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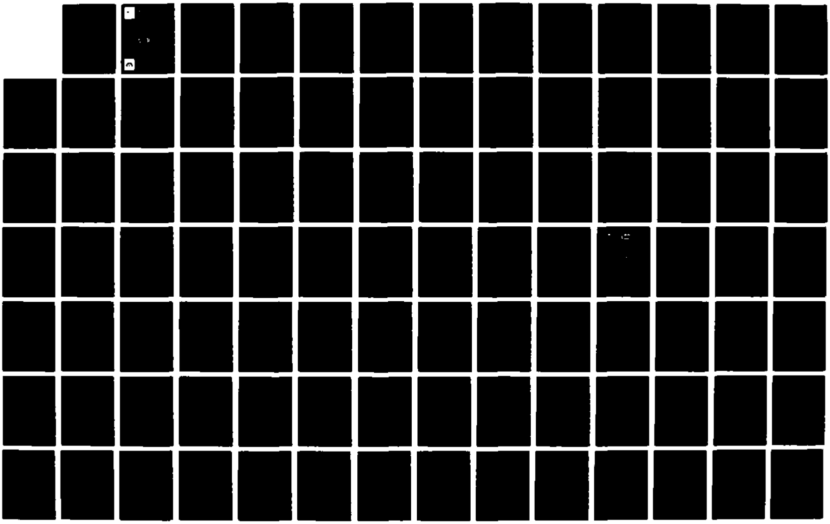

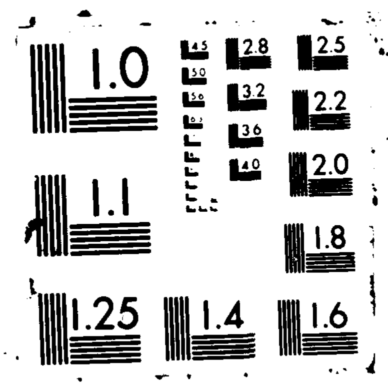
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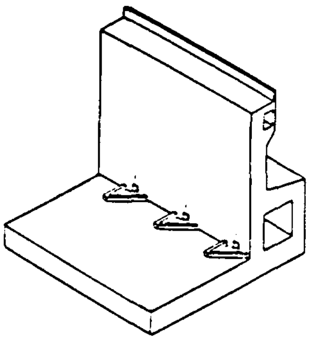

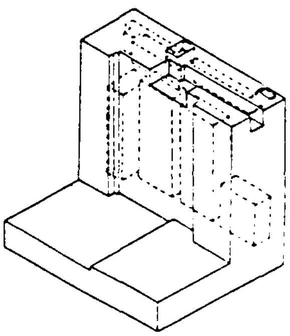

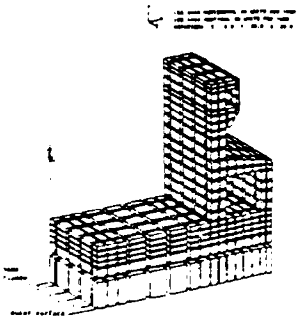

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TECHNICAL REPORT SL-87-21

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THERMAL STRESS ANALYSES OF MISSISSIPPI RIVER LOCK AND DAM 26(R)

by

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Structures Laboratory

and

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Information Technology Laboratory

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Waterways Experiment Station, Corps of Engineers
PO Box 631, Vicksburg, Mississippi 39180-0631

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This report describes an investigation to analyze selected monoliths of Mississippi River Lock and Dam 26 (Replacement) (L&D 26(R)) for thermal and construction induced stresses using three-dimensional (3-D) finite element methods (FEM). The St. Louis District recommended that one of several commercially available general purpose FEM codes be used to perform the analysis. The guidelines to accomplish the goals of the study were developed into evolutionary four-phase plan. The first phase was to evaluate and select a code from the recommended candidates best capable of modeling the problem. Evaluation criteria included the capability to simulate incremental construction, materials aging, time-stepping, inclusion of a comprehensive element library with capability to easily implement user-defined material models, the ability to model large numbers of reinforcing bars, and have efficient numerical solutions with flexible means for selecting time steps. The program was also required to be user-oriented, be well supported by the developer, and

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Bombich, Anthony A.; Norman, C. Dean (Structures Laboratory); and Jones, H. Wayne (Information Technology Laboratory).

19. ABSTRACT (Continued).

have a high potential for remaining at the state-of-the-art level. After evaluation, a review committee selected the ABAQUS program as the code best suited to solution of the problem.

During the second phase, a solution/method verification was performed based on test case problems. Simple problems with known solutions were tested to verify that the ABAQUS program would give exact or reasonable results as appropriate.

In phase three a series of two-dimensional (2-D) solutions of L&D 26(R) monoliths L-13 and L-17 were conducted using both ABAQUS and the WES2DT programs. The WES2DT program had been verified during previous projects where 2-D approximations were appropriate. The 2-D solutions ranged from single-step, gravity-only loading through staged, incremental construction thermal stress analyses that included some or all of the effects of temperature, gravity, pile elasticity and creep. The WES2DT program employed a simple creep model. An aging-creep model developed for a related project was used with ABAQUS.

Phase four provided for 3-D FEM solutions of the two monoliths. All work was completed for the 3-D FEM analyses except for actually conducting the computer runs. Computer costs and limitations on computer resources prohibited execution of planned computer runs except for one gravity turn-on analysis of L-13. Although the computer runs were not made, complete documentation of the 3-D problem solution up to the actual execution of the computer runs are included in this report.

Even though the 3-D analyses, as planned, could not be completed, it was felt that the objectives relating to the conduct of incremental construction thermal analyses of mass concrete utilizing a modern, general purpose FEM code were realized. These included successful 2-D incremental thermal analyses in which all construction, environmental, and thermal properties aspects were adequately handled by ABAQUS. Most of the important aspects of 2-D incremental thermal analyses were also acceptable except for modeling early-age materials properties. Reliable early-age materials properties data did not exist for L&D 26(R) concrete at the time of the study; consequently, aging modulus, creep, and shrinkage data were taken from other test results. This led to calculation of excessive thermal stresses and creep relaxation at early time.

Results indicated that concrete stresses and the distribution of pile loads beneath the monoliths are significantly affected by the assumptions made in the analysis such as single-stage gravity turn-on versus staged, incremental construction with temperature effects, and also aging, creep, and shrinkage. Analyses such as described in this report are an effective means for establishing the bases for mass concrete construction temperature control plans. More research is required to fully develop incremental construction FEM analyses in this construction support role as well as to delineate the extent to which incremental construction analyses should be incorporated into structural design.

PREFACE

The work described in this report was conducted for the US Army Engineer District, St. Louis, by the Concrete Technology Division (CTD) of the Structures Laboratory (SL) and the Information Research Division (IRD) of the Information Technology Laboratory (ITL), US Army Engineer Waterways Experiment Station (WES). The investigation was authorized by DA Form 2544, Intra-Army Order for Reimbursible Services, No. ED84-12, dated December 1983.

The investigation was accomplished under the general supervision of Messrs. Bryant Mather, Chief, SL; James T. Ballard, Assistant Chief, SL; John M. Scanlon, Chief, CTD; and Dr. N. Radhakrishnan, Chief, ITL, and under the direct supervision of Mr. C. Dean Norman, Program Manager. This report was written by Messrs. Anthony A. Bombich and C. Dean Norman, CTD, and H. Wayne Jones, ITL.

COL Dwayne G. Lee, CE, is Commander and Director of WES. Dr. Robert W. Whalin is Technical Director.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
Btu (International Table) per pound (mass) . degree Fahrenheit	4,186.8	joules per kilogram Kelvin
Btu (International Table) . inch per hour . square inch . degree Fahrenheit	20.7688176	watts per metre Kelvin
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*
feet	0.3048	metres
inches	0.0254	metres
kips (force) per inch	1.213659	kilonewtons per metre
miles per hour (U. S. statute)	1.609347	kilometres per hour
pounds (force) per square inch	6.894757	kilopascals
pounds (mass) per cubic inch	27,679.899	kilograms per cubic metre
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre

* To obtain Celsius (C) temperature reading from Fahrenheit (F) readings, use the following formula: C = (5/9)(F-32). To obtain Kelvin (K) readings, use K = (5/9)(F-32) + 273.15.

THERMAL STRESS ANALYSES OF MISSISSIPPI R.VER LOCK AND DAM 26(R)

PART I: INTRODUCTION

Background

1. In November of 1983, the Waterways Experiment Station (WES) was asked by St. Louis District, Corps of Engineers, to analyze the lower gate monolith and one intermediate monolith of Mississippi River Lock and Dam 26(R) for thermal and construction induced stresses and also normal operating conditions using three-dimensional (3-D) finite element methods (FEM). It was also requested that WES use one of the computer progams ADINA, ANSYS, or ABAQUS to perform the analysis. The general objective of this analysis effort was to adapt a general-purpose finite element program with state-of-the-art numerical formulations, large element libraries, and easily implemented user-defined material model to the problem of thermal stress analysis of mass concrete structures. In a cooperative effort the Concrete Technology Division (CTD) of the Structures Laboratory (SL) and the Information Technology Laboratory (ITL) prepared and submitted a cost estimate and scope of work to conduct the analysis. Personnel of the St. Louis District (LMSED), CTD, and ITL, met at WES in December 1983 to review and discuss the cost estimate and proposal. All present at this meeting agreed to the general analysis approach to be used, but it was pointed out that the effective solution of a stress analysis problem such as this might require significant modifications of currently available general-purpose finite element programs. However, it was anticipated that an acceptable solution could be obtained with only minor modifications of existing finite element programs.

2. Monoliths L-13 and L-17 were selected for the analysis so that two-dimensional (2-D) and three-dimensional (3-D) effects could be studied both in

terms of thermal gradients and stress distributions. Symmetric half-section isometric projections of monoliths L-13 and L-17 are shown in Figure 1.

Objective

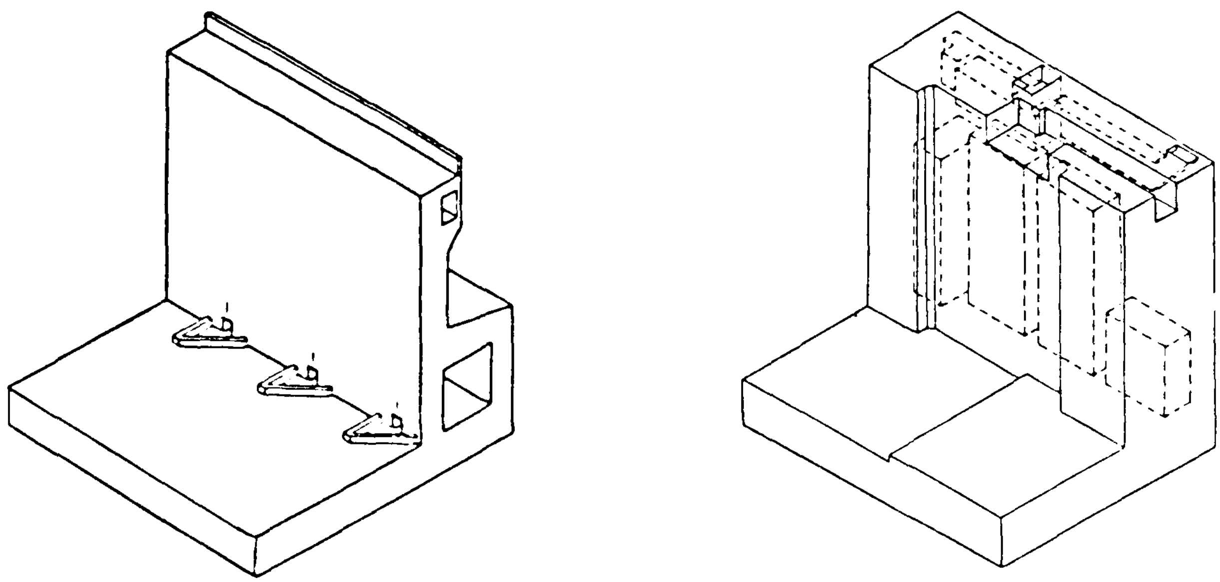
3. The objective of this investigation was to conduct 2- and 3-D thermal stress analyses of selected monoliths of Lock and Dam 26(R) using a modern general-purpose finite element program.

Scope

4. To accomplish the objectives of this study within the guidelines set by the St. Louis District, a four-phase investigation plan was developed. The origionally developed plan is presented below.

Phase	Finite Element Investigation Plan
I	Selection of most effective finite element program(s) to accomplish the goals of the investigation. This involves evaluating the capabilities of the available three-dimensional programs to model the problem.
II	Solution-method verification based on test case problems. This involves solving simple problems for which solutions are available and verifying that the program gives exact or reasonable results as appropriate.
III	Solution of two-dimensional problems. Two-dimensional solutions will be obtained for monolith L-13 using the WES2DT program which has been verified based on previous projects where 2-D approximations were appropriate. The WES2DT program also has a simple creep model. Two-dimensional solutions will also be obtained for monolith L-13 using the new code and compared with results from the WES2DT program. A decision was made later to include 2-D analyses of monolith L-17 with both the new program and WES2DT. Results from these 2-D analyses form a basis for interpreting and evaluating results from 3-D analyses.
IV	Solution of three-dimensional problems. A 3-D analysis will be conducted on monolith L-13. This analysis is primarily designed to demonstrate the effects of 3-D thermal gradients on essentially a 2-D structural geometry. A fully 3-D analysis will be conducted on monolith L-17 which is truly a 3-D structure. Although at the beginning of the study it was intended that complete 3-D thermal stress analyses would be conducted, the computer costs and limitations on computer resources prohibited

this work. In this report any discussions concerning 3-D thermal stress analyses of L-13 and L-17 are directed toward work performed up to conducting the actual computer runs. Also, due to lack of reliable early-time materials properties data for L&D 26(R) at the time of this study, aging modulus, creep, and shrinkage were taken from other concrete test results. The point to be made here is that the objective of the study was to conduct rational, consistent incremental construction analyses of mass concrete structures. It is quite simple to go back and rerun any of the analyses presented in this report with different early-time material properties.



(a) Monolith L-13

(b) Monolith L-17 with internal voids indicated

Figure 1. Symmetric half-section isometric projections of Lock and Dam 26(R) monoliths used in thermal stress investigation.

PART II: SELECTION OF THE FINITE ELEMENT PROGRAM

General

5. The approach taken in selecting the finite element program to be used in the Lock and Dam 26(R) analysis was to review the capabilities and flexibility of each recommended program in light of the requirements of the problem to be analyzed. Specific requirements included capability to simulate incremental construction, a large element library with capability to implement user-defined material models with relative ease, capability to model significant numbers of reinforcing bars with relative ease, efficient numerical solution procedures with flexible means for selecting solution time steps, etc. In addition, it was desired that the program be user-oriented, receive a high caliber of technical and scientific support from the developer, and have a high potential for staying at the state-of-the-art level.

6. The review of the FEM programs was conducted by personnel of the ITL and the CTD. The review consisted of discussing actual experiences with the different programs, reviewing technical journal articles which compare FEM programs (1)*, meeting with representatives of Cybernet Division - Control Data Corporation, and discussions with personnel of other governmental laboratories directly involved with FEM applications.

7. Based on the criteria and review method discussed above, the review committee unanimously agreed to select ABAQUS for the Lock and Dam 26(R) project.

ABAQUS - General Description

8. ABAQUS, developed by Hibbitt, Karlsson, and Sorensen, Inc., is a general-purpose structural and heat transfer analysis program. The theoretical

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* Numbers in parentheses refer to references at the end of this report.

formulation is based on the finite element stiffness method with some hybrid formulations included as necessary. The program includes both user and automatic control of solution step size. Input is in free format, key worded, and makes use of set definitions for easy cross reference. A broad element library is included in ABAQUS. and any combination of elements can be used in the same model. A wide variety of constitutive models is also provided in ABAQUS, and these model can essentially be used with any element type. User-defined material models are incorporated with relative ease through the UMAT subroutine. Reinforcement (rebar) can be added to any element. Static and dynamic response in stress analysis can be conducted as well as steady-state and transient heat transfer problems. The incremental construction problem can be effectively simulated through the model change option where previously defined elements can be included or removed from the analysis in a specified solution step. Specific details of element type and boundary conditions used will be presented in the various analysis phases of this report.

PART III: ABAQUS PROGRAM - CODE VERIFICATION AND MODIFICATION

General

9. The code verification phase was to serve two purposes: (a) to verify the operation of the program on problems with known solutions and its extension to problems where results were not known but could be analyzed by the investigators to determine that solutions followed rational and expected behavior patterns, and (b) to verify the investigators' ability to direct the program operation to solve desired problems by using the many different program features.

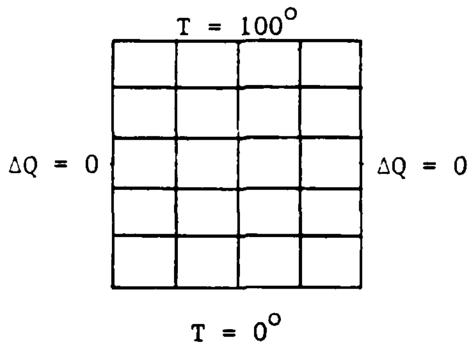
Code Verification

10. To verify the code, several simple example problems were used and are discussed in terms of two groups. Group A consists of problems with known solutions. The finite element (FE) grids for these example problems are shown in Figure 2. Group B consists of the example problem shown in Figure 3 which was used to exercise and test most of the procedures needed to solve the mass concrete incremental construction problem under consideration.

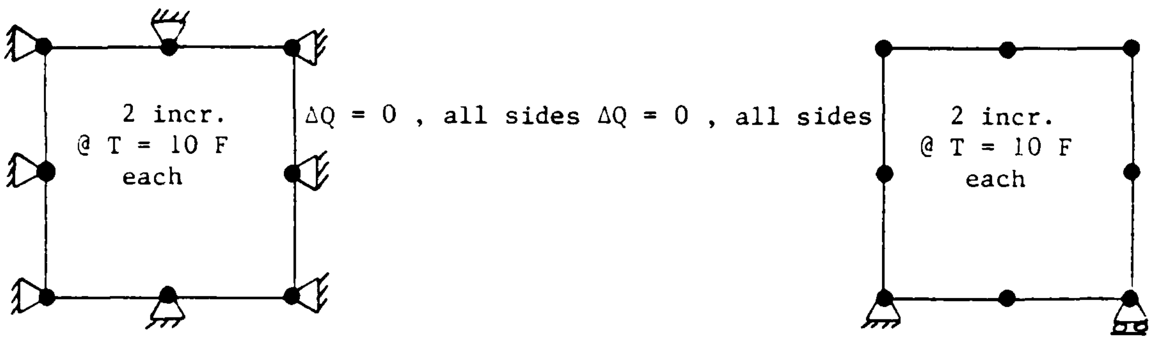
Group A: problems with known solutions

11. Figure 2a shows a square plate with constant temperature specified on each boundary. The steady-state temperature distribution was determined with ABAQUS and checked against the closed form solution. Very good agreement was found between these results.

12. Figures 2b and 2c show two single-element models using the eight-node plane strain element. These models were subjected to two temperature steps of 10 degrees F each while E changed with age. All nodes were restrained during the temperature change in model 2b, whereas, only two nodes



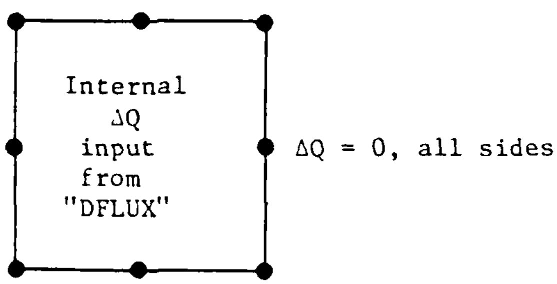
(a) Grid used to test steady-state temperature calculations



(b) Fully restrained

(c) Unrestrained

Single-element models to test thermal stress calculations with variable "E" versus age



(d) Single-element heat transfer model used to test user subroutine "DFLUX"

Figure 2. Finite element grids used in ABAQUS code verification for Group A problems with known solutions.

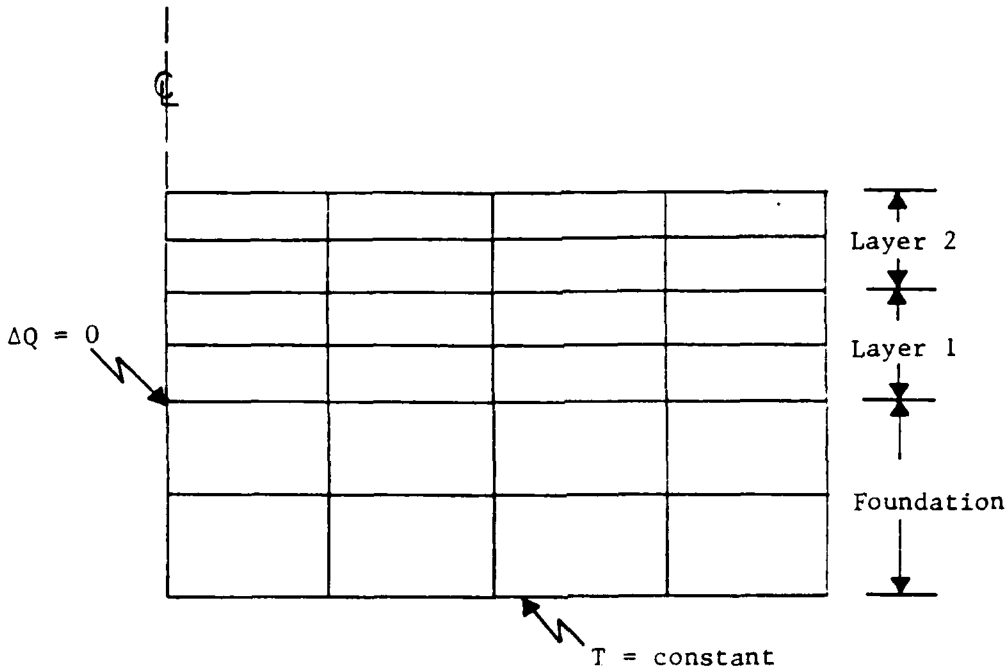
were partially restrained in model 2c. Results showed correct, equal stresses in the x , y , and z normal directions at each calculation step proportional to the temperature change and E values. All nodes except the two shown were free to translate in model 2c. The results showed that the restraint provided in the z normal direction by the plane strain conditions produced correct, equal stresses in the x and y directions due to the Poisson effect at each calculation step.

13. Figure 2d shows a single-element model using the eight-node, 2-D heat transfer element. In this example problem, the user subroutine DFLUX was tested. DFLUX was written to provide concrete heat of hydration input to ABAQUS thermal simulations. The adiabatic boundaries of the model prevented heat exchange. The results showed that the sequences of temperature changes in the model exactly reproduced the heat generation data provided to DFLUX.

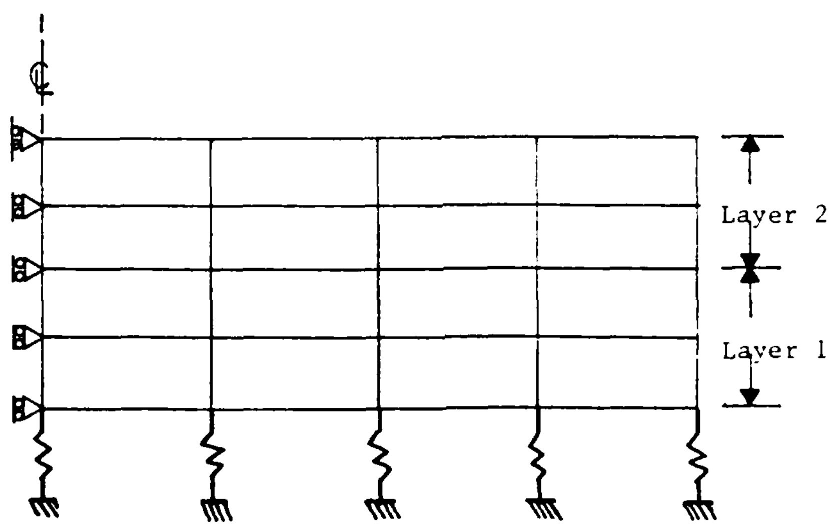
Group B: problems simulating incremental construction

14. Figure 3a shows a problem consisting of 24 eight-node elements which was used to simulate most of the procedures needed in the actual thermal stress analyses of monoliths L-13 and L-17. This example has a soil foundation and two lifts of concrete which were placed at 5-day intervals. The temperature distribution is determined in the FE system throughout the incremental construction process. Next, the grid in Figure 3b was used to perform the stress analysis. The soil foundation was not included in the stress analysis, but linear springs to simulate piles were added to support the structure just as in the actual problem. The structure was then constructed in two lifts to simulate the incremental construction process. The temperatures which were calculated in the earlier temperature analysis were included as loads to the stress analysis. The following procedures were examined.

a. Eight-node, 2-D element behavior for temperature analysis and stress analysis.



(a) Grid used for temperature analysis during incremental construction with heat generation



(b) Grid used for stress analysis during incremental construction with temperature loadings

Figure 3. Finite element grids used in ABAQUS code verification for Group B problems simulating incremental concrete construction.

b. Linear spring element behavior.

c. Gravity loading.

d. Thermal stresses.

e. Incremental Construction behavior.

f. Combination of temperature analysis and stress analysis.

g. Time-dependent modulus of elasticity.

h. Gap element behavior.

i. Applied pressures and concentrated loads.

j. Plotting of displaced grid and stress contours.

