AASHTO Bridge Design System: A Status Report

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The Bridge Design System (AASHTO-BDS) is a proprietary computer software product under development by the American Association of State Highway and Transportation Officials (AASHTO). AASHTO-BDS is a product of the joint development process by which AASHTO member departments voluntarily pool their resources to produce mutually acceptable computer software products, and to propose specifications for unique transportation-oriented computer equipment.

Over twenty state highway departments, a Canadian province, and the Federal Highway Administration are contributing to the development of computer software which can be utilized by all parties for the design of highway structures. BDS, like other joint development products, is available for licensing to public and private agencies through AASHTO.

BDS software planning and development began in 1986 with selection of an engineering software contractor, BAKER/IAI, a joint venture of Michael Baker, Jr., Inc., and Imbsen & Associates, Inc. The development is monitored by a BDS task force comprised of representatives from five state bridge agencies and assisted by an AASHTO liaison officer. Release 2.6 of the BDS product is currently in use by more than twenty-five AASHTO members for production purposes.

AASHTO BDS is a bridge design system under development by the American Association of State Highway and Transportation Officials (AASHTO). This system is being implemented into production use by more than twenty-five AASHTO members since July, 1989 (AASHTO BDS Release 2.4). The complete bridge design process has been carefully considered in developing the BDS program architecture. The traditional practice of analysis and design on a component basis, the considerable body of software in use by design organizations, as well as the regional variation in type of bridge construction, has been factored into the system design.

These considerations resulted in a bridge design system which uses a database, database management system and a standards processor to allow iterative component-by-component design. When complete, BDS will allow an engineer to analyze, design and rate bridges within a single integrated software system.

In developing BDS, two general categories or user options have been established: A bridge model generation option for the routine bridge design and a general structure option for the finite element analysis of complex structures.

The bridge model generation option includes model generation for the analysis and subsequent design check of steel, reinforced concrete and prestressed concrete girder bridges. Bridges may be single span or multiple span with simply-supported or continuous spans. Structural framing characteristics include intermediate hinges, monolithic connections between the superstructure and the substructure, skewed supports at the abutments and bents, and sloped leg supports. Boundary conditions for the bridge model generation may be fixed, pinned, or roller. Bridge cross sections include slabs, T-beams and I-girders. I-girders may be either steel (built-up or rolled) or prestressed with noncomposite and composite concrete or steel decks.

Design checks are made for compliance with the AASHTO's *Standard Specifications for Highway Bridges, 13th Edition* for either the Service Load Design Method or the Strength Design Method. Future enhancements will include expanded design-check capabilities for rating and automated design. Force envelopes for the AASHTO design truck (with variable rear-axle spacing) and corresponding lane loadings are automatically generated. Additionally, special permit vehicles or alternative design vehicles may be stored in the vehicle library and easily referenced to produce design-force envelopes. The bridge model generation option available in Release 2.6 (June, 1990) includes only superstructure design. A high-priority enhancement to include substructure analysis and design is scheduled for the next release.

The general structure option was developed to give the designer access to the sophisticated analysis capabilities of the finite element method often needed for complex structures and unusual loading conditions. To date, bridge designers have relied on general-purpose structural analysis programs for these capabilities. Release 2.6 of BDS includes the finite element capabilities needed to conduct plane-truss, plane-frame, plane-grid and space-frame analyses. Node point and element generation capabilities are included to simplify the task of modeling large and complex structures. The node point and element generation capabilities are also useful in modeling a bridge for a seismic analysis in accordance with procedure 1 of the AASHTO "Guide Specifications for Seismic Design of Highway Bridges, 1983." BDS loading capabilities are tailored for bridge design needs to enable the designer to produce force envelopes for live loads, gravity loadings for members that are arbitrarily oriented in space (e.g., truss members, diagonal bracing), and other loads which are applied as permanent loads or temporary loads. The BDS general structure option may be used to simulate construction stage loadings by activating previously-stored members and supports. Boundary spring elements included in the general structure option allow the user to model unusual support conditions. Future releases of BDS will include special finite elements used in modeling bridge components and connections. Additionally, these capabilities may be expanded to include dynamic analysis capabilities needed for seismic analysis.

