Application of MSC/pal 2 and MSC/NASTRAN-WS to Design of CEBAF Experiment Stations

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The use on personal computers of MSC/pal 2 in the design and MSC/NASTRAN-WS in the redesign of CEBAF (Continuous Electron Beam Accelerator Facility) experiment stations is described. These stations are cylindrical tank type structures with spherical domes of reinforced concrete. Included are descriptions of the models employed, the features of the programs used to capture the important structural actions, and the problems encountered. Also included are welcome additions to both programs, both in structural modeling and display of results. The hardware used is given and run times of models with both programs are compared.

Introduction

The CEBAF (Continuous Electron Beam Accelerator Facility) experiment stations, now under construction in Newport News, Virginia, are three very large underground reinforced concrete cylindrical tank type structures. The three structures, identified as Stations A, B, and C, are shown in Figure 1. The components of each of these structures are a circular floor slab, a cylindrical wall topped by a dome ring, and a spherical dome roof. The dome ring is prestressed to counteract the tension forces that would otherwise be induced at the top of the wall by the dome thrust. Each station has large openings in the cylindrical wall to permit the entrance and exit of the electron beam and the entrance of trucks and personnel. The slab is located about 50 feet below the final grade in ground with a high water table, and the dome roofs are covered with up to five feet of earth.

The primary loads are the self-weight, weight of earth on the dome roof, lateral earth pressure on the wall, and the prestress force on the dome ring. Of lesser importance are the loads induced by cranes that are suspended from the dome roofs or the tops of the walls, and spectrometers weighing up to 1400 tons that ride on the floor.

The primary internal load systems induced into the primary structural components by the applied loads are plate bending of the slab, hoop compression in the cylindrical wall and the dome ring, and compression in the dome roof. These can be accurately calculated by hand from plate bending theory and the membrane theory of shells. Less accurate estimates can be obtained by hand calculation of the discontinuity stress resultants and moments at the base and top of the wall and the edge of the dome. Only rough estimates can be obtained by hand calculation of the redistribution of the hoop force and the bending in the cylindrical wall near openings. The discontinuity forces and moments and the redistribution of forces near the openings are best calculated with finite element models.

At first the owners of the facility intended to pump the ground water so that the stations would not be subjected to uplift and the cylindrical walls would not have to resist the high lateral pressure of submerged earth. The structures were designed for this condition. The finite element models used to support the design activity were processed with MSC/pal 2. Subsequent to the completion of the design the owner decided to pump only over the central portion of the slab. This required the redesign of the cylindrical wall and the edge of the slab to carry the increased lateral pressure. The finite element models used in redesign were processed with MSC/NASTRAN-WS (hereafter referred to as NASTRAN). (NASTRAN was not available to us on desk top computers during the original design.) This has afforded us the opportunity to compare the capabilities of and our experiences with these finite element programs as applied to the design of these structures.

Described below are some of the models that were used, the features of the programs used to capture the important structural actions, and the problems encountered. Also included are some useful features lacking in both programs. The hardware used is given and run times with both programs are compared.

Models

The models used to support the design activity fall into two categories: axisymmetric and non-axisymmetric. The axisymmetric model is a pie-shaped section of the dome, cylindrical wall and the slab. The included structure is modeled with a single tier of plate elements as shown in Figure 2. Rigid elements are used at the juncture of the slab with the base of the wall and at the juncture of the dome ring with the edge of the dome. Vertical spring elements represent the subgrade reaction forces at the bottom of the slab. This type of model was used to obtain stress resultants and moments in regions that are far removed from the openings.

The non-axisymmetric models include half of each station structure as cut by a vertical plane. This assumes that the excluded half of the structure is a mirror image of the included one, which it is not. If the openings are not too close to the plane of assumed symmetry, this type of model gives accurate stress resultants and moments at the openings, and away from the openings gives results that agree well with those of the axisymmetric models. However, the axisymmetric models, being simpler, provide information to the design activity sooner. The included half of the structure is modeled, as in the axisymmetric models, with plate, rigid and spring elements (Figure 3).

