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EVALUATION OF COMPUTER-AIDED DRAFTING AND DESIGN CAPABILITIES IN THE HIGHWAY DEVELOPMENT ENVIRONMENT

Final Report

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16. ABSTRACT

Significantly expanded highway construction and rehabilitation programs by the Arizona Department of Transportation resulted in an increase of design work load within the Highway Development group. Improvements in design and drafting production were attempted through the use of Computer Aided Drafting and Design (CADD) system. Originally the hardware and software for a small standalone CADD system with one work station was installed in order to evaluate the effectiveness of the system. The TERAK CADD system submitted by BFA Corporation was chosen for testing.

Initial studies concluded that the TERAK CADD system did not have the hardware that had the capability nor the software available to effectively prepare most highway construction plan sheets. The types of plan sheets that were evaluated along with other types of drafting functions that were conducted are described in the report.

During the early stages of the project a decision was made by the Department to purchase and install a major CADD system which would have the capabilities of serving the entire organization. The decision to purchase a major CADD system was based on the technology in use by various Departments of Transportation across the nation.

The study has concluded that a CADD system with proper hardware and software has an unlimited potential to reduce the cost and time in preparing plan sheets. However, the cost of such a CADD system is much greater than the amount that was budgeted for this project.

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INTRODUCTION

Throughout the past several years, the Arizona Department of Transportation has pursued an energetic and significantly expanded highway construction and rehabilitation program for improving highway transportation throughout the state. This expanded program resulted in an increase of design work load within the Highway Development Group and, in particular, Highway Plans Services.

With this increase of design work load, it became apparent that some action to increase production capacity was required, in particular an increase in drafting capacity. Research of the Engineering Consultant profession and other state agencies showed that improvements in drafting production could be accomplished through the use of Computer Aided Drafting and Design (CADD) rather than increases in personnel. In regards to drafting production, this research also indicated that the trend within the engineering field was toward a tremendous increase in the use of CADD.

CADD is a new concept of using computers to do the drafting and design. The concept is called interactive computerized graphics design. When an engineer/technician feeds the data for a design into a computer, the response he gets on the screen is a drawing of his design. The CADD equipment being used by the engineer/technician has the ability to graphically represent the design on the screen almost instantaneously.

In addition to getting the final design produced quicker, interactive graphics also provide the potential for a better design than before. The process allows an engineer/technician to develop numerous design approaches to any particular project. Once the design data is entered into a CADD system, additions, modifications, or deletions can be made very easily.

By mid-1983, a research project involving evaluation of a Computer Aided Drafting and Design system had been proposed and approved.

In October of 1983, the vendor's proposal for a CADD system was accepted and the system was delivered in January of 1984.

OBJECTIVES

The original objective of this research project was to determine if Highway Plans Services would benefit by converting to a computerized method of completing the Highway Design process, and to provide a recommendation on the future use of CADD in the design process within the Highway Development environment. The hardware and software for a small standalone CADD system with one work station was installed to provide Highway Plans design staff the use of the CADD in order to evaluate the effectiveness of the system in regards to equipment and usage procedures.

Investigation of various drafting applications was to find out which methods would prove to be more productive through utilization of the CADD system. An important part of this study was to determine the level of training that would be required.

During the early stages of the project a decision was made by the Department to purchase and install a major CADD system which would have the capabilities of serving the entire organization within the next two years. The new major CADD system would have the capabilities of networking all the CADD users together within the same system, thereby, making it possible for users from different services to transfer and exchange drawings very quickly and efficiently. The decision to purchase a major CADD system was based on the technology in use by various other Departments of Transportation in the United States. Consideration was given to proposed change in work load, work/service measurements, benefits (such as reduction in drafting costs, increase in productivity, and decrease in staff size), impact of not funding such a system, and capital outlay.

The decision to purchase a major CADD system together with the initial findings that the small standalone CADD system did not appear to have the capabilities in either the hardware or the software to efficiently develop the majority of the plan sheets required in a typical highway project prompted a re-evaluation and revision in the original scope of the research project.

The new direction of the research project was to use the small standalone CADD system to teach potential future users of the major CADD system how a CADD system operates and how it can be used to create the various types of drawings that are necessary to prepare a set of highway construction plans. A small group of Highway Plans design personnel were selected and two-person teams were formed to work with the CADD equipment.

Training sessions were conducted for each team to familiarize them with the basics of CADD software and hardware. Each team was allotted a minimum amount of CADD time each week and allowed to progress at their own individual pace. Because of the software and hardware limitations discovered during the initial testing of the system, the use of the CADD system was restricted to Overlay projects, typical section and detail sheets.

The system was also to be used to gauge the level of training that the users require to become proficient in the use of the system. Training and usage of the system was to be restricted to those ideas, methods and software commands that appear to be able to be transferred over to the new major CADD system. The new objective was to familiarize as many people as possible in the processes of a CADD system.

The standalone CADD system was also to be used to supplement any special drafting functions (Awards, forms, standards, etc.) being performed by Highway Plans Services personnel.

DESCRIPTION OF WORK COVERED UNDER THIS RESEARCH PROJECT

The plans to be prepared using the standalone CADD system for highway construction along with the specifications are the final result of the preliminary planning and survey of the area. They show the extent to which the design requirements are to be carried out and, above all, they constitute the documents on which a contractor is expected to figure his bid price and to construct a finished road. They also must be reviewed and thoroughly understood by the approving authority of the state and other organizations involved in building the road. Therefore, the plans should be completely and accurately drawn.

A typical full set of plans for an Urban or Rural highway consist of the following:

1. The Face Sheet:

   The Face Sheet includes the name and number of the project along with a vicinity map showing the location of the project with provision in the lower right corner for FHWA and Departmental approval signatures.

2. The list of Standards Sheets:

   These sheets list all applicable roadway Standard Drawings - Construction Details by number, name, and latest revision date.

3. The Design Sheet:

   This sheet shows length of project, index of sheets, general notes, present and design ADT, design speed, and a fully-dimensioned typical roadway cross-section and pavement structure composition. If required, tables are used to show location of changes in pavement structure composition thicknesses, cut ditch dimensions, cut and embankment slopes, and earthwork quantity summaries.

4. The Detail Sheet:

   This sheet provides construction drawings of all miscellaneous, nonstandard items not covered in the Standard Drawing - Construction Details.

5. The Quantity Summary Sheet:
This sheet lists summarized quantities, dimensional specifications for all drainage-related items and guard rail-related items.

