COMPUTER GRAPHICS IN REACTOR SAFETY ANALYSIS

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by

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ABSTRACT

This paper describes a family of three computer graphics codes designed to assist the analyst in three areas: the modelling of complex three-dimensional finite element models of reactor structures; the interpretation of computational results; and the reporting of the results of numerical simulations. The purpose and key features of each code are presented. The graphics output used in actual safety analysis are used to illustrate the capabilities of each code.

INTRODUCTION

The safety analysis of reactor structures and components oftentimes leads to the development of large complex finite element models. These models may require a considerable amount of time for finite element mesh generation, numerical simulations, and evaluation of results. In order to assure that these models are properly constructed and that the computed response to loadings are reasonable, it is absolutely necessary to use computer graphics. The objectives of this paper are: (1) to present our graphics developments, and (2) to illustrate their use in the analysis of reactor safety problems.

Our efforts in developing computer graphics packages began in the mid-seventies as a task to display three-dimensional finite element meshes. Over the years we have added capabilities on an "as needed" basis, and today the graphics packages cover the complete range of needs from mesh generation to high quality publication figures.

Three separate graphics based computer codes have been developed. The first code, named PRENEP, was designed as a pre-processor code. Its purpose is to generate finite element meshes and to display them on graphical output devices. The second graphics code, named POSTNEP, was designed to retrieve element and nodal time-histories and element stress and strain histories. In addition, the configuration of the model can be displayed at user selected instants during the deformation process in several hard copy formats. A key graphics feature of POSTNEP is the capability to generate 16mm movies of the deforming structure. PLOTNEP is the third graphics code and its purpose is to produce publication quality plots. The use of the above codes is demonstrated for three reactor safety analyses.

CODE DESCRIPTIONS AND APPLICATIONS

The graphic-based codes PRENEP, POSTNEP, and PLOTNEP were developed to augment the nonlinear computational mechanics code NEPTUNE (Kulak and Fiala, 1988), which has been developed in the Reactor Analysis and Safety Division of Argonne

National Laboratory to assist in the design, safety evaluation, and licensing of reactor structures and components subjected to static or transient mechanical loadings. In addition, these codes have also been used to provide graphics capability to the following computer programs: TEMP-STRESS (Marchertas et al., 1988) and WHAMS-3D (Kennedy and Belytschko, 1987).

There is a wide variety of computer software available to produce ad hoc graphical displays. This software contains a command set that can be arranged to produce specific types of plots. The approach we followed was to develop specific codes that use the available graphics command set from commercial plot packages; the commercial package that we chose was CA-DISSPLA (1987).

The remainder of this section describes the key features of each code and illustrates their use on previously performed safety analysis.

PRENEP

The purpose of the PRENEP code is to preprocess input data. This includes automatic data generation, data-error analysis, and graphical display of the finite-element meshes used to model reactor components. The inclusion of many options allows the user to generate an error free mesh. The following options are included: (1) the capability to generate elements within a region by specifying a minimal number of points on its bounding surface, (2) the capacity to generate both hydrodynamic and structural elements within the region and on the boundary, (3) the capability to generate a cylindrical mesh of quadrilateral plate elements and to position it at a desired location and orientation in 3D space, (4) the capability to obtain a mirror image of a previously generated mesh by reflecting the original about a plane, (5) the capability to reflect a cylindrical mesh about a cylindrical surface, and (6) the capability to display the orientation of reinforcing steel within concrete structures. A three-dimensional plot of the mesh is used to quickly check the geometric data and boundary conditions.

