A Bridge Automated Design and Drafting System (BRADD-2)

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This paper contains the preliminary findings, recommendations, and development status of the BRADD-2 system research project. The objective of the initial phase of the research was to design a software system capable of performing computer-aided design and drafting of certain simple span bridges. This design involves the interfacing of new or existing analytical computer programs with computer-aided graphics display technology. Evaluation of existing analytical programs as well as state-of-the-art applications of computer-aided design and drafting (CADD) in bridge designs were also required.

This paper documents the preliminary findings, recommendations, and development status of the BRADD-2 system research project sponsored by the Pennsylvania Department of Transportation (PennDOT) *(1)*. The objectives of the research were to design and develop a software system capable of performing computer-aided design and drafting of certain simple-span bridges. These objectives involve the interfacing of new or existing analytical computer programs with computer-aided graphics display technology. The software design required evaluation of existing analytical programs as well as state-of-the-art applications of the computer-aided design and drafting (CADD) system in bridge designs.

The basic capabilities of the software include the following:

1. The system allows interactive input of basic geometric and engineering data needed to perform structural analysis and design of pertinent bridge components and to prepare complete bridge design drawings. The bridge components include the various superstructure and substructure types, as follows:

Substructure types
a. Stub abutment on spread and pile footings,
b. Reinforced concrete cantilever abutment on spread and pile footings,

Superstructure types
a. Precast channel beams,
b. Adjacent prestressed concrete box beams,
c. Spread prestressed concrete box beams,
d. Prestressed concrete I-beams, and
e. Steel multibeams and girders.

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2. Quantity and cost estimate calculations are automatically generated for desired bridge types. This procedure allows comparison and value engineering studies to be performed and conclusions to be drawn before final design drawings are generated.

3. The design drawings generated by the proposed system are to the appropriate scale and orientation typical of designs that are conventionally drafted. The drawings are generated in graphic design files and therefore accessible through the graphics workstation for review, modification, and additions as they normally occur during the design process.

4. The system has the ability to provide hard copy documentation of all required quantity, cost, analysis, and design calculations and full-size design drawings as requested by the user.

5. The system can be used as a design tool for separate bridge components without using drafting routines if desired.

6. Routines to partially draft bridge components designed separately are available.

BACKGROUND

In 1981, PennDOT retained a consultant, Buchart-Horn, Inc., to develop ready-to-use standardized bridge plans for simple-span steel, prestressed concrete, concrete, and wood structures. Development of "Bridges Low-Cost" (BLC) standards was completed in January 1985. The preengineered design and preprinted plans made it possible for a designer to greatly reduce the time required for generating contract documents even though the process relied on conventional manual computational techniques.

In 1983, PennDOT contracted Michael Baker, Jr., Inc., as a subcontractor to Intergraph Corp., to automate these standards in conjunction with the installation of an Intergraph CADD system. The new system was the bridge automated design and drafting (BRADD) system. The manual procedure of basic data entry, straight forward equation computations, and tabular lookups was replaced with a CRT data entry, interactive computations, alternative cost evaluations, and automatically produced drafted documents. Two out of six series of the BLC standards were completely automated, reducing design and drafting time to a few hours.

The BLC standards and the initial BRADD system (BRADD-1) proved that development of preengineered and predrafted systems was both feasible and practical and could save a substantial amount of design time. However, the obvious

limitations of the initial work, such as lack of scaled drawings, limited bridge types, foundation restrictions, and so forth, indicated the need for further improvement in the automation of bridge design and drafting.

The PennDOT evaluated two basic alternatives for improvement: the first was to expand the BLCs to remove geometric, structural, and foundation limitations, incorporating the expansion in CADD; and the second was to develop an interactive bridge design and drafting system. It was envisioned that in the long run the interactive bridge design and drafting system would be more cost-effective and more versatile, and could more easily permit future expansion than the BLCs.