6. The Plan and Profile Sheet:
This sheet shows the centerline of construction, with the bearing of tangents, stations of beginning and ending of curves, curve data, and station points; the right of way, and all existing detail drawn with dash lines. Also shown are the edges of the new road, new culverts and bridges, and all special features such as guard rail, retaining walls, turnouts, drainage, and all related notes.

7. Structural Sheet:
This sheet is prepared by the Structures Section and provides all details of the structures on the project.

8. Traffic Sheet:
This sheet is prepared by the Traffic Engineering Section and provides all details concerned with signing, lighting, traffic control, and delineation.

9. Roadside Development Sheet:
This sheet is prepared by Roadside Development Services and provides all details concerned with landscaping, landscaping irrigation, rest areas, and other roadside beautification facilities.

10. Material Sheet:
This sheet is prepared by Material Section and comprise:
    A. Sketch maps of borrow and aggregate sources.
    B. Test results for borrow and aggregate sources.
    C. Subgrade information and soil profile.

A typical full set of plans for an Overlay project consists of the following:

1. The Face Sheet.
2. The list of Standards Sheets.
3. The Design Sheet.
4. Material Sheets.

CADD SYSTEM REQUIREMENTS

The system to be acquired needs to satisfy the following minimum requirements:

A. The equipment should stand alone and be located in and operated by Highway Plans Services.

B. The software should offer security, not require a programmer for service, be capable of layering, accept some customizing, preferably accept other engineering oriented software and be user oriented.

C. The plotter should accept various paper sizes through "D" size plan sheets, operate with various sizes of ink pen line widths and pen qualities.

D. All of the equipment should operate on the normal 110 volt system and in the normal office environment.

E. The preferable system should offer ease of use, data base intelligence, associativity between graphic and non-graphic descriptive information, if possible third level software, drafting functionality to permit defining ADOT graphic symbols and quantitative calculations from the drawings.

SELECTION PROCESS FOR THE STANDALONE CADD SYSTEM

An invitation for bid was issued for the purpose of receiving cost quotations and technical proposals for a two-dimensional (2D) computer aided drafting and design (CADD) system for civil engineering applications.

The packages submitted by the vendors were analyzed and the handling capability of each software was rated using the following standards: Level I was considered to be below standard, its capabilities falling below the majority of the systems studied. Level II was average, its capabilities exceeding those of Level I but not those of Level III. Level III was above standard, its capabilities exceeding both Levels I and II. The performances of some of the hardware software combinations were observed and the documentation provided by the vendors was reviewed whenever demonstrations could not be provided .

One of the requirements of the system was that it be capable of driving a full "D" size engineering oriented plotter. Most observed systems used a Hewlett-Packard Model 7580A or were compatible with that plotter. In searching for the desired plotter, no other plotter could compete in price and quality with the ability to draw complete "D" size plan sheets.

The following is a brief description of the systems that the vendors submitted in response to the invitation for bid and subsequently were given consideration in the awarding of the contract:

The first package studied was CEADS provided by Holquin & Associates Inc. of El Paso, Texas. The price of the total package was $13,500 and operated on a Hewlett Packard Computer. The software rated at Level I.

The research included a Design Oriented Graphics system (DOGS) developed by PAEC in England. They have a representative in Knoxville, Tennessee. This CADD system is around Level III. It runs on Prime, Data General, VAX (DEC), Harris, Perkin-Elmer, Apollo and requires a minimum of 1 meg floppy disk, 20 meg fixed disk and 512 RAM. This software cost $20,000 for 1 user,

$30,000 for two users, and then $300 for each additional user thereafter.

A system by General Drafting systems (GDS) was also researched. This system was developed by Applied Research of Cambridge in England. GDS is a Level III software package that is available from McAuto. The price range was comparable to Design Oriented Graphics system (DOGS).

The studies included a system named MEDUSA that appeared to be an enhanced GDS. MEDUSA will only operate on a Prime Computer. The MEDUSA software cost $35,000, Prime Computer 2250 with a PW 200 Work Station cost $16,000, and the Hewlett Packard Model 7580A Plotter cost $16,000, giving the total package cost of $77,000.

The last system studied was the TERAK CADD system submitted by BFA Corporation from Scottsdale, Arizona. The components of the TERAK CADD system are listed in Figure 1. Figures 2, 3, and 4 illustrate some of the major components of the system. The software was rated at Level III. The price on their system including both hardware and software was $71,000.

The proposal submitted by BFA Corporation which consisted of the TERAK CADD system was rated the best overall and was selected. The TERAK CADD system was the only system that was able to provide local support for both the hardware and software which was a major consideration in making the final selection.

TERAK Model 8600B-23DGA Color Design Graphics system includes:

1. LSI 11/23 (16 bit microprocessor).
2. 128K bytes of memory.
3. Two floppy disk drives (2.4 megabytes total).
4. Quad RS232 serial interface.
5. 320x240 monochrome monitor.
6. 4601-19LFI 19" color monitor.
7. Keyboard.
8. GTCO Corporation DIGI-PAD 11"x11" digitizes tablet with one button puck.
9. Hewlett Packard HP7580B "D" Size Plotter.
10. 8518B-40WA Winchester Technology Hard Disk with 40M byte informatus storage capacity.
11. #84864 Mode Powermaker Topaz Uninterruptible Power system.
12. Programmable Design Graphix software.
13. DG-COGO Software Package.
14. OKIDATA MICROLINE 192 Printer