15. During the analysis of the results of this example it was determined that the incremental construction process was not simulated properly. The program developers were asked to supply a version of ABAQUS which could perform this task as required. To obtain this capability the new ABAQUS Version 4.5 was developed.

16. To model the initial temperature equilibrium behavior at the interface of an intact element and a newly placed element, the use of gap elements was examined. After making runs without elements, with gap elements, and with modified temperatures at those interfaces, it was determined that adequate results were obtainable by using modified temperatures along only the interface between the soil foundation and the first lift of concrete during the temperature analysis. This was very desirable since the use of gap elements would have greatly complicated that grid generation for the actual models to be analyzed.

Program modification

17. As a result of the verification examples, four modifications were made to the program. The first modification was to enable the program to use time-dependent material properties (E and ν). The second modification was to enable the program to perform the incremental construction analysis in a more consistent manner. Although the program was already able to remove and include elements of the structure as desired, this procedure had to be modified to be consistent with the E and ν time variations for newly added materials. This was implemented in ABAQUS. The third required modification to ABAQUS was to develop and implement a time-dependent, aging creep model for material behavior. This was performed by adding a new material subroutine to the program. This subroutine has been developed and implemented in ABAQUS for 2-D problems, and a version for 3-D problems is being developed. The fourth modification was to produce the user subroutine DFLUX to permit incremental concrete heat of hydration data to be generated by ABAQUS for the incremental thermal calculations.

PART IV: WES2DT PROGRAMS

General

18. This section describes the two-dimensional WES2DT FE programs that have been used at WES for more that 10 years for conducting thermal studies of Corps projects. WES2DT is based on two FE thermal analyses programs prepared for the Corps during the late 1960's. The first program, developed by Dr. Edward Wilson of the University of California at Berkeley (2) and modified for use at the WES, calculates the temperatures within a mass concrete structure. A second program, written by R. S. Sandhu et. al. also at Berkeley (3) and modified at WES, calculates the thermal stresses and strains within the structure resulting from gravity and the thermal loads. In the WES2DT program construction layer (lift) and material interfaces must correspond to an element boundary. The element type used in WES2DT is a four-node quadrilateral with linear temperature and displacement fields.

Temperature Calculation Program

19. The temperature program calculates temperatures at each node in the FEM model. These calculations are based upon concrete placement temperature, heat generated, and the thermal properties of the concrete which govern heat flow within an element and loss or gain across boundaries due to ambient conditions which are controlled by a surface heat transfer coefficient simulating wind or surface insulation or both. Calculated temperatures are output at prescribed intervals for all nodes in the model at a particular stage of construction. A value of temperature is determined for each new concrete element at 6 hr after placement which is assumed to be the final temperature at which an element is stress free. Element stress-free temperatures and calculated nodal temperatures are then used for stress/strain calculation by WES2DT.

Stress and Strain Calculation Program

20. This program calculates the displacements at each node and the strains and stresses developed in each element in the FEM model due to thermal and gravity loads. It was discovered that the program was designed with a plane strain formulation in which both z-direction stresses and strains are zero. In thermal stress problems this eliminates z-direction Poisson effects on x- and y-direction stresses. When creep is considered, stresses at each time step in the analysis are modified for stress relaxation at constant strain. Creep parameters are stored and the change in stress stored as residual stress to be included in the next time step analysis. When these stored values are applied during the next time step analysis, strains are then modified for creep.

21. A modification to account for pile restraint was incorporated into the thermal stress program as a direct result of requirements for previous thermal studies. The pile element used is a simple two-node element modeled mathematically as a linear spring. Actual pile stiffness data are used to determine stiffness of the pile elements. The individual stiffnesses in a pile group are totaled so that the stiffnesses can be applied on average horizontal area bases rather than a discrete pile basis to facilitate 2-D analysis with piles included. The pile groups in this study were rows of piles parallel to the flow axis of each monolith.

22. A one-dimensional bar (truss) element is used to simulate reinforcement steel. Since the program is 2-D, the reinforcement parallel to the model is input as the equivalent cross-sectional area per unit depth. Reinforcement and pile elements are superimposed on the finite element model sharing nodes with quadrilateral, plain strain elements.

PART V: INPUT DATA AND MODELED PARAMETERS

General

23. This section describes the input data and modeled parameters used in all FEM analyses conducted for this investigation. The first section describes the materials properties for concrete and foundation as well as pile stiffnesses used. The second section describes the construction parameters and boundary conditions assumed in the analyses.

Concrete and Other Properties

24. The input data used for the thermal and mechanical properties of concrete were either the same values used in earlier thermal studies for Lock and Dam 26(R) or were based upon tests conducted in the interim period since these studies were completed. The concrete is assumed to have a nominal compressive strength of 3000 psi* using Type II cement with a heat of hydration limit and 25 percent replacement by solid volume of pozzolan (fly ash).

25. Concrete properties data carried over from previous studies included adiabatic temperature rise and creep. New data based upon tests of Lock and Dam 26(R), Phase I, project mixture 4A includes modulus of elasticity, Poisson's ratio, specific heat, thermal conductivity, and coefficient of linear thermal expansion.

Age-dependent concrete properties

26. Adiabatic temperature rise data assumed in the study are shown in Figure 4a Modulus of elasticity as a function of age used by the WES FEM program WES2DT and the ABAQUS UMAT1 subroutine (without creep) is shown in Figure 4b.

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* A table of factors converting non-SI units of measurement to SI (metric) units is presented on page 5.

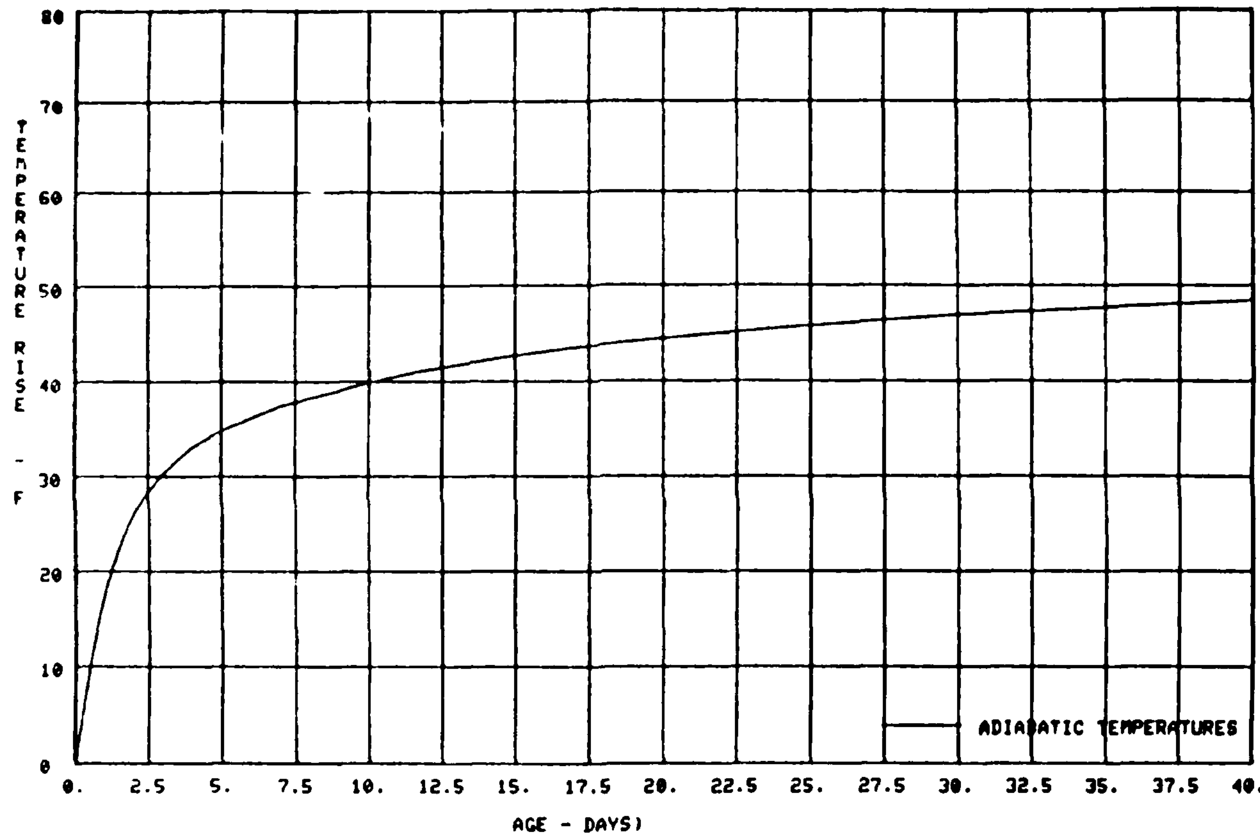


FIGURE 4a. ADIABATIC TEMPERATURE RISE FOR 3000 PSI CONCRETE USED IN ALL THERMAL SIMULATIONS OF CONSTRUCTION.

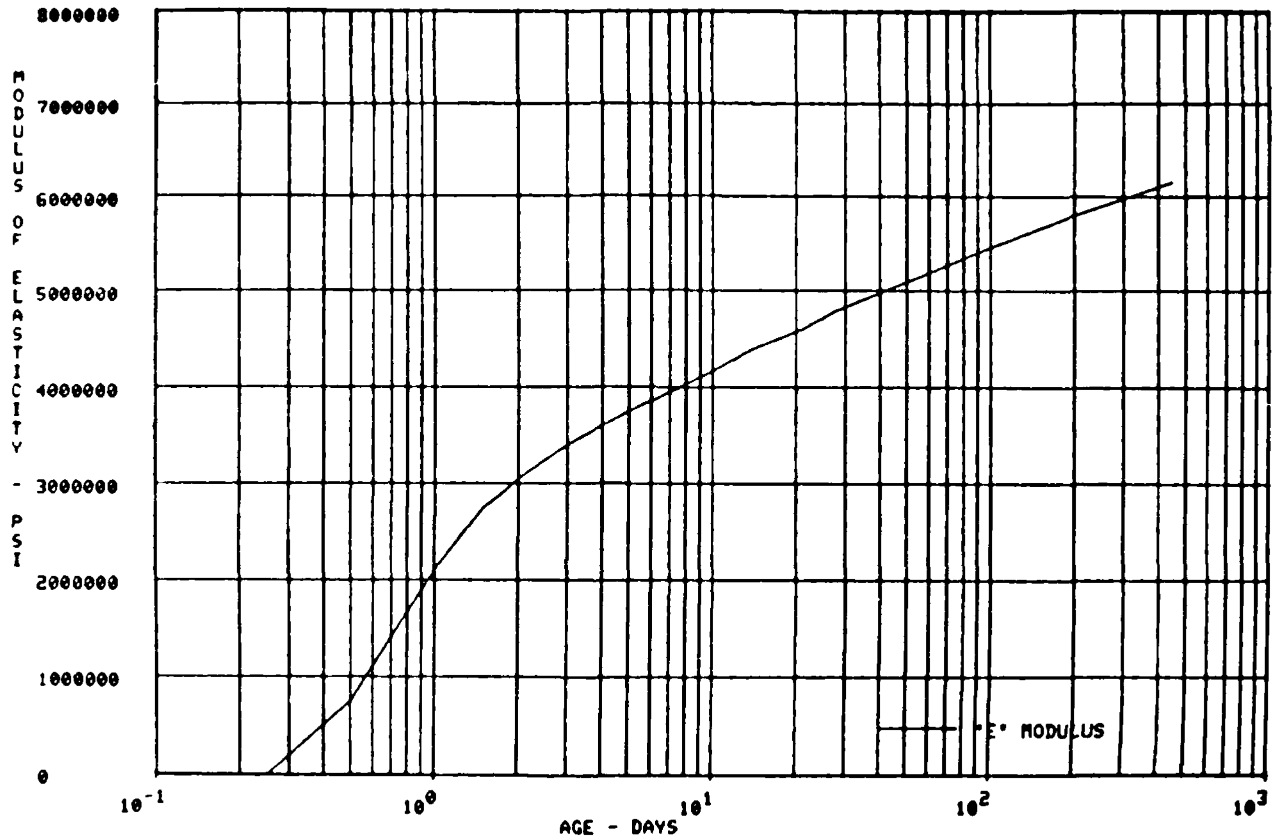


FIGURE 4b. MODULUS OF ELASTICITY VS AGE FOR 3000 PSI CONCRETE USED IN ALL STRESS CALCULATIONS.

27. Creep properties used in the WES2DT code were taken from tests conducted at WES on concrete from Port Allen Lock (4). Generally, creep strains for this concrete are low, thus conservative, for mixtures in the current investigation. The creep data were fit to McHenry's equation (5,6),

$$\epsilon_c(\sigma, t, T) = \sigma \sum_{i=1}^{N} A_k(T)(1 - e^{-mi(t-T)})$$

where

σ = applied stress

ϵ_c = creep strain

t = time after placement

T = age at loading.

N = 2 was found to give a satisfactory fit of experimental data. Values of creep relaxation coefficients A1 and A2 versus time are given in Figure 4c. Values of constants $m_1 = 0.45$ and $m_2 = 0.0285$ were used. Figure 4d shows the creep data at several loading ages produced by the creep coefficients shown in Figure 4c using McHenry's equation.

28. Creep modeling in ABAQUS was accomplished with an aging-creep model that was developed in a related research program at WES (7). The 2-D aging creep model with cracking was developed in the ABAQUS-UMAT subroutine format. The model, designated UMAT2 for this investigation, includes the effects of aging on the elastic modulus and cracking strength and the effects of changing temperatures on the creep compliance, the elastic modulus, and the ultimate/cracking strength. Creep properties are given in the form

$$\epsilon^c/\sigma = [A(1-e^{-rt}) + Bt]\ e^{-Q/RT}$$

where

ϵ^c = creep strain due to stress o

σ = applied stress

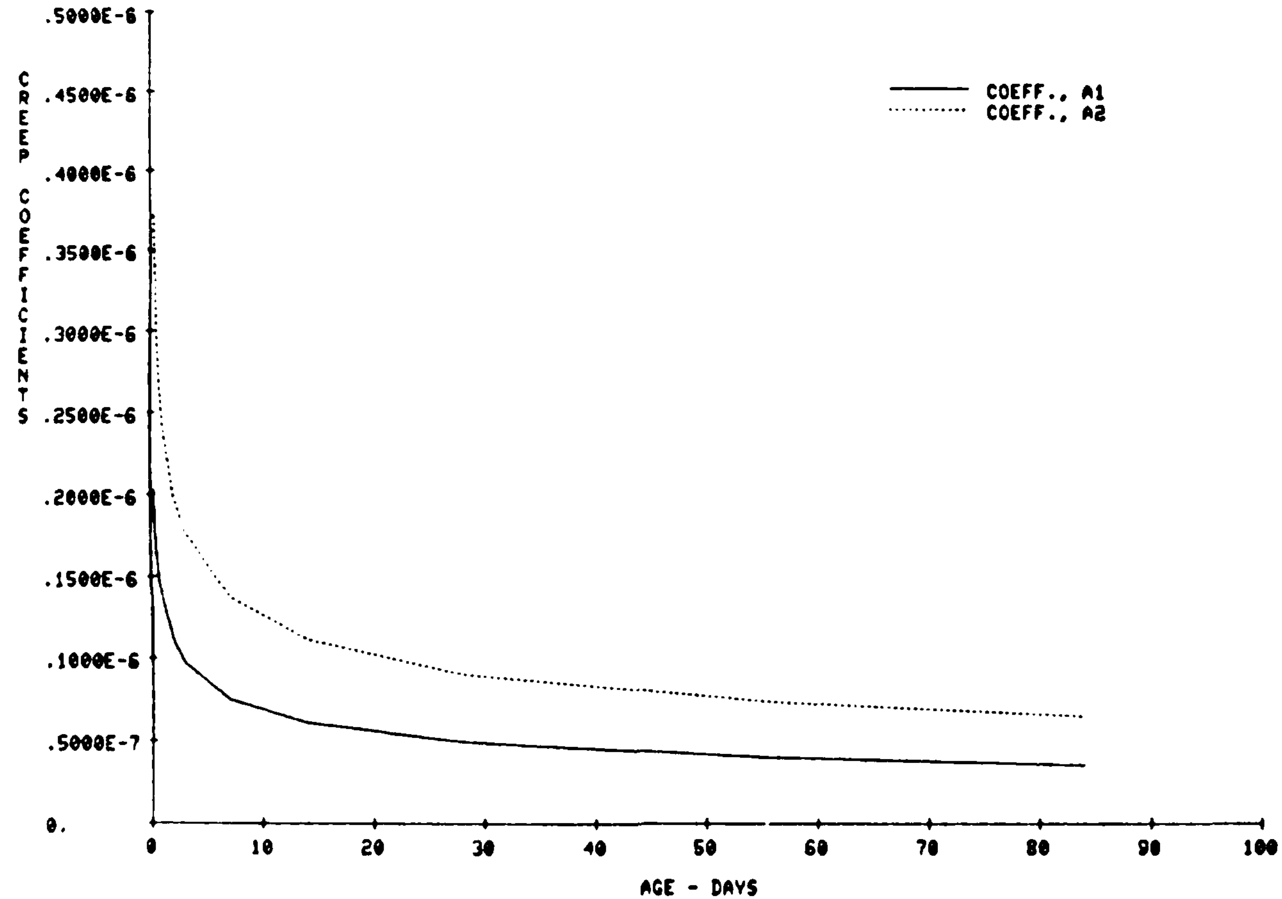


FIGURE 4c. CREEP RELAXATION COEFFICIENTS ASSUMED FOR CONCRETE AS A FUNCTION OF AGE AS USED IN THE THERMAL STRESS-STRAIN RUNS.

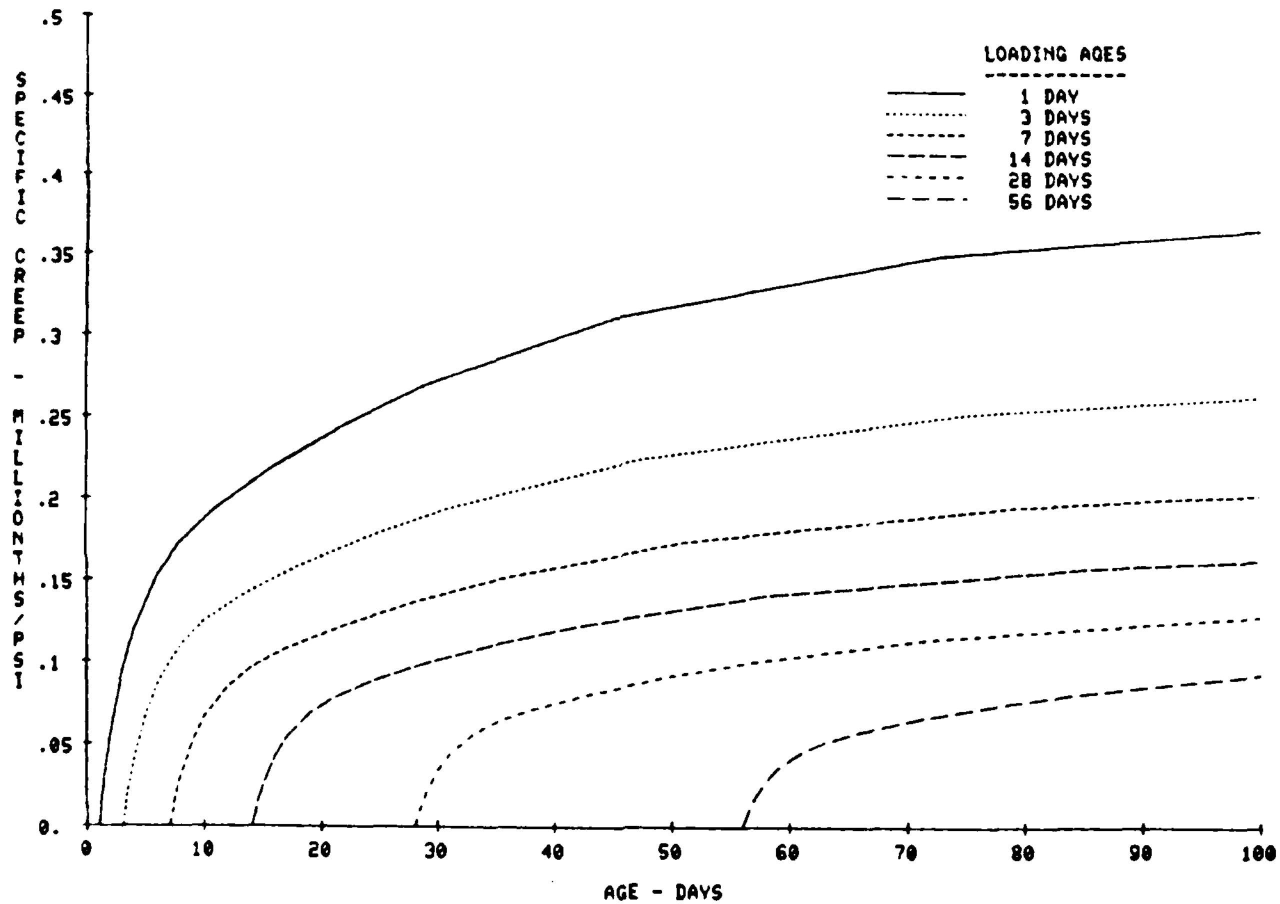


FIGURE 4d. SPECIFIC CREEP OF CONCRETE AS A FUNCTION OF AGE AT LOADING AS USED IN THE THERMAL STRESS-STRAIN RUNS. DATA COMPUTED BY MCHENRY'S EQUATION USING COEFFICIENTS FROM FIGURE

t - time

T - temperature

R - gas constant

r,A,B,Q - material constants.

The elastic modulus and ultimate strength can be expressed as functions of age (t) and temperature (T) as E(t,T) and $\sigma_u(t,T)$, respectively. The cracking strain (ϵ^c) is assumed to be 10 percent of the absolute value of the compressive strain at ultimate strength. Poisson's ratio (ν) is assumed to be constant. The creep properties and the properties E(t,T), $\sigma_u(t,)$, ϵ_f, and ν are included in a separate subroutine in a form that can be modified by the user. The E versus time data used in UMAT2 was based upon the data shown in Figure 4b except that the numerical fit provided by the model developer produced higher values of E for the first two days of age. The creep data used came from tests of silica fume concrete and produced specific creep values slightly higher than the creep data shown in Figure 4d. Shrinkage data was linear until 1 day at a rate of 100 millionths per day and non-linear thereafter with typical values of approximately 300, 350, and 400 millionths at 10, 25, and 50 days, respectively.

Other properties

29. Additional properties data used as input to the computer programs are shown in Table 1. Included are data for concrete, the soil foundation, and air when modeling the internal voids of monolith L-17. The values for some of the properties are modified to accomplish a modeling technique. For example, the density and modulus, E, of the soil in the WES2DT stress analyses were assigned very low values to effectively eliminate the soil because the actual elements could not be removed. An abnormally high value of thermal conductivity was assigned to air to simulate the combined heat transfer effects of convection and conduction when air elements are actually included in the model.

Table 1.

Materials Data Used in FE Investigation.

Concrete	
Thermal conductivity	0.09789 Btu-in./hr-in.^{2}-^{o}F
Specific heat	0.21 Btu/lb-^{o}F
Density	0.08714 lb/in.^{3} (151 lb/ft^3
Coefficient of thermal expansion	4.5 x 10^{-6} in./^{o}F
Poisson's ratio	0.17
Foundation	
Thermal conductivity	0.066 Btu-in./hr-in.^{2}-^{o}F
Specific heat	0.45 Btu/lb-^{o}F
Density (temperature calculation)	0.0758 lb/in.^{3} (131 lb/ft^3)
Density (stress calculation)	0.0000006 lb/in.^{3} (or ~ 0)*
Coefficient of thermal expansion	4.5 x 10^{-6} in./^{o}F*
Poisson's ratio	0.35
Modulus of elasticity	1.0 psi*
Air (for voids in L-17 with ABAQUS temperature calculations only)	
Thermal conductivity	1000. Btu-in./hr-in.^{2}-^{o}F**
Specific heat	0.24 Btu/lb-^{o}F
Density	0.000046 lb/in.^{3}

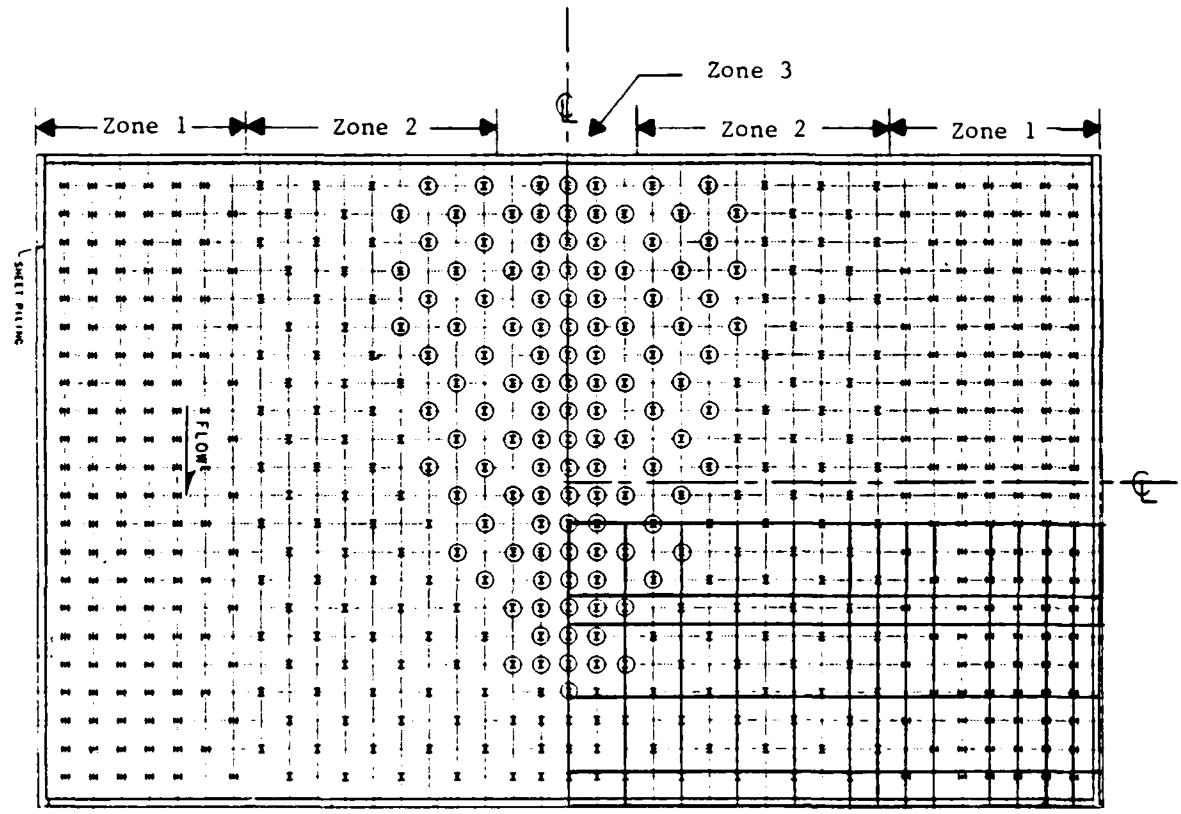
* Values used in runs with WES2DT program only to eliminate soil effects. Foundation not included in stress runs with ABAQUS.