The *BDS POL Reference Manual* and its two companion documents, *BDS Users Guide* and *BDS Example Problem Manual*, describe the current capabilities and use of BDS. The *Users Guide* is intended to introduce the user to BDS. The *POL Reference Manual* describes in detail the use of the system, the language syntax and its semantics. The *BDS Example Problem Manual* presents selected problem solutions to illustrate how BDS is used for particular applications.

To date, the development of BDS basic architecture and database management capabilities have pre-empted the development of design features and capabilities. With the basic system developed, future enhancements will easily expand BDS into a comprehensive bridge design system.

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CURRENT STATUS OF AASHTO-BDS

The initial release of AASHTO-BDS (release 2.4) was delivered to participating states in July 1989 for implementation in production environment. A number of additional states have also licensed the product and taken delivery of the system following the initial release. Current BDS user states include Arkansas, California, Colorado, Illinois, Iowa, Kansas, Kentucky, Maine, Maryland, Missouri, Nebraska, Nevada, New Mexico, New York, North Carolina, Ohio, Oklahoma, Oregon, Pennsylvania, South Dakota, Tennessee, Texas, Virginia, Washington, West Virginia, Wisconsin and Wyoming, Federal Highway Administration and Province of Manitoba in Canada. AASHTO-BDS is now fully operational on VAX/VMS, IBM-MVS/TSO, and IBM-VM/CMS, and Intergraph Clipper platforms. The Clipper work station version of BDS was ported to for the State of Nevada and was subsequently accepted by AASHTO for maintenance and licensing.

The current release of BDS (release 2.6) was delivered in July, 1990. This release includes some of the enhancements which were suggested and prioritized by the users. Major releases of AASHTO-BDS to date are shown in the following table:

Release	Versions	Purpose
1.0	VAX, IBM	Interim Release
2.0	VAX, IBM	Beta Test
2.4	VAX, IBM	General Implementation
2.6	VAX, IBM, Intergraph	Enhanced Superstructure

The distribution package includes a tape containing the software, an *Installation Guide and System Managers Document, Users Guide, POL Reference Manual, Example Problem Manual* and *System Design Documentation and Programmers Guide.*

The AASHTO-BDS system is available for licensing on VAX and IBM equipment through AASHTO. workstation versions for Vaxstations and Integraph Clipper workstations are also available. The contractors will be available for continued support and maintenance of all of the released versions of the system.

Major enhancements are currently underway which will enhance the capabilities of the program in superstructure rating, user interfaces and .substructure design.

BACKGROUND OF AASHTO-BDS

The primary objective in developing BDS as a comprehensive bridge design system was to automate the total design by coupling the design of individual components with a database and an interactive process control system. Traditionally, bridges have been designed on a component-by-component basis using computer programs to complete each task. This approach has resulted in the development of a large number of programs which are not readily shared by the AASHTO member departments or by the private sector providing consulting services to these member departments. The AASHTO Joint Development Process was organized to provide a means whereby AASHTO member departments can pool their resources on a voluntary basis to produce a system such as BDS.

A secondary objective was to utilize, to the greatest extent possible, existing software in order to minimize the development costs and to preserve the confidence acquired in using home-grown software developed within the member departments. This second objective was somewhat difficult to achieve, in some cases, because the data handling by the database management system required substantial modifications to the existing software. Additionally, BDS was to be developed using stringent programming standards for ease of maintenance and future expansions. Software which potentially could be incorporated into the system was grouped into four categories, as shown in the following table. The categories were determined on the basis of such factors as internal documentation, programming style, functionality and completeness.

Level of Use	Modification	Examples
Entire Programs	None-Minor	POLO, SICAD
Group of Subroutines	Minor	OMBAS
Selected Subroutines	Minor-Moderate	SEISAB, STDS
Selected Algorithms	Rewritten	BRASS, SIMON

The level to which existing software was used varies from the incorporation of entire programs to the selection of computation algorithms which were modified for use in the environment of a database management system. As shown in the table, some programs were used with little or no modification while others were rewritten to achieve the same results.