Eight axisymmetric and five non-axisymmetric models and their variants were processed with MSC/pal 2 and ten axisymmetric and five non-axisymmetric models and their variants were processed with NASTRAN.

MSC/pal 2 Experience

The MSC/pal 2 axisymmetric models, although small and simple, were encumbered by the lack of a cylindrical coordinate system for specifying displacements and boundary conditions [1]. Therefore, the boundary conditions on that edge of the slice that could not be placed in a plane containing a pair of coordinate axes were simulated by attaching a beam normal to the surface at every node point on that edge. The beam is stiff in torsion and bending in the circumferential direction but has no axial stiffness and no bending stiffness in the direction normal to the circumferential direction. The necessary rigid connections were simulated with reasonably stiff beam elements.

A combination of MSC/pal 2's generating capabilities and spreadsheets were used to develop the input for the non-axisymmetric models. MSC/pal 2's capability to generate node point geometry and plate element connectivity was useful in establishing the bulk of the input. The "Report of Model Data Set" option of the ADCAP2 program within MSC/pal 2 was used to expand the connectivity generating statements to individual statements for each element. This data was then imported into a spreadsheet to develop pressure load statements for the plate elements. Another spreadsheet was used to calculate the spring constants and to develop input statements for the spring elements used to model the vertical subgrade reaction forces on the bottom of the slab.

The design of reinforced concrete slabs and walls is based on thrusts, shears and moments. Unfortunately MSC/pal 2 does not output these for plate elements. Hence, we developed a post-processor that converted the calculated stresses to thrusts and moments. Transverse shears were found to be of concern at a few locations, and these were calculated by hand from the MSC/pal 2 output.

Deformed structure plots and color contour plots of stresses (Figure 4) were useful in visualizing the structural actions near the openings.

During the processing of the models the following problems were encountered:

1. MSC/pal 2 internally numbers elements based on the order of the connectivity statements. Therefore, the addition or deletion of an element or elements alters the

element numbering sequence. This is a nuisance for large models because it complicates the recovery of limited output and the comparison of results.

2. Frequently, the stiff beams simulating rigid elements were too stiff and caused bad pivot ratios of the system equations during decomposition, terminating the computation.

3. The large size of the non-axisymmetric models caused the system error message "REDUCE: CX <= 50" to appear. This was determined by MSC analysts to be an error in MSC/pal 2 that appears only for very large models. The problem was cured by overriding the internal node renumbering with the AUTO statement.

The largest non-axisymmetric model was one for Station A. It consisted of 1939 node points, 1529 plate elements, 312 spring elements and 84 beam elements, and had 9702 degrees of freedom. The other four non-axisymmetric models were of comparable size. Thus these models very nearly exhausted the node point limit of MSC/pal 2.

MSC/pal 2 models were run on a Compaq 386/20 with a 20 Mhz coprocessor chip, 8 megabytes of memory, 60 megabytes of hard disk, and two 20 megabyte external drives. A Hewlett Packard PaintJet color printer was used to produce hard copy printouts of the color contour plots. The largest non-axisymmetric model ran in five hours.

MSC/NASTRAN-WS Experience

The axisymmetric models were not converted from the MSC/pal 2 models but were created from scratch. The use of a cylindrical coordinate system for displacements and the use of rigid elements produced much simpler models [2]. Post-processing of the stress output was not necessary because NASTRAN outputs the desired thrusts, shears, and moments of plate elements. This considerably improved the speed with which results could be made available for design. Other advantages of NASTRAN over MSC/pal 2 include the availability of QUAD4 with variable thickness for representing thickness transitions in the cylindrical wall and the ability to control element numbering.

