary design and route location because of the way it builds and handles the terrain model. It includes approximately 250 clearly defined programs and subroutines with a large data base of design and terrain-related information, which enables the roadway design engineer to work simultaneously with multiple roadway configurations toward an optimized design. The data base, referred to as project data files (PDF), consists of tabular design information (e.g., template criteria, slope criteria, and equation tables), station-oriented design data (e.g., horizontal and vertical alignments and templates), and individual cross-sectional data (e.g., terrain and design cross sections with related pointers and values). The comprehensive data structure of the PDF permits access by IGRDS to prepare its response to user requests for data and graphic displays.

The design concept of IGRDS acknowledges the probability that design approaches vary among individual designers, and it is to be expected that changes or additions to the system command set will be desired. The design concept is not tied to a particular fixed command set in advance of first trial use; rather, it is one of providing the user

with a comprehensive set of commands, software to modify these commands to operate, and a convenient means of modifying the set to fit his own desires.

There are three major divisions of command components that IGRDS must contain to enable the design engineer to function effectively while interacting with the RDS application and its project data files.

1. Geometric, vertical alignment, and cross-sectional design components;
2. Design data input as a direct data entry to PDF; and
3. Analytic displays including mass haul diagrams via earthwork computations, perspective views, and combinations of orthogonal and perspective projections.

The project report contains about 60 design-oriented commands.

The objective of the command structure is to provide a primarily production-oriented system. The concept employed in the user command capability is that, at each step in the roadway design interactive process, the user should have a set number of known, suitable commands available for his selection. Upon selection of any command, the system should act in some specific, expected way, and another set number of suitable commands will be made available for selection in the next step. The selection of each new command is based on the results of the last.

A detailed description of the command structure is not possible in a paper of this scope. Rather, to achieve an understanding of the effect of the commands, the paper will describe the steps an engineer might take as he effects a series of design changes through IGRDS.

DESIGN-ORIENTED COMMANDS

Commands that enable the user to perform design functions in IGRDS occur exclusively in the design command component of the system. They are typified by their effect on the PDF, which is updated to reflect the intended result specified by a selected command.

Horizontal Alignment Geometrics

When working with a horizontal alignment, the user will see it displayed against a grid representing the design coordinate system. There will be no topography or planimetry in the background inasmuch as no such display data are available in the RDS data file; therefore, the design work he performs at the interactive device will generally be already laid out on the design mapping prior to initiation of the interactive process. It is possible to display special grid reference symbols, however, that would represent some controlling feature the user wants to locate in a trial-and-error process.

Upon entry to the horizontal alignment segment of the system, the user defines initial specifications for the display he needs to perform the intended design function. Included in these specifications is a definition of scale and range of interest. Even the largest commercially available display units will not be able to satisfy all users' needs concurrently. If he wants to see the entire station range, the scale will necessarily be very small. This handicap may be overcome, at least partially, by the zoom and window features of the system. He may "zoom in" on a point of immediate interest to a degree where he is able to work with the display. Simultaneously, however, the "window" through which he sees the display permits him to observe an increasingly smaller station range. This impediment may also be overcome by providing him with the ability to move the viewing window from time to time in the design process, or he may "zoom out" to again obtain an overview of the alignment.

The commands will permit the user to build and extend horizontal alignments, or to review them, in a number of ways. The horizontal alignment is reduced to its elemental parts, and each command is aimed at doing something to an element that generally results in a reconfiguration of the alignment. The reconfiguration is reflected in the PDF and displayed on the interactive device. Before the design change is passed on to the RDS application for file update, however, IGRDS will display the new geometric alignment for visual verification.

Upon entry to horizontal alignment, the screen is blank except for the project file identification and the command lists. The user's first action is to choose a number of commands in the display specification list, which result in the painting of the picture shown in Figure 1. The system's simplified space allocation techniques have generally put the labels he requested where they can be read and understood; however, their arrangement may not please him, and he may choose to enter the display administration command list to obtain a more satisfactory presentation.