AASHTO-BDS SYSTEM ARCHITECTURE

BDS is a modular system, designed for expandability and ease of maintenance. The overall architecture of the system is shown in Figure 1. Each of the elements shown in the diagram is, with the exception of the central database, a subsystem or module with prescribed tasks as explained briefly below.

Database

Database files may be viewed as the core of BDS as depicted in Figure 1. This is the control location where all bridge description data, run time data, and library information are stored. The BDS system contains some permanent database files and some temporary work files. The permanent database files include a DBMS control file, used by POLO-II; a standards file, storing a compiled form of the standard specifications; a library file, storing standard cross sections, vehicles, rebar information, etc.; a message file, storing system information, warning, and error messages; and a multi-bridge database, storing bridge descriptions for an unlimited number of bridges. The database work files are used for communication between modules. The pertinent data is obtained from these files via the DBMS and made available for each subsystem or module.

Database Management System - POLO II

POLO is the name of a software package developed at the University of Illinois under the direction of Dr. L. A. Lopez. The POLO DBMS constitutes a set of specialized modules designed to allow the programmer to construct complex hierarchical data structures that would appear to be in memory even though the total data space is many times the size of available primary memory.

Process Control System

This subsystem controls the flow of the program from subsystem to subsystem. The Process Control System (PCS) is responsible for overall management of the system. PCS can be viewed as the connection between DBMS and various subsystems as depicted in Figure 1. The functions of PCS can be listed as follows:

- Invoke execution of a portion of the program. This portion may consist of a set of subsystems, single subsystems, or portions of subsystems.

- Allow communication between subsystems through database and/or memory.

- Provide user flexibility and control in processing parts of the system. The user is allowed to process geometry alone, or change the list of output reports requested and receive a new output, or redirect the output file or device, etc.

- Promote modularity. It is important for the PCS to work in a way to encourage programmers to write modular code. This is achieved by an easy interface for PCS which allows a list of requests to be specified easily and efficiently.

User Interface

The user interface for the current release of BDS is a problem-oriented language (POL). The POL may be input through a file, it may be created via an integrated text editor (TXEDIT), or entered directly. In either case, the PCS will interpret the incoming POL command and activate appropriate modules or subsystems which may receive input data (POL) or perform calculations. When POL commands are read from a file, or created by the BDS text editor, they will be available for modifications or corrections during that session. The POL consists of control commands, which invoke various processes in BDS, and input data blocks which receive the bridge description and save it in the database.

Commands given for the input data description are organized into blocks such as BASIC DATA, BRIDGE COMPONENTS, etc. Each block may be repeated as many times as desired and there is no required order. Comments can be included in the command input lines for additional description and are separated by a semicolon (;)

START ABUTMENT 1;	Abutment and bent numbers are
OVER BENT 1;	arbitrary and should be
END ABUTMENT 2;	described separately.

Once a syntax error is detected by the system, the appropriate action is taken depending on the mode of input and process. In batch mode, the execution is halted. If the mode of input is interactive and the data is entered from a file or created by TXEDIT, the control is given to the BDS text editor at the erroneous line and the user is requested to correct the syntax. If the input is given directly, a message indicating the error is given and the user will have the chance to correct the input.

A utility program (MAKE_POL) is added to the VAX version of the system in Release 2.6. This utility allows BDS users to specify the bridge properties for common bridge configurations without having to learn the POL. The MAKE_POL utility will then use this information and prepare the POL input file for BDS.

Geometrics

This subsystem, shown in the top right corner of Figure 1, processes the input data related to the geometrics; i.e., reference systems, alignments, cross-section properties, and cross-section capacities. Many different local coordinate systems may be defined for node points and support directions. The input data are processed and relative angles between reference systems are calculated. During alignment processing, nodal coordinates are obtained from alignment stations and offsets. Cross-section processing includes calculation of area and inertia values for standard sections or obtaining data from BDS libraries. Section capacities are calculated to be used for specification checks. The geometrics subsystem also calculates the stress coefficients for various cross sections. These coefficients are applied to forces and moments to obtain stresses during solution. Figure 2 shows some cross sections processed by BDS.