FIGURE 1 - TERAK CADD SYSTEM COMPONENT LISTING

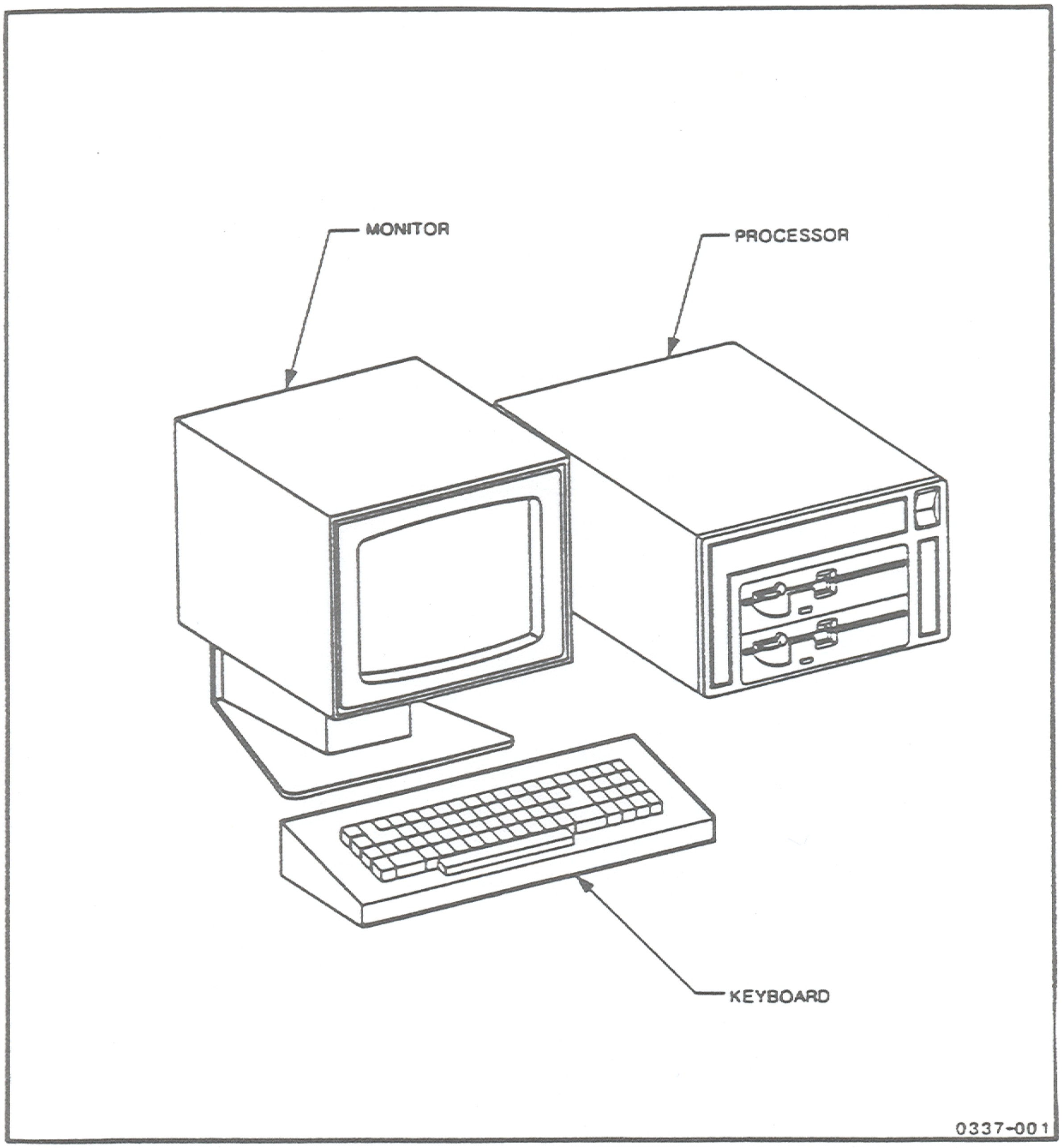


Figure 2 - TERAK PROCESSOR, MONITOR AND KEYBOARD

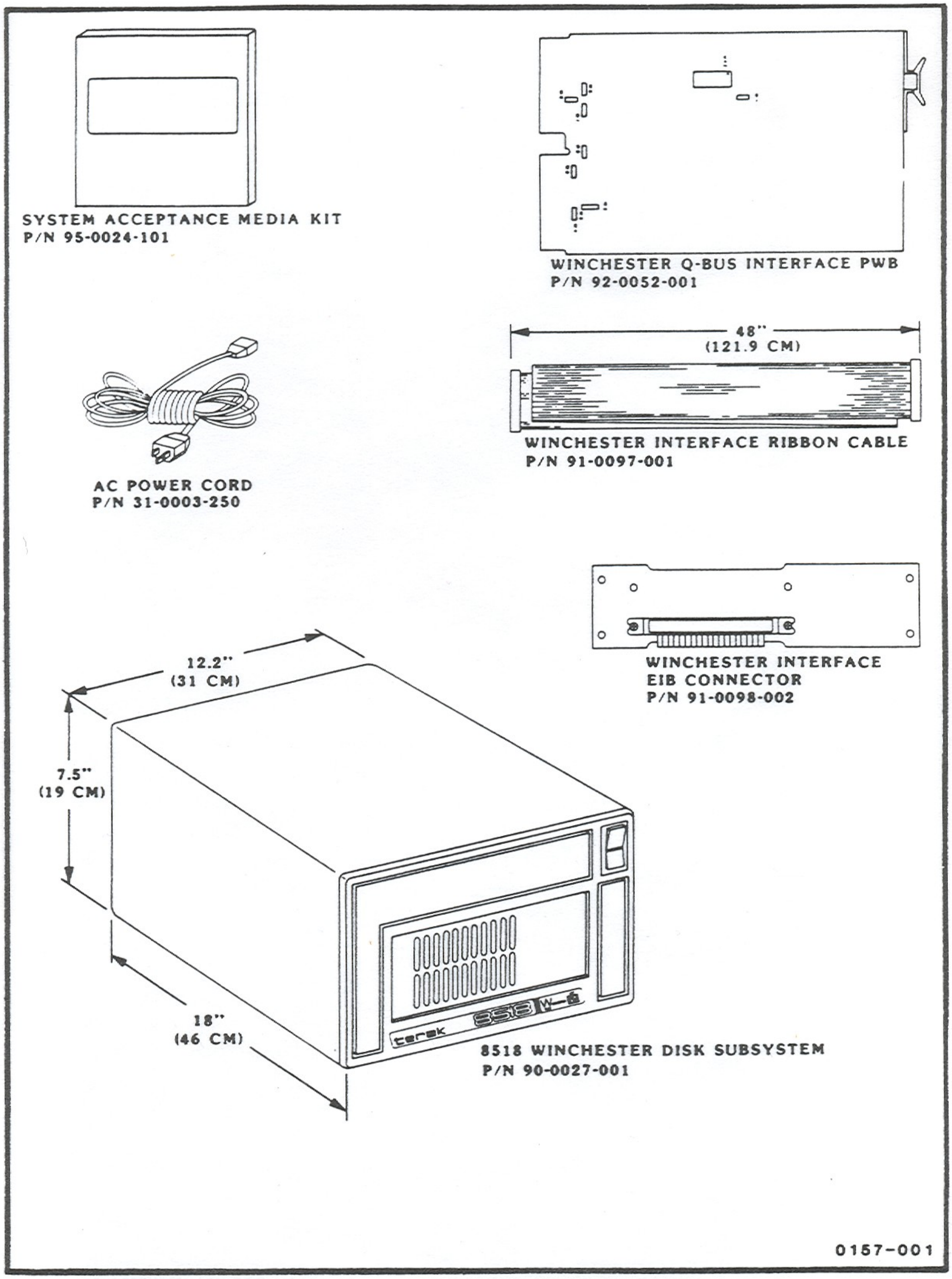


Figure 3 - COMPONENTS - 851B WINCHESTER DISK DRIVE ASSEMBLY

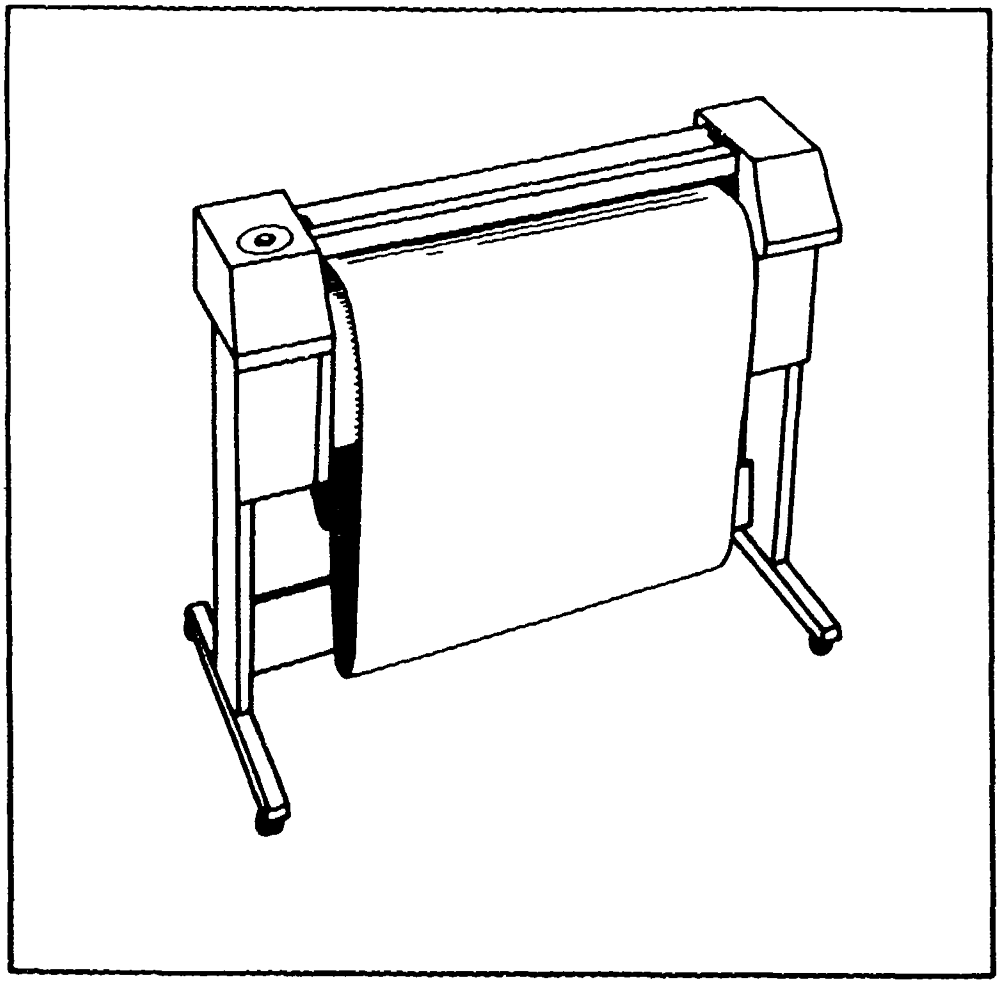


Figure 4 - HEWLETT-PACKETT 7580B PLOTTER

TERAK CADD SYSTEM EVALUATION PROCESS

The first step of the study after having received the training provided by the vendor was to research the system's capability to construct the various types of geometric elements including constructing tangent lines, parallel lines, perpendicular lines, points and arcs as they relate to the development of a highway plan sheet. One of the main concerns was to investigate the system's ability to develop coordinate geometry which is a critical part of the development of a typical roadway design project. A very large percentage of the items placed on a typical plan sheet are related in one way or another to a survey or construction centerline alignment. Therefore, the system's capability to enter a centerline alignment including station tick marks is very important. Another critical requirement is the ability to place elements on a drawing that are referenced to an alignment by a station and offset. The placement and manipulation of text strings and notes is also very important. Text notes are modified and moved on a plan sheet numerous times during the normal development of a project.

The following categories of a plan sheet development according to the original work plan were evaluated to compare the equipments' capabilities with normal manual conventional methods.

A. Layout and development of a Rural or Urban plan view sheet. See Figure 5.

   Major Tasks included:

   1. Develop and draw roadway alignments on a plan view sheet
   2. Draw existing topography and new roadway elements on a plan view sheet.
   3. Place and move text notes on a plan sheet.
   4. Move, copy or replace existing elements on a plan sheet.

It has been concluded that the TERAK CADD system does not appear to have the capabilities to easily develop and place