Initially (in the spring of 1984), it was thought that development of a new interactive system should include simple, multiple, and continuous bridges using basically steel, concrete, and prestressed concrete construction materials. However, preliminary cost estimates indicated that a substantial investment of funding, time, and effort would be required to develop such a system. The interactive design and drafting (to scale) technology for civil engineering application is still in its infancy. The risks in going to such a broad system were considered to be great. Hence, it was decided to limit the development to single-span structures, expanding to multiple and continuous spans on success of the initial effort and availability of funding.

The success of BRADD–1 indeed led to a major expansion of the concept involving a second project (BRADD–2) to develop more sophisticated bridge design and drafting software. The later activities were projected to result in an automated system of analysis and drafting routines that allow the designer to consider a wider array of bridge types and have substantially more flexibility in the creation of contract documents than before.

Highway planning and research funding was secured, and with the concurrence of the FHWA, PennDOT retained a researcher, Michael Baker, Jr., Inc., who started the BRADD–2 project in early January 1985.

The initial phase (Task 1) of BRADD–2 was completed in October 1985; a report was published in November 1985 (2). The software development phase (Task 2), underway since July 1985, was scheduled to be completed by October 1986. System acceptance and availability of the software to other transportation departments was expected during the first quarter of 1987.

PROJECT DESCRIPTION

The overall objective of BRADD–2 was to develop an integrated software system that would combine and automate the design, analysis, and drafting steps for certain types of highway bridges. The system was to fully use state-of-the-art computer-aided design and drafting (CADD) technology in order to improve design productivity and reduce the time required to produce contract documents. It was envisioned that the software system would be expandable, permitting a wider array of bridge alternatives to be added to it in future projects.

Anticipated Results and Product Description

The general result of the BRADD–2 research program was to be computer software developed to run on an Intergraph

CADD system. The Intergraph system was rapidly becoming the standard for highway design purposes, having been chosen by many of the leading state transportation agencies and the FHWA. The software was to be developed on the contractor's Intergraph system and then installed on the PennDOT system for actual production use.

The operation of the software was to be interactive in nature. A designer, by interactive dialog with the computer, enters appropriate information, span length, deck width, elevations, loading type, and desired superstructure and substructure types, as prompted by an alphanumeric terminal. The software processes the input information necessary to make an informed decision regarding general bridge type and specific structural components. Documentation of the input information, analytical results, and cost estimates is supplied to the user in printed form if requested. On selection of a bridge design, the user can instruct the computer system to create a set of design documents within a specific CADD graphics file. These drawings can be edited or enhanced at an interactive graphics workstation using normal CADD drafting techniques available with the Intergraph equipment. Final plots, suitable as finished contractor documents, can be created for subsequent construction procurement processes on user request.

Research Methodology

The work for BRADD–2 was to be accomplished (3) in three major tasks covering system design (Task 1), actual software development (Task 2), and system installation on PennDOT equipment (Task 3). A lesser task (Task 4) was included for report production, documentation, and user manual creation. The precedence diagram (Figure 1) depicts the general work flow; each major task is briefly outlined in the following paragraphs.

Task 1—Evaluations, Recommendations, and Design of a Proposed Computer-Aided Design and Drafting System

Included in this task was a survey of existing bridge analysis and design software and CADD drawing generation routines. The purpose of the task was to investigate the feasibility of developing the proposed system and if feasible to design such a system. The result of Task 1 was a final report including an outline of a software system design presented for client review and approval.

Task 2—Development of the Proposed Computer-Aided Bridge Design and Drafting System