One of our recent tasks was to predict the response of a 1/6th-scale steel lined reinforced concrete containment model (Kulak and Fiala, 1988) that consists of a cylinder with several penetrations, a spherical dome, and a foundation mat. The three-dimensional finite element model developed using the PRENEP code is shown in Fig. 1. It represents a 50 degree segment of the cylinder and dome and includes one-half of a penetration. The finite element model was constructed in the following sequence: the upper half of the cylinder was automatically generated; the upper half of the penetration region was blended into the cylinder; the upper cylinder with penetration was reflected about a horizontal plane passing through the center of the penetration to produce the lower half of the cylinder and penetration; and the dome region was added. Figure 2 displays the orientation of the rebars within the concrete walls of the structure. The finite elements of the mesh are indicated by dotted lines and the rebars by a single line passing through the center of each element. It should be noted that the arrangement of the rebars is correctly shown in Fig. 2; however, for the sake of clarity, only one rebar per direction is shown in each element. The pitch, which is the distance between rebars, is inputted into the code so that the correct number of rebars participate in the response. Figures 1 and 2 provide the analyst with the visual assurance that his mesh is correct.

A necessary feature for viewing complex finite element models is hidden line plotting. Illustrated in Fig. 3 is an all lines visible plot of a finite element model of a seismic isolation bearing. It is clearly seen that it is very difficult to understand the model when all lines are visible. Figure 4 shows the model of the bearing when the hidden lines are removed. The hidden line technique that we incorporated into the PRENEP and POSTNEP codes was developed by Jones (1982). It is based upon the concept of dividing the viewing space into a three-dimensional array of bins and only considering the finite element surfaces that fall in the outermost bins as potentially visible. This technique produces a very fast hidden line algorithm.

POSTNEP

Once the computations are completed, the analyst faces the task of data interpretation. This task becomes tractable with the POSTNEP code by post-processing the computed results obtained from a file generated by NEPTUNE. Element and nodal time histories can be displayed in digital and graphical formats for interpretation. The systems configuration can be displayed at various instants during the deformation process in several hard copy forms from pen plotters, electrostatic plotters, laser plotters, or 35 mm slides. Also, a 16 mm movie can be produced from a tape file of computed results to view the continuously changing system configuration.

The results from three safety analysis will be used to illustrate the use of some of the features of POSTNEP. The first study was the dynamic simulation of a cylindrical tank impacting against a rigid floor. The impact and rebound of the tank is shown in Fig. 5. It should be noted that this sequence is taken from a 16 mm movie generated by POSTNEP. The movie generation capability of POSTNEP has been one of the most useful features of the code for interpreting computational results, for getting a "feel" for the dynamics of the problem, and for presenting complete transient simulations at technical meetings.

The second analysis was the previously described reinforced concrete containment study in which the structure is internally pressurized. Figure 6 shows a deformed plot of the finite element model; note, an inward dimple formed between the bulges of the upper and lower half of the concrete cylinder. Figure 7 depicts the cracking pattern that was predicted on the inside concrete surface; recall that this surface is lined with steel plate and is not visible. The cracks indicate that the inner surface of the dimple is subjected to tensile stresses.

The following illustration shows how deformed mesh plots can be used to locate input data errors. This example was taken from the dynamic analysis of the previously mentioned seismic isolation bearing. After reviewing the digital results of an initial computer run, we were convinced that the results were incorrect. A look at a plot of the deformed mesh (Fig. 8), generated by POSTNEP, led us to the fact than an incorrect value for the density of the second elastomer layer was inputed. Once corrected, satisfactory results were obtained as shown in Fig. 9.

PLOTNEP

After the computed results have been reviewed and accepted, the final task for the analysts is the preparation of high quality figures for reports and publications. We developed the PLOTNEP code for this purpose. It uses data files obtained with POSTNEP to produce publication quality figures. The graphical features were designed to provide a set of default options that produce draftsman quality figures on a first try when plotted with either a high quality pen plotter or laser printer. The default values can be overridden to produce a tailored plot, however, this customizing may require several iterations. Nevertheless, this customizing can be performed on a graphics terminal and does not add much to the total time to produce the final plot. Figure 10 is an example of a publication quality plot produced with PLOTNEP.

CONCLUSION

A family of computer graphics programs that is tailored to display three-dimensional finite element models and the results of numerical simulations of reactor structures and components has been developed. Because of their effectiveness and low cost, they have been used extensively in the Computational Mechanics Section of the Reactor Analysis and Safety Division at Argonne for modelling, interpretation, and report presentation of reactor safety analyse.