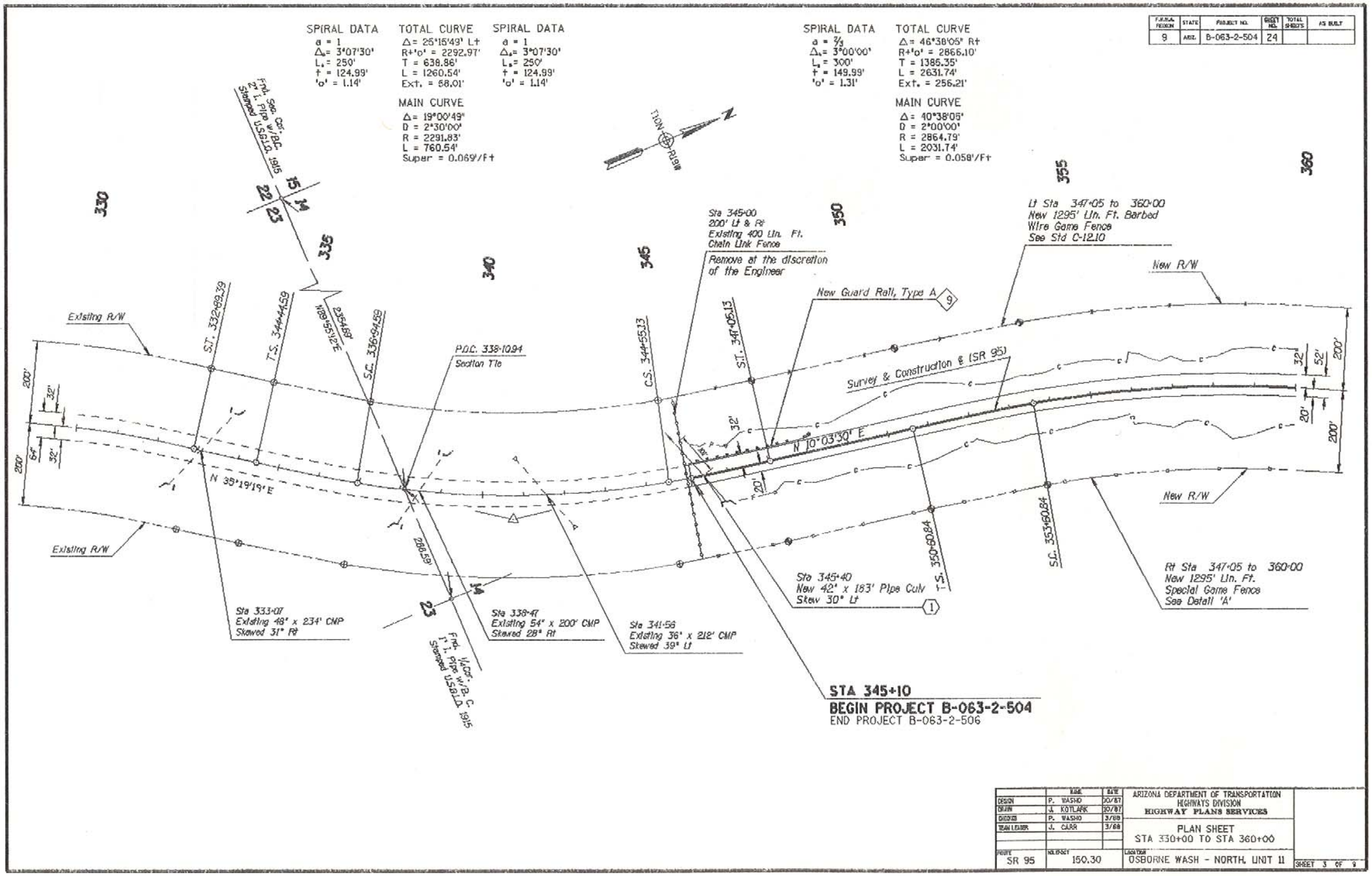


FIGURE 5 - PLAN VIEW SHEET

roadway geometrics on a plan sheet. Most roadway geometrics are difficult to do with the commands available on the system. The editing and redraw screen functions for large files are too slow (in excess of 20 minutes per occurrence). The slow editing and redraw screen functions makes the placement and revisions of text notes very difficult and time consuming.

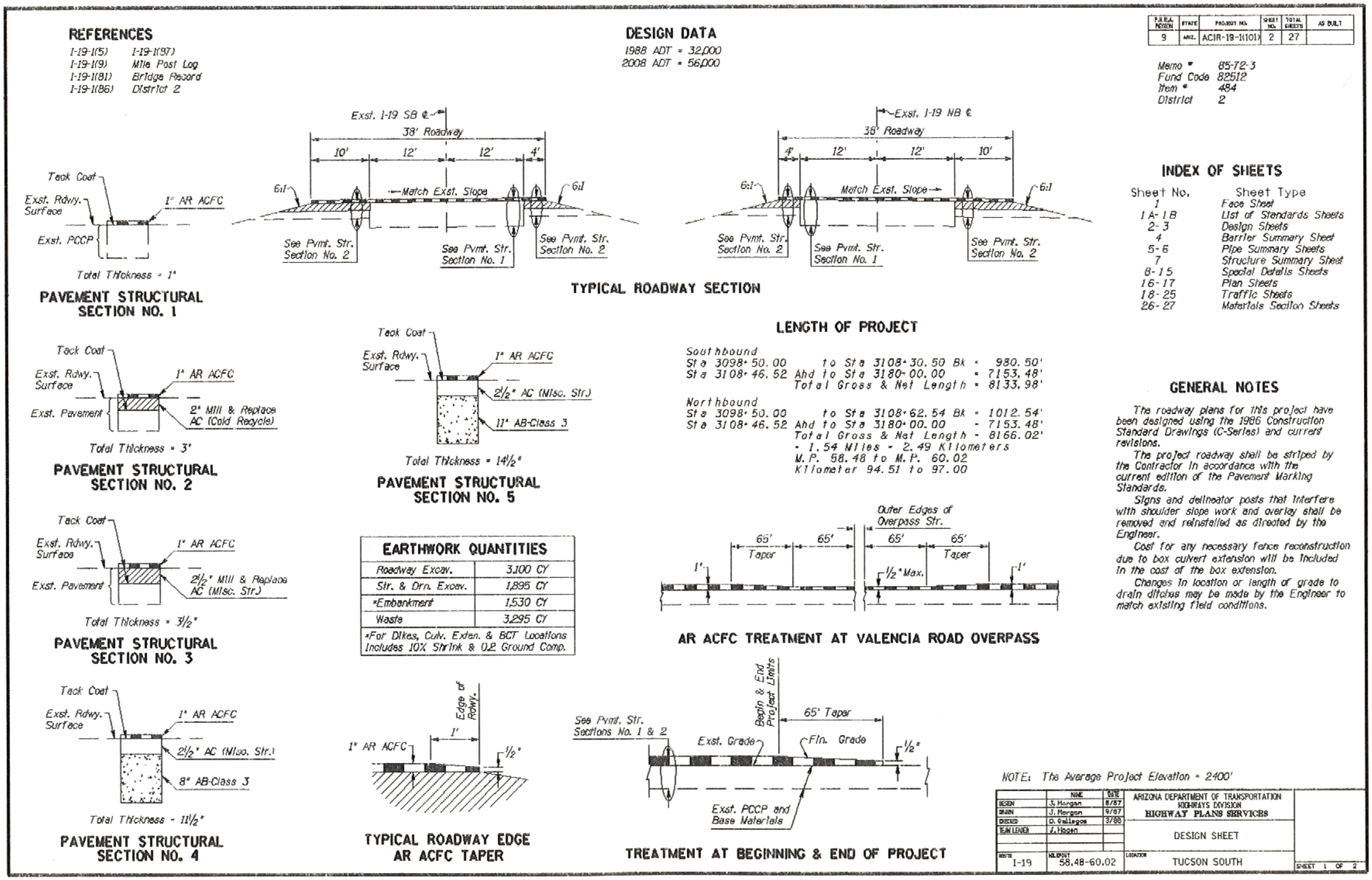
B. Overlay and Seal Coat Projects. See Figure 6.