** Modeled value for air used combines the effects of convection and conduction in an enclosed void with ABAQUS.

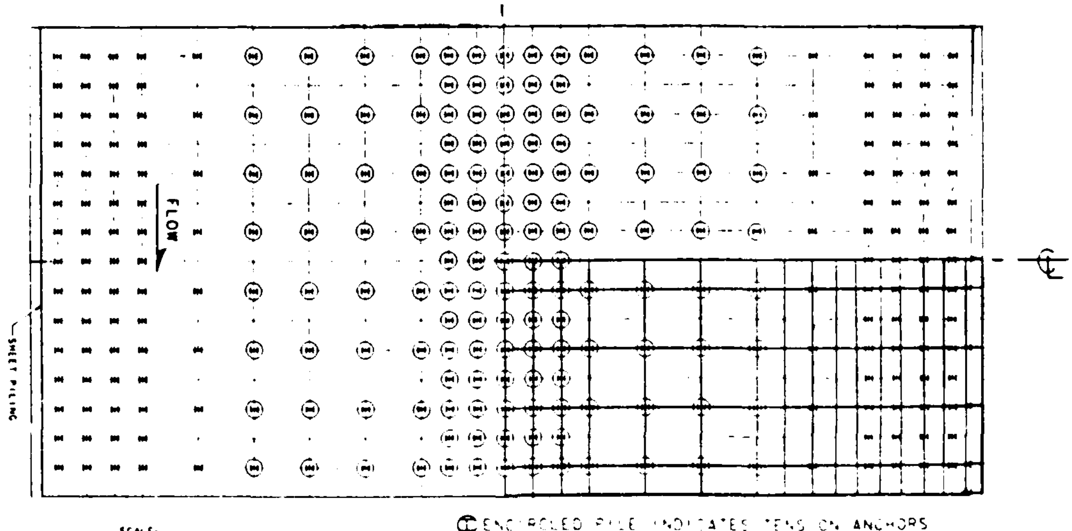
Pile Stiffnesses

30. Individual pile stiffnesses for H-piles were supplied by St. Louis District. Pile stiffnesses for strong soil pile support were used because earlier thermal studies on several projects conducted at WES indicated that the strong pile constant assumptions produced the highest thermal stresses.

31. Each two-dimensional FE model of monoliths L-13 and L-17 represents a plane transverse to the flow axis of the structure. The pile stiffnesses actually used represent the average stiffness of each row of piles parallel to the flow axis per inch thickness into the model. Figures 5a and 5b show the plan pile layouts for monoliths L-13 and L-17.



(b) Monolith 17



(a) Monolith 13

Figure 5. Location of piles in monoliths L-13 and L-17 including plan overlay of three-dimensional finite element grids.

32. Monolith L-13 In monolith L-13 there are either 8 or 15 piles in the flow dimension of the monolith at increasing horizontal distances from the axis. All individual piles were specified to have the same pile stiffnesses and all are oriented with the strong axis in the horizontal direction of the model (transverse to the flow). Therefore, the stiffnesses used in the 2-D analyses differ by the two pile densities only. These stiffnesses and bases for calculation for monolith L-13 are shown in Tables 2 and 3.

Table 2.

Individual Pile Stiffnesses, Monolith L-13
(Strong Pile Constants)

	Stiffness/Pile (kips/in.)
F_x (horizontal, strong axis)	54.6
F_y (horizontal, weak axis)	44.2
F_z (axial)	896.4

Table 3.

Pile Stiffnesses Used in Two-Dimensional Stress Analyses, Monolith L-13
(Flow-direction distance = 84 ft)
(Stiffnesses are per 1.0-in. thickness)

	Distance of Flow-Direction Row of Piles from Flow Axis (ft)		
	0, 5, 10	15, 25, 35, 45, 55	65, 70, 75, 80
No. of Piles in Row	15	8	15
Stiffness (k) (kips/in.)			
Vertical	13.349*	7.1143	13.339
Horizontal	0.8125*	0.4333	0.8125

* Values at 0 ft reduced by (0.5 x k) due to location at symmetric boundary.

33. <u>Monolith L-17</u> In monolith L-17 there are either 11 or 22 piles in the flow direction. The transverse distance from the flow axis outward was divided by St. Louis District into three pile stiffness zones as shown in Figure 5b. Piles in zones one and two have the same individual pile stiffnesses, however, the strong axis of the piles in zone one are transverse to the flow axis while the strong axis of piles in zone two are in the flow direction. Zone-three piles are also oriented with the strong axis in the flow direction. The stiffnesses used and bases for calculation for monolith L-17 are shown in tables 4 and 5. The stiffnesses were determined for each flow-direction row of piles individually and not for an area average of all piles in a pile zone.

34. In 3-D models of monoliths L-13 and L-17, individual piles are discretely modeled. Therefore, the stiffness values used are those provided in the first table above for each monolith. Piles were oriented in the directions described earlier and shown in Figure 5.

Table 4.

Individual Pile Stiffnesses, Monolith L-17
(Strong Pile Constants)

	Stiffness/Pile (kips/in.)	
	Zones 1 and 2 (HP 14 x 73)	Zone 3 (HP 14 x 117)
F_x* (horizontal, strong axis)	66.88	66.88
F_y* (horizontal, weak axis)	44.61	36.10
F_z* (axial)	2375.	1478.

* As per axis direction convention provided with data from St. Louis District.

Table 5.

Pile Stiffnesses Used in Two-Dimensional
Stress Analyses, Monolith L-17
(Flow-Direction distance = 116 ft)
(Stiffnesses are per 1.0-in. thickness)

	Distance of Flow-Direction Row of Piles from Flow Axis (ft)					
	0	5	10	15, 20, 25, 30, 35, 40, 45, 50, 55	60, 65	70, 75, 80, 85, 90
Pile Zone	3	3	3	2	1	1
No. of Piles/Row	22	22	11	11	11	22
Strong Axis Direction	with flow	with flow	with flow	with flow	with flow	transverse to flow
Stiffness (k) (kips/in.)						
Vertical	11.680*	23.359	11.680	18.768	18.768	37.536**
Horizontal	0.285*	0.570	0.285	0.352	0.528	1.057**

* Values at 0 ft reduced by (0.5 x k) due to location at symmetry boundary.
** Values at 90 ft reduced by (0.663 x k) due to larger area of influence associated with this row of piles.

Construction Parameters and Boundary Conditions

Lift heights

35. Lift heights used in the FE models for both monoliths L-13 and L-17 were based upon those provided in the plans supplied by the District. Five-ft lifts were used in the base and 8- to 10-ft lifts were used in the wall of monolith L-13. Lift heights ranged from 3 ft to 5 ft in the base, 6 ft in the lower wall, and 5 to 5.5 ft in the upper wall of monolith L-17. The actual locations of lifts are shown on the FE models in Figures [illegible]a-[illegible]e in Part VI of this report.

Placement rates

36. A concrete placement interval of 5 days between lifts was used throughout the study. Although actual placement may progress more slowly, a rate of 5 days per lift was used as the most possible case. This rate also allows less time for lift surfaces to cool between placements of lifts than at slower rates of placement. The higher internal temperatures and thermal stresses that result become the maximum values attainable at the most rapid allowable placement rate.

Ambient air temperature and foundation temperature

37. Air temperatures used were provided by the District and are representative of the project site. Figure 6 contains the mean ambient temperature versus time of the year data used in the study. The data are characterized by a sinusoidal curve peaking in August and having minimum temperatures in January. Including daily variation in temperature was felt to be beyond the scope of this study.

38. Foundation temperature was assumed to be a constant 55^{o} F at a depth of 20 ft below the lowest elevation of each monolith. In this manner the constant temperature was specified at el. 344 ft in monolith L-13 and el. 338 ft in monolith L-17. The value of 55^{o} F represents mean annual temperature for the project site. The initial temperature distributions within the soil were determined in a preliminary finite element calculation in which the upper surface of the soil was exposed to the ambient temperature data shown in Figure 6 and the constant value of 55^{o} F along the lower model bound. ry. This heat flow simulation was run over a scaled time period exceeding one year so that final values accounted for the thermal momentum of the soil mass in responding to ambient temperature changes.

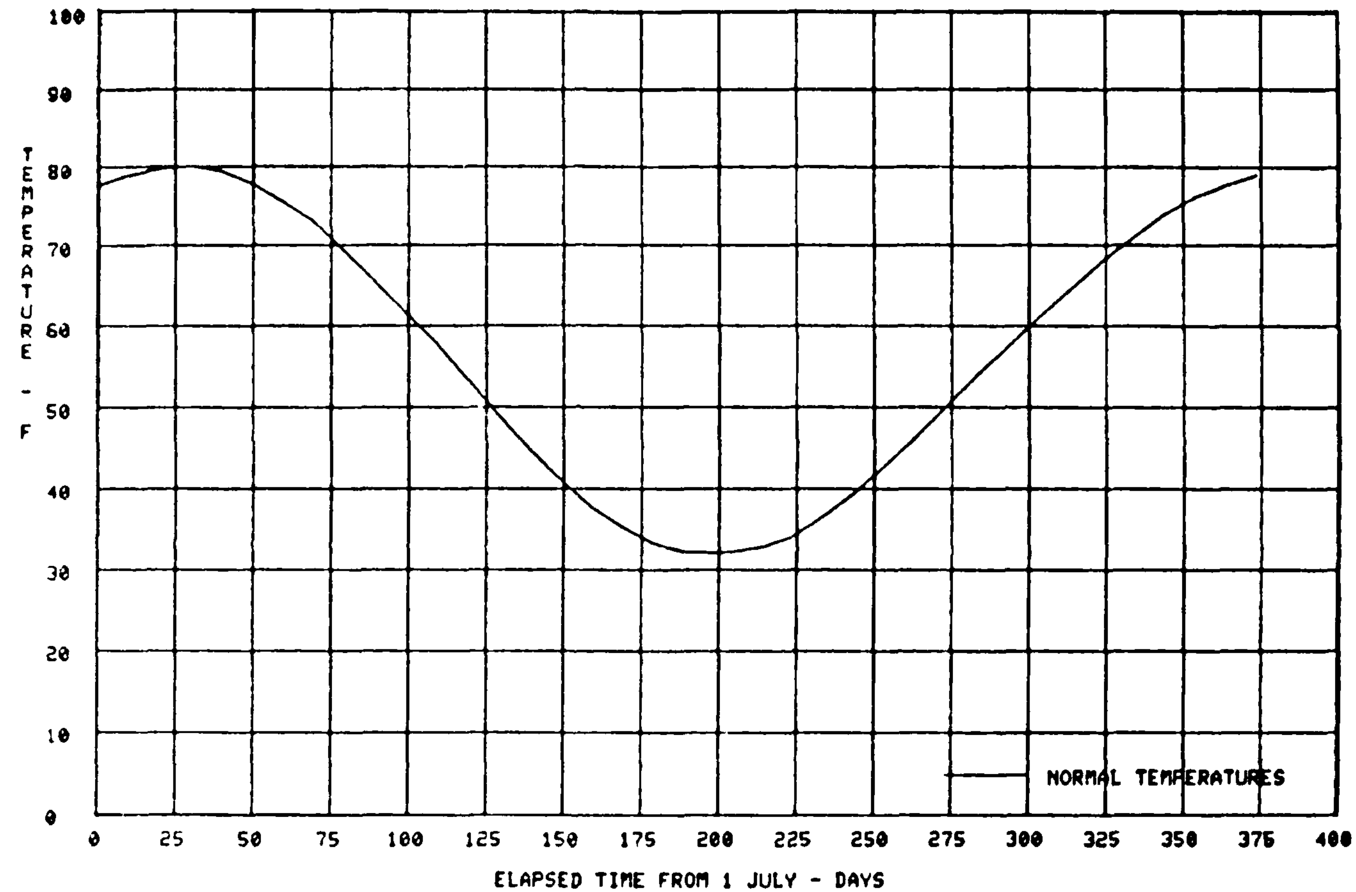


FIGURE 6 - MEAN DAILY AMBIENT TEMPERATURES FOR ALTON, IL. USED IN TEMPERATURE RUNS. DATA REPRESENTS EXPECTED NORMAL TEMPERATURES.

Construction start dates, placement temperature

39. All computer runs in this investigation were based upon a construction start date of 1 July. Previous investigations indicated that an early summer construction start generally produces highest thermal stresses when compared to other start times during the year.

40. A maximum placement temperature of 65° F was used in all areas of the structure. During summer construction this will probably require that some of the mixing water be added as crushed ice.

Thermal boundary conditions

41. The lower boundary of the soil was fixed at 55 F as described earlier. No horizontal heat flow was permitted through the vertical soil boundaries. Heat flow was also not permitted horizontally through the vertical centerline of the monoliths represented by the extreme left side of the models.

42. The thermal boundary condition that controls heat exchange between the structure and the ambient air is a surface heat transfer coefficient. It is composed of a convection coefficient that defines heat exchange with surrounding air as well as a conduction heat transfer coefficient which defines the heat flow through the formwork.

43. The convection heat transfer coefficient is based upon surface air velocity. An air velocity of 10 mph was used for external surfaces and a velocity of 1 mph was used for the surfaces of unenclosed voids such as galleries, culverts, and recesses. It was assumed that unenclosed voids would be exposed to and ventilated by ambient air, but with reduced air flow. The enclosed voids (internal rooms) in monolith L-17 were treated similarly until the enclosing concrete of lift 8 was placed. At void closure, the FE grid in the void area was activated as air elements. This permitted the temperature of the void to vary as a function of surrounding concrete temperatures as in

reality. This modeling scheme was considered adequate even though convection heat exchange between the void and concrete surfaces and the vertical stratification of the air could not be included.

44. On external, vertical surfaces and non-enclosed recesses the insulating effect equivalent to 3/4-in. plywood forms was included in the heat transfer coefficient for the first 2 days after placement of a lift. After the second day in order to simulate form removal, the heat transfer coefficient included only convection effects of the wind. On internal, vertical formed surfaces and the horizontal upper void surfaces of monolith L-13, the effect of forms was left in place until seven days after placement of the enclosing cover lift to simulate the forming practices in such areas. In monolith L-17 all formwork heat transfer effects were removed at the time that the void cover lift was placed as described in Paragraph 43 above. All exposed horizontal surfaces were given heat transfer coefficients equivalent to convection wind effects only. No supplemental insulation was included. In 3-D runs, the flow-direction end of the monoliths were assumed free. That is, adjoining monoliths were not assumed to exist in these simulations.

Mechanical boundary conditions

45. Because it was assumed that the piles elements would carry the concrete loads, the soil was ignored in all stress runs. The symmetric boundaries were fixed in the horizontal directions. All other surfaces were assumed free including the ends of the monolith in 3-D runs.

PART VI: FINITE ELEMENT MODELS

General

46. The primary goal of this investigation has been to analyze selected monoliths of Lock and Dam 26(R) for thermal and construction induced stresses based upon calculations using state-of-the-art FE technology. While efforts were directed toward this goal, a substantial amount of developmental work and investigative analyses were conducted to implement the mechanics of using ABAQUS for incremental construction thermal stress analysis, to assess the requirements for acceptable modeling accuracy, and to evaluate the results of these analyses. These factors required development of many FE models, both two- and three-dimensional, in order to complete this investigation. The following sections describe these models, including the analytical bases, and the other considerations taken in their development.

47. Monoliths L-13 and L-17 were requested for FE analyses in this investigation. L-13 represents a typical lock chamber monolith, which due to its common transverse-section geometry, was considered ideal for comparative two- (2-D) and three-dimensional (3-D) analyses. L-17 is the lower gate monolith which is more massive, and has geometric features which include large, non-symmetrically located internal voids or rooms, non-symmetrical external recesses, and different chamber floor thicknesses. These features point strongly toward a requirement for 3-D analysis. Symmetric, half-section isometric projections of monoliths L-13 and L-17 are shown in Figure 1. Internal voids in L-17 are indicated.

48. All 2-D models developed for this investigation represent sectional planes transverse to the flow axis. The monoliths were assumed symmetric relative to the flow axis, therefore, each 2-D model consists of one-half of the transverse cross section. In all cases the axis of symmetry lies at the

left side of the model. The 3-D models consist of quarter sections of the monoliths with symmetric axes located at the flow axis and halfway between the upstream and downstream faces. Actually, the 3-D model of L-17 is not exact geometrically because the monolith is not symmetric in the flow direction. This subject is further explained below.

49. In all FE models the soil was included for the temperature analysis. With ABAQUS, the soil was removed from the stress analysis with spring (pile) elements added to support the structure. The WES2DT program did not permit removing the soil elements. As an alternative, the mechanical properties of the soil were changed to appropriate values (see Table 1) which effectively removed the soil. Pile elements were added to support the structure in a manner identical to that when using ABAQUS.

Two-Dimensional Models, L-13

ABAQUS model selection

50. Based primarily on past experience with the WES2DT program, a grid was selected for use with ABAQUS that was expected to have an adequate number of degrees of freedom to capture the essential features of the temperature and stress response expected for the problem especially considering the higher order elements available in ABAQUS. This FE grid referred to as the coarse grid is shown in Figure 7a and is characterized by two elements per lift, vertically, and two elements wide across individual sections of the culvert and wall stem. To insure that this grid was adequate, a more refined grid, Figure 7b, was also developed to be used for the 2-D analyses. The refined grid is characterized by three elements per lift, vertically, and three elements wide across individual sections of the culvert and wall stem. The assumption made was as follows: if the results of analyses using the two grids are in close agreement, the amount of refinement in the first grid would be sufficient since

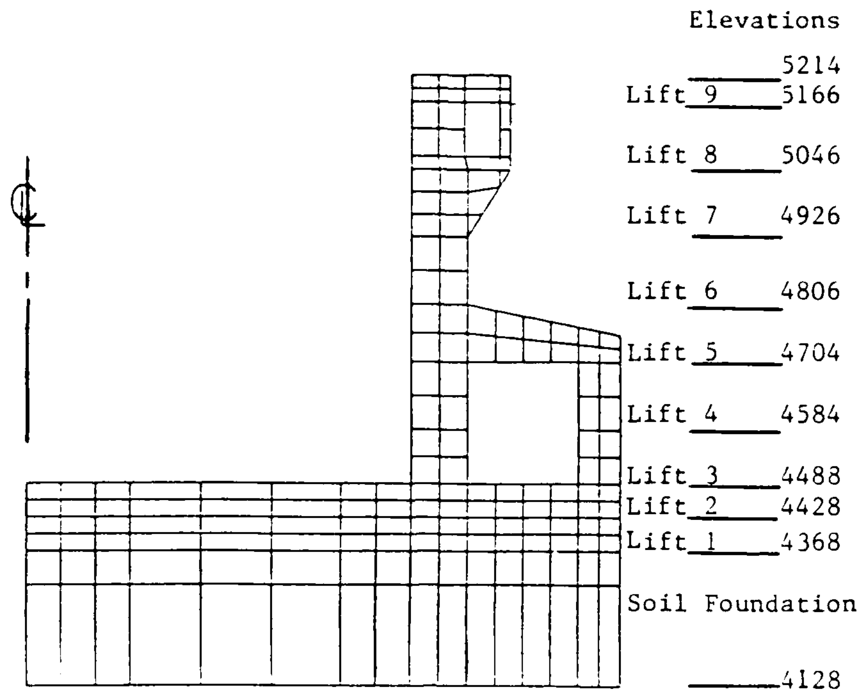


Figure 7a. Monolith 13, two-dimensional finite element grid 1 (160 Element Model) for ABAQUS

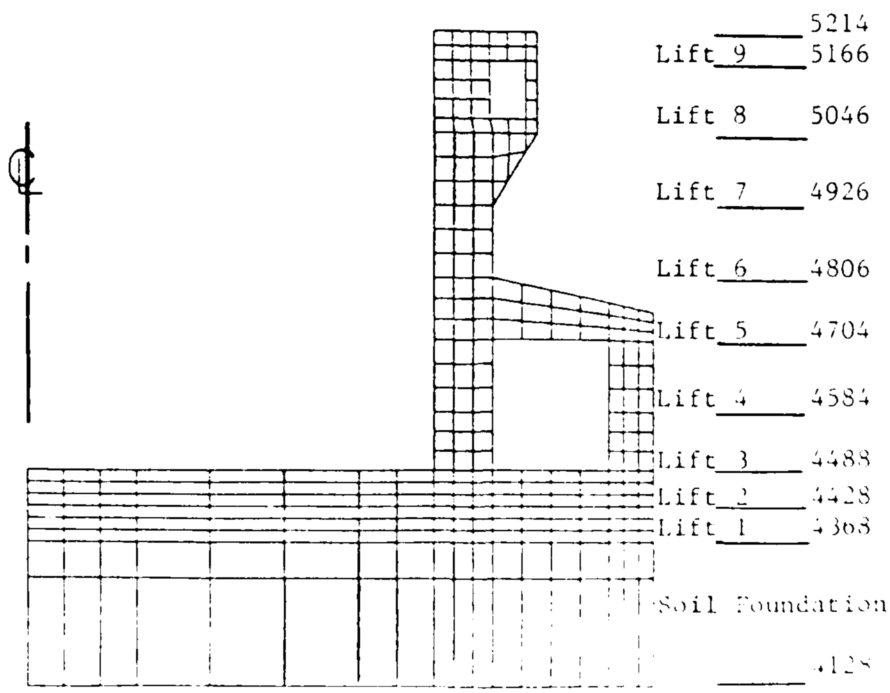


Figure 7b. Monolith 13, two-dimensional finite element grid 2 (264 Element Model) for ABAQUS

similar grids have been used in the past with WES2DT. This being the case, preparation of only one grid each would be required for 2-D analyses of L-17 and for all 3-D analyses.