The original painting produces a clear overwrite conflict between the station equation and the label for PI 4, and the user moves the equation label (Fig. 2a). He also asks that one latitude and one departure on the background grid be identified so that he will be better oriented. Now, for a zoom of PI 2, he moves some other labels, including the north arrow, closer to the alignment so that they will remain in his viewing window.

The zoom action produced three unique pictures in the viewing window, each with an apparent scale double that of the last. Although this final scale does not please the engineer, he is willing to work with it because it is not necessary to use an engineer's scale. The zoom was reasonably good (Fig. 2b). He has an excellent picture of the curve he wants to work with, and he managed to keep the north arrow in the viewing window. The station label for 400+00 also stayed in the window, but it is no longer referencing the correct station tick. Although the graphics are all in the picture, he wants a little more information about them before proceeding with the intended design revision.

Figure 2c resulted from the user's choice of commands from three separate command lists. First, he reentered the display specifications and changed the interval for displaying labels on station ticks. He also asked that a crossroad alignment be included in the display. From the data request table, he obtained curve control stationing, tangent bearings, and complete curve data for the curve at PI 2. Finally, in the display administration command list, he asked for identifying labels on two of the background grid lines and on the main alignment.

Following a rearrangement of the screen display by choosing a number of commands in the display administration command list, the user finally reaches the goal of his entry into the horizontal alignment branch of the system, that of relocating PI 2 (Fig. 2d). He has chosen the command "MVPITR" from the design command list and has been advanced in state to accomplish the relocation in the desired manner. At the conclusion of the required actions, the system displays his reconfigured alignment for verification.

Before finally deciding that the design change is what he wants, the user may see the effect of the revision at PI 3. He therefore "windows" down his alignment until the curve at PI 3 is in view (Fig. 2e).

General Geometry

When general geometric computations are performed under IGRDS, an initial display is generated for the user on the display device after he specifies certain parameters that define a skeleton configuration with which he wants to work. These specifications are akin to those occurring in the horizontal alignment segment; the major difference stems from the fact that he has the permanent file of geometrics available to him, and the "skeleton" might be a partially, or fully, completed configuration that he had previously constructed. The relatively small working surface is an ever-present handicap, but it is probably less serious in general geometry. The reach of alignment of interest to him when he is working geometry is much more confined; therefore, he will often be able to see his entire area of interest displayed at a reasonably satisfactory scale. The zoom and window features of the system are available to solve problems that might arise. The fact that he has no background, other than the coordinate grid, is also less serious inasmuch as geometry seldom depends on topography, and special grid reference symbols may be used to represent controlling features of planimetry.

The command set designed to provide geometric design capabilities for IGRDS is based on the existing capabilities of RDS. To be able to perform geometry efficiently on an interactive graphic device requires that the unique hardware and software features of the device be used and the command structure additionally be unique to effect utiliza-

tion. It is much easier and faster to point to an item of interest than it is to find an element identification and enter it through a keyboard.

A highway-oriented geometric configuration is constructed from unique line elements. Points tie these elements together by mathematical definition. Most of the command set is designed to create unique line elements. The remaining commands enable the user to define relationships between sets of elements. Once specific geometric elements have been defined as a set, the set may be saved in a file for future recall use or modification.

The user enters the general geometry segment with only the command lists appearing on the display. Through display specifications, he gets the centerline of his alignment to appear in a workable orientation, and he adjusts the viewing window to provide space where he needs it. Based on design policies of his highway organization, he establishes the nose of a left-turn lane into an entrance ramp at station 26+35 and then uses commands to establish a construction line normal to the centerline at this station.

With this basic skeleton as a beginning, he proceeds to establish construction points, lines, and curves to build his geometric configuration. Because it takes fewer commands to construct the geometry without controlling the length of line and curve segments, his configuration begins to take on the rather wild appearance shown in Figure 3a. For a time, he is mentally able to keep the maze sorted and continue building the geometric configuration components. The point in time arrives, however, when he must take time out to clear up redundancies before proceeding.

The result of "debris removal" is shown in Figure 3b.