ACKNOWLEDGEMENTS

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Marchertas, A.H., Kennedy, J.M., and Pfeiffer, P.A. (1988). Reinforced Flexural Elements for TEMP-STRESS Program. Nuclear Engineering and Design, Vol. 106, pp. 87-102.

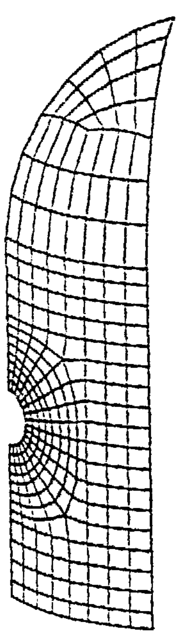

Figure 1. Three-Dimensional Containment Model (PRENEP)

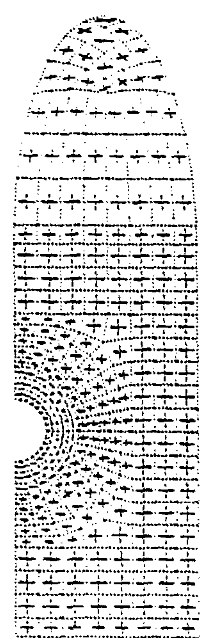

Figure 2. Display of Reinforcing Bars (PRENEP)

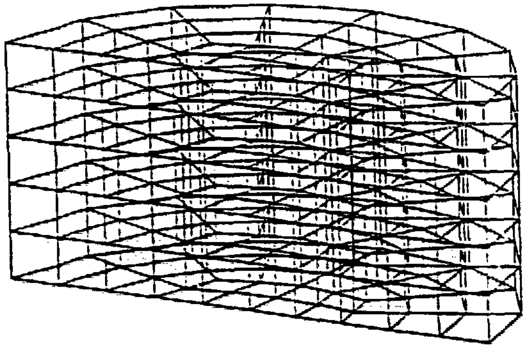

Figure 3. All Lines Visible Plot of Seismic Isolation Bearing (PRENEP)

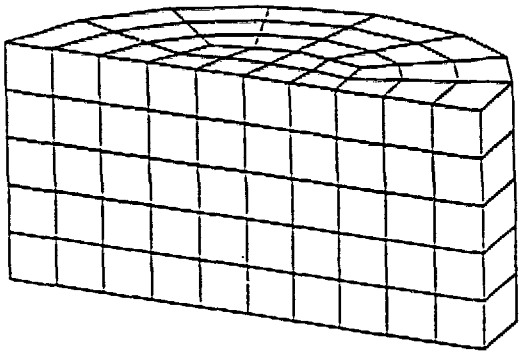

Figure 4. Hidden Line Plot of Seismic Bearing (PRENEP)

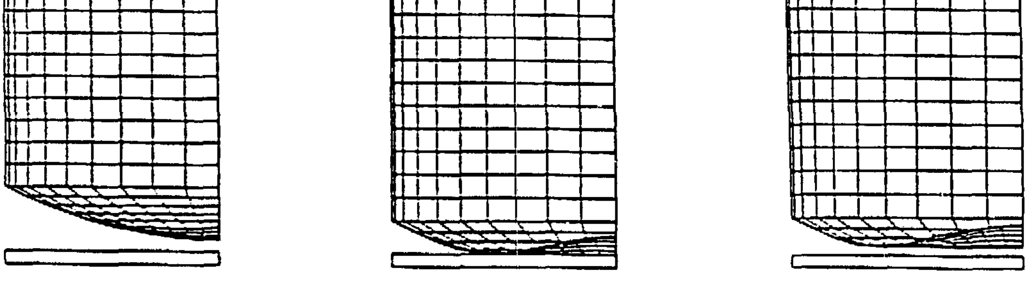

Figure 5. Frames from a 16mm Movie of an Impacting Cylindrical Tank (POSTNEP)