Task 2 began in July 1985 with the purpose of transforming the conceptual system design prepared in Task 1 into a functional software system. To provide practical limits to the project, specific superstructure and substructure types were identified. Engineering development such as the preparation of designs or design procedures for specific bridge components generally precedes actual software programming. Existing and acceptable bridge analysis and design routines were to be used
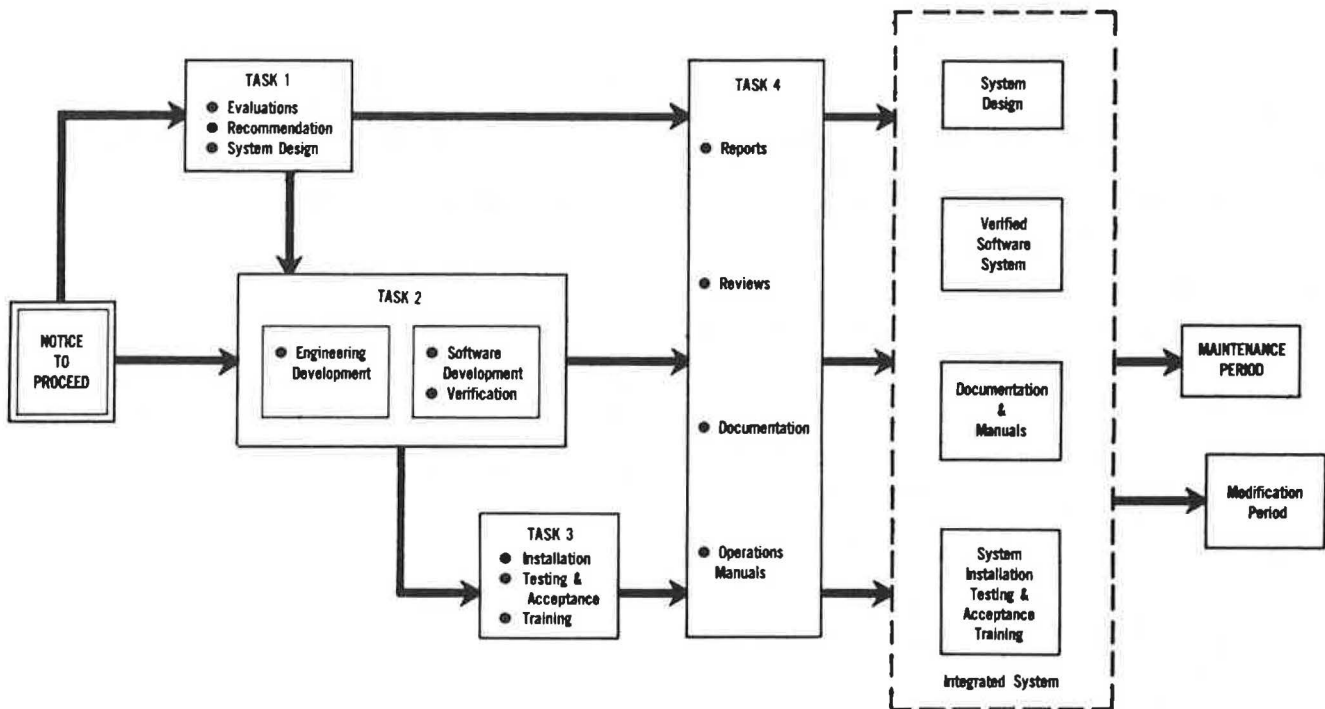
FIGURE 1 Precedence diagram—bridge automated design and drafting (BRADD–2) system development.

wherever possible so that the programming effort would be integration and interface oriented. Actual coding, testing, debugging, and verification were to be conducted at the consultant's computer facilities. The product of Task 2 was to be a working computer software system for bridge design, analysis, and drafting. The completion of this task was scheduled for October 1986.

Task 3—Installation of the Bridge Design and Drafting Software onto the PennDOT Intergraph System

This task entails installation of the software onto the department's system, testing and acceptance, training of PennDOT staff in its use, and a maintenance and modification period of 2 years. Testing and system acceptance are expected to be completed sometime during the first quarter of 1987.

Task 4—Preparation of Quarterly Reports, Final Report, Software Documentation, and Operational Manuals

In addition to quarterly reports documenting the general progress of the research, it was proposed that four documents be prepared. At the completion of Task 1, a final report was prepared (2). Following software development, the team was to produce a project summary, a system documentation manual, a procedural manual, and an operations manual. The system documentation and operations manuals were to be directed toward programming staff and to provide information necessary for program modifications and maintenance. The procedural manual was to be oriented to the bridge engineer or designer who actually uses the system.