Vertical Alignment Design

The command set for vertical alignment is similar to the horizontal alignment command set. The principal difference between them lies in the manner in which design functions are performed, and this dissimilarity may be traced to the difference in which measurements are made. In horizontal alignment, measurements are made in an infinite number of directions; only two, vertical and horizontal, have meaning to vertical alignment. This simple measuring scheme, together with the use of parabolas with vertical axes to effect curvature, renders the vertical alignment decidedly less complex than the horizontal.

The very things that simplify vertical alignment have somewhat of an opposite effect on IGRDS. The zoom and window features are available in the vertical alignment segment. Windowing is equally as effective as it is elsewhere, but zooming loses some of its effectiveness. A zoom is a scaling device that changes scale equally along both axes. It does not recognize differences in the vertical and horizontal scales. Therefore, a zoom that results in a satisfactory horizontal scale will seldom retain a satisfactory vertical scale, so the vertical scale will have to be reset following the zoom.

The background grid of a vertical alignment will consist of station reference ordinates and elevation reference lines. Design functions may be carried out more effectively in the vertical alignment segment because all the basic background data needed for vertical alignment design may be represented in the display. Most important is the terrain profile at centerline and, if need be, additional terrain profiles along offsets to the centerline. The command set also gives the designer the ability to display a number of "grade control symbols" consisting of points that may be moved horizontally and vertically to positions that control the design of the vertical alignment, e. g., culvert and structure clearance points.

The most effective use of the vertical alignment segment will occur when the design engineer wants to design a profile grade for a new alignment. After bringing out his terrain profile on the display device and setting all known grade controls, he can establish an initial "grade" by describing a single tangent segment extending the length of the specified station range. This might be likened to the initial step of the manual process of laying grade where the profile paper roll containing the plotted terrain profile is spread on a long table and black thread, pinned at one end, is held taut by a dangling weight at the other. Commands to introduce a series of new VPIs replace the manual function. VPIs may then be relocated, just as the designer would move selected pins, to effect an apparent optimization of the grade layout. The manual process is interrupted at this point while the thread is replaced by penciled lines and vertical

Figure 1. Horizontal alignment.

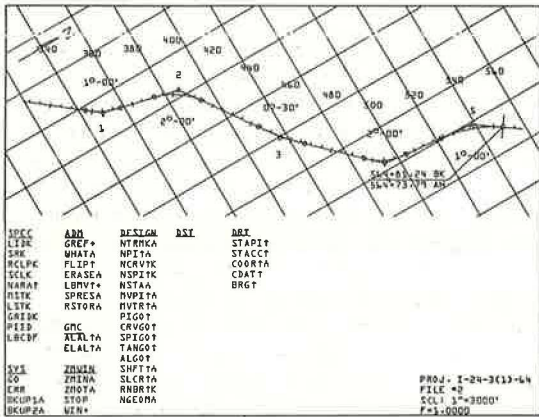


Figure 2. Figure 1 after user-specified commands.

