LARGE USER-ORIENTATED SYSTEMS OF PROGRAMS FOR STRUCTURAL ANALYSIS AND DESIGN

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SUMMARY

The trend in the use of the structural analysis programs is towards larger, more integrated user-orientated systems. The main aim of organising structural analysis systems of programs appears to be, to provide users with more versatile tools to reduce the required man-days and computing costs and to increase the scope and potential of the programs.

A large modular system is described constituting the most widely used structural analysis packages developed by CEGB. The principal motivation in developing the system is to rationalise and simplify the considerable diversification of applications and techniques currently available. The applications encompass elastic, thermal, dynamic, creep and plastic analyses of arbitrary two-dimensional and three-dimensional structures.

The system uses a standardised form of input for all applications and provides user-aides such as mesh generation, error facilities, output facilities (on-line and graphical) as integrated system modules. Calculational packages at present integrated into the system comprise FLHE-BERSAFE (thermal and elastic, two and three dimensions), TESS (creep and plasticity, two-dimensions), STAG21 (visco-elastic, two-dimensions). Various element types and a comprehensive selection of different solution techniques based mainly on finite element displacement model can be used in the analyses.

All data presented to the system are in the form of files (datalists) stored on 3330 magnetic disks. A comprehensive permanent disk library containing thermal and mechanical properties of the most commonly used materials is available to all users. The system is designed to be "open-ended" in the sense that new sub-systems can easily be augmented. It is envisaged that these additions will include structural analysis applications which are strictly outside the area of finite element analysis, e.g. frameworks.

The internal structure and mode of operation of the system are described in detail. Several diverse examples of nuclear design problems which have been studied are given. An examination and comparison with other large structural analysis systems currently available are given, together with a discussion of possible future developments in this field.

1. Introduction

The trend in the use of the structural analysis programs is towards larger, more integrated user-orientated systems. The main aim of organising structural analysis systems of programs appears to be, to provide users with more versatile tools to reduce the required man-days and computing costs and to increase the scope and potential of the programs.

The term 'system of programs' has at present a broad meaning and is used for large 'self sufficient' programs as well as for large and small program 'networks' (see for example Ross [1], Enderby [2], Horne and Wilson [3], Bergand & Alstedt [4], Argyris et al [5] and Zienkiewicz [6]). In this context we understand under 'system of programs' a large network of programs which are provided with common standardized input/output data interfaces and procedures to manipulate data and programs.

The principal motivation in developing the system software described in this paper is to rationalize and simplify the considerable diversification of applications and techniques currently available at CEGB. The expected benefits of developing common system facilities are two-fold. First it is to make easy the user's task of selecting the most appropriate stress analysis program to use in a given application, of assimilating the necessary basic expertise in using the chosen program and of assembling the data on geometry, loading and materials. Secondly, it is expected that common system facilities will provide a feedback and influence the future developments of new programs within the system 'network'. Using system facilities a number of programs within the network will probably be gradually eliminated and some will become more widely used than before, since the information about which particular program is best for a particular class of problem will be more readily available. For example, for costly time-dependent stress analyses the choice of methods and solution techniques is important and the system facilities will make it easier to compare alternatives and choose the most suitable models and techniques for further development. The system facilities will also increase the scope of complex analyses and the potential of users to solve more sophisticated problems (see for example Jezernik, Leech and Whitlam [7]). The 'open-ended' design of system network will enable the linkage of new sub-systems or programs with the existing system software.

In the presented condensed form of paper a short description of system facilities is given. The importance of the central disk library to store permanent or temporary standardized datasets which can be used by all programs in the network is underlined. Design analysis of a typical engineering example using system modules is described. Some conclusions are summarized.

A detailed description of system software and a review of several diverse examples of nuclear design problems which have been studied using the system facilities will be given in the final paper.

An examination and comparison with other large structural systems currently available will be given with a discussion of possible future developments in this field.

2. Description of System Input/Output Facilities and Disk Library

2.1 The CEGB System of Structural Analysis Programs

The system incorporates the most widely used finite-element structural analysis packages that have been developed in recent years at the CEGB. The general mode of operation of Phase 1 is illustrated in Fig. 2. Part of the development of the system has involved making modifications to the input and output routines of existing "stand-alone" programs. Fig. 1 shows the operation of the FLHE and BERSAFE suite of programs developed by Fullard [8] and Hellen [9] in the "classic" mode, together with compatible input and output facilities. Within the system (Fig. 2) these input/output facilities are available to all calculational modules.

2.2 PACK Datasets and Libraries

The basic feature of the system is the use of PACK datasets stored in libraries on 3330 disk. These datasets contain the data required by any of the system modules, and are in a standardised format. The datasets can be set up or updated directly from cards using the system module PACI (Fig.2), or can be set up by system modules, e.g. mesh generators, or calculational modules where results are required to be passed to another system facility. The datasets are accessible to users by way of keys which define the location on disk. System modules may then reference the dataset by means of direct access READ or WRITE statements. The data key consists of a six-character expression, the first of which defines the library name in which the dataset resides. The system at present consists of two libraries, the first of which contains thermal and mechanical properties of the most widely used structural analysis materials. This library is maintained and augmented at the Central Computing unit in a systematic way and its use is restricted to reading only. The other library consists of all other system datasets and system users may write into, or read any, but update or delete only their own datasets within this library.