Various other types of sheets such as Seal Coat, Overlay, Detail & Summary sheets were studied to determine if they could be done more efficiently using CADD as opposed to using conventional manual methods.

It has been concluded that the composition of this type of design sheet is an ideal application for the TERAK CADD system. Most of the information on this type of sheet changes minimally from one drawing to another. Another aspect of this type of sheet is that it is normally put together from a series of smaller drawings which allows the user to work with the smaller drawings individually before combining them all together to form a larger plan size sheet. This is a feature that is not possible with the regular roadway plan sheet having a roadway alignment and its related notes.

C. Standard Construction Details. See Figure 7.

A quick evaluation of the development of Standard Construction Details revealed that this function was a very good application for any CADD system mainly due to the repetitious nature of most of the drawings that are used to compile most standard construction detail sheets. Additionally, the majority of the details include separate larger complex drawings which show the placement of all the hardware (nuts, bolts washers, etc.) and complete details of construction. This type of drawing is normally difficult to draw manually because everything is drawn to actual scale and every piece of hardware that is part of the detail has to be shown and referenced in its respective location. The capability in CADD of expanding the drawing while working on it and later reducing the drawing to place it on a standard size plan sheet is ideal for this function. Also ideal is the capability of copying a portion of

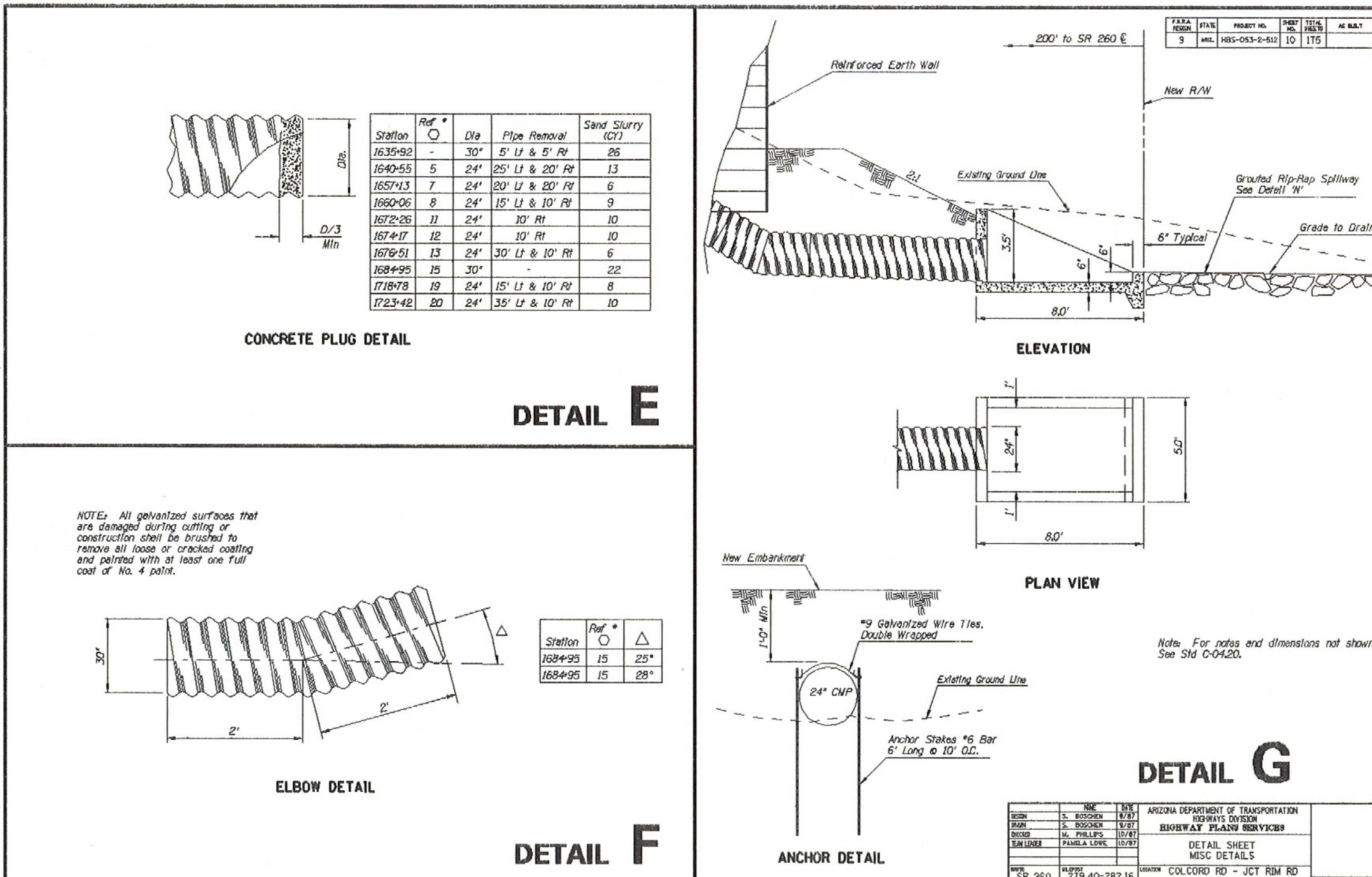


EARTHWORK QUANTITIES

Roadway Excav.	3,100 CY
Str. & Drn. Excav.	1,895 CY
*Embankment	1,530 CY
Waste	3,295 CY

*For Dikes, Culv. Exten. & BCT Locations Includes 10% Shrink & 0.2 Ground Comp.

FIGURE 6 - OVERLAY SHEET



Station	Ref # ⬡	Dia	Pipe Removal	Sand Slurry (CY)
1635+92	-	30"	5' Lt & 5' Rt	26
1640+55	5	24"	25' Lt & 20' Rt	13
1657+13	7	24"	20' Lt & 20' Rt	6
1660+06	8	24"	15' Lt & 10' Rt	9
1672+26	11	24"	10' Rt	10
1674+17	12	24"	10' Rt	10
1676+51	13	24"	30' Lt & 10' Rt	6
1684+95	15	30"	-	22
1718+78	19	24"	15' Lt & 10' Rt	8
1723+42	20	24"	35' Lt & 10' Rt	10

Station	Ref # ⬡	△
1684+95	15	25°
1684+95	15	28°

FIGURE 7 - STANDARD CONSTRUCTION DETAIL

a drawing and expanding it for clarity whenever it is necessary. The vast number of Construction Details having to be developed on the CADD system would cause a CADD work station along with an operator to be tied up for a very long length of time. The lower priority normally given to nonproductive types of design drawings along with the potential loss of one of the work stations from production work would force ADOT to treat this type of CADD usage as a future application to be done when additional equipment along with trained operators is available.