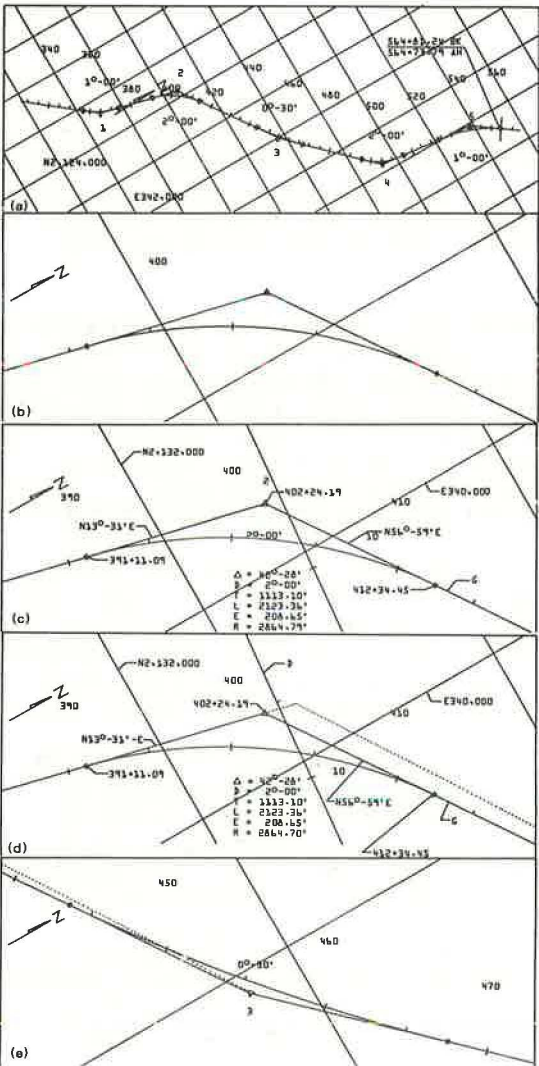


Figure 3. (a) Constructed geometry and (b) geometry with "debris" removed.

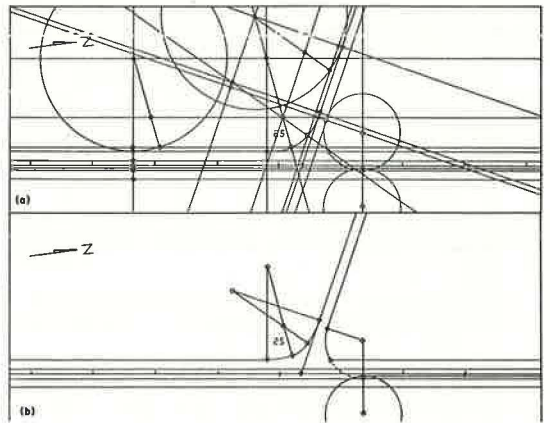


Figure 4. Vertical alignment (a) overview and (b) at working scale.

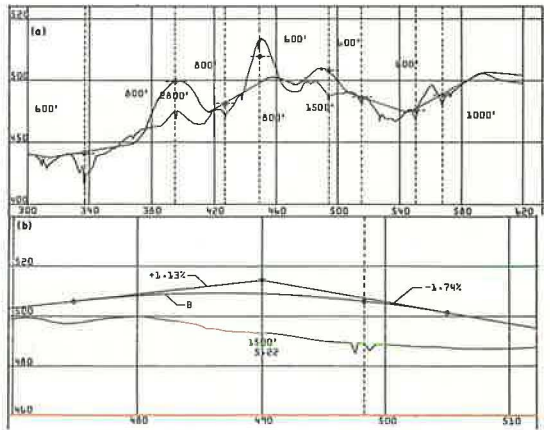
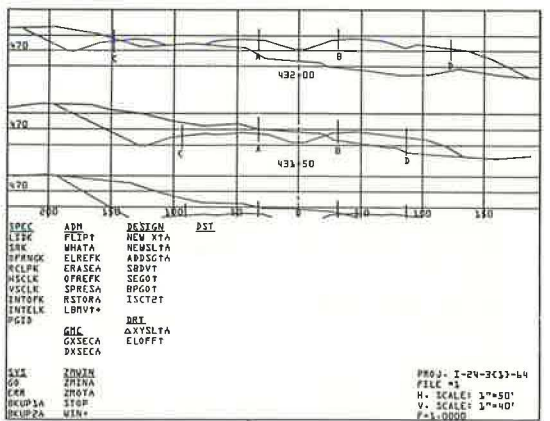


Figure 5. Terrain cross section to be interpolated.



curves, and further adjustments are made without the benefit of the thread. The IGRDS user retains his "thread" throughout the process, and, once vertical curves are defined, they will follow VPI adjustments, which will enable him to see their exact effect on the design.

Approximately 6 miles of vertical alignment and terrain profile at centerline are shown in Figure 4a with vertical curve length labels. Curve control symbols and tangents to the parabolic curves have been suppressed in the display because they are distracting at such a small scale. A number of grade control symbols have been brought out and maneuvered into meaningful positions.

Figure 4b shows the results of a combination of zooming in on Figure 4a through four successive frames on the VPI at station 490+00 and respecifying a vertical scale. The grade control symbol originally specified remains in the picture, and, in addition, the user asks for the parabolic constant to appear with vertical curve length.