Michael Baker, Jr., Inc., served as the prime contractor on the BRADD–2 project. Buchart-Horn, Inc., provided engineering support through a subcontract arrangement. These two firms brought together a staff with considerable experience in the development of standard bridge design components and procedures and the automation of those procedures using Intergraph equipment. Overall direction of the Michael Baker, Jr., Inc., work effort was assumed by J. C. Hayward. Project management of the software development was the responsibility of T. J. Tiberio.

GENERAL CONCLUSIONS OF TASK 1

Survey Evaluation

The highway survey of CADD (2) usage indicates that there is a strong interest to supplement computer-aided design programs with computer drafting packages. Some industries have already accomplished this link for special applications. The extent of computer-aided drafting varies for each application. In general, some packages assist operators in producing graphics files interactively whereas others produce them automatically.

The automotive industry uses specialized software to assist operators in creating graphics files interactively. This system suits automotive needs because of the large numbers of automobile components, each of which has numerous variations. Standard details are impractical because of the wide range of component configurations encountered in automobiles. Automated drafting of scaled details has a low priority because of the need for an operator to create custom drawings and the lack of standard details.

The survey indicated that building, highway, and bridge designs are well suited for automated drafting applications.

Designs for these applications are time-consuming and produce design drawings that are unique and useful for single projects only. These areas of design engineering lend themselves well to standard details. Reduction in the design and drafting effort, uniform plan presentation, use of standard details, and elimination of repetitious information during the design and drafting stages are some of the benefits that can be realized from automated drafting software.

Feasibility Study

Some examples of computer-automated drafting applications that have been integrated with computer-aided design include the following.

In 1972, the Oklahoma DOT developed a design and drafting package for prestressed I–beam superstructures, abutments, and piers. This comprehensive package produced complete design drawings and could be considered a forerunner of the BRADD system. This software package was developed before CADD systems were widely available.

Butler Buildings Systems developed a software system for analysis, design, and drafting of one-story steel buildings. This system designs structural members and connections. Final drawings are produced to scale complete with an erection diagram and materials list.

Westinghouse Corporation developed an integrated system for the design of pipe support systems in nuclear plants. This system allows an engineer to design the pipe support interactively using a finite element program. Final construction drawings can be generated from the output of the finite element analysis.

The CANDID program developed by Louis Berger International, Inc., provides automated drafting for highway geometry, earthwork, culverts, bridges, and buildings. Bridge drawings produced by this system include plan and elevation, abutments, and piers. This software produces generic drawings using data read from cards. The generic drawings require operator interaction to add details that are unique to each client.

As demonstrated by the preceding systems, integrated design and automated drafting systems are feasible. They have been developed for a variety of applications and provide an efficient means of designing bridges.

Development Requirements

In the development of the BRADD–2 system, it was important to consider certain limitations and requirements.

For example, development of an automated design and drafting package had to be followed by continued maintenance to update the system to current codes and standards. Failure to do so would result in an obsolete program and a loss of the initial investment. For example, the Oklahoma DOT bridge design system became obsolete because it was not updated for code changes and revisions to the standard details. The BRADD–2 system was to be modular, making future changes and enhancements easier and preventing the system from becoming obsolete.

Development Feasibility

An automated bridge design and drafting system was feasible; some versions had already been developed. Detail standardization, uniform plan presentation, and reduction in design and drafting effort were some of the benefits. The ability to efficiently modify and update designs, and perform cost comparisons made the system even more attractive. A state-of-the-art bridge design and drafting system enables highway industry users to achieve more benefits from their CADD investments.