2.3 The System Software

All modules within the system make use of standard software routines (PACKINDEX) which provide ease of communication between the modules and the data libraries. Fig. 3 shows how these routines may be used by any system module. A user name NAMUSR consisting of about four characters is supplied on an input card. The routine OPLIBS is then used to open those libraries for which the user has a write permit. Any attempt by the user to write into a library which has not been opened by OPLIBS will result in a system message and termination of job. The dataset key is usually read from a card or from a directory dataset (see 2.4) and is divided into two parts; LETTRX defining the library name and NUMBRX being an internal identification within the library. As an example, HO4003 would refer to data 4003 in library H. If the data key refers to an output dataset, one of the PACKINDEX routines will make a check that LETTRX corresponds to one of the library names opened by OPLIBS. Having made relevant checks, the PACKINDEX routines will

return appropriate values of LOGUNT and NRECRD so that the system module can access the dataset in the following way:-

```
(READ  
(WRITE (LOGUNT/NRECRD) List ----
```

Fig. 3 indicates that for a normal system user, only READS are permitted from the "permanent" data library.

2.4 Contents of System Datasets

The data required by any given system module usually consists of a number of datasets, each of which comprises data of a particular type. The different datasets used in Phase 1 of the system can be described in terms of the following headings:-

DIRECTORY
CONTROL
MESH
THERMAL LOADS
MECHANICAL LOADS
PRESCRIBED DEFLECTIONS
DECOUPLING
MATERIAL PROPERTIES

Each dataset is located on the disk by means of its data key (see 2.3). Normally only one dataset of any given type is required for a particular run. However, in the case of material properties, each dataset is used to define the properties of a given material. Thus, as many material properties datasets may be specified as are required to define the structure.

2.5 Input Facilities

All system datasets may be set up from cards using the module PACI (see Fig.2). This module may also be used to delete or update datasets, in the latter case only data items which are required to have changed values need be referenced. In the case of the FLHE and BERSAFE suite of programs communication with system facilities can be achieved using the "classic" form of card-deck input and conversion modules FLHECON and BERCON (Fig. 2). The main mesh generation facilities to be adopted into the system are BERMESH for 2-D and BERGEN for 2-D and 3-D. These two programs are the most advanced mesh generators so far developed at the CEGB. Older and less sophisticated 2-D mesh generation facilities such as TRIAD3 can be used within the system by means of the module MESHCON which converts a MESHGEOM tape file into a system mesh dataset.

2.6 Output Facilities

System datasets may be printed out in a standard form using the PACO module (Fig. 2) for the purposes of input diagnostics. Graphical mesh checking can be carried out either using facilities within the calculated modules or alternatively in the case of 2-D meshes by operating TESSPLOT on the mesh dataset. This latter module can produce either on-line or Calcomp mesh plots.

Results plotting may be carried out using BERPLOT which can produce Calcomp contour and deformation plots in 2-D and 3-D. For two-dimensional problems an alternative output facility is provided by TESSPLOT.

3. Example

The problem below illustrates the use of the system to carry out a thermal analysis on a typical CEGB power station component. Fig. 4 shows a cross-section of a boiler tube together with a small thermocouple container welded to the main tube. The structural integrity of the attachment is considerably affected by the peak temperature. It was required to carry out a number of calculations with different thermal loading conditions to determine the effect of weld thickness and thermocouple tube thickness on the temperature distribution within the boiler tube and attachment. Fig. 4 shows the four geometries considered for the study. The finite element mesh consisting of EP6 (simple triangle) elements, was created from a DMAC digitisation and program TRIAD3. Fig. 5 shows the mesh idealisation for Geometry 1. Fig. 6 gives the mode of system operation employed in solving the problem.

The basic data for presentation to the system was created as follows. The MESH dataset was created from TRIAD3 output tape using module MESHCON. Other datasets required for the run comprised DIRECTORY, CONTROL, THERMAL LOADING and MATERIAL PROPERTIES and were set up from cards using PACI. The THERMAL LOADING dataset corresponded to the conditions given in the table in Fig. 4. The program FLHE was used to carry out the thermal analysis. Initially one run was carried out to check that the mesh idealisation produced satisfactory results, before proceeding with the costly bulk of runs. The module PACI was then used to update the THERMAL LOADING and MATERIAL PROPERTIES datasets, by specifying on cards the data items required to be changed from the "base" case. The calculation thus proceeded in a logical manner, using PACI and FLHE in alternate "jobsteps", all 23 cases being calculated in one computer submission. The output was edited into an assimilable form using TESSPLOT to produce on-line and Calcomp contour plots of the temperatures. Table 1 gives peak temperatures calculated in the series of runs.

4. Summary and Conclusions

The system network and facilities have been described and illustrated briefly in previous chapters.