The input of the MSC/pal 2 non-axisymmetric models was converted to NASTRAN format with the ADCAP2 program. The NASTRAN input as produced by ADCAP2 required several changes. ADCAP2 produces grid point geometry in the basic coordinate system from MSC/pal 2 input in which grid-point geometry is specified in cylindrical coordinates. Geometry changes in a model of a cylindrical structure specified in a rectangular coordinate system are cumbersome. Therefore, a spreadsheet was used to revert the grid point geometry to a cylindrical coordinate system. Similarly, ADCAP2 converted all pressures on plate elements to nodal loads referred to the basic coordinate system. When working with pressures the nodal loads are difficult to interpret and change. Therefore, we edited directly the MSC/pal 2 pressure statements to arrive at PLOAD statements. Further, ADCAP2 converted the spring elements to beam elements. We deleted these beams and the grid points at the grounded terminal of the MSC/pal 2 springs and added CELAS2 elements.

The soil stiffness was modeled by vertical springs from all grids on the slab to ground. The spring stiffnesses were obtained from the modulus of subgrade reaction, whose dimensions are force per unit volume (tons/cu. ft.), and the contributory area around the grid point. In regions of the slab where the layout of the grids is regular, the CELAS2 statements were generated by a spreadsheet using grid point statements as input. In irregular regions the spring constants were calculated by hand. If the mesh of the slab needs to be changed or refined, as was the case during the redesign of the slab near one of the openings of Station A, the spring constants need to be recalculated. It became apparent that an element statement was desirable on which the modulus of subgrade reaction could be specified for a quadrilateral or triangular area and which would compute the stiffnesses a la CELAS2. Lacking such an element, the following procedure was improvised:

1. The modulus of subgrade reaction was specified as the pressure on PLOAD statements for plate elements in the slab.

2. NASTRAN was run and OLOAD was requested. The loads in OLOAD are the spring constants.

3. The OLOAD file was input to a spreadsheet which output a file of CELAS2 statements.

The largest NASTRAN non-axisymmetric model consisted of 1718 grids, 1464 plate elements, 377 spring elements, 79 rigid bars and 1 beam element. The model had 7696 degrees of freedom and ran in 90 minutes in MSC/NASTRAN-WS Version 65c2 under Interactive Unix and X11 Windowing System. The hardware consisted of a Compaq 386/33 with a 33 Mhz coprocessor, 8 megabytes of memory, and 300 megabytes of hard disk. Although somewhat smaller than its companion MSC/pal 2 model (7696 versus 9702 DOF) and run on a faster computer (33 versus 20 Mhz) this comparison shows that NASTRAN ran considerably faster than MSC/pal 2. The other non-axisymmetric models also ran faster in NASTRAN than in MSC/pal 2.

Hard copies of contour plots of stresses displayed with MSC/XL could not be produced because a Unix driver for color printers had not been developed.

Conclusions

We preferred MSC/NASTRAN-WS over MSC/pal 2 for this application for the following reasons (in order of importance):

1. Output stress resultants, shear forces and moments for plate elements (QUAD4 and TRIA3). This is a required analysis output for any plate and shell type concrete structure.

2. Displacements could be specified in a cylindrical coordinate system. This simplified the enforcement of boundary conditions on axisymmetric models.

3. Ran faster.

4. Rigid elements were available.

5. No problems were experienced with reordering of grid points.

6. Element numbers could be controlled.

Welcome additions to MSC/NASTRAN-WS capabilities include:

1. Elements for modeling distributed spring stiffness over quadrilateral and triangular areas.

2. Ability to make color plots (dump the color on the screen onto a color printer) via MSC/XL.

Welcome additions to MSC/pal 2 capabilities include:

1. Output of stress resultants, shear forces, and moments for plate elements.

2. Displacement specification in cylindrical coordinates.

3. Rigid elements.

4. User assigned element numbers.

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References

[1] "MSC/pal 2 User's Manual, Version 3.5," The MacNeal-Schwendler Corporation, 815 Colorado Boulevard, Los Angeles, CA, February 1989.

[2] "MSC/NASTRAN User's Manual, Verson 65," The MacNeal-Schwendler Corporation, Los Angeles, CA, November 1985.