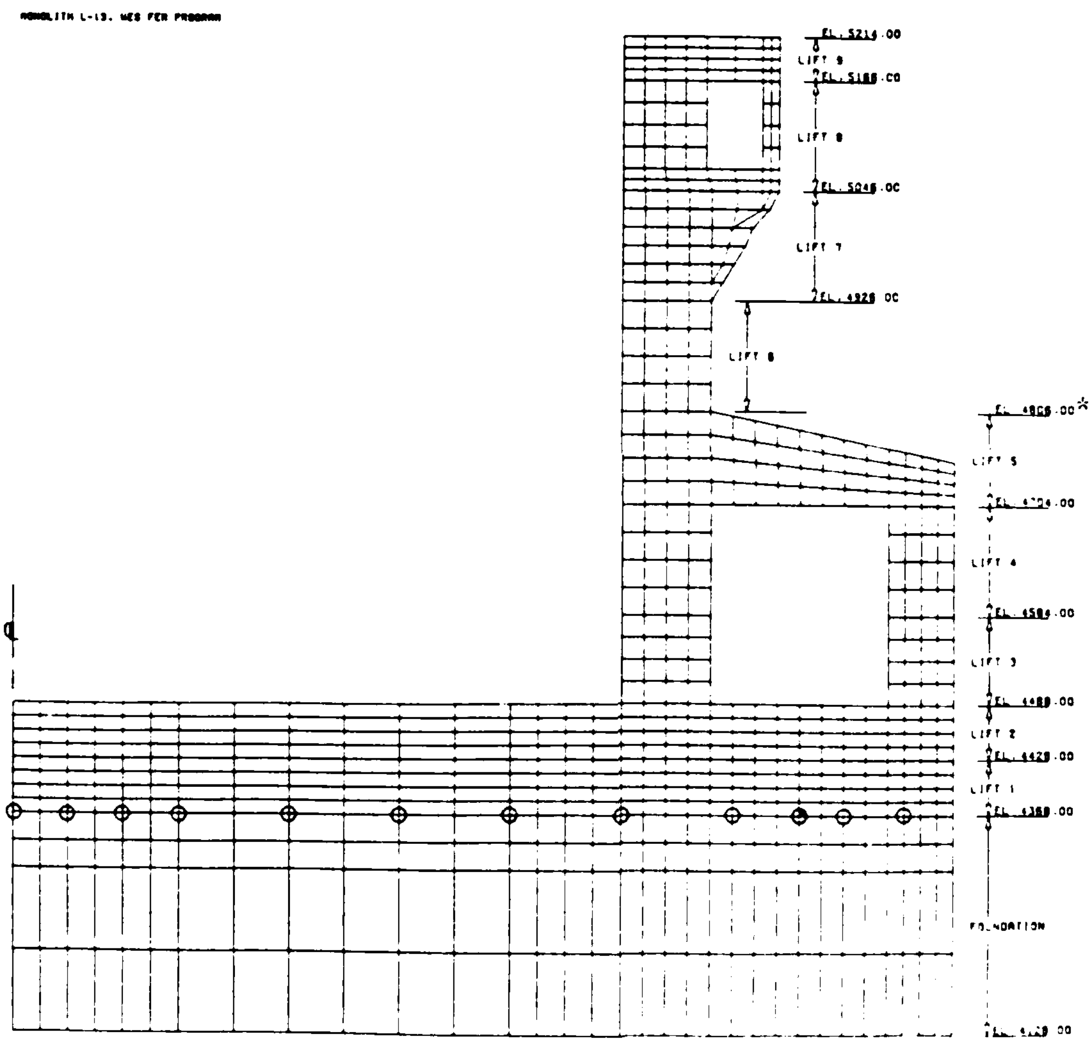
WES2DT model selection

51. The FE grid of L-13 developed for use with the WES2DT program was based upon the coarse-grid model used with ABAQUS, but with an exception. The WES2DT program uses four-node elements with linear temperature distribution and linear displacement functions while ABAQUS was run with eight-node elements using quadratic temperature and displacement functions. In order to make reasonable comparisons between the two programs the grid developed for WES2DT was designed to coincide with the nodal locations in the ABAQUS model. This process yielded four elements in the WES2DT grid for every one in the ABAQUS equivalent grid. The FE grid used to model L-13 for the WES2DT program is shown in Figure 7c.

Two-Dimensional Models, L-17

ABAQUS model selection

52. The element density criteria used to establish the 2-D grid for L-17 was similar to that used for the coarse-grid FE model of L-13, namely, using two elements vertically per lift. The element density horizontally generally conforms to the locations of rows of piles which are oriented parallel to the flow axis and also to the location of internal voids. The 2-D section of L-17 chosen was that located at Station 26 + 13 near the downstream end which contained the smallest amount of voids. This section was expected to experience the largest temperature rise and was the same one used for an earlier temperature study using the WES2DT program. This section passes through the smaller of the internal voids in L-17 and through a machinery recess at the top of the monolith.



0 - indicates pile element locations
* - elevations are in inches

Figure 7c. Monolith 13, two-dimensional finite element grid used with WES-2DT programs.

53. Voids and recesses were not gridded in all previous FE models. With ABAQUS, elements can be activated or deactivated dynamically as the incremental construction process is simulated. This feature provided an opportunity for a new approach in FE grid preparation for L-17. A sectional grid which represents the maximum floor and wall thicknesses was fashioned. By locating the grid to coincide with recesses and voids as well as construction joints between lifts, virtually any cross section of L-17 could be modeled by merely deactivating the appropriate elements which represented voids or recesses. This was particularly useful when dealing with the internal voids.

54. In L-13 the culvert and upper access gallery pass through the entire length of the monolith. It was assumed when modeling the thermal boundary conditions that these voids would be ventilated by ambient temperature air, but with a lower velocity than that on exposed external surfaces. In L-17 the internal voids are exposed to ambient temperature air only until the enclosing concrete is placed. Except for doorways to the adjacent voids, these voids are enclosed. After closure, the air temperatures in the voids must become a functions of the concrete surface temperatures surrounding each of the voids.

55. The ABAQUS 2-D model of L-17 shown in Figure 7d contains the full sectional grid as described above with two shaded areas included. The elements in the upper shaded area represent the machinery recess and were deactivated permanently. The elements in the lower shaded area, which represents the internal, closed void, were deactivated only until the covering lift (No. 8) was placed. The void elements were then activated with the properties of air. Thereafter, these air elements were an integral part of the model. This procedure was an effective means of modeling the thermal boundary of the void. The only limitation to this modeling technique is that convection heat transfer will in reality cause air in the void to stratify with the warmer air rising to

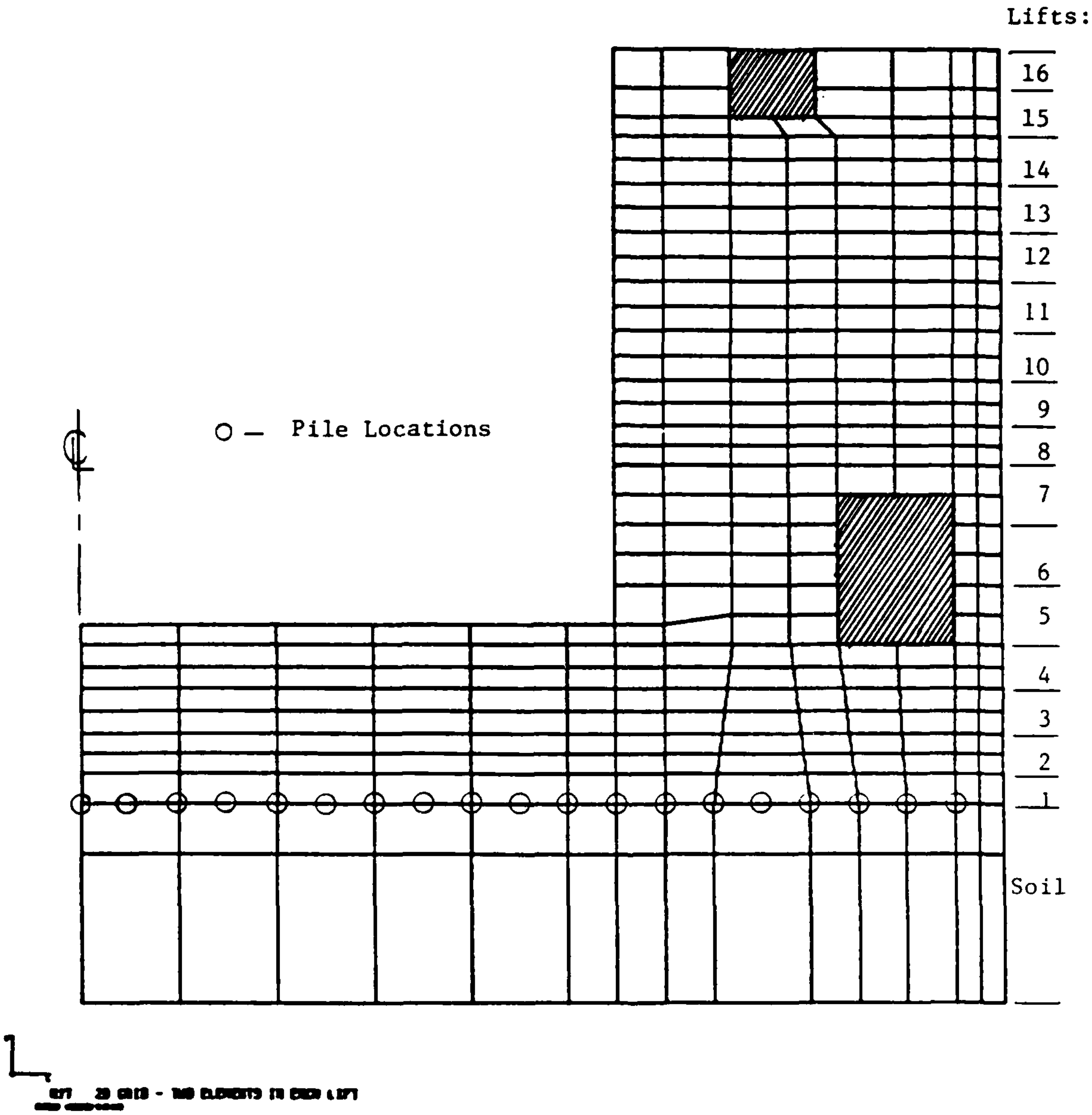


Figure 7d. Monolith 17, two-dimensional finite element model, ABAQUS, program (316 elements)

the ceiling. This minor error is acceptable in light of the benefits derived from implementing this modeling technique.

WES2DT model selection

56. The 2-D FE grid of L-17 designed for use with WES2DT program for an earlier thermal study of L & D 26(R) is shown in Figure 7e. This grid, therefore, does not compare exactly with the one prepared for use with ABAQUS as was the case for L-13. However, if the four-element-for-one technique for designing a comparable WES2DT FE grid from an ABAQUS grid was followed for L-17 as was employed for L-13, the WES2DT grid generally compares. One major difference is that the WES2DT grid only extends vertically through lift 13 (el. 420.5 ft.) whereas the ABAQUS grid extends the full 16-lift height of the monolith (el. 434.5 ft.). Through the first 13 lifts, the WES2DT grid consisted of over 900 elements which was considered a practical upper limit. Because the primary areas of interest were the chamber floor and lower wall, the top lifts were not gridded. Instead, the top surface of lift 13 was insulated appropriately at the scheduled time of placing lift 14 to simulate the correct temperature conditions in the monolith. Equivalent gravity loads for lifts 14-16 were simulated by applying surface pressure to the top of lift 13 at the appropriate times of placement of the subsequent lifts.

Three-Dimensional Model, L-13

57. As described earlier, the 3-D FE model prepared for L-13 is a quarter section of the monolith. This model shown in Figure 8a is made up of five element planes in the flow direction each with a sectional grid identical to the coarse-grid 2-D model. The four interfaces planes between these five element planes coincide with the location of those complete rows of piles oriented transverse to the flow direction. Figure 5a shows a plan view of the quarter-section L-13 3-D model superimposed on the pile layout with vertical

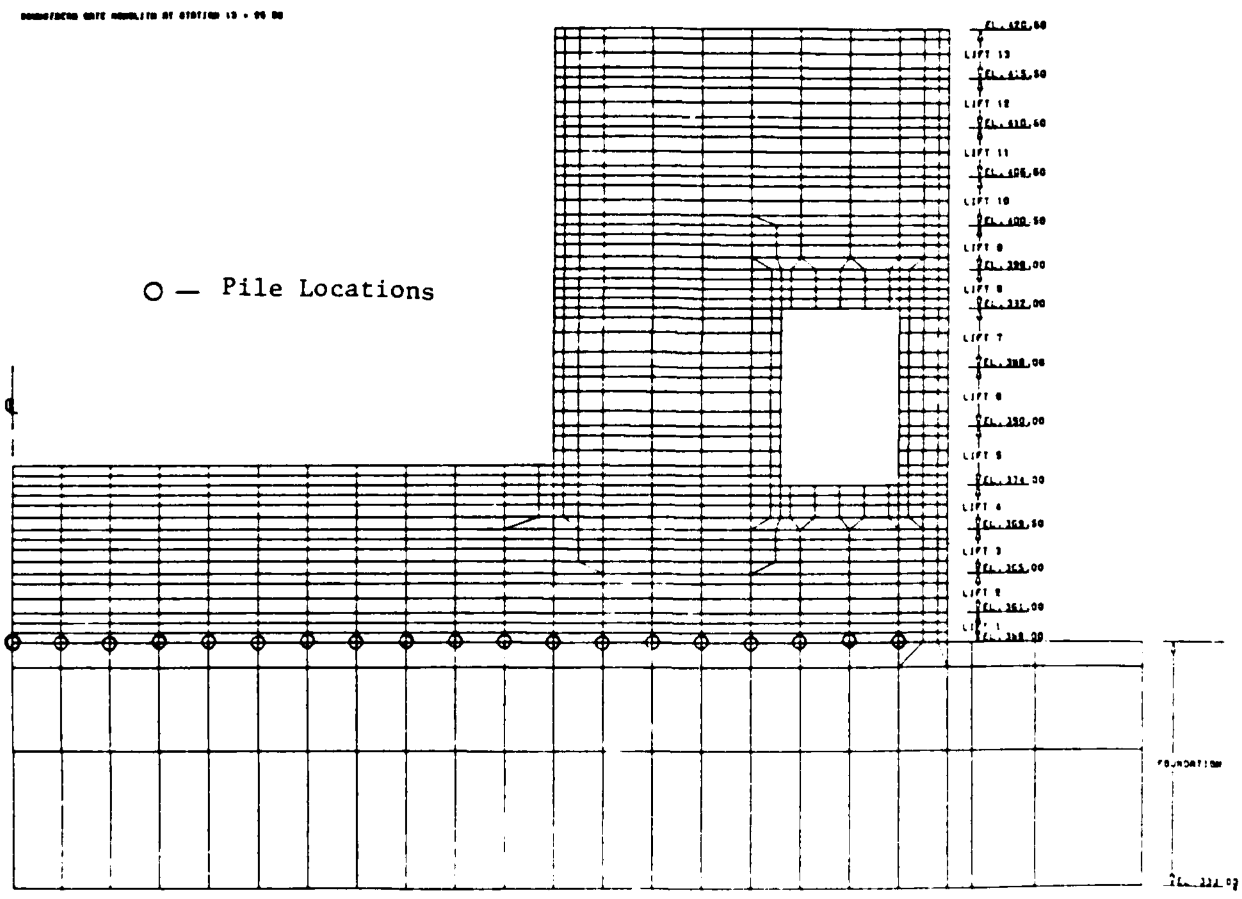


Figure 7e. Monolith 17, two-dimensional finite element model, WES2DT program (908 elements)

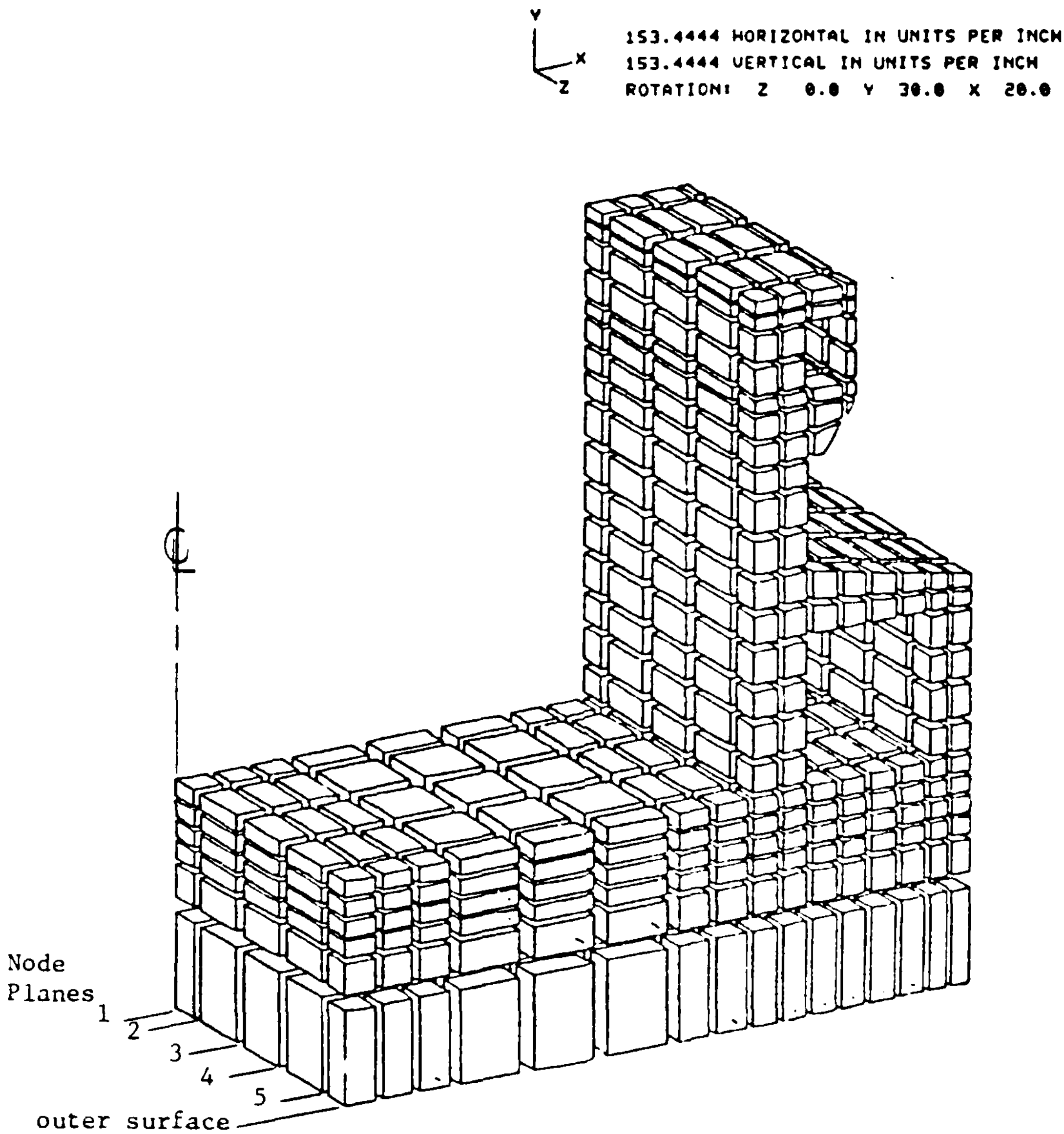


Figure 8a. Three-Dimensional Grid of Monolith L 13

element boundary projections shown. The grid was designed to model the geometry of the monolith with a minimum number of elements in the flow direction which were adequate to provide acceptable results and have element boundaries coinciding with pile locations. The 20-node 3-D elements that were used have nodes located at the element corners and midway between corners. As seen in Figure 5a, most of the piles coincided with these nodal locations in the model. For those that did not, a capability within ABAQUS was used that permited creation of extra nodes at these unassigned pile locations.

Three-Dimensional Model, L-17

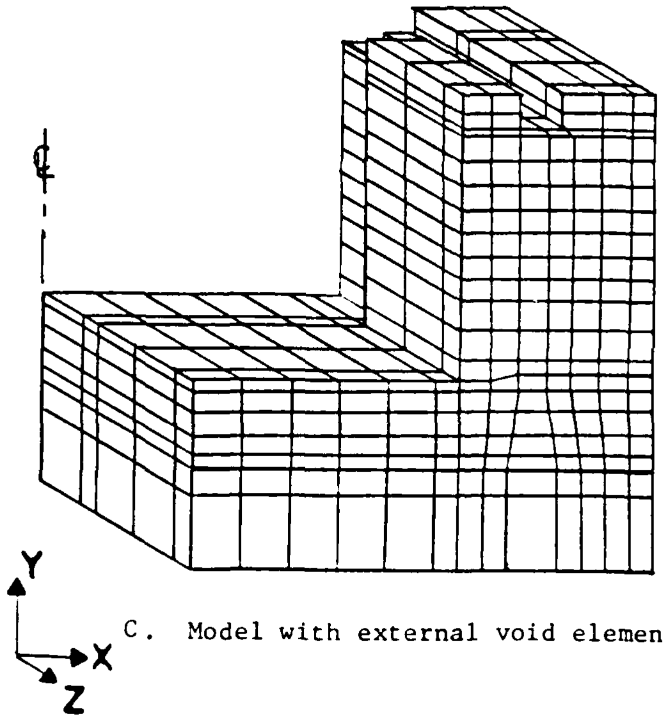
58. It was recognized very early in the investigation that proper 3-D modeling of L-17 would require a half-section symmetric representation of the monolith. This was due to the non-symmetric geometry in the flow direction. However, constraints identified by the developers of ABAQUS and those recognized by the investigators indicated that a half-section model was not feasible. In fact it was recognized that even a minimally discretized quarter-section model would severely tax available computer and project resources due to the massiveness of the monolith. The primary constraint was a practical upper limit of approximately 1000 elements.

59. It was evident that several trade-offs would be necessary for the L-17 3-D model. The construction plan for L-17 indicated concrete placement in 16 lifts. It had been determined from the ABAQUS incremental construction evaluations and L-13 2-D grid comparisons that at least two elements vertically per lift were preferred for adequate calculation accuracy. It was also evident after examination of the geometric features that a minimum of six elements were required in the flow direction in order to model the geometric features, which included voids and recesses, and to include the actual flow direction axis of symmetry. Based upon the 5-ft by 5-ft spacing of the basic pile location grid,

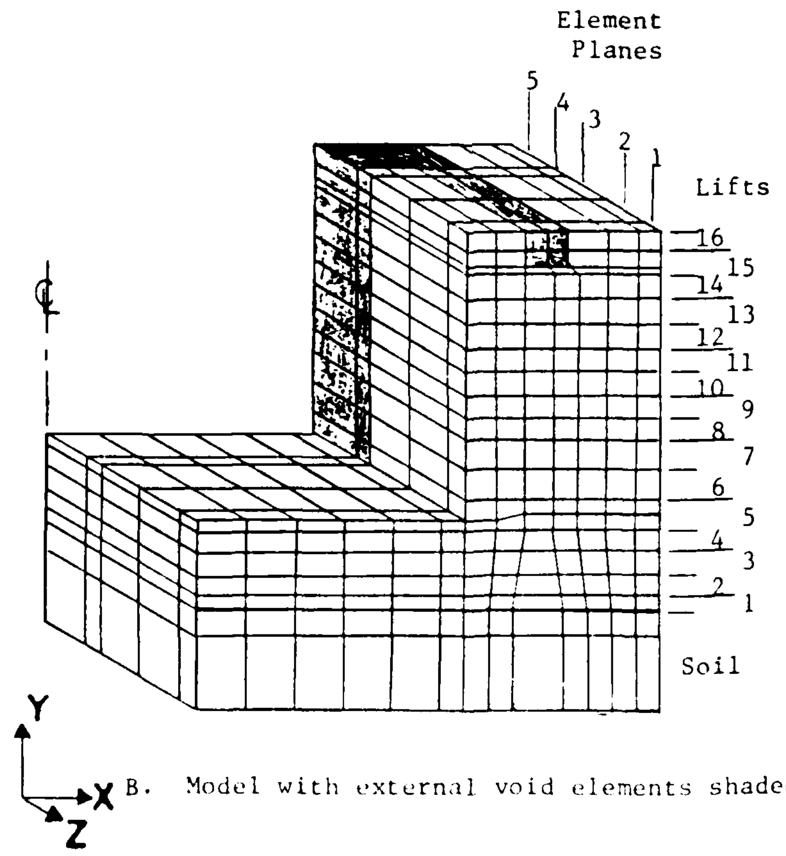
it was evident that the maximum size of a 3-D element in the floor slab was 10-ft square in plan. Smaller elements were necessary in the wall. These criteria were used to lay out a preliminary grid. The resulting grid size was close to 2000 elements or nearly double the practical limit.

60. To keep within the 1000-element practical limit several changes had to be made. First, except for lift 5, each lift was gridded with only one element vertically rather than two. The number of element planes in the flow direction had to be reduced from six to five. In order to properly model the monolith and discrete piles, it was necessary for element boundaries in the flow direction to correspond to every other transverse row of piles. Therefore, the resulting quarter-section boundary transverse to the flow is not located at the monolith midpoint in the flow direction. The 3-D nodes is slightly less than one-half the monolith dimension in the flow direction.

61. The basic 3-D grid resembled an reversed "L" shape for the floor and wall similar to that used for the 2-D L-17 model. All voids and recesses were similarly obtained by deactivating the appropriate elements. Figures 8b and 8c are isometric projections of the L-17 3-D grid. Figure 8b shows the basic grid with external, deactivated elements shaded while Figure 8c shows the grid with the deactivated elements removed. Figure 8d shows the basic sectional element plane and the five elements planes with the internal and external deactivated elements shaded.