BRADD–2 SYSTEM DESIGN

Overview

The BRADD–2 system consists of five major subsystems, input, design, reports, generation, and plot. These subsystems are connected as shown in Figure 2 and further detailed in Figure 3. The input subsystem controls the interaction of the user with the other BRADD–2 subsystems. The input subsystem gathers input data from the user for input to the database.
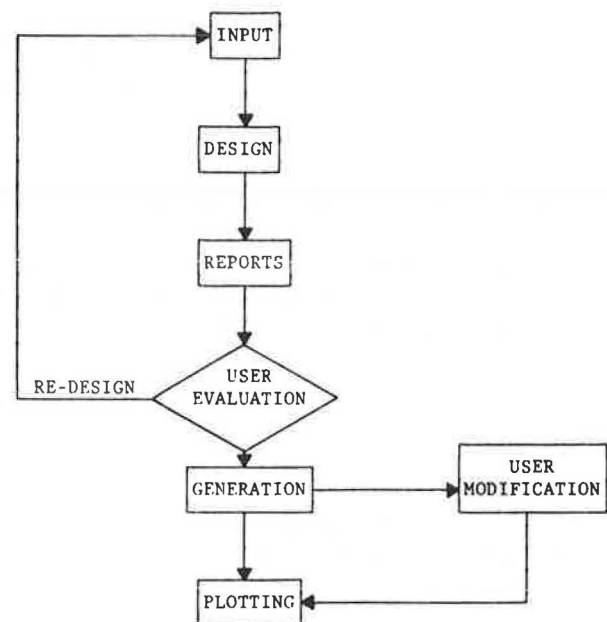

FIGURE 2   BRADD–2 subsystem flow chart.

From the input subsystem, the user can choose to proceed to the design subsystem. This subsystem contains all of the programs for the design of each component of the bridge. From the design subsystem, the user can proceed to the report subsystem. This subsystem generates additional data as requested by the user to help the user evaluate the design. After the report subsystem, the user may elect to execute the generation subsystem. This subsystem generates graphics design files containing the design drawing in standard scales and showing proper orientation and skew. The final subsystem is the plot subsystem. This subsystem generates plots from the graphics design files. This subsystem primarily consists of the standard Intergraph plotting package plus routines to automate the generation of the plots.

System Outline

The following gives a more detailed description of each of these subsystems.

Input Subsystem

This portion of the system consists of menus and prompts modification programs. The prompts programs cue the user for input data and store it in the BRADD–2 database. Prior to saving the data, the program checks the validity of the input and rescues the user when necessary.

The prompts modification program allows the user to modify input data and default parameters encountered in the design process. This program displays a current summary of the input data and permits the user to select the parameter to be changed. On selection, the user is prompted for the new information. Then the new data is validated and updated in the BRADD–2 database.

The BRADD–2 system has the flexibility of using simple interactive menus and prompting for input for the less experienced user but also allows abbreviated commands that permit more rapid movement through the system by the more experienced user.

Design

The design subsystem consists of three types of programs: preprocessor programs, component application programs, and postprocessor programs. Each type of program actually is a battery of programs for each design component.

Preprocessor Programs. Preprocessors extract data from the BRADD–2 database file to generate the input data necessary for each component design program. Data required for the design but not defined in the database are requested from the terminal. Temporary input files are generated for each design program.