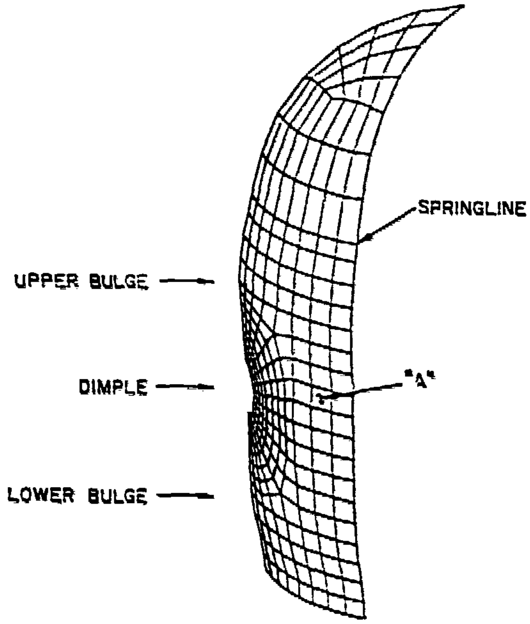

Figure 6. Deformed Mesh of Containment Model (POSTNEP)

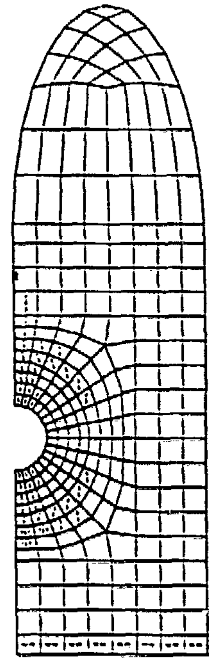

Figure 7. Cracking Pattern on Inside Concrete Surface (POSTNEP)

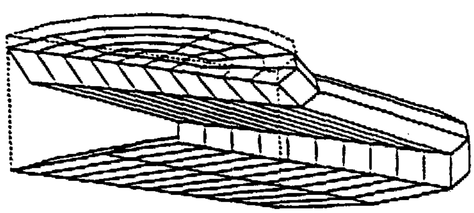

Figure 8. Deformed Mesh of Seismic Isolation Bearing with Erroneous Density in Third Elastomer Layer (POSTNEP)

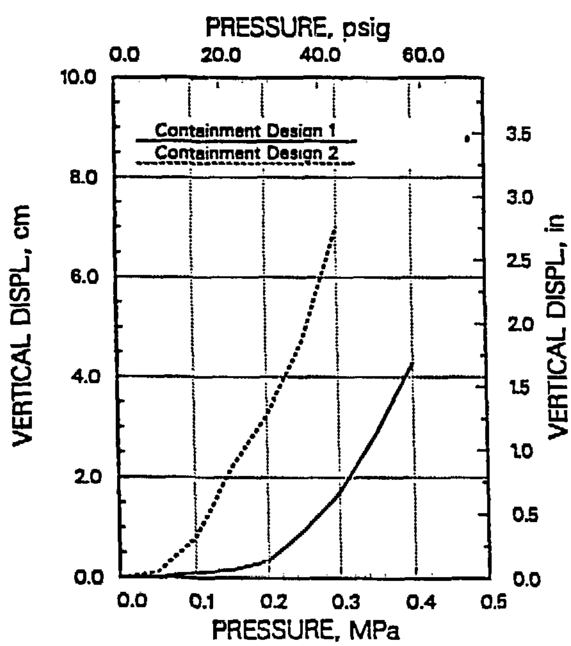

Figure 10. Publication Quality Plot (PLOTNEP)

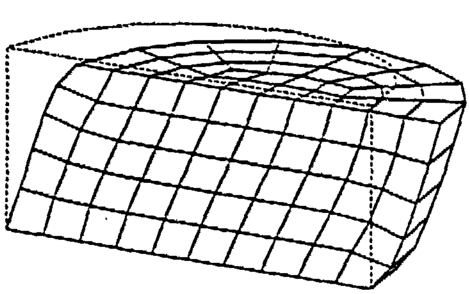

Figure 9. Deformed Mesh of Seismic Isolation Bearing with Correct Density in Elastomer Layers (POSTNEP)