C. Model with external void elements removed



B. Model with external void elements shaded

Figure 8. Monolith 17, three-dimensional finite element model, ABAQUS program (910 elements)

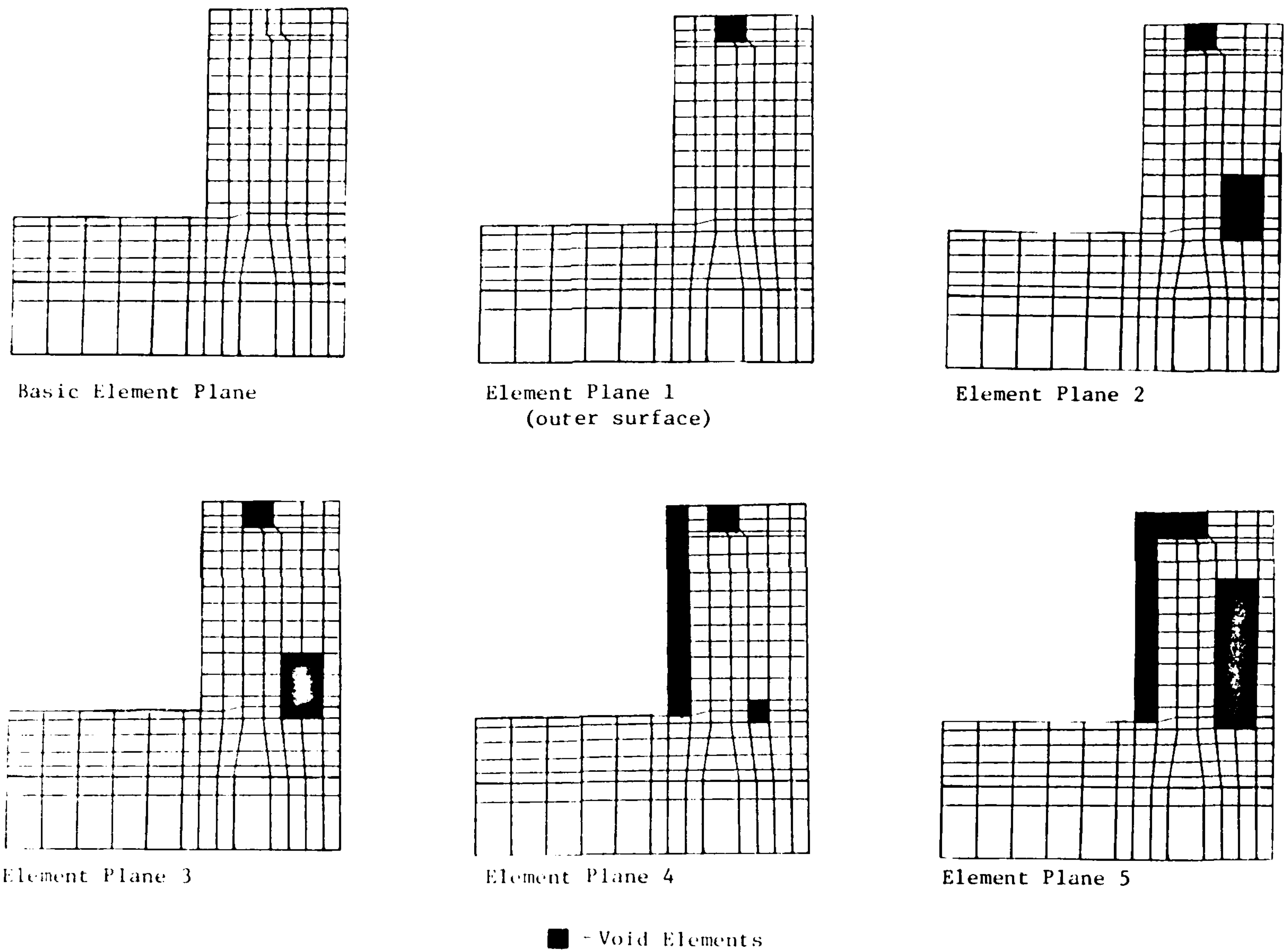


Figure 8d. Element Planes for Monolith 17, three-dimensional model showing internal and external voids.

PART VII: THERMAL ANALYSES OF MONOLITH L-13

Presentation of Results

Two-dimensional temperature analysis

62. Temperature analyses of monolith L-13 were performed using both the ABAQUS and WES2DT programs. Figures 9a thru 9d show results from the ABAQUS program using FE grid 1 (Figure 7a) at four stages of construction. Figures 10a thru 10d show the results of the ABAQUS program using FE grid 2 (Figure 7b) at four stages of construction. Results from the WES2DT program using a FE grid (Figure 7c) functionally equivalent to that of ABAQUS FE grid 1 are shown in Figures 11a thru 11d for the same four stages of construction used for presenting ABAQUS data.

Three dimensional temperature analysis

63. The ABAQUS program was used to make a 3-D analysis of monolith L-13 using the FE grid shown in Figure 4. These results are shown using contour plots (Figures 12a - 12d thru 15a - 15d) which show temperatures on faces of elements in the five element planes (Figure 8) of the structure at four stages of construction. Four of the element planes are internal, one is an outer surface.

Discussion of Results

Two-dimensional temperature analysis

64. The ABAQUS results for FE grids 1 and 2 were virtually identical. it was evident from these runs that the refinement in grid 1 was adequate for the temperature analysis. The comparison of ABAQUS results to WES2DT results was also excellent. The only minor discrepancy came in the contours 5 days

after lift 5 was placed (Figures 9c, 10c, and 11c) in the lift 5 concrete. Here the ABAQUS results show a larger area with temperatures above 95° F in lift 5. This seems more realistic since the base slab exhibited a similar contour pattern at the the same time after placement (Figures 9a, 10a, and 11a). Only localized differences were seen between these different analyses, with maximum values and the general temperature distribution in very good agreement at all stages of the construction sequence.

Three-dimensional temperature analysis

65. Upon examining the temperature contour plots of the base slab, Figures 12b thru 12c, it is evident that the temperature distribution was constant along the monolith in the direction of flow (z-direction). This was expected since the problem closely approximates 2-D assumptions for constant boundary conditions on the outer surface and centerline. Only in the vicinity of five feet of the outer surface did any variation take place. This is shown in Figure 12a. Similar response is shown by the contours for all other stages of construction (Figures 13 thru 15). The contours within the monolith (away from the exposed outer surface) also match, almost identically, the ABAQUS 2-D plots from Figures 9 thru 10. These contours show that monolith L-13, for these boundary conditions, is a 2-D problem.

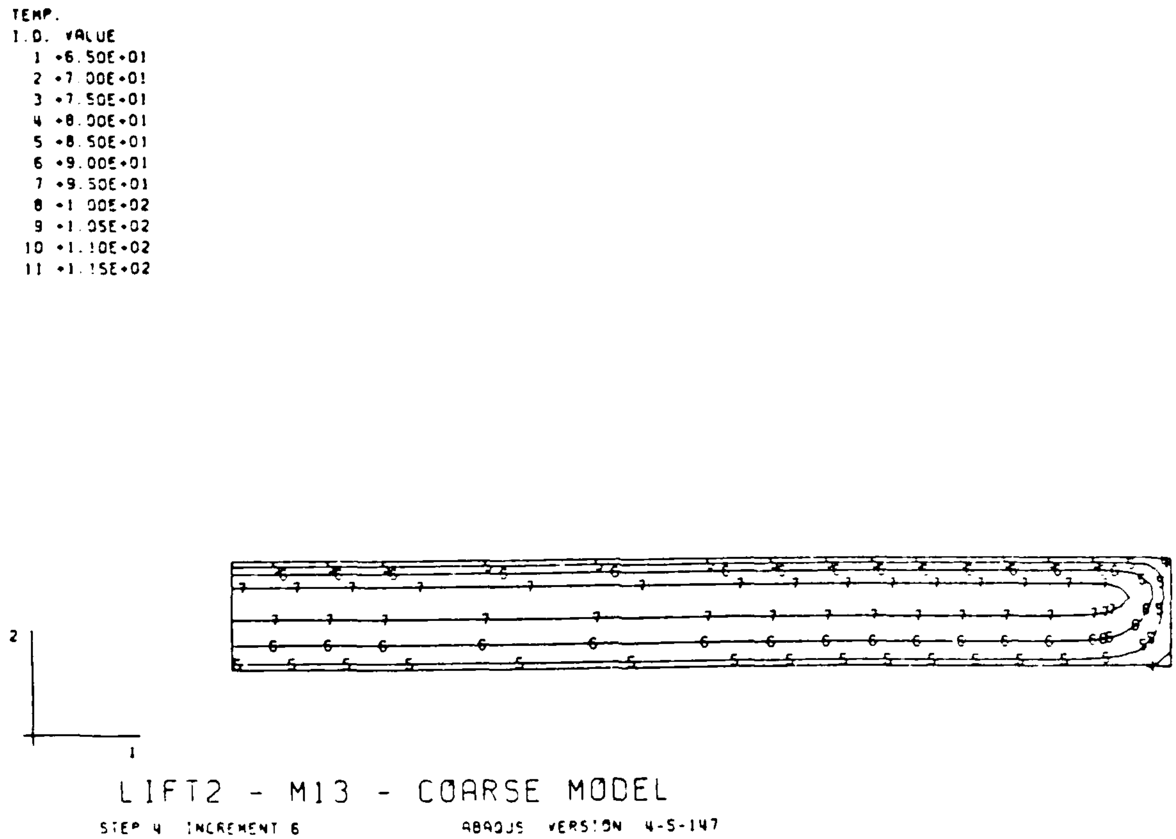


Figure 9a. Temperature distribution in structure 5 days after lift 2 is placed (from analysis using first grid)

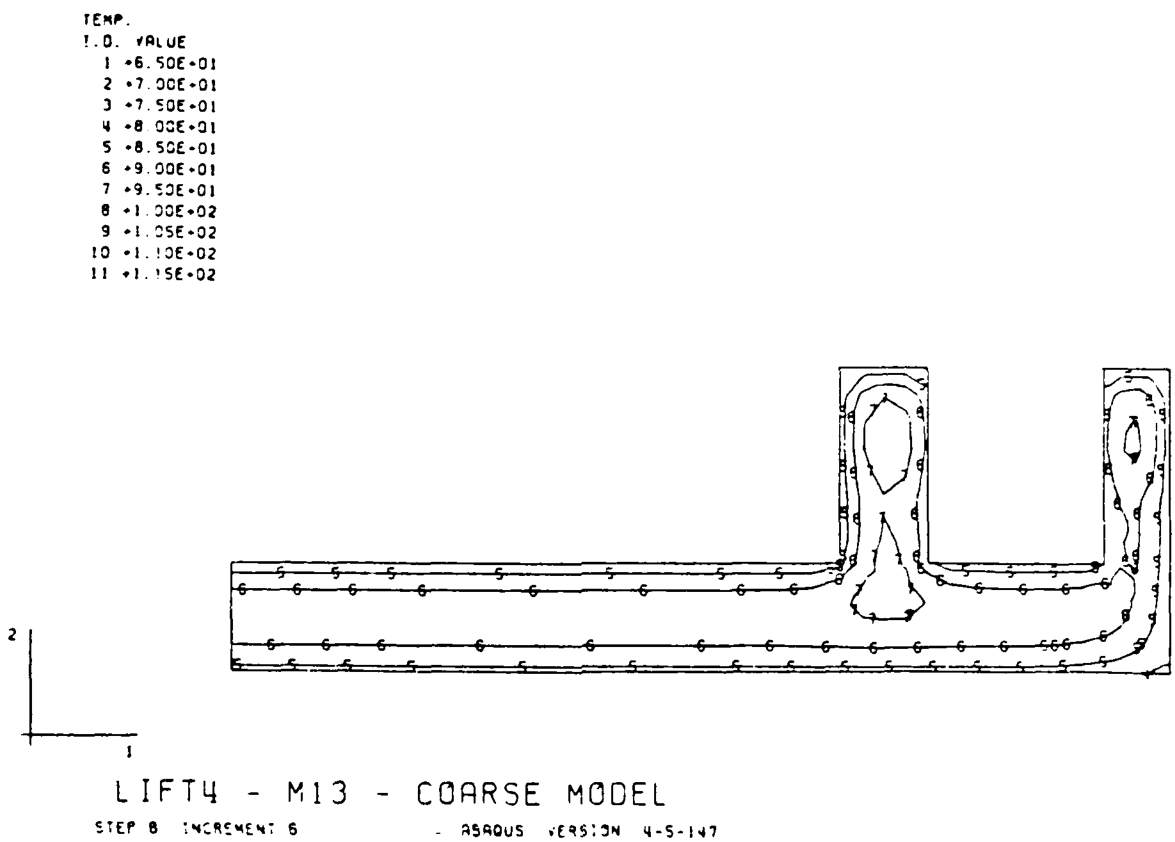


Figure 9b. Temperature distribution in structure 5 days after lift 4 is placed (from analysis using first grid)

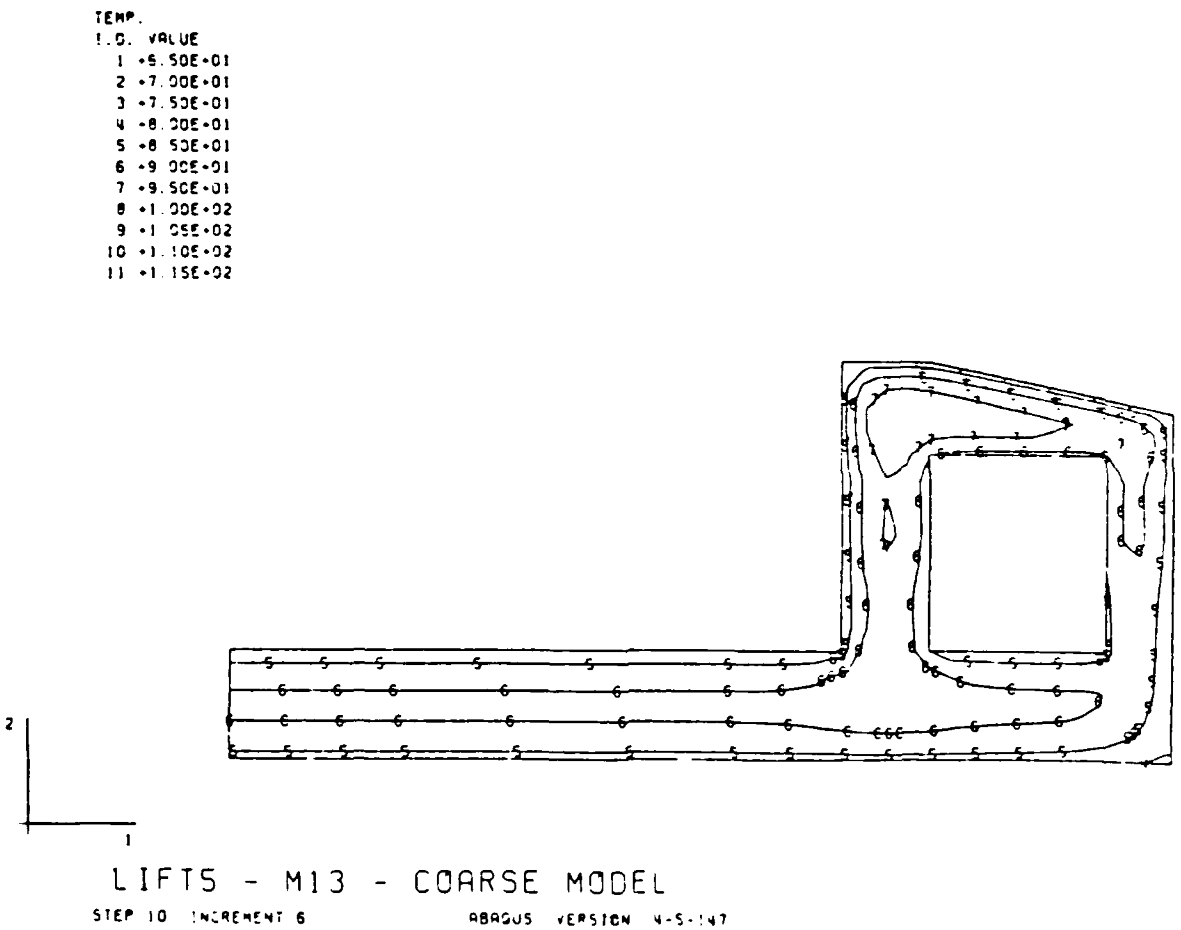


Figure 9c. Temperature distribution in structure 5 days after lift 5 is placed (from analysis using first grid)

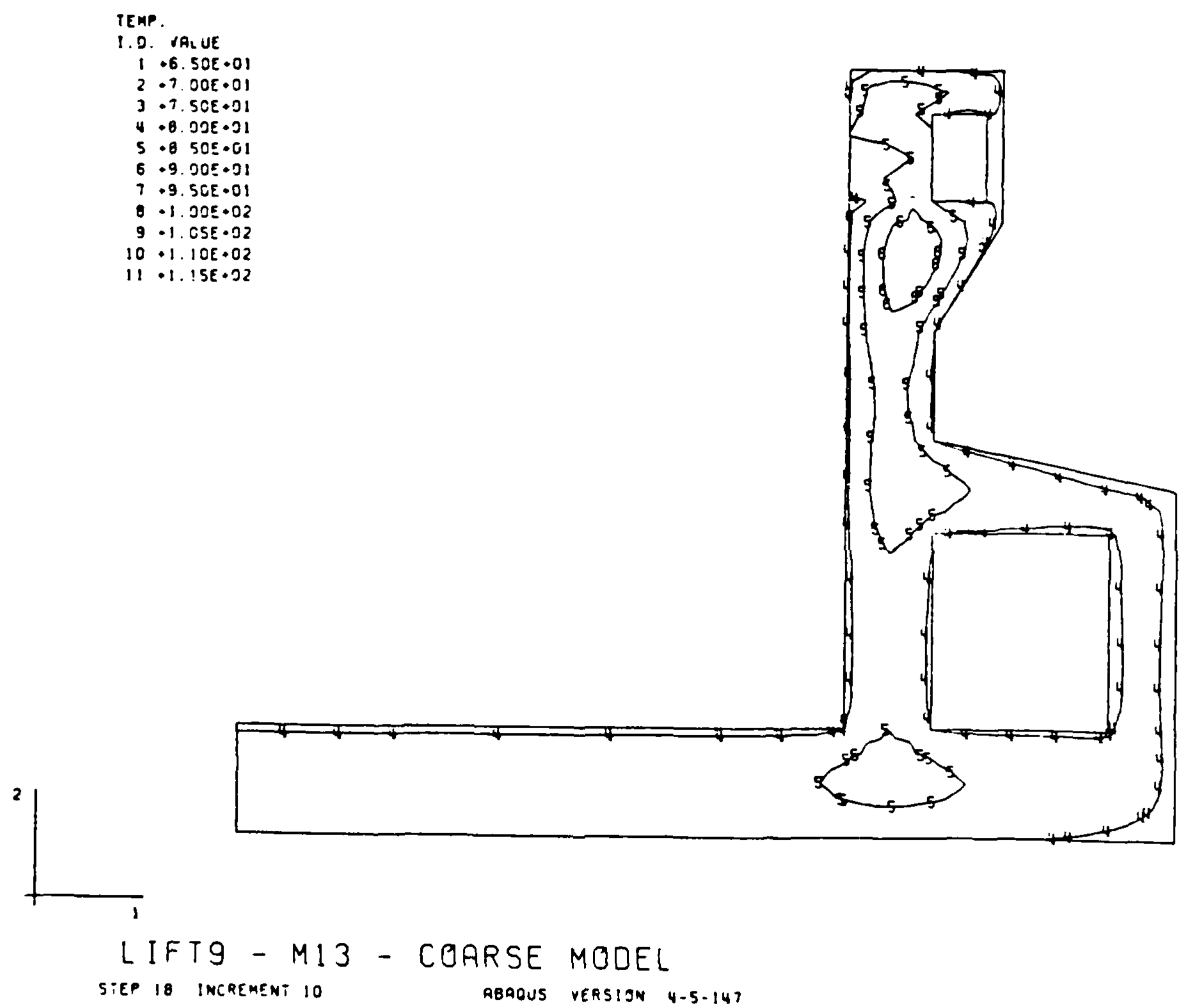


Figure 9d. Temperature distribution in structure 7 days after lift 9 is placed (from analysis using first grid)

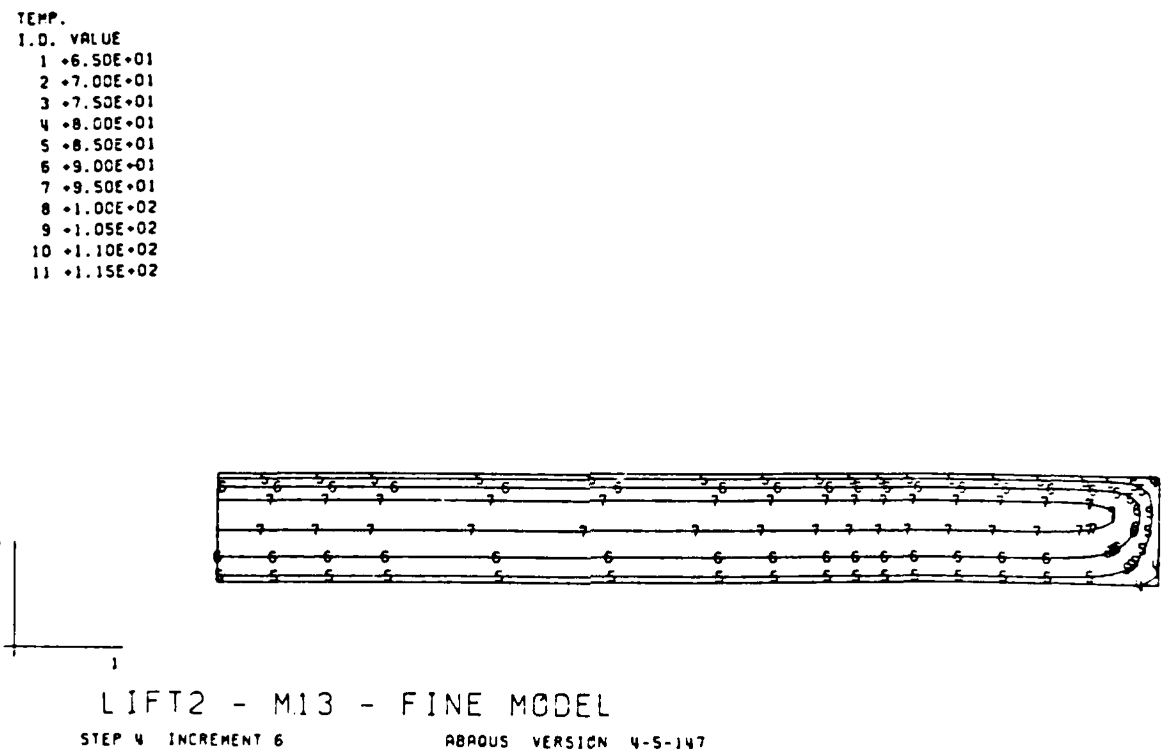


Figure 10a Temperature distribution in structure 5 days after lift 2 is placed (from analysis using second grid)

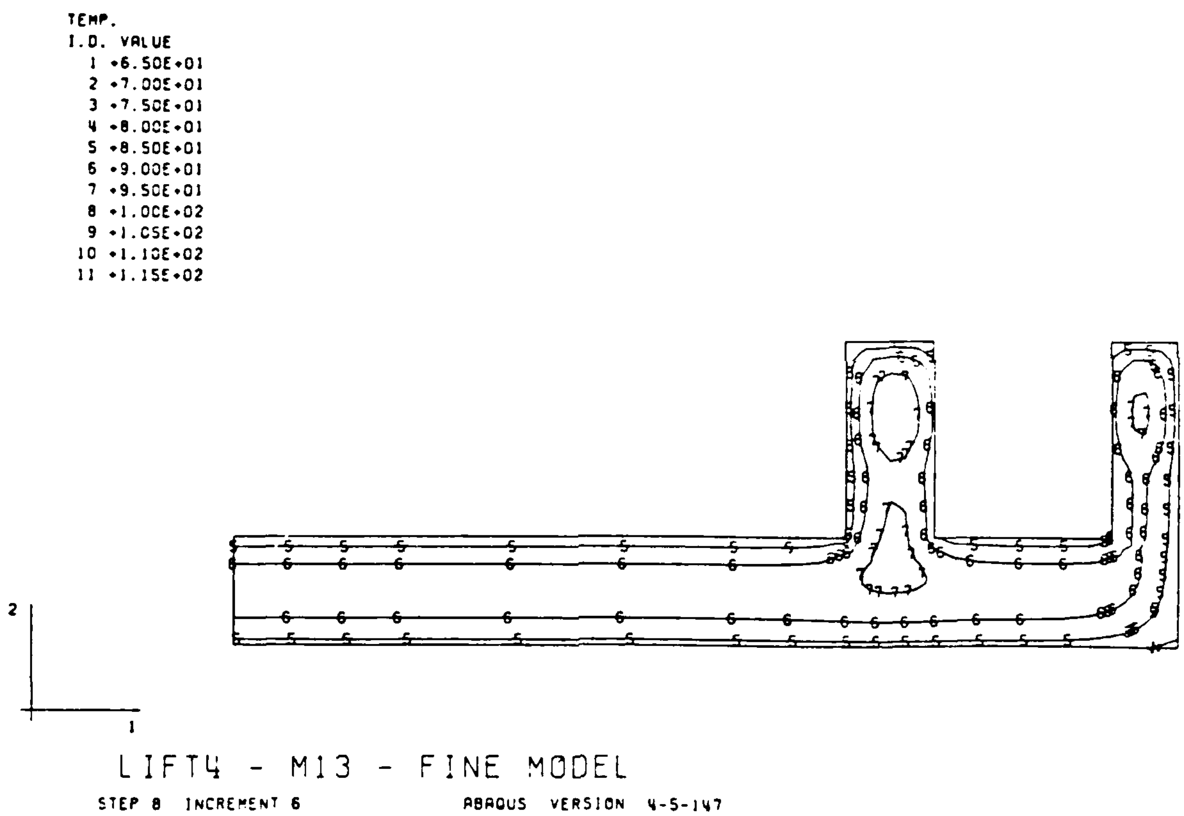


Figure 10b. Temperature distribution in structure 5 days after lift 4 is placed (from analysis using second grid)