One of the main benefits of using system facilities for the user-engineer is the simplicity of data and program manipulation. As explained previously the standardized datasets created by using standard procedures are stored on a 3330 magnetic disk and can be retrieved, deleted or updated by using six character keys for identification. Any variable in a dataset on disk can be updated directly without referring or specifying other unchanged quantities. All datasets in the permanent and temporary disk library could be used by any stress analyst and any program in the system network.

Another advantage of using the system facilities is that the network can be used at any 'level' appropriate to the knowledge of the user from very simple to sophisticated combined analysis. Only a limited knowledge of system facilities is required by the user and any program in the network can be used individually or in combination with any other programs. Thus every user can familiarise himself with only the appropriate program or group of programs within the network required for the analysis and because of 'standard' input/output only limited knowledge of the features of the particular program is required.

The structural evaluation of nuclear power plant components requires increasingly more complex analysis considering combined thermal and mechanical loading conditions. Typical examples are the reactor components of HTR and CFR at high temperatures which under thermal and mechanical loading conditions have to be examined for creep, plasticity and dynamic effects in steady state and transient conditions. In these applications an easier selection of the most appropriate and economic system module for a particular analysis can be made and a number of analyses performed in one combined run.

The main benefits for further research and development of new programs for specific applications are expected to arise from qualitative comparison of various routines, programs, models, solution techniques etc., within the network and the selection of the most suitable units for further development. The possibility of combined analysis using a number of system modules could propagate the development of particular features in specific programs to enable new modes of combined analysis.

Another possible direction represents further development of disk library facilities and system software programs (PACI, PACO) to manipulate data and programs. This development is expected to lead to further simplification in preparation, utilisation and presentation of data and results. It is thought that the development of general system facilities should be 'backward compatible', i.e. it should not affect the existing usage and previous software development.

5. References

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Table 1. Peak Temperatures from Boiler Tube Study

Peak temperatures occurred at:-

Node 131 for Geometry 1
 Node 113 for Geometry 2
 Node 131 for Geometry 3
 Node 113 for Geometry 4

Case	Peak Temp °C	Case	Peak Temp °C	Case	Peak Temp °C	Case	Peak Temp °C	Case	Peak Temp °C	Case	Peak Temp °C
1	670	5	782	9	719	13	690	17	567	21	722
2	748	6	913	10	797	14	760	18	567	22	828
3	646	7	743	11	695	15	661	19	567	23	690
4	705	8	841	12	755	16	715	20	567	24	768

USED FOR THE LINEAR ELASTIC ANALYSIS OF ANY 2-D OR 3-D STRUCTURES AS MANY AS 20 TYPES OF FINITE ELEMENTS ARE AVAILABLE AND THE IMPOSED LOADING CONDITIONS MAY INCLUDE: POINT, PRESSURE, CENTRIFUGAL OR GRAVITY LOADS, PRESCRIBED DISPLACEMENTS AND THERMAL LOADING CAUSED BY INTERNAL OR EXTERNAL HEAT SOURCES.

FIG. 1. THE BERSAFE AND FLHE SUITE OF PROGRAMS

FIG. 3. PERMANENT AND TEMPORARY DISK LIBRARIES

GEOMETRICAL DATA

$D_1 = 5.08 \text{ cm (2")}$
 $D_2 = 0.9525 \text{ cm (0.376")}$
 $t_1 = 0.6985 \text{ cm (0.296")}$
 $t_2 = 0.16256 \text{ cm (0.064")}$
 $= 0.23368 \text{ cm (0.092")}$

GEOMETRY 1 & 2;
 GEOMETRY 3 & 4

STANDARD THERMAL LOADING CONDITIONS

Steam temperature $T_s = 500^\circ\text{C}$
 Heat flux $H = 1.895 \times 10^5 \text{ W/m}^2$
 Angle of heat flux $\alpha = 0^\circ$
 Heat transfer coeff. $h_s = 6.25 \times 10^3 \text{ W/m}^2\text{ }^\circ\text{C (steam side)}$
 Weld efficiency $W = 1.0$
 Thermal conductivity $K = 33.6 \text{ W/m } ^\circ\text{C}$

THERMAL ANALYSIS

Case 1-4 : Standard loading conditions except for $H = 1.66 \times H$
 Case 5-8 : Standard loading conditions except for $T_s = 550^\circ\text{C}$
 Case 9-12 : Standard loading conditions except for $W_s = 0.50$
 Case 13-16 : Standard loading conditions except for $\alpha = 90^\circ$
 Case 17-20 : Standard loading conditions except for $K = 24.4 \text{ W/m } ^\circ\text{C}$
 Case 21-24 : Standard loading conditions except for $K = 24.4 \text{ W/m } ^\circ\text{C}$

FIG. 4. THERMAL ANALYSIS OF BOILER TUBE CONFIGURATIONS

FIG. 5 BOILER TUBE MESH

N.B. DOTTED LINES INDICATE AN 'OFF-LINE' ACTIVITY.

FIG. 6 USE OF SYSTEM IN SOLVING BOILER TUBE EXAMPLE