IMPLEMENTATION OF SAP-IV ON A MINICOMPUTER DISC OPERATING SYSTEM

R. B. SPENCER, G. E. HOWARD
Applied Nucleonics Company, Inc.,
P.O. Box 24313, Village Station, Los Angeles, California 90024, U.S.A.

SUMMARY

The objective of the described effort was the implementation of a linear elastic finite element structural analysis program version on a minicomputer operating system while maintaining (as much as possible) the general features of the original program. SAP-IV has been successfully implemented on a minicomputer operating system as one component in a portable vibration testing, data acquisition and processing, parameter identification and design optimization system for field work. The primary features in SAP-IV facilitating conversion and implementation on a minicomputer are: (1) the calculational procedures of SAP-IV are well documented and the subroutine structure easy to follow; (2) SAP-IV is organized in a highly modular fashion; (3) it is versatile with respect to its calculational options; and (4) the element library can be readily expanded.

SAP-IV was installed on a Data General NOVA 32K memory disc operating system which utilizes various input-output peripherals and a single 1.2 megaword disc. The entire theoretical analysis-vibration test-data analysis-parameter identification-model modification system required such additional components as analog/digital converters, computer-driven electro-mechanical vibrators, a maximum of 512 transducers, and special-purpose software for test planning, execution, data processing, and matrix manipulation.

The software system capabilities which allowed implementation of SAP-IV on the minicomputer were: (1) the availability of double precision; (2) the ability to use multiple OVERLAYS; (3) the ability to read and write programs from the disc to memory without destroying the programs (SWAP); (4) the ability to CHAIN a series of connected programs into the memory and execute them sequentially; and (5) the ability to utilize random access disc files.

As would be expected, several limitations are placed on the size of the structure to be analyzed and on the calculational options available to the design engineer. The present minicomputer version has the capability to analyze structures with up to 450 nodes and 200 degrees-of-freedom. The resulting equations must have a bandwidth of less than 50.

The present version will solve for the first 20 eigenfrequencies of the model structure. These restrictions limit the minicomputer version of SAP-IV to relatively uncomplicated models of structures.

The minicomputer implemented version of SAP-IV is a useful tool for performing survey calculations of structures requiring dynamic analysis. Extensive dynamic analysis can be performed on the minicomputer system for a relatively low cost to the user. Future modifications to the current minicomputer version will further enhance the capabilities and increase the speed of performing dynamic calculations of structures. The addition of powerful pre- and post-processors will further enhance the capability of the minicomputer SAP-IV software package and will result in an extremely powerful combination of programs for performing extensive preliminary dynamic analysis of structures.
1. Introduction

SAP-IV has been successfully implemented on a minicomputer system (BATHE, WILSON, and PETERSON) [1]. The objective of the modification and implementation was to provide the capability of a finite element program as a key part in a complete vibration analysis system for performance of on-line dynamic testing and analysis of structures (APPLIED NUCLEONICS COMPANY) [2].

The vibration analysis system was generated around a Data General Nova minicomputer utilizing a 32K word memory with each single precision word composed of two bytes with 16 bits per word. The total system includes the computer and several peripheral devices (a teletype, A/D converter, and disc system with 1.2 megaword storage capacity).

The Data General hardware and software system was selected because of its extensive FORTRAN-IV capabilities and combination of desirable features of the disc system which included the required software for implementation of SAP-IV (DATA GENERAL CORPORATION) [3]. The important FORTRAN-IV capabilities included the use of double precision arithmetic (providing 32 bits per word), the ability to CHAIN programs in the computer, the ability to SWAP programs from the disc to the memory and reuse of the SWAPped programs, and extensive OVERLAY capabilities, all of which are compatible with the real-time disc operating system (RDOS) software.

2. System Requirements

2.1 Vibration Analysis System

Full-scale vibration tests are frequently a most effective method for investigating the dynamic characteristics of a complicated structure or piece of equipment. The performance of a vibration test can be exceedingly time consuming, depending upon the complexity of the test structure and the number of measurements and instruments used in the test. With the development of small, dedicated computers, most of the tedious and time consuming tasks can be performed automatically or semi-automatically under the control of a computer.