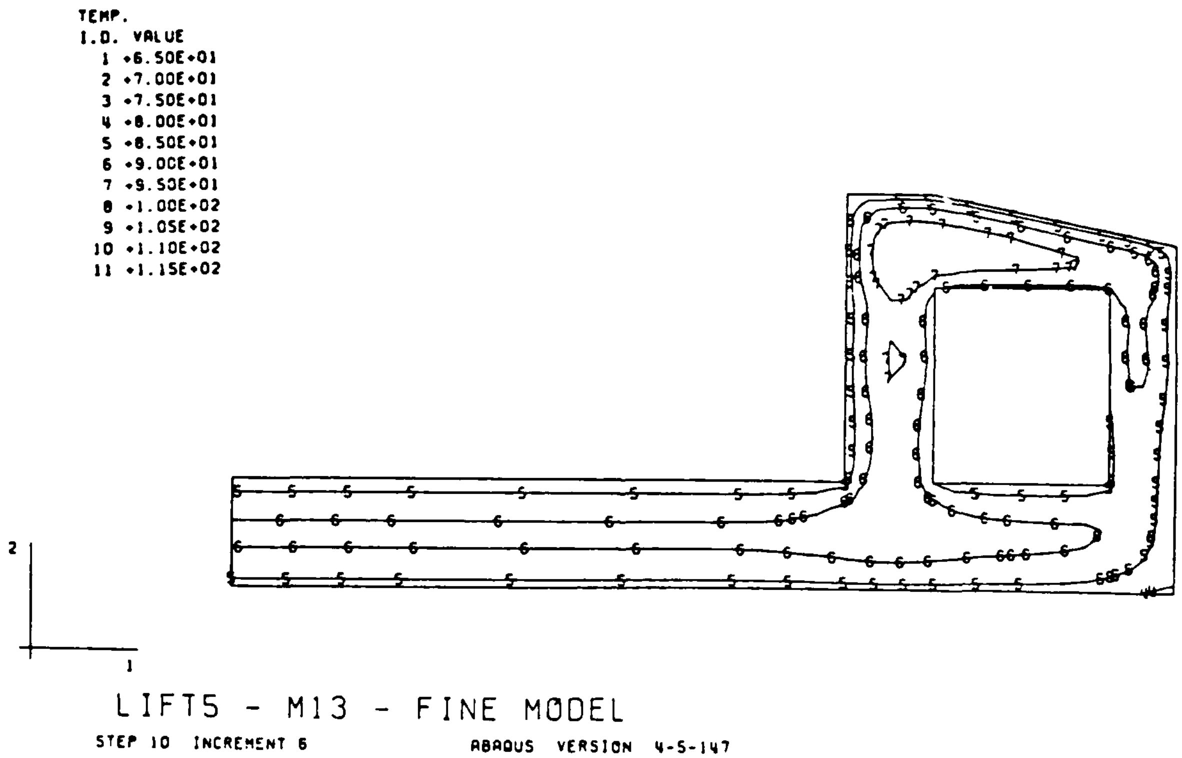


Figure 10c. Temperature distribution in structure 5 days after lift 5 is placed (from analysis using second grid)

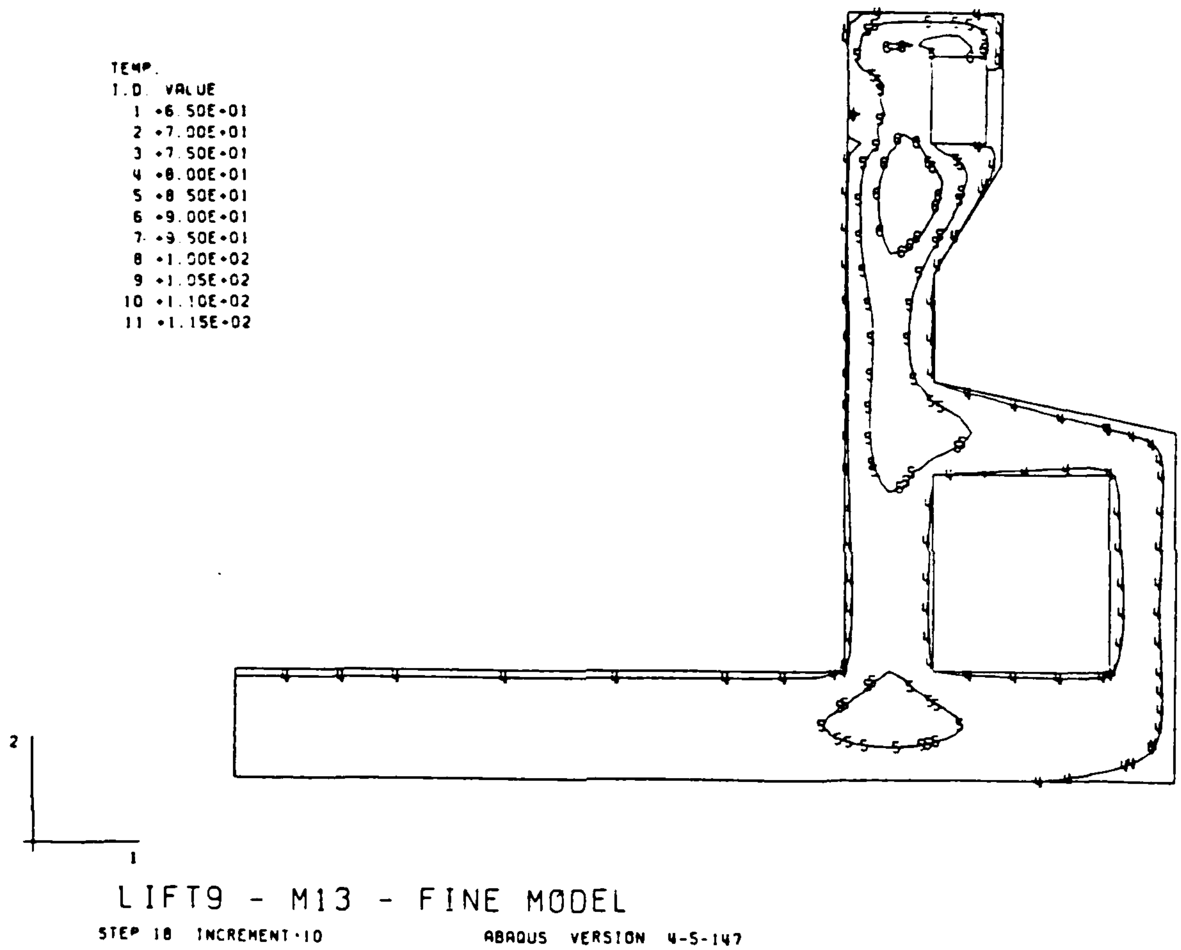


Figure 10d. Temperature distribution in structure 7 days after lift 9 is placed (from analysis using second grid)

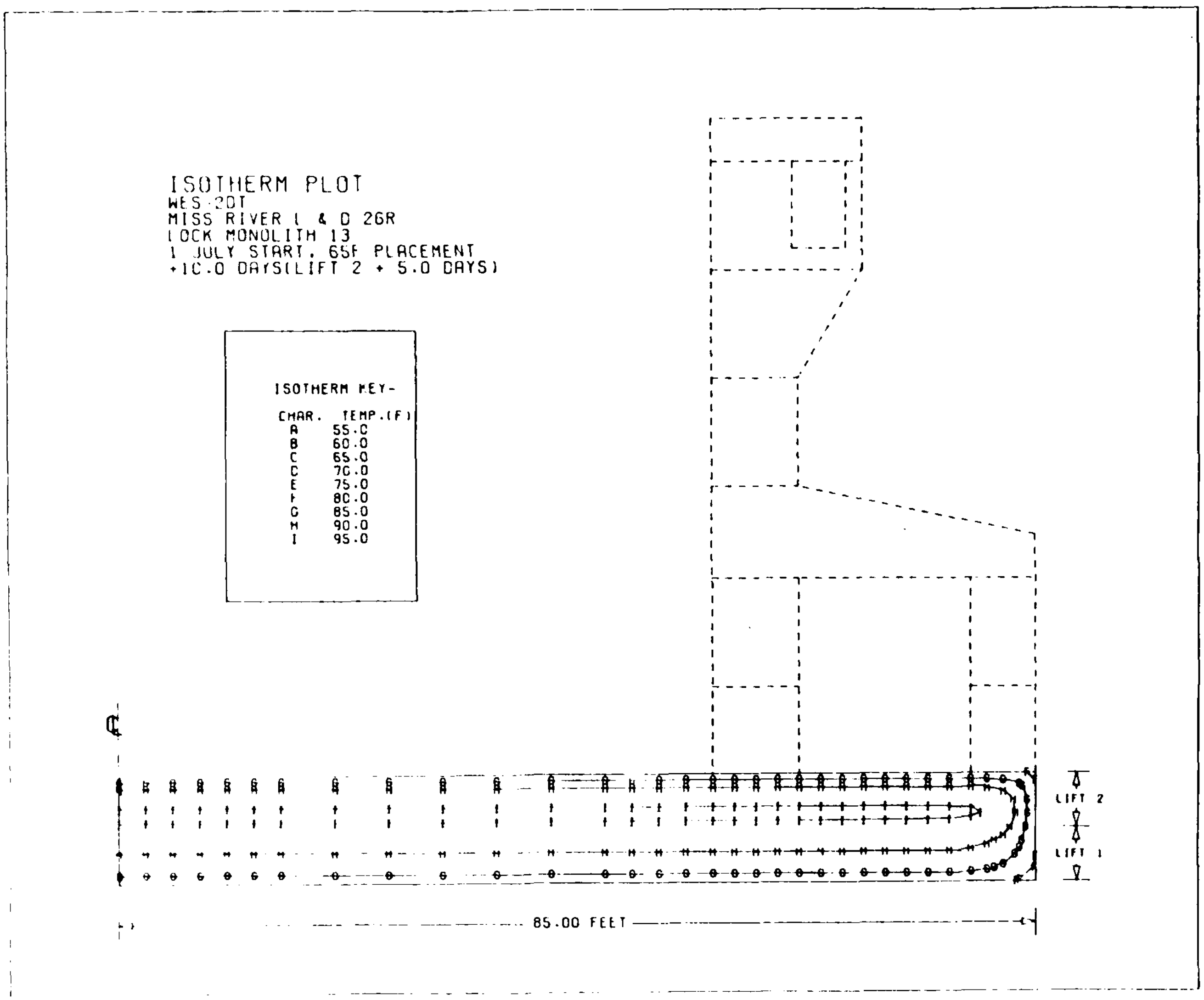


Figure 11a. Temperature distribution in structure 5 days after lift 2 is placed from WES-2DT program.

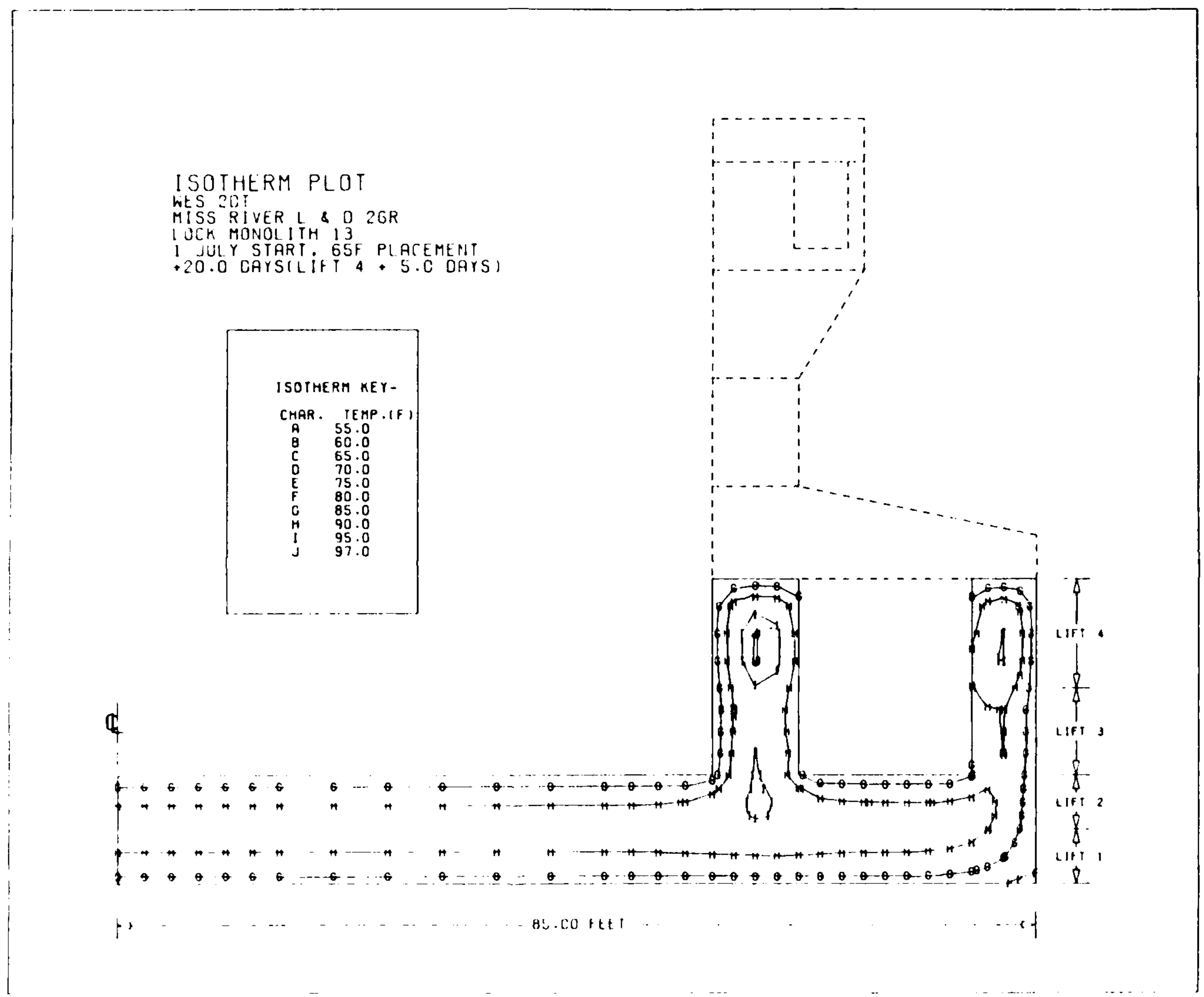


Figure 11b. Temperature distribution in structure 5 days after lift 4 is placed from WES-2DT program.

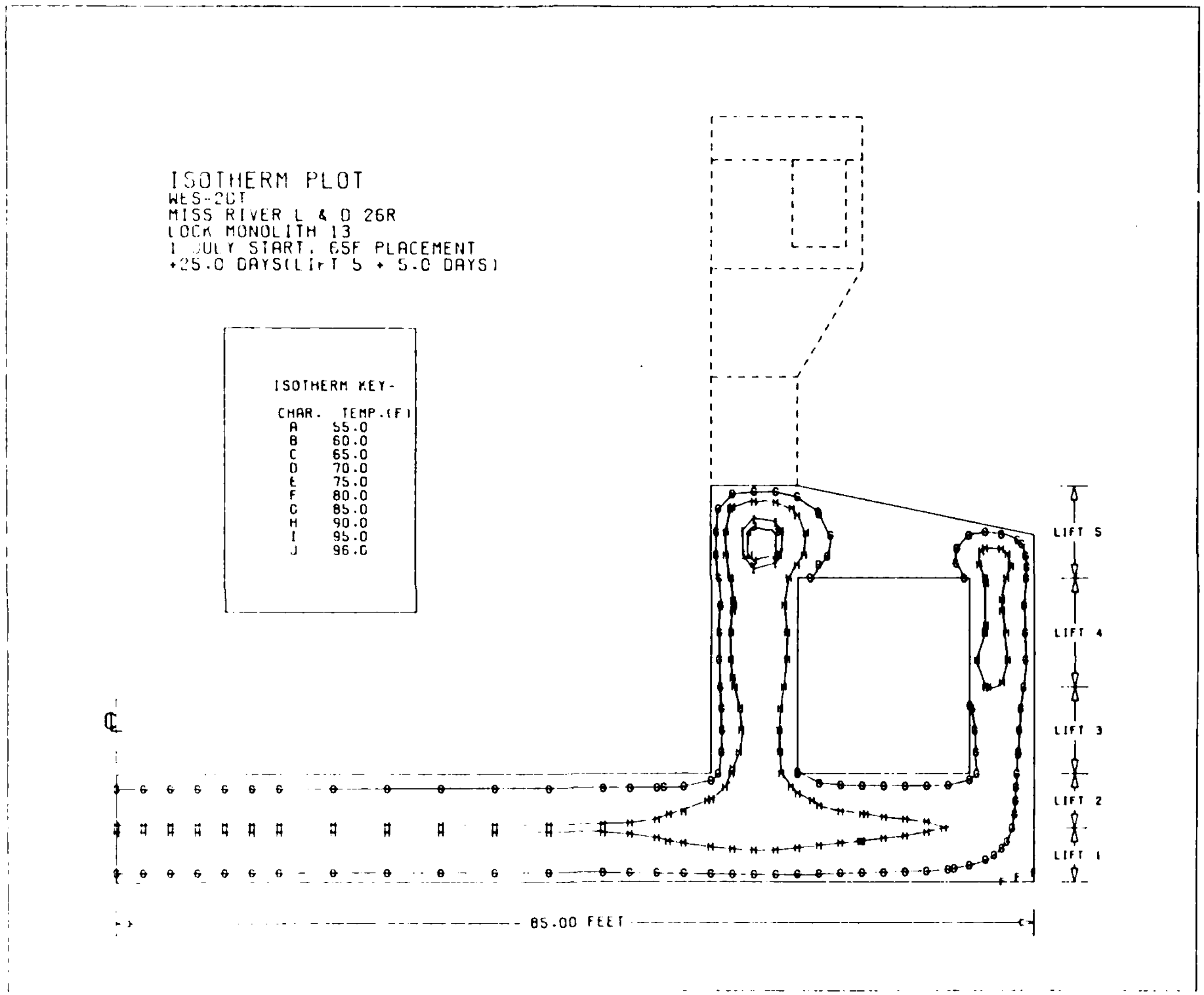


Figure 11c. Temperature distribution in structure 5 days after lift 5 is placed from WES-2DT program.

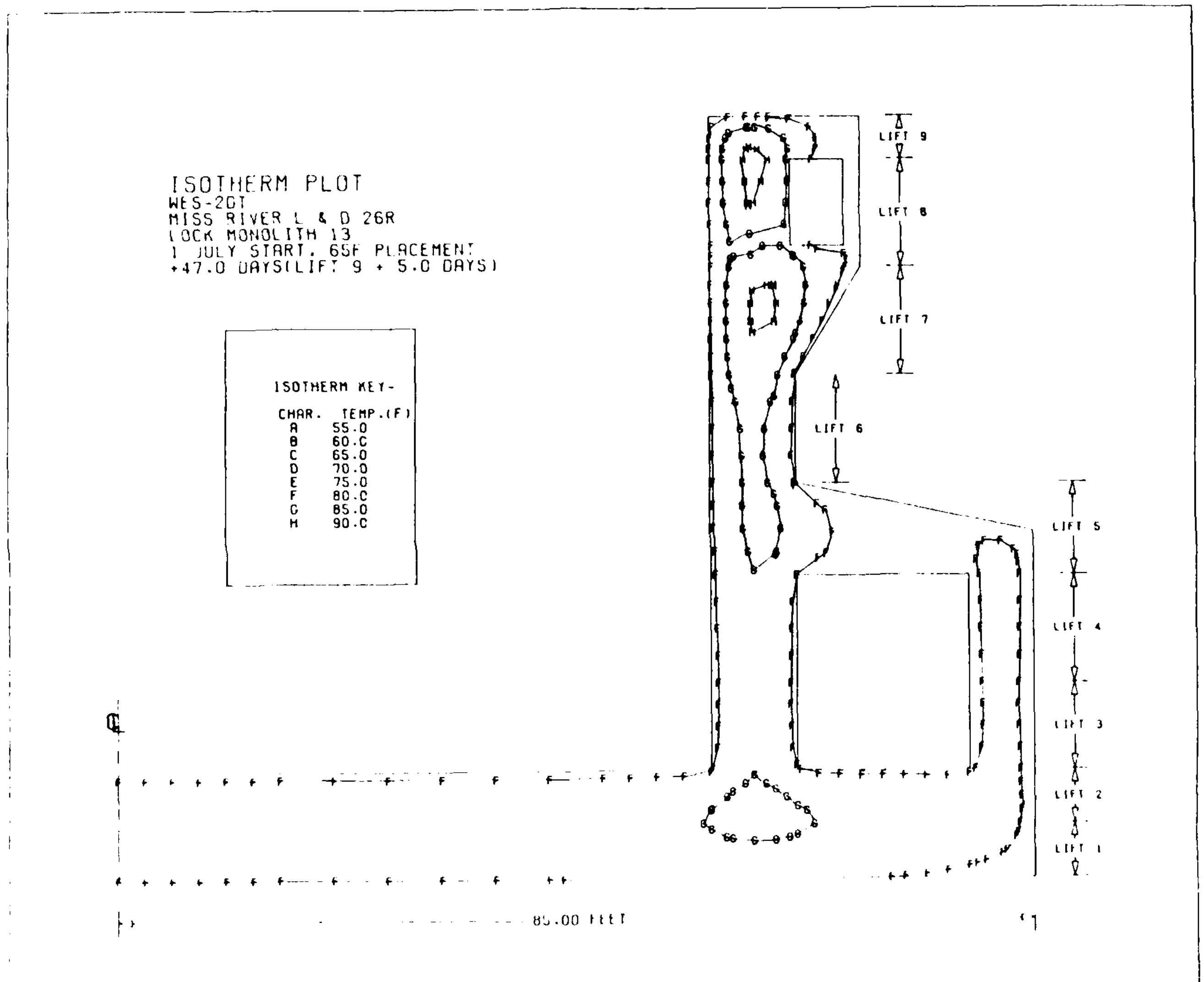


Figure 11d. Temperature distribution in structure 7 days after lift 9 is placed using WES- 2DT program.

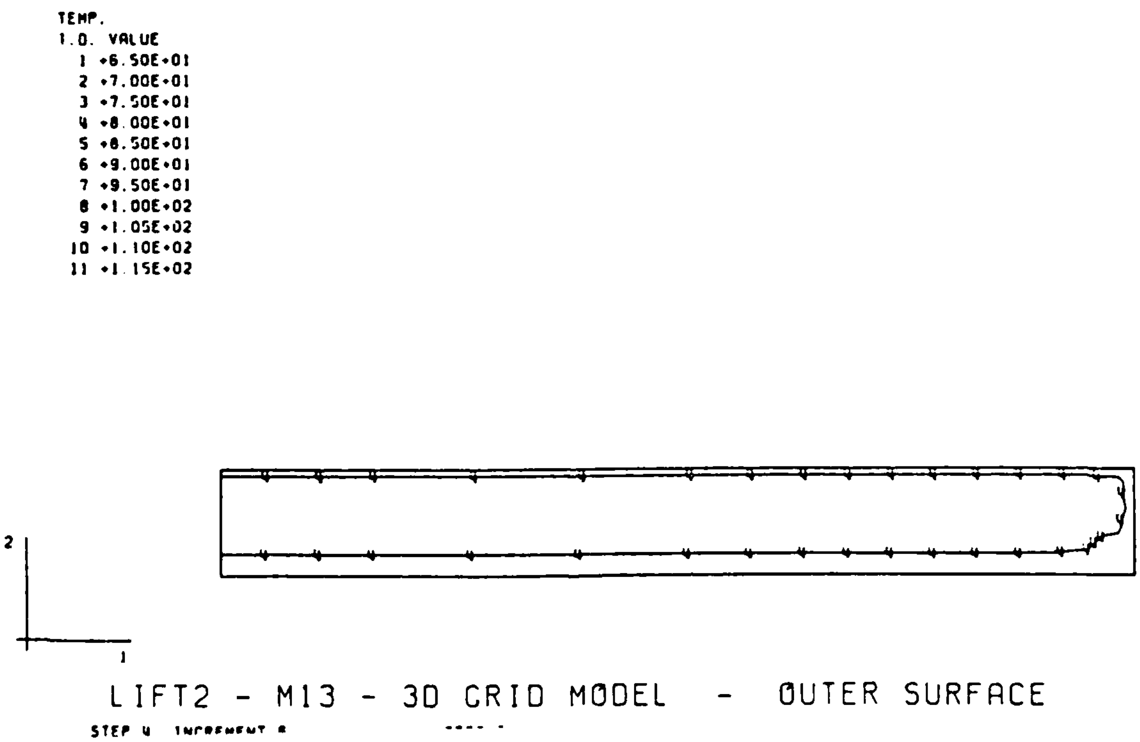


Figure 12a. Temperature distribution in outer surface of structure 5 days after lift 2 is placed.