Load Builder

The load builder subsystem is responsible for calculating element stiffness matrices and preparing load vectors for self weights, additional loads, moving loads, influence lines, and prestress loads. When the structure is constructed in stages, this subsystem calculates the equivalent loads for all leaving or entering elements and supports. This subsystem also calculates the losses in prestress forces, digitizes the cable forces, calculates the element loads due to prestressing, and builds the load vectors. In summary, this subsystem performs the finite element idealization of the bridge and prepares a mathematical representation of it for the solution subsystem.

Analysis, Modeler, Solver

This subsystem is normally invoked after the Load Builder, as shown in Figure 1. The three major tasks performed within this subsystem include analysis, model generation, and solution of equations. In the following, first the modeler, then the solver and analysis are described briefly.

The model generation capabilities of BDS allows the users to describe the bridge using bridge terminology without using nodes and elements directly. A bridge may be modeled as continuous beam, a plane frame, or a space frame. The three levels of model generation provide an option for the user to build a model which is appropriate for a given bridge. These models are referred to as Model 1, Model 2, and Model 3 in BDS. Figure 3 shows schematics of the three models available in BDS.

Model 1 is a continuous beam model with optional intermediate hinges. To describe this type of model, location of abutments and bents must be specified, the girder must be described, and located, and the support conditions must be specified by describing bearings and locating them at abutments and bents.

Model 2 is a plane frame model which is suitable for analyzing straight bridges with integral piers. The piers may be vertical or sloped. For Model 2 description, column and pier descriptions are needed in addition to Model 1 input.

Model 3 is a space-frame model which would be suitable for bridges on other than straight alignment or bridges with skewed abutments or bents. For Model 3 description, alignment description is needed in addition to Model 2 input.

The analysis package prepares the global system stiffness and load matrices. The solver then performs forward reduction and back substitution; i.e., solution of the equations. The remainder of the analysis package will calculate the forces, moments, stresses, and reactions due to various load cases, such as self weight, influence line, prestress, etc.

Loading Response Processor

This subsystem is responsible for organizing the results obtained by solver, loading the influence lines using the truck and lane loadings specified earlier, and calculating the load combinations.

The dead load results applied in each stage are accumulated and prepared for output. The self weight and prestress results are also obtained at specific points specified by the user. The user may request results at specific points in the girder by the distance into the girder or by percentage of span length. It is also possible to ask for results at specific intervals such as 5th points or 10th points.

The response processor will also apply the truck and lane loads to the influence lines generated by the Solution Module, and obtain the maximum results at the specified points. The impact factors are calculated based on the span length and applied to the results along with the input load distribution factors.

The response processor also calculates load combinations according to the AASHTO Table 3.22.1A. The factors in the table may be modified by the system managers at the installation time, but the individual users are not allowed to make any modifications.

The system was enhanced for release 2.6 to calculate and report the effect of sidewalk live loads, as well.

Standards Processing and Specification Check

The standards processor/specification checker subsystem consists of two parts. One is the standards processor (SICAD), and the other is the AASHTO specifications checker.

The SICAD is a standards processing system developed under the guidance of Professor Lopez at the University of Illinois for the National Bureau of Standards. Since this system is fully compatible with POLO, it was incorporated into BDS without much difficulty. The SICAD system compiles the standards and stores them in database files. The run time portion of SICAD performs the retrieval of standards and makes them available for specification check.

The specification checker portion of this subsystem includes the mapping of the results from the database to SICAD nodes and performs the actual check. The current release of BDS includes the AASHTO specifications for primary superstructure members. Steel, reinforced concrete, and prestressed concrete are available. The girders may be composite or non-composite, and both Load Factor Design and Working Stress Methods are available for either flexure or shear.

This subsystem was enhanced for release 2.6 to allow specification check on stiffeners, shear connectors and fatigue criteria. Also, a design option is added which calculates the required stiffener spacing and shear connector spacing.

The modular design of BDS and the structure of the specification checker are such that specification modifications, changes, or updates can be easily incorporated (such as those anticipated with the completion of NCHRP Project 12-33, "Development of a Comprehensive Bridge Specification and Commentary").