Component Design Programs. The component design programs perform the actual engineering design required for
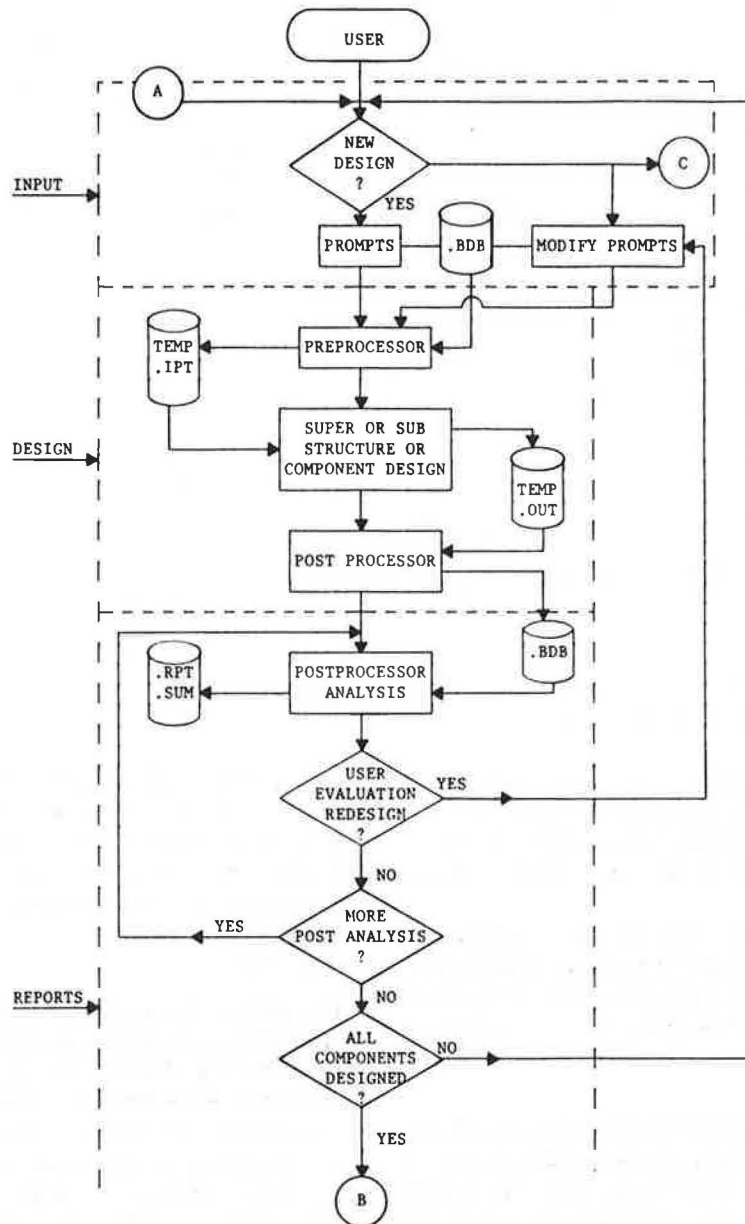

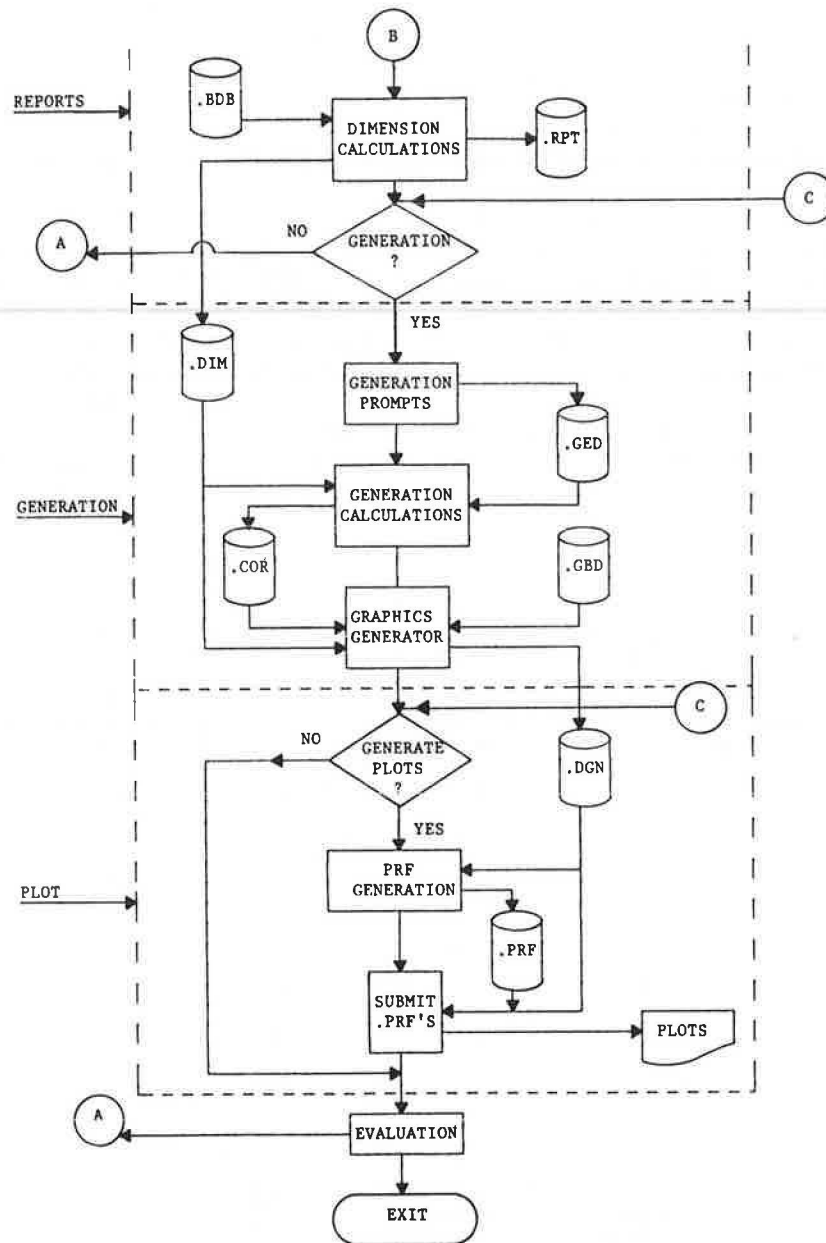FIGURE 3   Detailed BRADD–2 flow chart.