Cross-Sectional Design

Four separate segments are included under the cross-sectional design component of IGRDS. Only one may truly be considered a design function. The others, given below, are design aids:

1. Edit terrain cross sections,
2. Interpolate terrain cross sections,
3. Edit and adjust design cross sections, and
4. Trace profile of selected cross-sectional points.

In the first segment, the roadway design engineer can have the digital terrain cross-sectional data residing in the PDF displayed in graphic form for purposes of visual inspection. No interactive data purification capabilities are provided for two important reasons. First, when the display reveals suspicious data, correction should be preceded by verifying that the data are erroneous. There is danger that the ease of interactive purification would introduce as many errors as it corrects. Second, even when an obvious error is found, the user is not likely to have the information at hand that is needed to make the correction, and, even if he does, the time required for the research would detract from the efficiency of the interactive process.

Fully automated interpolation of terrain cross sections has never been a complete success, primarily because there is no programmed fail-safe method of logically finding longitudinal lines of interpolation, i.e., ridge and valley lines. The interaction of IGRDS provides user decision capabilities to assist in this task.

A shallow, natural drainage channel meanders diagonally across the alignment where a terrain cross section is to be interpolated (Fig. 5). Normal longitudinal interpolation would be erroneous, so the user tells the computer how to do it correctly. There is insufficient data on the right side of the two base cross sections to guarantee complete accuracy at the same end of the interpolated section, but the ground trend indicates that any errors that might be introduced would be small.

The interpolation provision in IGRDS will divide the display area on the graphic device into two subareas. One area displays the base cross sections for the interpolation process. The other displays the centerline (normal lines representing the base cross section superimposed with visible offset points representing break points) and a line representing the subject cross section to be interpolated. The user can define all the lines of interpolation and see them represented in the plan view, or he may ask that the RDS application generate these lines, by using its own technique, and that IGRDS display them. He may then purge erroneous or redundant lines and replace them with lines of his own choosing. Finally, he may trigger the interpolation process and have the interpolated cross section displayed for his inspection.

The one true design function of the cross-sectional design component occurs in its third segment. The roadway design engineer can access the design cross sections logically generated by the RDS application and make individual adjustments dictated by engineering judgment.

Figure 6 shows the typical cross-sectional display used for final adjustment of the section. The two roadways of a divided highway and a pair of ramps diverging as sta-

Figure 6. Cross-sectional display used for final adjustment.

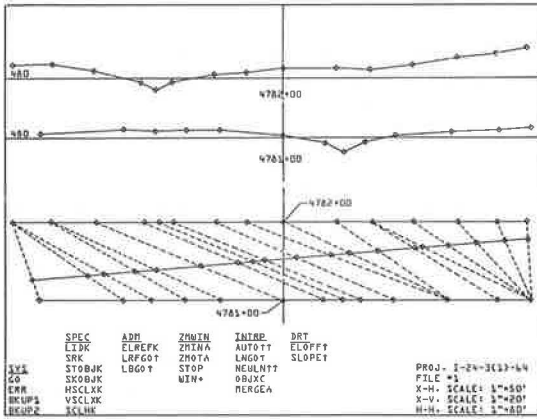


Figure 7. Profile trace of selected point.

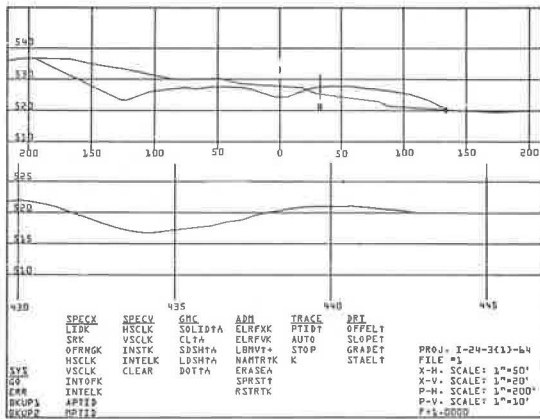
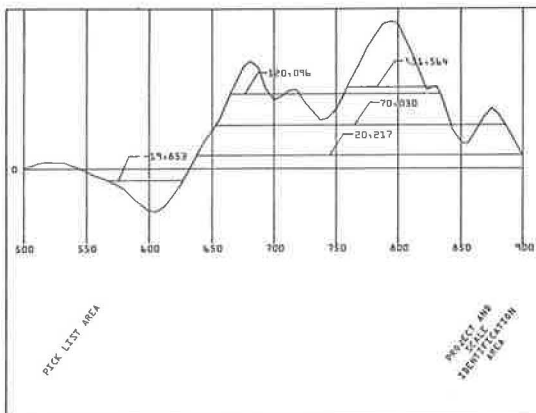