The objective of the computerized vibration analysis system is to provide a means of controlling vibration tests and analyzing the data obtained from such tests. The computerized system consists of three main parts. The first part is the hardware comprised of a Nova computer and associated peripheral equipment including the analog-to-digital (A/D) conversion hardware; the second part is the control portion of the system, which includes specialized software for controlling the vibration tests, acquiring the test data, and assisting the engineers in conducting tests of the equipment; the third part of the vibration system consists of the analysis software, which includes: a computer-generated a priori dynamic model of the structure to be tested, programs which are used for reduction of the data from the dynamic testing, programs for modifying the a priori model to reproduce the test data, programs to determine the operational forces from the adapted a priori model and various operational tests, programs to determine the response of the model and the actual structure to high loads, and programs which provide information for the limited redesign of the structure to meet specified stress and vibration criteria. SAP-IV was selected as the basis for the computer program to generate the a priori dynamic model of the structure to be tested.

Figure 1 shows the vibration analysis system general flow diagram. This figure illustrates the relationship of the various computer program requirements for the system and
indicates the general sequence in which the computer programs are used in a normal mode of operation. The total software package consists of 16 separate computer program requirements with several of the programs being used more than once during the normal analysis and test procedure.

The modeling software consists primarily of the SAP-IV finite element program. The interactive data input for SAP-IV can be by either of two means; one is based on the SYCOD intelligent terminal key cassette system and the other is by means of a direct terminal interactive program. Both of these methods will prompt the engineer for the proper data input and will perform certain internal checks on the consistency of the input data.

After the modeling activity has been completed and the eigenparameters have been determined, the engineer can then proceed with the main portion of the vibration analysis system operation. Based on the results of the modeling activity, the engineer can generate a vibration test plan to select the optimal positions for the force inputs on the structure for the modes of interest and the optimum locations for the response measurements on the structure. After the vibration test plan has been generated for the engineer and the instruments automatically calibrated under computer control, the vibration test can proceed. The engineer has the option of allowing the vibration test to proceed under the automatic control of the computer using the vibration test plan or he may choose to interact at various points during the test to modify the test plan as the on-line results appear on the various display devices.

After the vibration test of the structure has been completed, analysis of the experimental data is automatically performed and the experimental eigenparameters of the structure are identified. Following eigenparameter identification, the original model, which was obtained from SAP-IV, can be modified to reproduce the response results that were experimentally obtained. In this way, a better model is obtained of the structure and can be used for subsequent vibration test planning and test execution control.

The other software requirements for the vibration test system shown in Figure 1 essentially repeat the vibration test process for various operational conditions and varying force levels input to the structure. The overall testing procedure may be repeated by varying the model parameters to obtain a limited optimization of the structural design. One final program summarizes all of the calculational output in a condensed form for a summary report of the entire process.

2.2 Hardware Description

The complete vibration analysis system is composed of the 12 main hardware items shown in Figure 2. The main computer consists of the Nova minicomputer central processor unit including 32K word memory and the various required interfaces. The A/D conversion system is used to digitize the incoming signals from the response accelerometers. The D/A conversion system is used to transmit force signals under computer control to the force exciters attached to the structure.

The teletype terminal provides keyboard data entry and printed page copy for the various interactive operations of the system. The paper tape reader and punch are used for both the automatic recording of data and programs in the computer and the permanent storage of data and specialized programs on permanent paper tape. The key cassette unit, with its associated cathode ray tube, is used primarily for off-line data entry into SAP-IV.
The disc subsystem is used to complement the fast core memory and is used for the rapid access of stored programs and data information. The magnetic tape units are used for reading and writing of information which is not used regularly by the computer and for the storage of large volumes of information. The printer and plotter are used to obtain hard copies of information generated by the computer for reports and visual inspection.

The cathode ray tube (CRT) graphic display is used for the temporary display of information as it is gathered and generated by the computer. The operator has the option of selecting the particular information displayed by the CRT that he wishes to display as a permanent record on the printer and plotter. The complete system also includes a hard-wired real time analyzer for performing rapid, on-line determination of various transforms and other significant attributes of the incoming signal data.