PLANNED ENHANCEMENTS

Three major enhancements are planned for near future, namely: rating, user interface, and substructure modeling and design.

The rating module will include calculation of the deteriorated section properties and calculation of operating and inventory ratings. The AASHTO Maintenance Manual and the new guide specifications both will be available, and the user can select either the working stress or the load factor method. It is anticipated that these enhancements will be available within the two releases following the release 2.6.

The new user interface will be based on menus and will allow interactive invokation and use of the system. This user interface will concentrate on the frontend, i.e. the data entry and processing tasks.

The substructure module will bring a number of new capabilities to the system. Some of these capabilities include Seismic analysis using response spectrum, bent model generation, transverse loading of a space frame model, substructure response calculation, bent cap design check, and column design check. As part of the substructure loading the truck and lane loads will be moved longitudinally and transversely to determine the maximum effect in the bent cap and columns.

Other enhancements include further upgrade of the user interface to a "point and shoot" windowing system; incorporation of on-line help; knowledge/rule based "expert" system to aid novice designers; more control of output options and format; and schematic graphics. The following schedule lists the tentative sequence in which the enhancements will be added to BDS:

- Superstructure — Haunced Element
- Substructure — Superstructure Load Transfer
- Substructure — Substructure Load Descriptions
- Substructure — Load Combinations and Envelopes
- Substructure — Seismic Analysis
- Substructure — Bearings
- Substructure — Bent Design
- Substructure — Foundations
- Substructure — Pilings
- Translators — BRASS
- Translators — AASHTO BARS
- Superstructure — Longitudinal Stiffener
- Superstructure — Slab Analysis
- Superstructure — Iterative Design
- Superstructure — Secondary Members
- Superstructure — Multiple Girder Lines
- Superstructure — Camber, Blocking Diagrams, etc.
- Superstructure — Grid Analysis
- Superstructure — Bid Quantities
- Superstructure — Schematic Graphics of Input
- Graphics — Moment Diagrams, Envelopes, etc.
- Graphics — Plan Sheet Generation
- Graphics — Three-dimensional Renderings
- Attaching Software to BDS
- User Friendliness — On-line Help
- User Friendliness — "Point and Shoot" Graphical Input
- User Friendliness — "Expert System"
- User Friendliness — Output Control

TESTING AND VERIFICATION

One of the important tasks in developing a comprehensive and versatile software such as BDS is the verification and testing. BDS is capable of analysis and design check of reinforced concrete, prestressed concrete and steel bridges, and many different configurations and loadings can be considered. In order to test and verify all aspects of the program an organized and rigorous testing procedure was developed and the product is tested according to this procedure before every release. This procedure is as follows.

During the first phase of testing and verification, i.e., the alpha testing, a number of bridges of various types are used and all major parts of the system are verified. In a subsequent beta testing period the system is installed and tested by a minimum of four highway departments of transportation. The problems which are identified during the alpha and beta testing are resolved to prepare the product for distribution. It must be noted that a system as large as BDS cannot be fully tested in a few months and minor problems may be found by the users. However, the contractors are available to receive problem reports and resolve them in a timely fashion.

SUPPORT AND MAINTENANCE

A team of qualified engineers, made of design engineers and software developers, is available for user support. This team has been helping the users with the installation, customization and use of the system since it was released. Some bugs have also been discovered and fixed since the initial delivery of the system. However, none of the bugs was serious enough to warrant an interim release of the system.

IMPLEMENTATION AND TRAINING

BDS release 2.6 has been distributed to the licensees. This release of BDS is available for VAX/VMS, IBM-VM/CMS, IBM-MVS/TSO, and Intergraph Clipper systems. User documentation to accompany the system includes Users Guide, POL Reference Manual, Example Problem Manual, and System Managers Guide. A Programmers Guide and System Design and Documentation Manual is also provided so that the participating states can develop their own subsystem or modify the current subsystems to fit their needs. It is anticipated that the workshops, documentation, and user support will provide enough information for BDS users to take advantage of many unique features of AASHTO-BDS system and provide enthusiasm and guidance for its continued maintenance and enhancement.