FIGURE 3 *continued.*

each component. These programs depend on the software selected from any survey of available programs. Some programs may design a large percent of the superstructure or the substructure whereas other programs may design smaller portions of the structure.

Postprocessor Programs. Postprocessors examine the output data from the design programs and place all needed data into the database file. Some data placed in the database may be from simple calculations made from the data in the output file.

Report

This part of the BRADD–2 system performs the detailed analysis of the results of the design programs. This analysis includes, for example, moment and shear output for a girder design, required area of steel for a concrete deck design, and quantity of prestressing strand for a prestressed beam. Another

analysis performed by the programs in this subsystem is detailed dimension calculations used for computing quantities, costs, and scaling data. The amount of postprocessing analysis is controlled by the user; more analysis may be requested to help the user evaluate the design.

Generation

This portion of the system, consisting of generation prompts, generation calculations, and graphics generation programs, generates final drawings in a graphics design file. The final drawings contain details placed at a specific engineering scale.

Generation Prompts. The generation prompts allow the user to specify the generation desired. Options include type, size, and location (TSL) drawings, superstructure drawings, substructure drawings, and a complete drawing set. These options allow the user to generate the drawings for only a portion

of the design. Redesign and generation of an abutment do not require the superstructure to be regenerated. The generation option selected by the user would be stored in a generation database to be accessed by other programs.

Generation Calculation. The generation calculation program computes necessary parameters to place each detail to scale. These parameters include node coordinates, detail location in the file, and detail scale value. These parameters are stored for retrieval in generating the design file.

Graphics Generation Programs. The graphics generator generates scaled design files using information from the dimension database, the coordinate database, and the graphics database. Elements read from the graphics database are placed in the design file at the coordinates specified in the coordinate database. Dimensions are then placed as defined in the dimension database.

Plot

This portion of the system generates plot request forms and submits them to the batch queue for plots. This portion consists of PRF generation and submit programs. The PRF generation searches the design file for drawing locations and creates PRF for these sheets. Then the submit program submits the PRFs into a queue to produce electrostatic plots.

MODULE FILE NOTATIONS

.BDB—BRADD Database
.IPT—Input
.OUT—Output
.RPT—Report
.SUM—Summary
.DIM—Dimensions
.GED—Generation Database
.GDB—Graphic Database
.COR—Coordinates
.DGN—Design
.PRF—Plotting Request

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