Figure 8. Mass haul diagram.



tioning increases are illustrated. Note that, although data are carried in the display files for the complete cross section at station 431+00, the viewing window is not quite large enough to show all of it. Windowing downward slightly would probably result in a visible display containing three full cross sections.

The final segment of the cross-sectional design component also divides the display surface into two display areas: one reserved for the display of a single terrain-design cross section and the other for a profile view. The user may designate a station range of interest and other pertinent specifications that will result in the display of the first cross section of the range indicated and a background grid of station reference ordinates and elevation reference lines for the profile. He may then choose a point of interest on the displayed cross section and request that a profile be traced that is representative of that point through the station range. When the project data file of the RDS application contains information that makes the chosen point identifiable on each successive cross section (e. g., slope stakes are generally identifiable), the process of obtaining the profile trace may occur automatically. If the point is not internally identifiable, the user must perform the identification on each successive cross section.

When point identification takes place, the sequence of events that follow on the display device provides the engineer with an attractive new design technique. Each successive cross section is displayed sequentially with its profile grade reference point fixed in one spot on the face of the interactive graphic device. Elevation reference lines are adjusted with each new display to accomplish this. With each new cross-sectional display, a line segment is added to the profile trace. When the last cross section in the station range appears, the completed trace is displayed for whatever analytical purpose the engineer had in mind.

One such purpose is to determine the requirements for special ditches and toe ditches. For instance, by tracing the profile of a slope stake of a section of embankment and simultaneously watching the slope trend of the existing ground adjoining the side slope, the engineer can quickly discover small pockets of ponding water where toe ditches are needed for drainage. The command set allows the user to request and obtain precise data from the two views, so that in another design step he may enter the data to include the toe ditch.

In Figure 7 the profile of the left slope stake is traced as successive cross sections appear in sequence on the display screen. The vertical scale in the profile view is purposely warped to make variations in slope more recognizable. Note that, if the sequenced cross section views had shown that the terrain were sloping downward to the left against the referenced slope stake between stations 430+00 and 440+00, a pocket or ponding would be indicated that would need to be drained with a toe ditch.

COMMANDS RELATED TO PRESENTATION OF ANALYTICAL DISPLAYS

In addition to commands that can change the nature of the roadway design itself, there are those that, at the user's request, provide him with displays of the data representing the current status of the roadway.

The first of the analytic displays permits the design engineer to trigger earthwork computations over a specified station range in which specified roadways contribute to the volumes. He describes various display parameters, and the mass diagram resulting from the earthwork computations appears for his analysis. He will need the ability in the command set to strike balance lines and to adjust them on the display. He will also need the ability to request data that the mass diagram is uniquely qualified to give and data resulting from the earthwork computations themselves.

Figure 8 shows a mass diagram with a zero reference ordinate originating at the initial specified station. The user may strike any number of supplementary balance lines and request data to be computed for volumes and haul quantities within each balance and between balance lines.

Perspective drawings, through use of real design and terrain data, of a highway as viewed from a driver's eye position will be possible with IGRDS. This will be accomplished by the perspective programs developed by the U. S. Department of Transportation, Federal Highway Administration, Region 9, that are currently being installed in RDS.

The perspective view component of IGRDS will permit the user to view selected reaches of his alignment when he specifies a station range of interest for each reach, together with a vantage point and a sight point.

The system described in this paper is both a production tool and a research tool. Such a system would be one of the first useful systems to aid the highway engineer through interactive graphic techniques. As such, it would leave much room for future improvement, in both breadth and sophistication. It would, however, provide the means to study these techniques in a production environment and to obtain the reactions and evaluations of practicing design engineers.