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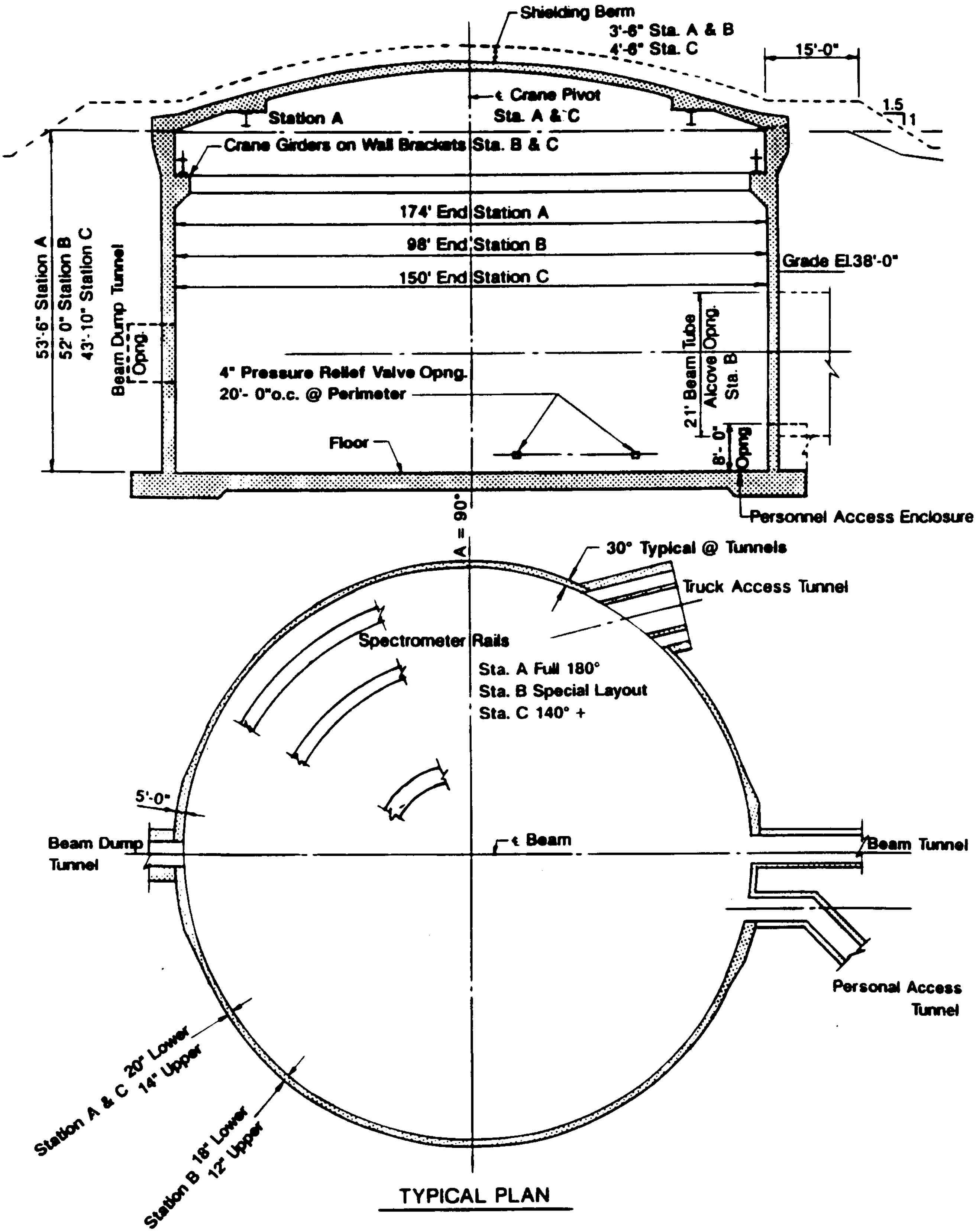

Figure 1 Structural Arrangement for Stations A, B, and C.