SUMMARY

The Bridge Design System (AASHTO-BDS) is a proprietary computer software product developed by AASHTO using the Joint Development Process. Over twenty state highway departments, a Canadian province and the Federal Highway Administration have contributed toward the development of computer software which can be utilized by all parties for the design of highway structures.

AASHTO-BDS is designed to be a comprehensive bridge design system. Special features of this system include a Database Management System, an interactive process control system, and modular design. Strong geometrics and analysis subsystems are included in this software as well as model generation, loading response processing and specification check capabilities. The input to BDS is in problem-oriented language which can be entered either interactively or from a file. The output reporting is very versatile in that reports are user selectable and any set of units or mixed units may be used for various reports.

BDS Product Release 2.6 has been distributed and is available on VAX/VMS, IBM/CMS, IBM/TSO, and Intergraph Clipper computers. BDS documentation includes a Users Guide, a POL Reference Manual, an Example Problems Manual, a System Managers Guide, and a System Design Documentation and Programmers Guide.

Enhancements planned for the near future include: substructure analysis and design check, rating, menu-driven user interface, and graphics. It is anticipated that with the support, maintenance, and enhancements planned for the system, coupled with the enthusiasm and feedback from the users, BDS would be one of the most useful tools for bridge design in the nation.

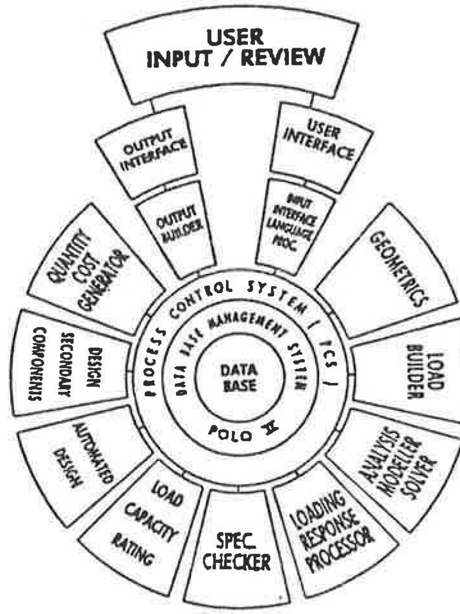

FIGURE 1: Overview of AASHTO-BDS System Architecture

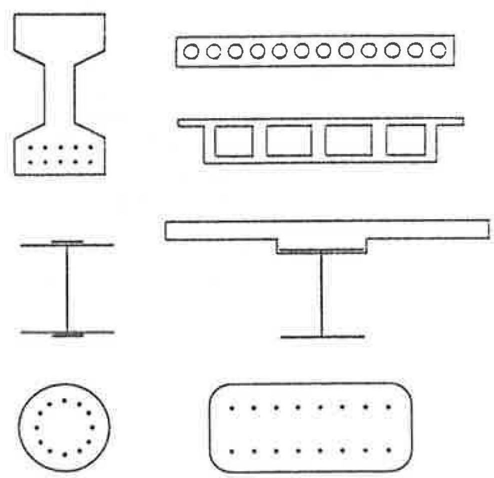

FIGURE 2: Typical Cross Sections

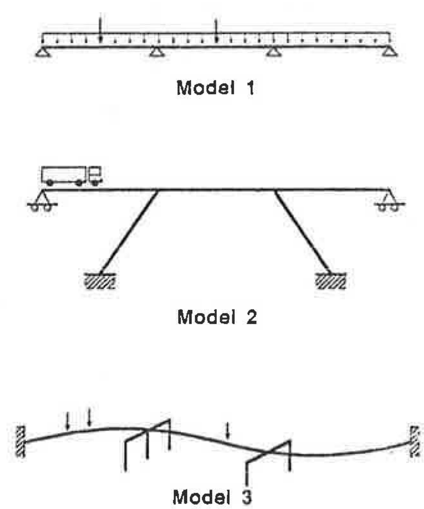

FIGURE 3: Model Generation in BDS