The minimum hardware required to execute the minicomputer implemented version of SAP-IV is shown in Figure 3. Basically, all that is required is the CPU and 32K word memory, the disc containing the executable programs, and a teletype for inputting data and producing hard copies of the output results. A typical minimum system such as this supplied by various minicomputer manufacturers currently costs less than $25,000.

2.5 SAP-IV Selection

SAP-IV was selected for use as part of the computerized vibration analysis system primarily because it fulfilled all the modeling requirements. In addition, SAP-IV had other features which made it desirable over other available finite element programs for its ease of conversion to a minicomputer. The primary features facilitating conversion and implementation to a minicomputer are: 1) the calculational procedures of SAP-IV are readily understood and well-documented; 2) the subroutine structure of SAP-IV is easy to follow; 3) SAP-IV is conveniently organized in a highly modular fashion; 4) it is versatile with respect to its calculational options; and 5) the element library can be expanded readily by implementing new elements as they become available.

The software system requirements which allowed implementation of SAP-IV on the minicomputer were: 1) the availability of double precision; 2) the ability to use multiple level OVERLAYS; 3) the ability to read and write programs from the disc to memory without destroying the programs (SWAP); 4) the ability to CHAIN a series of connected programs into the memory and execute them sequentially; and 5) the ability to utilize random access disc files. The effort required to convert, implement and maintain SAP-IV on the 32K word memory minicomputer has been approximately two man-years to date.

3. Programming Requirements

3.1 Implementation Strategy

The basic strategy was to implement only the minimum number of subroutines that would be required to execute a reasonable problem for modeling a structure typical of the type to be encountered during the utilization of the vibration analysis system. Once the minimum SAP-IV was implemented on the computer, additional options and elements could be added at a future time to increase the capabilities of the finite element analysis program. The vibration analysis system was designed to analyze the dynamic performance of structures. Therefore, an initial need for static analysis did not exist.

Most of the structures to be encountered during the anticipated use of the vibration analysis system could be adequately modeled by means of either three-dimensional beam
elements or thin plate/shell elements. In addition to these two elements, the boundary element would be required to specify a satisfactory model for real systems. Also, the ability to add point masses and translational and rotational springs at particular nodes was desirable. These basic minimum requirements thus defined the primary elements and calculational options which were required to fulfill the primary requirements of the vibration analysis system.

The three-dimensional beam element was selected because it could be used to simulate a truss element for many applications and would still retain the desirable features of the three-dimensional beam element. The thin plate and shell element was selected because of its modeling flexibility. The boundary element was selected primarily for the features of modeling an external elastic support at a node and to eliminate the numerical difficulty associated with shell analysis using thin plate/shell elements. Since the implementation of the first three elements, the three-dimensional truss element has been added to the element library for the minicomputer version of SAP-IV.

3.2 General Program Structure

Prior to a discussion of the minicomputer version of SAP-IV, it is instructive to review the OVERLAY structure of SAP-IV required for execution on a large computer system. A typical SAP-IV OVERLAY structure for execution on a large IBM computer is shown in Figure 4. This figure shows the major division of the subroutine OVERLAY groups which can be combined to facilitate the various calculational options of SAP-IV. Based on the vibration analysis system requirements discussed previously, several of the major subroutine groups may be eliminated from the required conversion process. Those subroutine groups which may be implemented at a future date are indicated by an asterisk on Figure 4. The group of subroutines representing the time history calculational option (shown by the double asterisk on Figure 4) was implemented shortly after the original conversion effort since the time history response would give a direct means of comparing the vibration experimental results with the analytical results obtained from SAP-IV for a particular structure.