D. Graphics for Concept Design Reports.

A quick study of the TERAK CADD system determined that this equipment was not suited to do the type of drawings that are prepared and placed in Concept Design Reports.

E. Prepare projects in a controlled environment using both the existing manual methods and the new TERAK CADD system for the sake of comparisons.

The comparison part of the original work plan in the research project was never completed because it had already been determined from the initial studies that the system was not capable of producing the majority of the types of plan sheets that are required in a roadway construction project.

SUMMARY

The directions in the TERAK CADD system manuals are clear and the commands are easy to learn especially while using them to do the examples in the manuals and whenever creating small and simple drawings. Drawings which contained any coordinate geometry became very time consuming and difficult to create. Large plan sheet size drawings also are difficult and take a very long time to create.

The commands that are available on the resident software to do coordinate geometry are very limited and difficult to use. The software package DG-COGO, which was purchased as a supplement source of coordinate geometry added some commands to do coordinate geometry in addition to providing the capability to run the commands in a batch mode. Running coordinate geometry in a batch mode allows the user to store all the commands in a file that can be accessed. Modifications are easily made without having to re-enter the commands into the system again.

The TERAK CADD system does not have the required number and types of coordinate geometry commands that are necessary to do most highway related plans sheets. See Figure 8. The software package DG-COGO appears to be better suited for much smaller coordinate geometry applications especially ones without major roadways having alignments requiring coordinate geometry. The steps required to develop a typical roadway plan sheet on the TERAK CADD system are difficult and very time consuming.

The items noted below are some of the more important roadway functions that are also very difficult and time consuming to do with the TERAK CADD system:

1. Store a curve with a radius greater than 32,000 feet.
2. Draw a roadway centerline alignment.
3. Place alignment stationing and station tick marks at 100 foot and 500 foot increments throughout the length of a alignment.
4. Draw a roadway profile grade sheet.

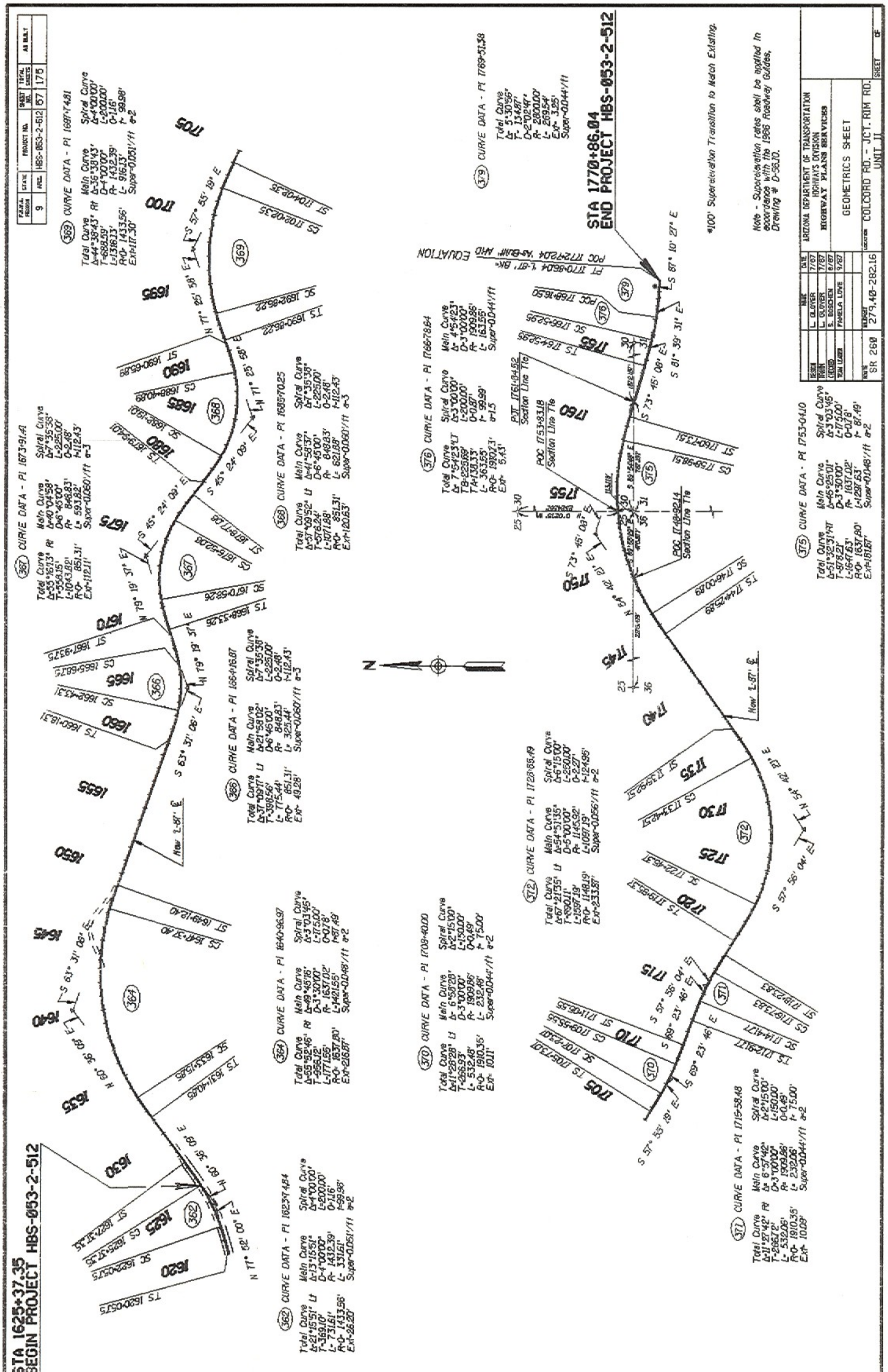


FIGURE 8 - GEOMETRY SHEET

5. Place and modify text notes on a full size (36"x24") Plan sheet.
6. Modifications to an existing plan sheet size file are difficult and time consuming. (Total edit and redraw time on the screen exceeded 30 minutes on most large files)
7. Zoom-in capabilities which are necessary for the accurate placement of elements are restricted due to the excessive time it takes to recreate the drawing on the screen. (Total redraw time on some plan sheet size files exceeded 10 minutes.