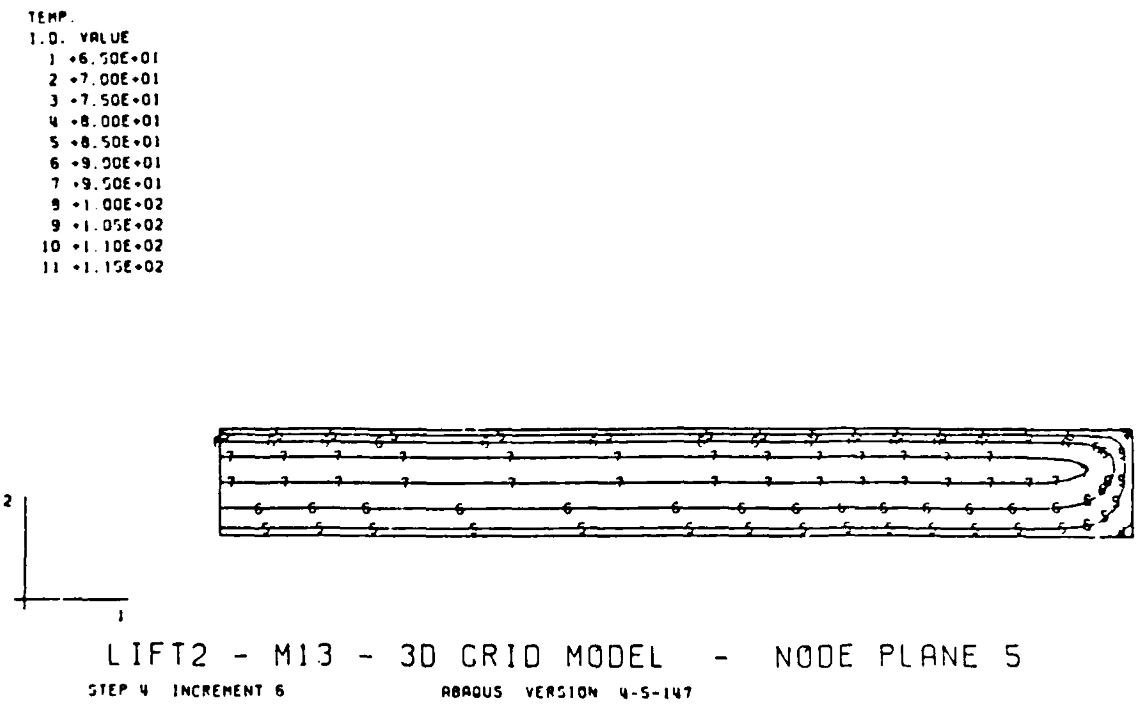


Figure 12b. Temperature distribution in node plane 5 of structure 5 days after lift 2 is placed.

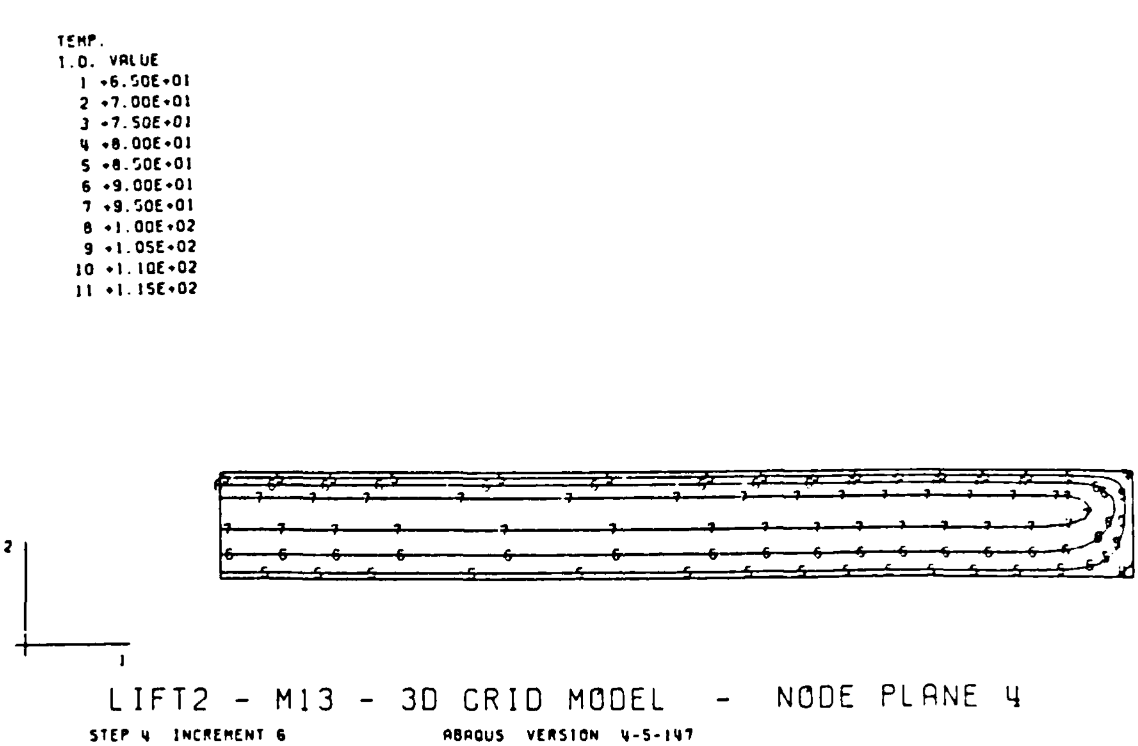


Figure 12c. Temperature distribution in node plane 4 of structure 5 days after lift 2 is placed.

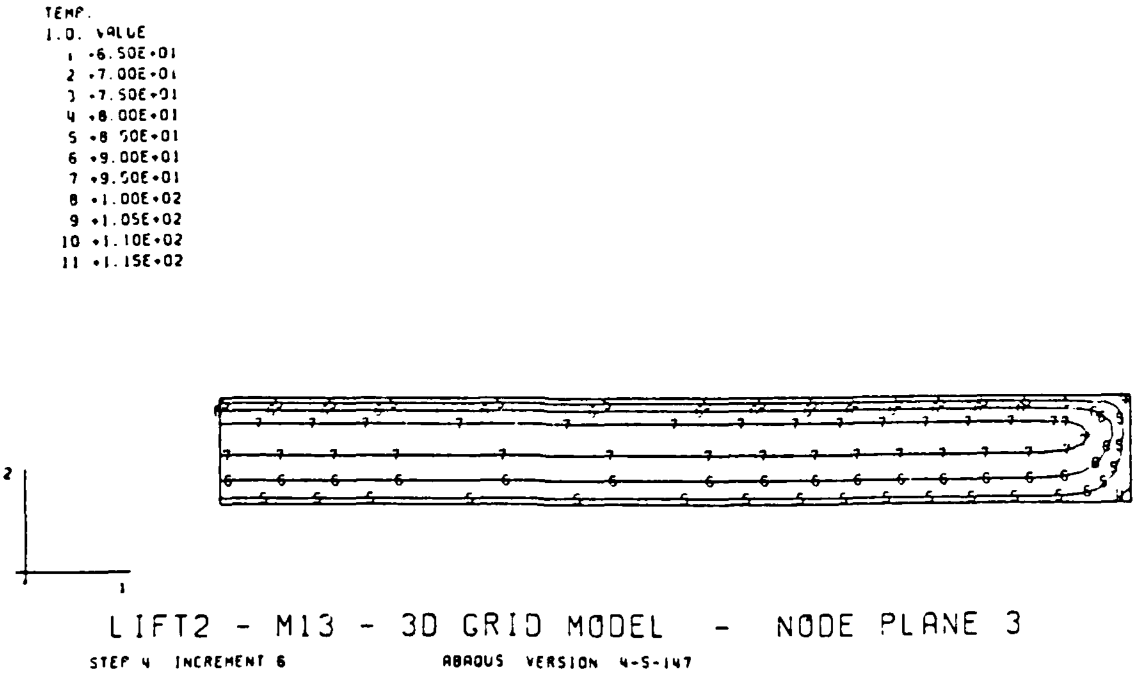


Figure 12d. Temperature distribution in node plane 3 of structure 5 days after lift 2 is placed.

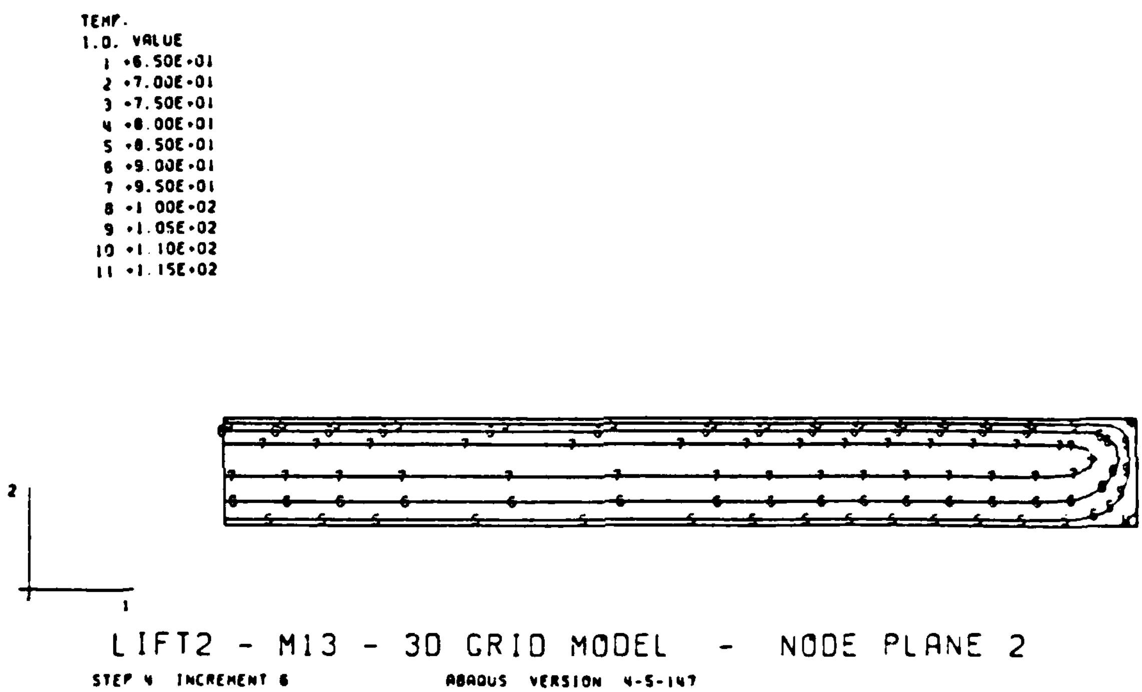


Figure 12e. Temperature distribution in node plane 2 of structure 5 days after lift 2 is placed.

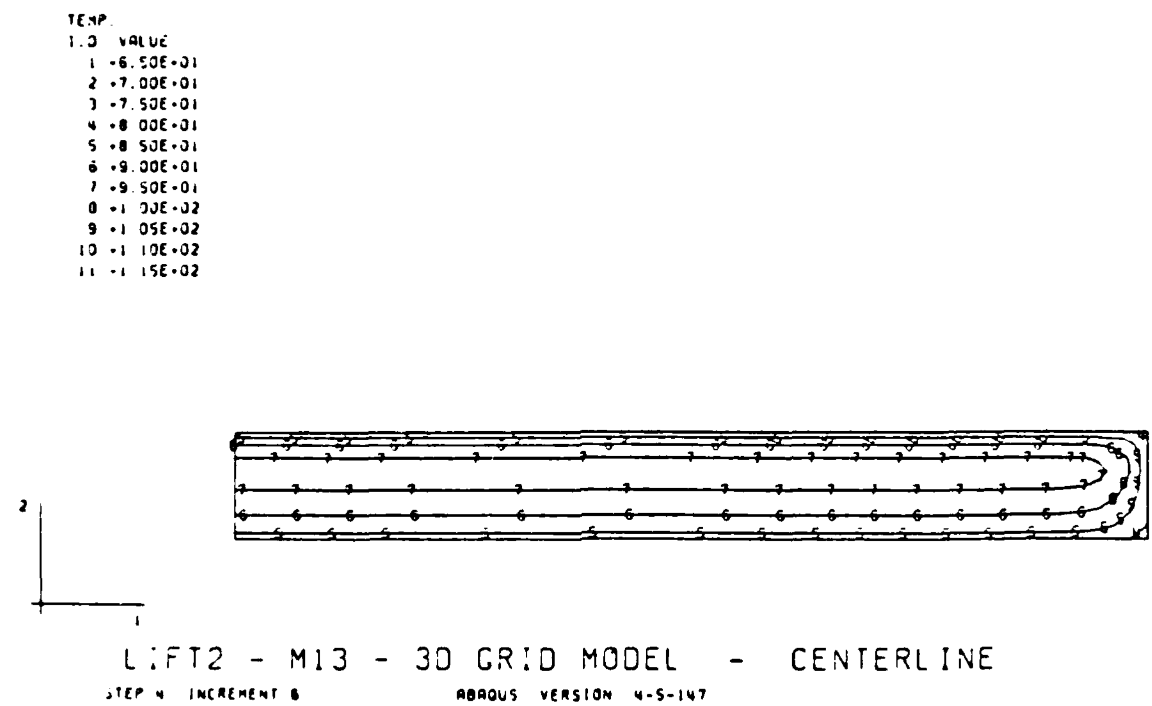


Figure 12f. Temperature distribution in the centerline of structure 5 days after lift 2 is placed.

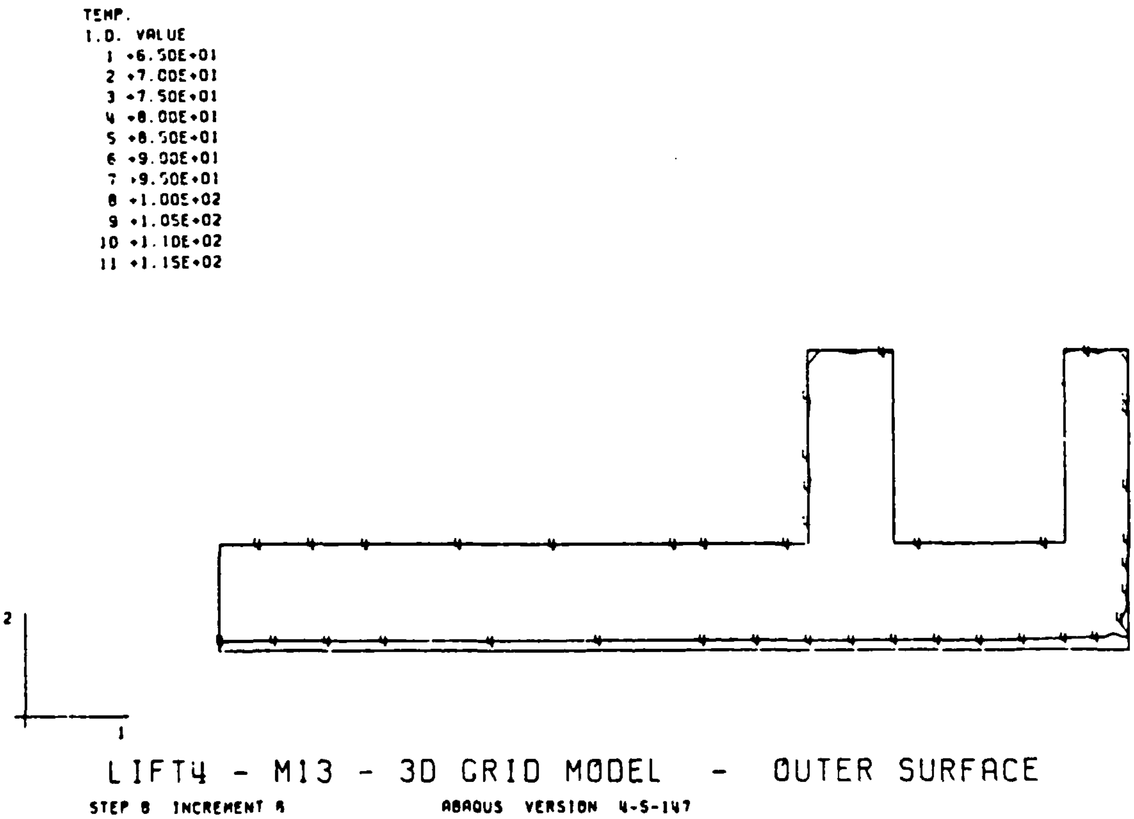


Figure 13a. Temperature distribution in outer surface of structure 5 days after lift 4 is placed.

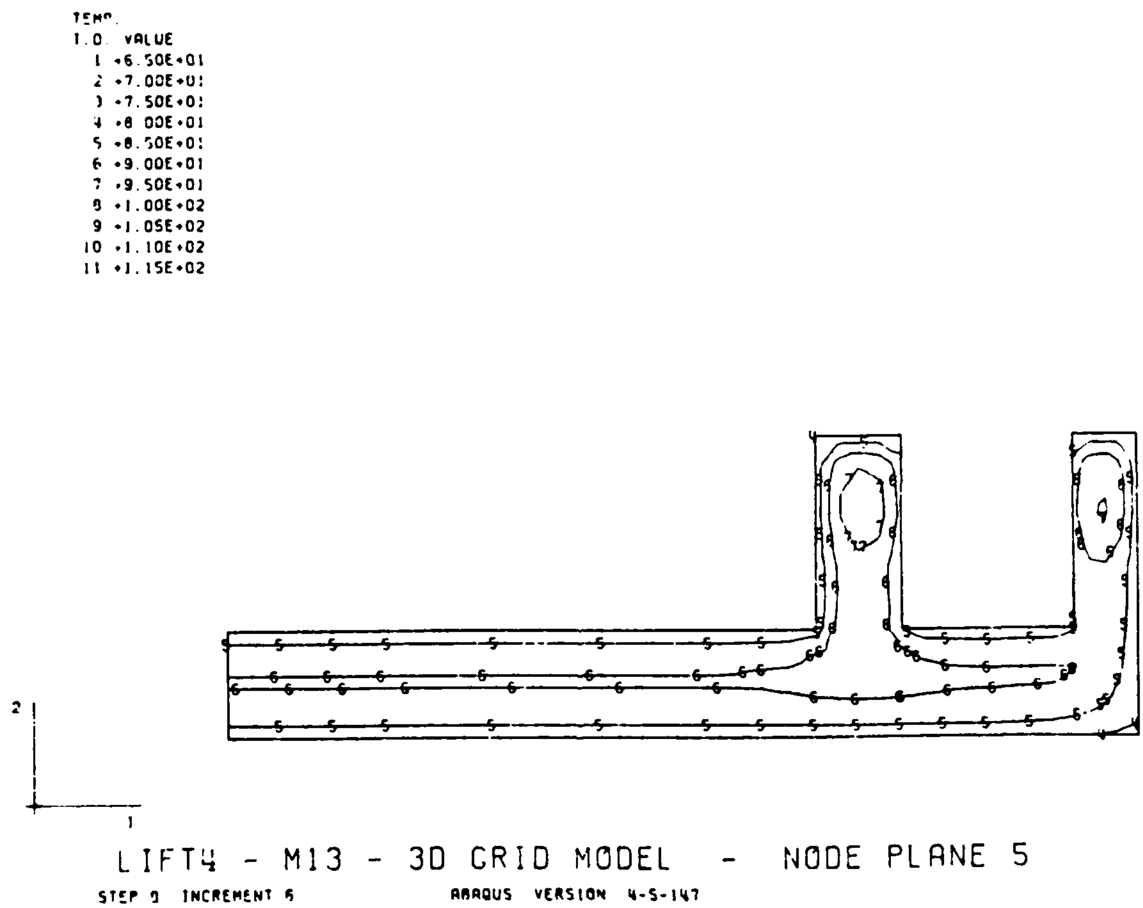


Figure 13b. Temperature distribution in node plane 5 of structure 5 days after lift 4 is placed.

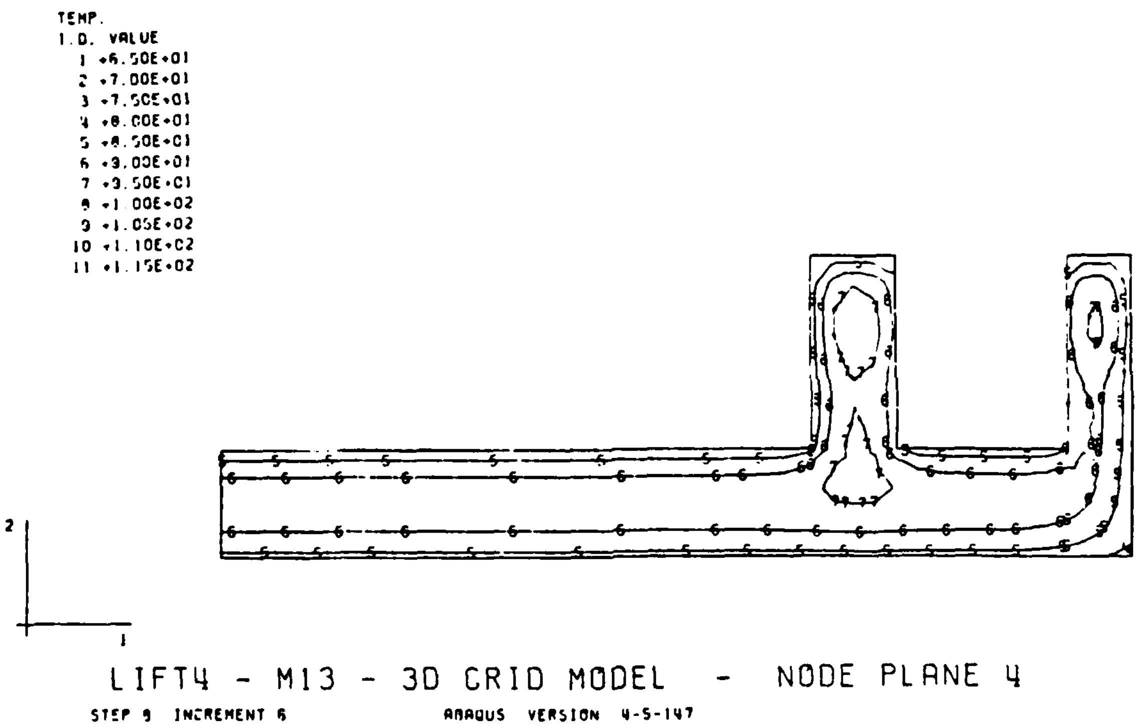


Figure 13c. Temperature distribution in node plane 4 of structure 5 days after lift 4 is placed.

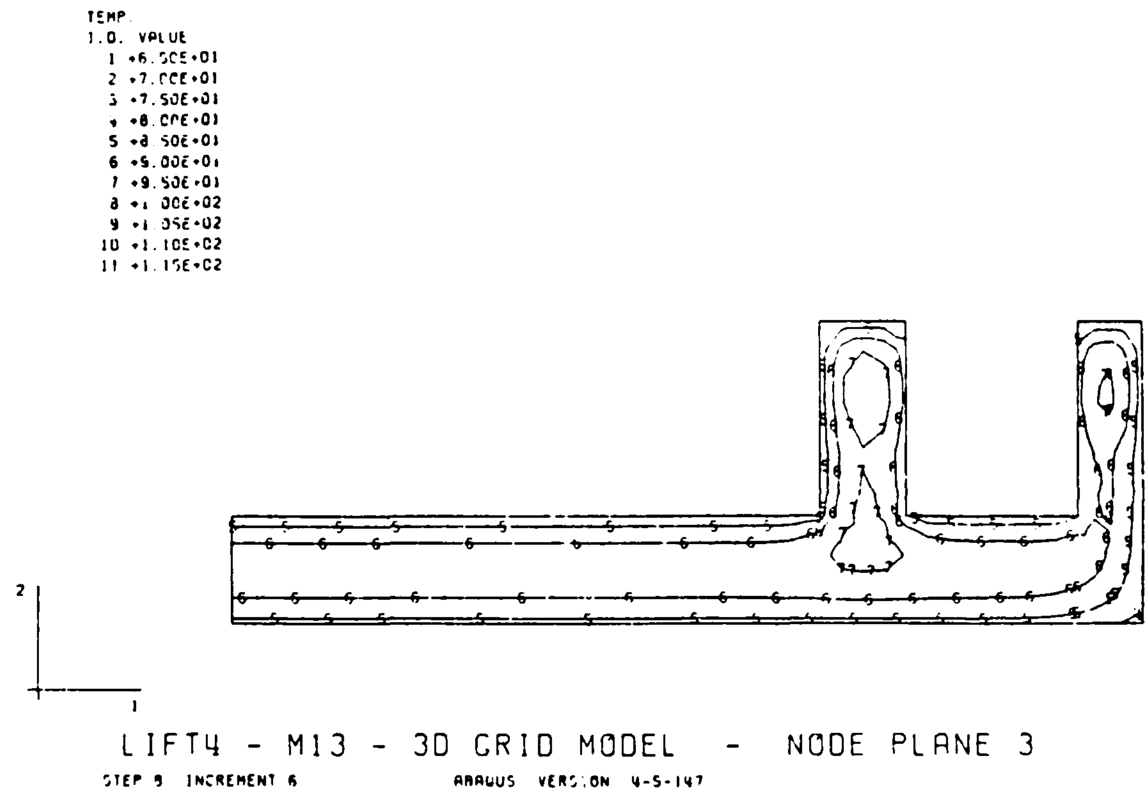


Figure 13d. Temperature distribution in node plane 3 of structure 5 days after lift 4 is placed.