The general structure of the NOVA/SAP implemented subroutines is shown in Figure 5. Each major block shown in Figure 5 represents a group of OVERLAYed subroutines which can be either SWAPPed or CHAINed into the main memory of the computer to execute a particular set of input conditions. The vertical sequence of subroutine blocks represents those sets of subroutines which are CHAINed into the computer. A CHAINed program has the characteristic that it writes over the existing program contained in the computer memory and the previous program is lost. The horizontal blocks of subroutines represent those sets which can be SWAPPed back and forth from the disc to the main computer memory. A SWAPPing operation has the characteristic that prior to SWAPPing a new set of subroutines into core, the old set is automatically written onto the disc with all of the updated data contained in the core memory. Thus, SWAPPing is, in effect, a type of "super OVERLAY" which retains all of the data values when the set of programs is reread into the core memory. The Data General software has the ability to go to four levels of SWAPPing and automatically return to the next higher level at the end of execution.

4. Operating Characteristics

4.1 Capabilities and Limitations

The minicomputer version of SAP-IV has some additional capabilities above those of the
original SAP-IV and also has many limitations relative to the original version or large computer version.

4.1.1 Capabilities

One additional capability provided with the minicomputer version of SAP-IV is the ability to use interactive input for the required modeling data. Two such interactive systems are available with the minicomputer version. One is based on the SYCOR intelligent terminal key cassette system. The SYCOR terminal has the capability of flashing a predefined format on the terminal CRT and the operator is forced to input the data in the proper format and location on the screen. The formats are stored on one cassette tape and are presented to the operator in the proper sequence. The input data are removed from the screen and stored on a second cassette tape and when the information is completed, the input data stored on the second cassette tape are transmitted to the computer and stored on the disc in the proper format.

The second method of interactive input is by means of direct terminal interaction. The operator sitting in front of the console is prompted by the computer to enter the required data relative to the structure being analyzed. The advantage of the direct terminal interaction over the SYCOR input method is that data may be input in any format and that the required number of prompting requests is automatically controlled by the computer based on the structural configuration defined by the prior input data. In addition, the interactive input programs will automatically select default values of input data and place these in the proper format in the input data file.

Subsequent to the generation of the input data file on the disc, the operating system provides for extensive editing capability so that the input file can be modified and edited prior to execution by SAP-IV. In addition, the input file may be renamed and saved for future executions and the operator need only rename the file to the proper file name and make minor changes in the data via the editing capability and the program can be run at a future date with very little input required from the operator.

The calculational timing feature of the original SAP-IV program has been retained in the minicomputer version by means of a real time clock under the control of the real time disc operating system. Elapsed clock times are printed out on the output after each CHAINing operation and after each element type has been calculated in the input and calculational process. The total elapsed time for calculation is printed out at the end of the program. These output elapsed times are very useful in establishing those areas where speed-up is required to increase the efficiency of the minicomputer version of SAP-IV.

The data checking capability of the SAP-IV has been retained in the minicomputer implemented version. Thus, the operator can quickly check the format and values of the input data without executing the complete dynamic solution as is allowed in the original SAP-IV version.

4.1.2 Limitations

As would be expected, several limitations are placed on the size of the structure to be analyzed and on the calculational options available to the design engineer. As mentioned earlier, the only option available in the present version is eigenvalue extraction (via subspace iteration) optionally followed by time history response calculations. The static analysis option and response spectrum analysis are not currently available. In
addition, the restart capability has not been fully implemented on the present minicomputer version.

The present minicomputer version of SAP-IV has the capability to analyze structures with up to 450 nodes and 200 degrees-of-freedom. The resulting equations must have a bandwidth of less than 50. The present version will solve for the first 20 eigenfrequencies of the model structure. These restrictions limit the minicomputer version of SAP-IV to relatively uncomplicated models of structures with the greatest expected use to be survey calculations to define various regions of analysis for more detailed calculations on large-scale computers.

4.2 Performance Characteristics

The performance characteristics of the minicomputer implemented version of SAP-IV have been established by executing many different types of test problems and fairly large examples of structures that were analyzed by means of the computerized vibration analysis systems. The analysis results of the minicomputer version have been compared to other test cases run on large-scale computers and the accuracy has been verified for a number of conditions to agree almost to the last significant digit. This is particularly satisfying when one realizes that double precision is being utilized and that the various hardware features of a minicomputer and large-scale computer are significantly different.