While it was found that creating plan sheets with the exception of Typical Section, Overlay and Seal Coat sheets is not very easily accomplished using the TERAK CADD system there are other uses for the system. The following items are drafting requirements that exist in many engineering offices that the TERAK CADD system is fully capable of performing:

1. Preparing new and special forms.
2. Design and development of small drawings using a very precise and exact scale. The drawing could then be scaled up or down for placement on a plan sheet.
3. Illustration of office room layouts including walls, partitions, electrical and telephone outlets and furniture. The system proved to be invaluable when it was used to determine how people and furniture could be rearranged to more effectively make use of the space that was available. See Figure 9.
4. Preparation of various types of special certificates that are presented to people at special occasions.
5. Training tool even after the new major CADD system was purchased because there is not enough equipment on the major CADD system to satisfy the demand for CADD time.

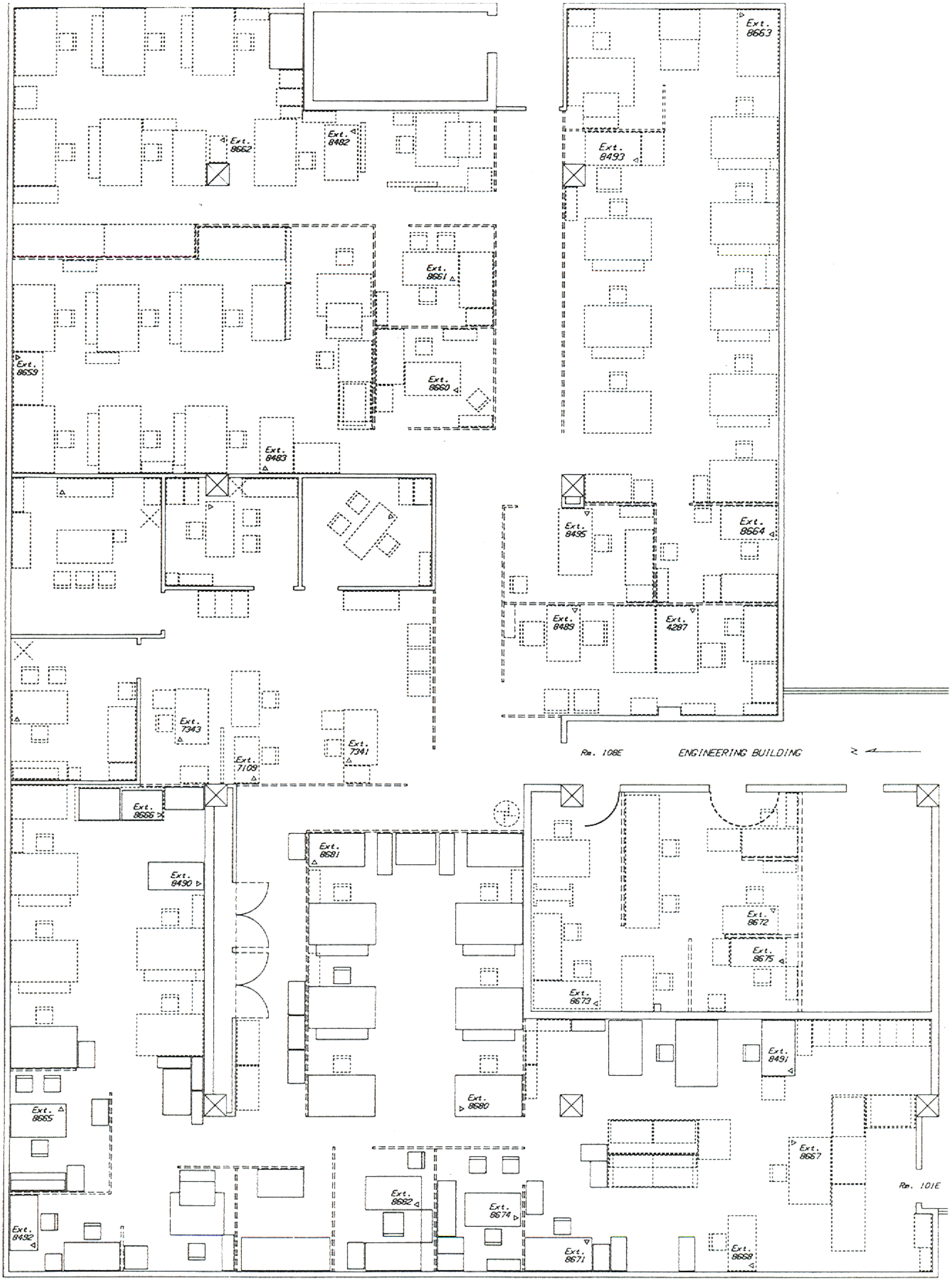


Figure 9 - OFFICE FURNITURE LAYOUT

RECOMMENDATION

The main purpose of this study was to determine if roadway plan sheets could be done efficiently using CADD. Despite the conclusion that the TERAK CADD system is not suited for this type of application it has been determined that the concept of automating the plan sheet development process is a very solid idea.

There are two basic reasons for the TERAK CADD system not being an effective manner of producing plan sheets. First, the equipment does not have the capability to display changes on the screen quickly. The user is losing valuable time while waiting for the screen to update. The second reason is that the TERAK CADD system does not have the software available to do the type of coordinate geometry that is required in major roadway design. There are CADD systems available on the market that have the capabilities in both the hardware and software packages to do major roadway plan sheets but the cost for those systems is much greater than the amount that was budgeted for this research project.

The study concluded that a CADD system with proper hardware and software has an unlimited potential to reduce cost and time in preparing plan sheets because of the system's ability to quickly modify drawings. Additionally, the system's ability to retrieve, combine and modify drawings will greatly save time and cost in creating new drawings.

In conclusion, the benefits that can be achieved by using a CADD system with the proper hardware and software requirements to prepare roadway plan sheets undoubtedly provide a definite improvement in both cost and product over the manual method of developing plan sheets.

The remarks about the TERAK CADD system are solely intended to serve as constructive suggestions to be used by anybody wishing to acquire a CADD system and should not be construed as an endorsement for or against the TERAK CADD system.