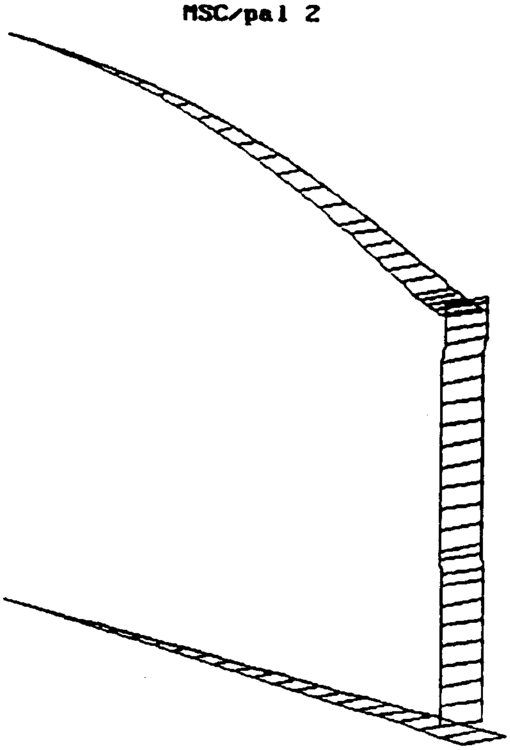

Figure 2 Typical Axisymmetric Model

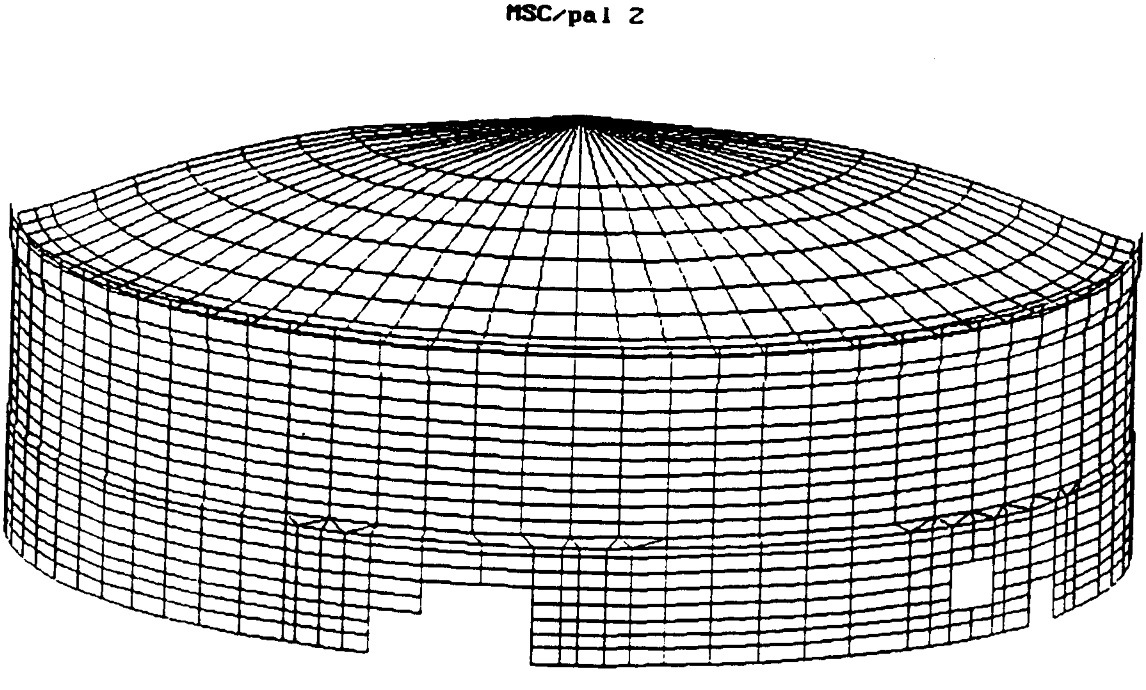

Figure 3 Non-Axisymmetric Model of One Half of Station A, Showing Cylindrical Wall and Dome Roof