The running times for typical problems are, as would be expected, many times longer than for the large-scale computer version. There are, however, many methods available on the real time disc operating system which can be utilized to speed up the present minicomputer version. Typical ranges of running times for small problems (few elements, few nodes and small bandwidth) to large problems (50 to 100 elements, approximately 200 nodes and bandwidths on the order of 20 to 30) are on the order of five minutes to four or five hours, respectively. The main thrust of the near term continuing effort will be directed at reducing the running times for large problems.

5. Future Modifications

5.1 Elements

In addition to the four member element library in the minicomputer version of SAP-IV, additional finite elements will be incorporated in the future. The anticipated priority and order of implementation of the elements are given as follows:

1. plane stress, plane strain, and axisymmetric elements,
2. thick shell element,
3. three-dimensional solid element, and
4. pipe element.

These elements will be included as requirements dictate and funds and time are made available.

5.2 Options

Several of the options which are not now available on the minicomputer version of SAP-IV will be incorporated in the future. The anticipated order of incorporating the options are as follows:

1. restart capability,
2. static analysis, and
3. response spectrum analysis.

These options will be incorporated as the need arises for various applications.
5.3 Program Speed-Up

Various methods are available to speed up the calculational process for the minicomputer version of SAP-IV. One method which has been incorporated in a few of the CHAINed blocks is to provide block read and write for the COMMON arrays which are transferred from the core memory to the disc and back from the disc to the memory after the CHAIN operation. By reading the data in blocks as opposed to data records, a significant speed-up can be attained.

The Data General RDOS software system has the capability of optimizing the FORTRAN coding by means of a new compiler which will greatly enhance the speed of the program. The FORTRAN optimization software (FORTRAN-V by Data General) can be utilized to significantly increase the calculational speed of the program when combined with the floating hardware options that are available from the computer manufacturer (DATA GENERAL CORPORATION) [4]. Estimates have been made based on the use of FORTRAN-V on other similar software and reductions on the order of three to five times are typical.

5.4 Pre- and Post-Processors

To enhance the capability of SAP-IV, various pre- and post-processors are available which will be similarly implemented on the minicomputer system. The candidate processors which are anticipated to be converted in the near future are SAPLOT, SAPMIN, SAPOST, and ANASME. (HABIBULLAH, A.) [5 and 6].

SAPLOT is a pre-processor which will perform a plot of the input data to verify that the geometry and element location are specified correctly. A more detailed description of SAPLOT is given in Reference 5.

SAPMIN is a special pre-processor which will operate on the input data to renumber the nodes to minimize the bandwidth of the resulting equations. This pre-processor is very important to efficient operation of the minicomputer version of SAP-IV since the current version is restricted to a bandwidth of 50.

SAPOST is a post-processor for SAP-IV which will generate plots of the calculated mode shapes superimposed on the original structure geometry so that the engineer can readily observe the mode shapes for the various eigenfrequencies that are calculated (HABIBULLAH) [6].

ANASME is a proprietary post-processor of Applied Nucleonics Company and is used to perform stress calculations to meet the requirements of the ASME code utilizing the results from the SAP-IV analysis. This post-processor is still under development by Applied Nucleonics Company.

6. Conclusions and Summary

The minicomputer implemented version of SAP-IV is a useful tool for performing survey calculations of structures requiring dynamic analysis. Extensive dynamic analysis can be performed on the minicomputer system for a relatively low cost to the user.

Future modifications to the current minicomputer version will further enhance the capabilities and increase the speed of performing dynamic calculations of structures. The addition of powerful pre- and post-processors will further enhance the capability of the minicomputer SAP-IV software package and will result in an extremely powerful combination of programs for performing extensive preliminary dynamic analysis of structures.


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**FIGURE 1 : VIBRATION ANALYSIS SYSTEM GENERAL FLOW DIAGRAM**
FIGURE 2: COMPLETE VIBRATION ANALYSIS SYSTEM

FIGURE 3: MINIMUM HARDWARE REQUIRED TO EXECUTE SAP-IV
This overlay structure + file buffers + system overhead takes ~240K bytes on IBM 370/158

†Figure courtesy of Dr. R. Norton.
FIGURE 5: NOVA/SAP STRUCTURE