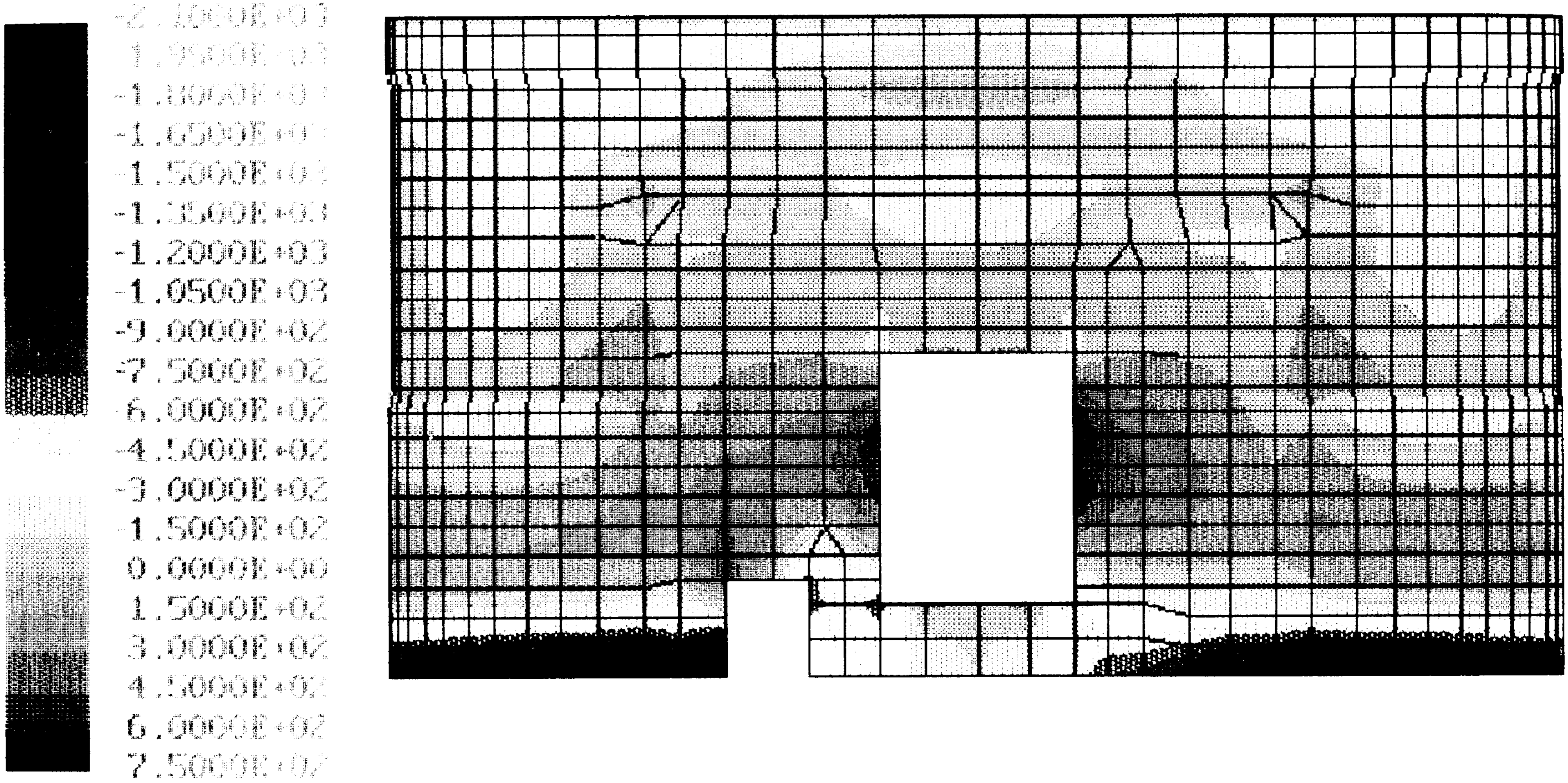

Figure 4 Contours of Vertical Stress on Inside Surface, Station B