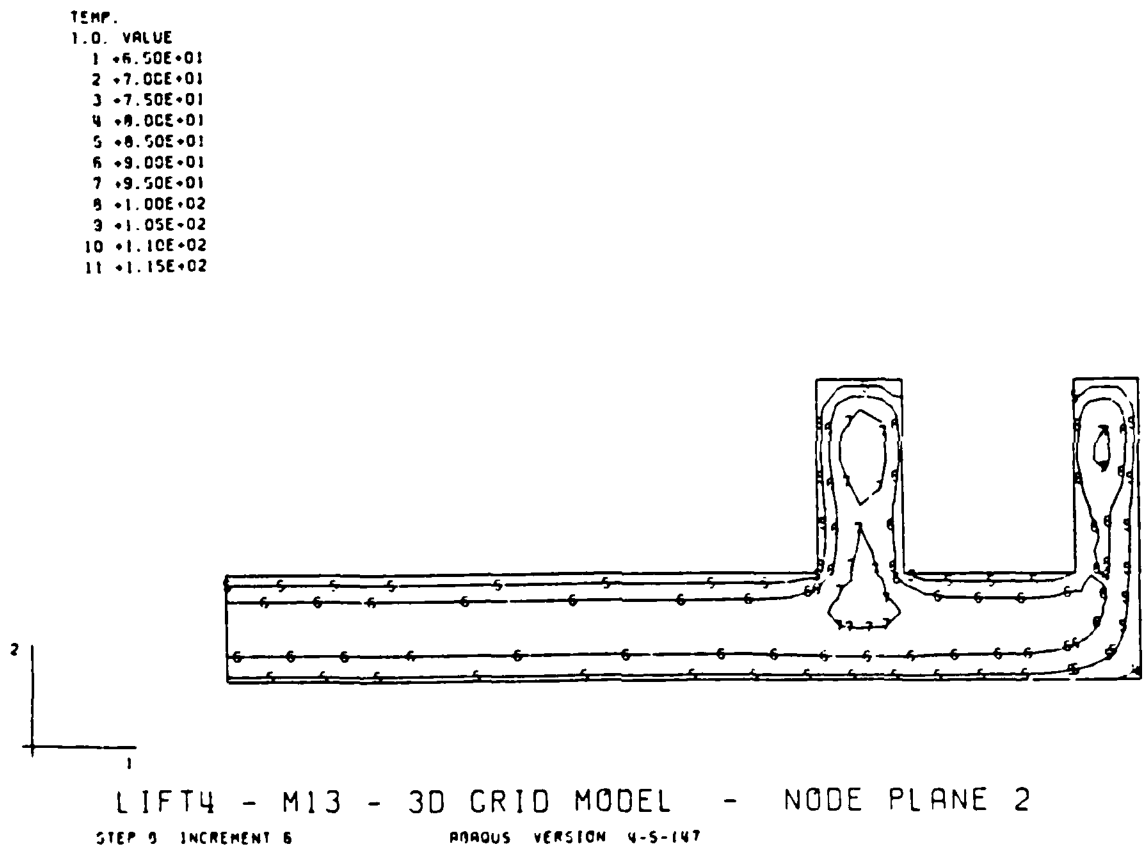


Figure 13e. Temperature distribution in node plane 2 of structure 5 days after lift 4 is placed.

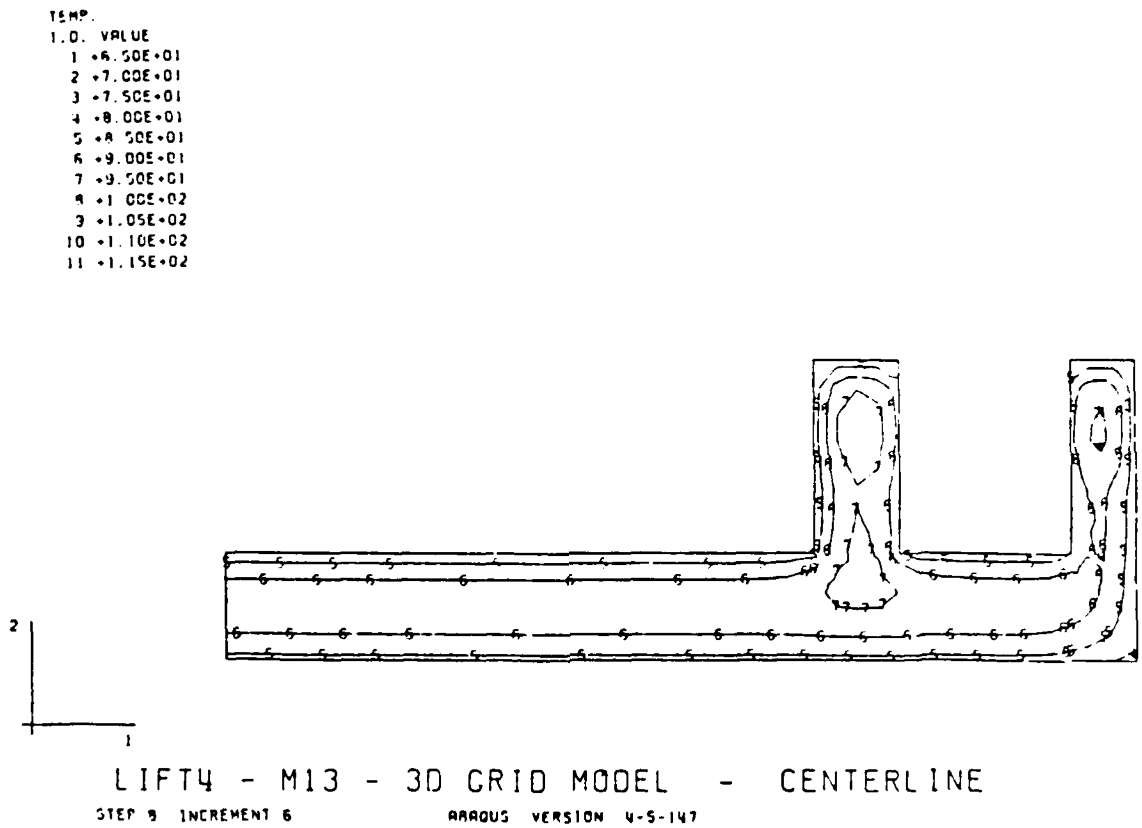


Figure 13f. Temperature distribution in the centerline of structure 5 days after lift 4 is placed.

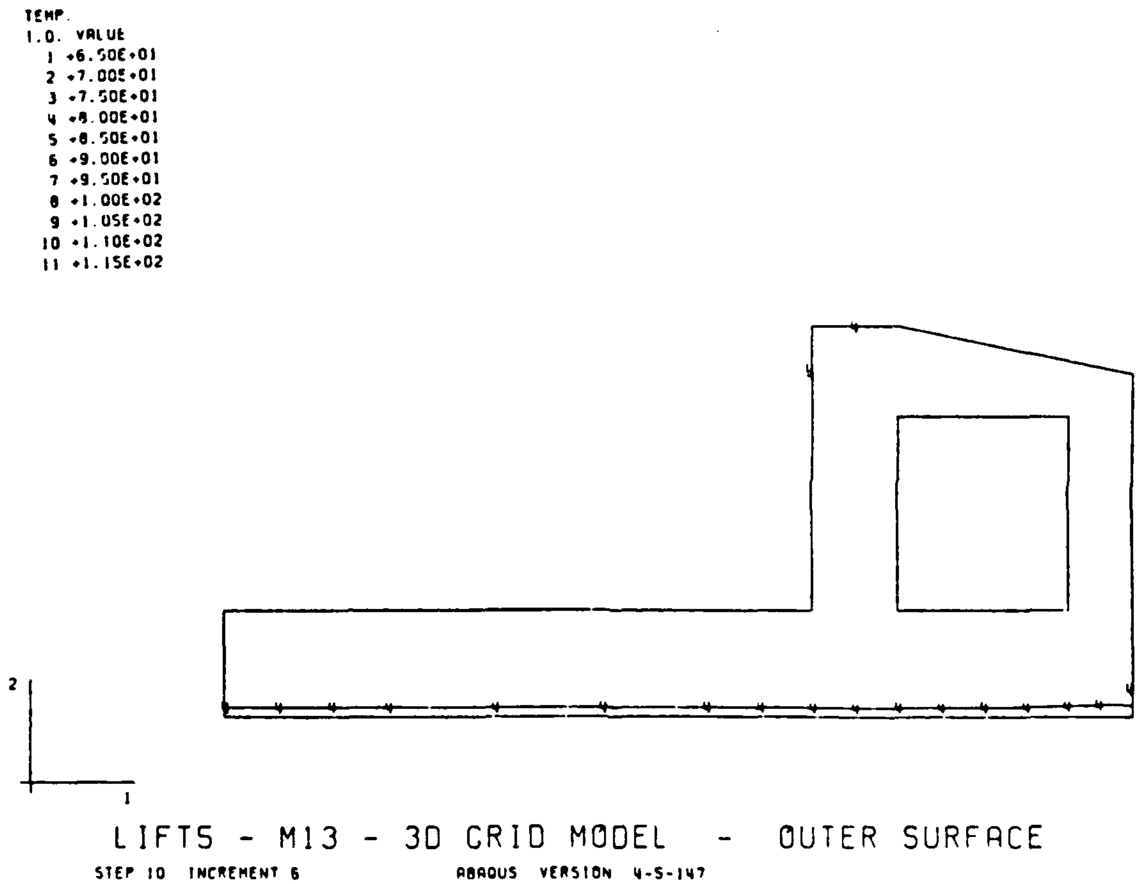


Figure 14a. Temperature distribution in outer surface of structure 5 days after lift 5 is placed.

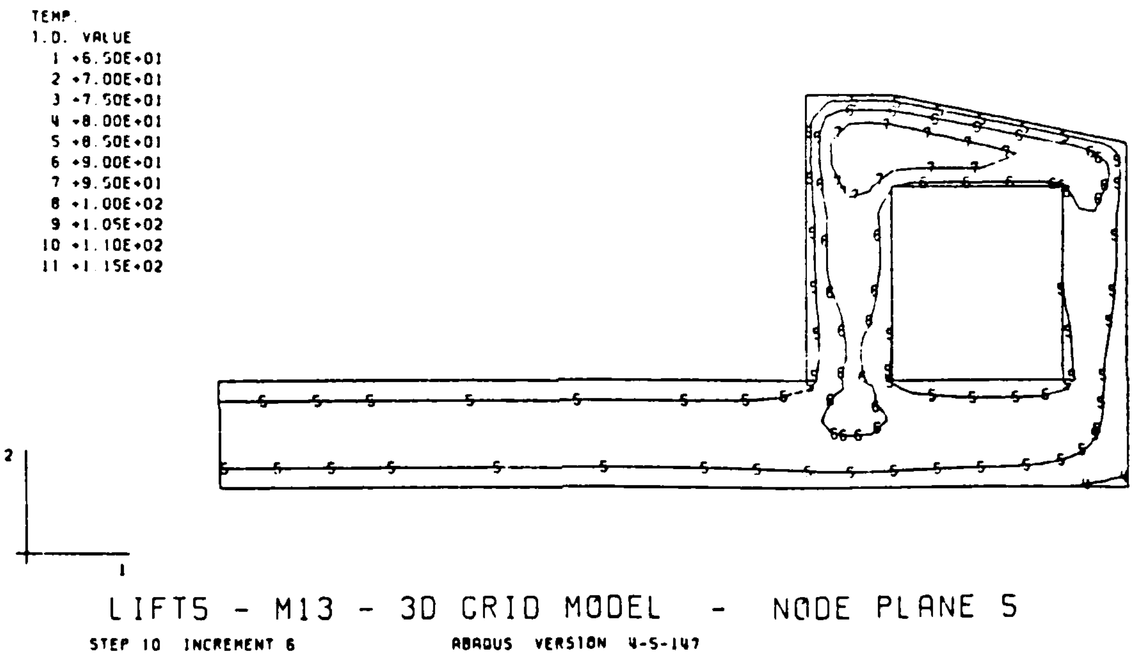


Figure 14b. Temperature distribution in node plane 5 of structure 5 days after lift 5 is placed.

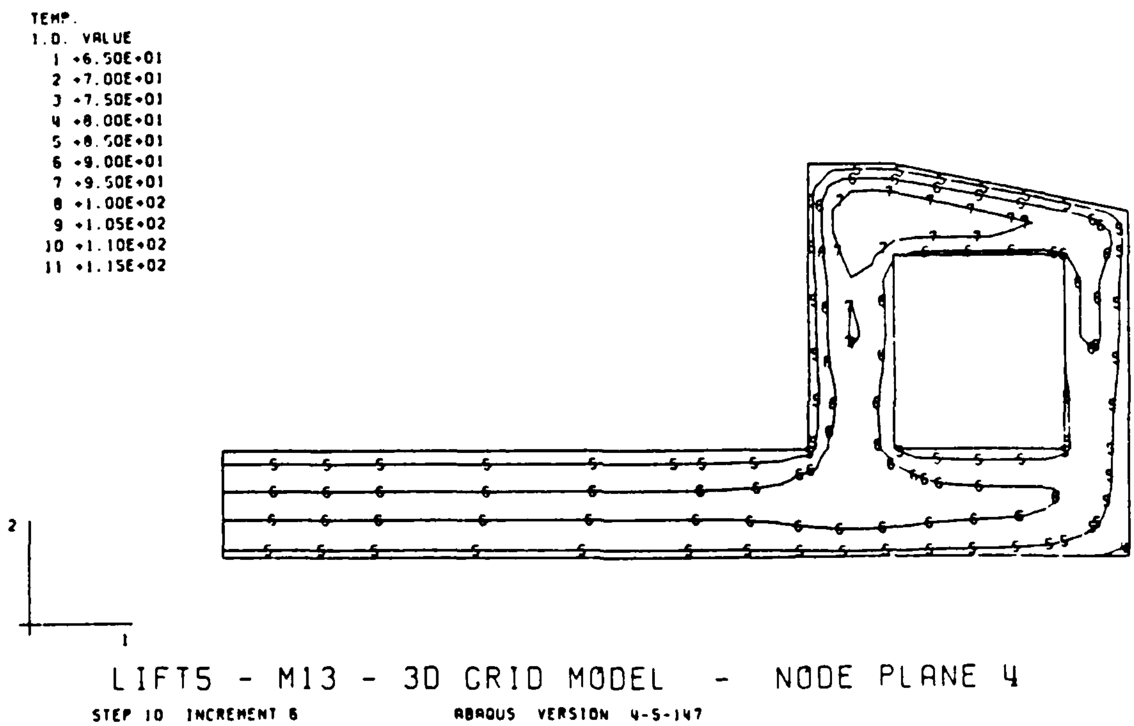


Figure 14c. Temperature distribution in node plane 4 of structure 5 days after lift 5 is placed.

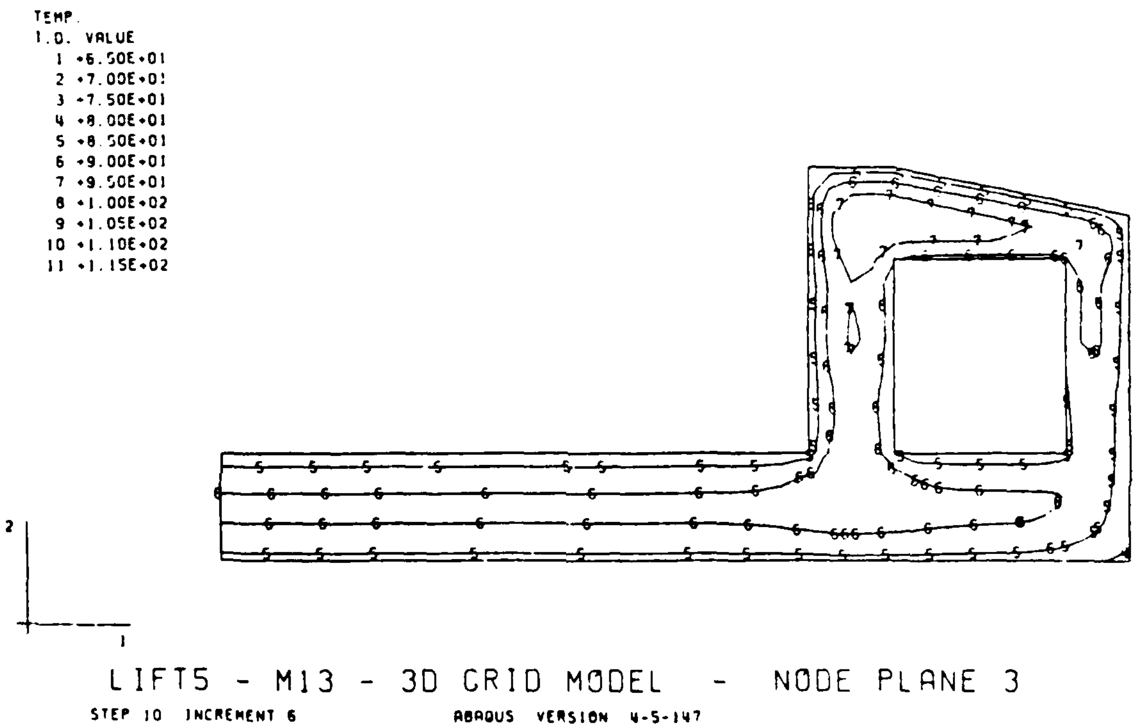


Figure 14d. Temperature distribution in node plane 3 of structure 5 days after lift 5 is placed.

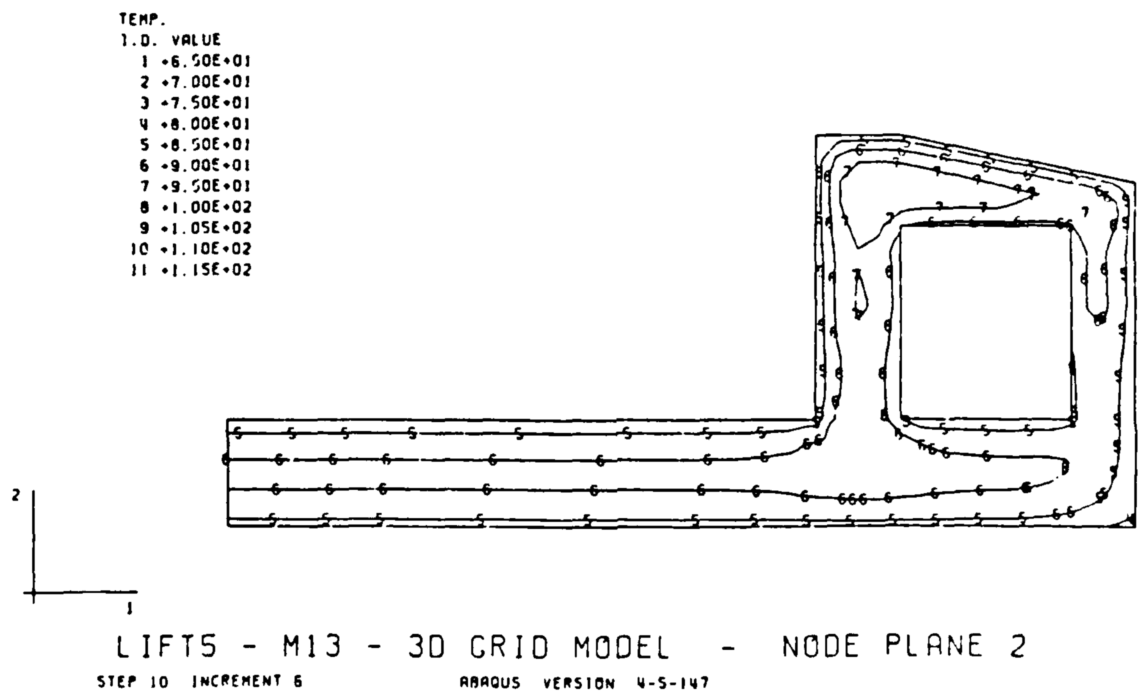


Figure 14e. Temperature distribution in node plane 2 of structure 5 days after lift 5 is placed.

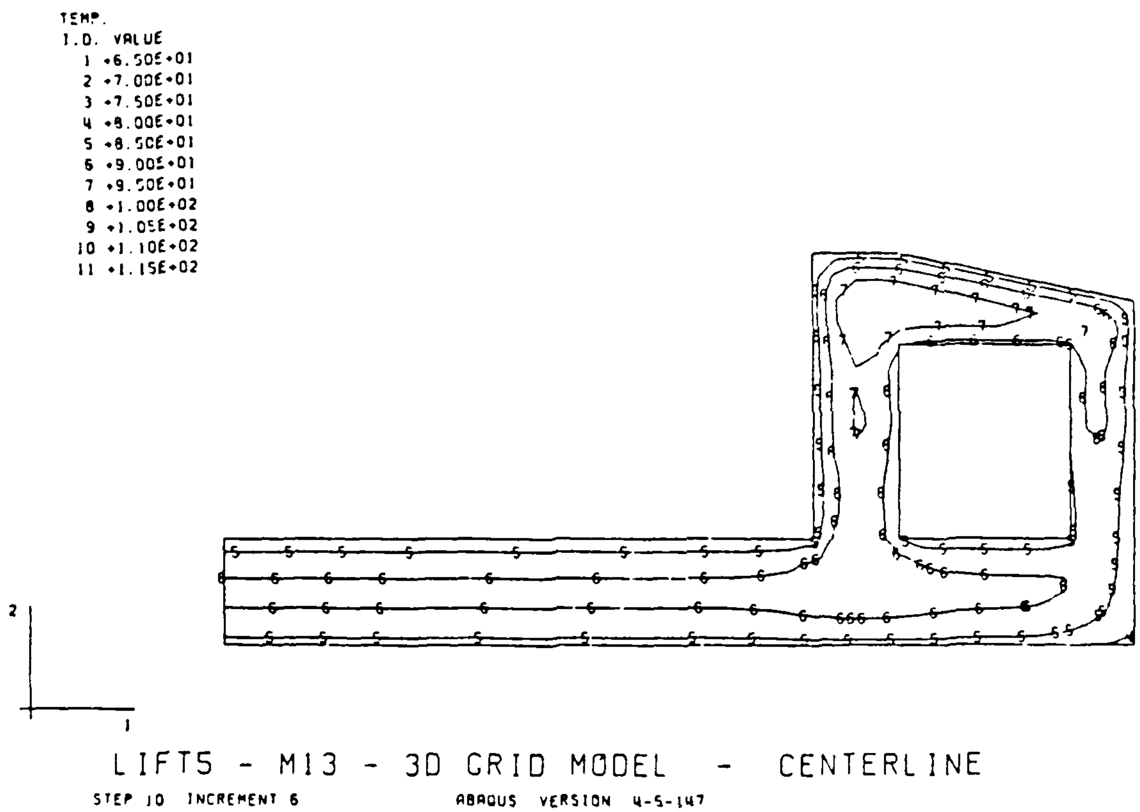


Figure 14f. Temperature distribution in the centerline of structure 5 days after lift 5 is placed.

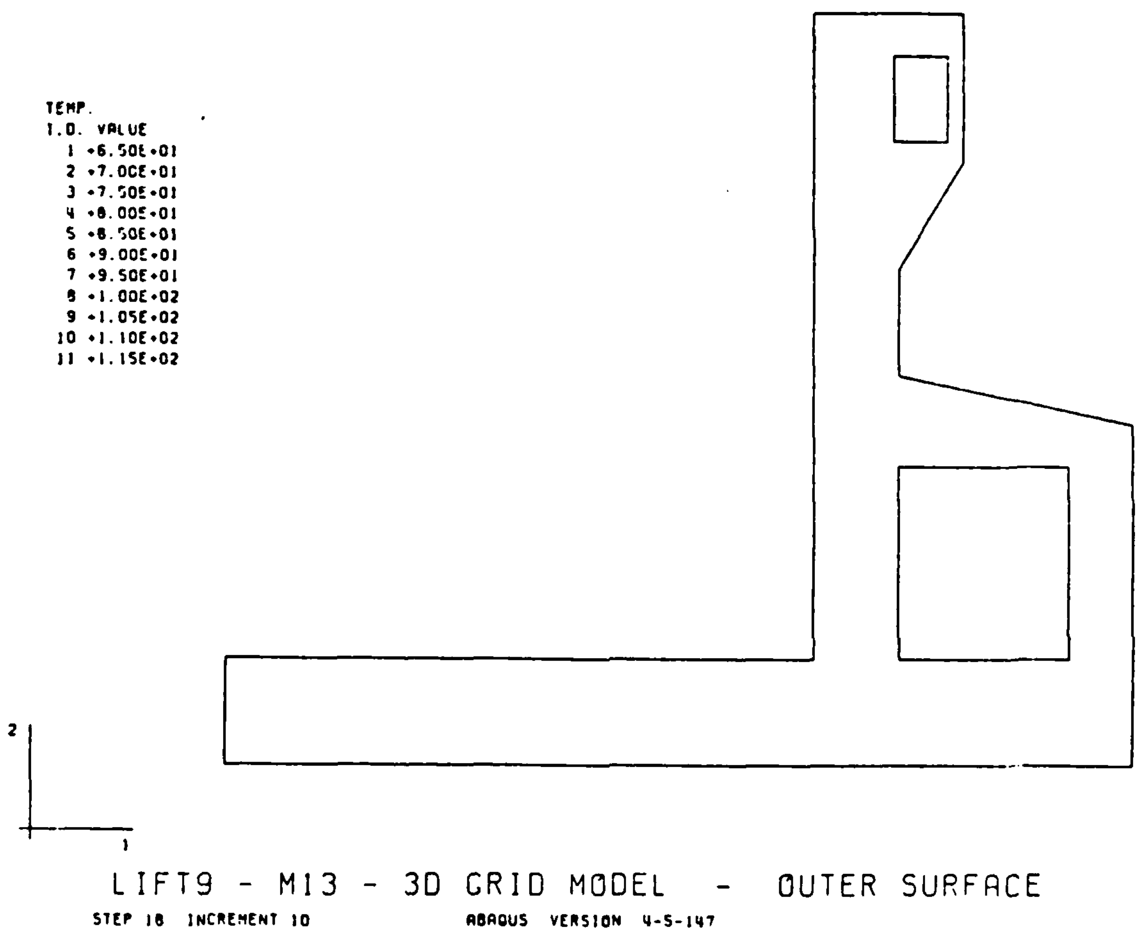


Figure 15a. Temperature distribution in outer surface of structure 7 days after lift 9 is placed.

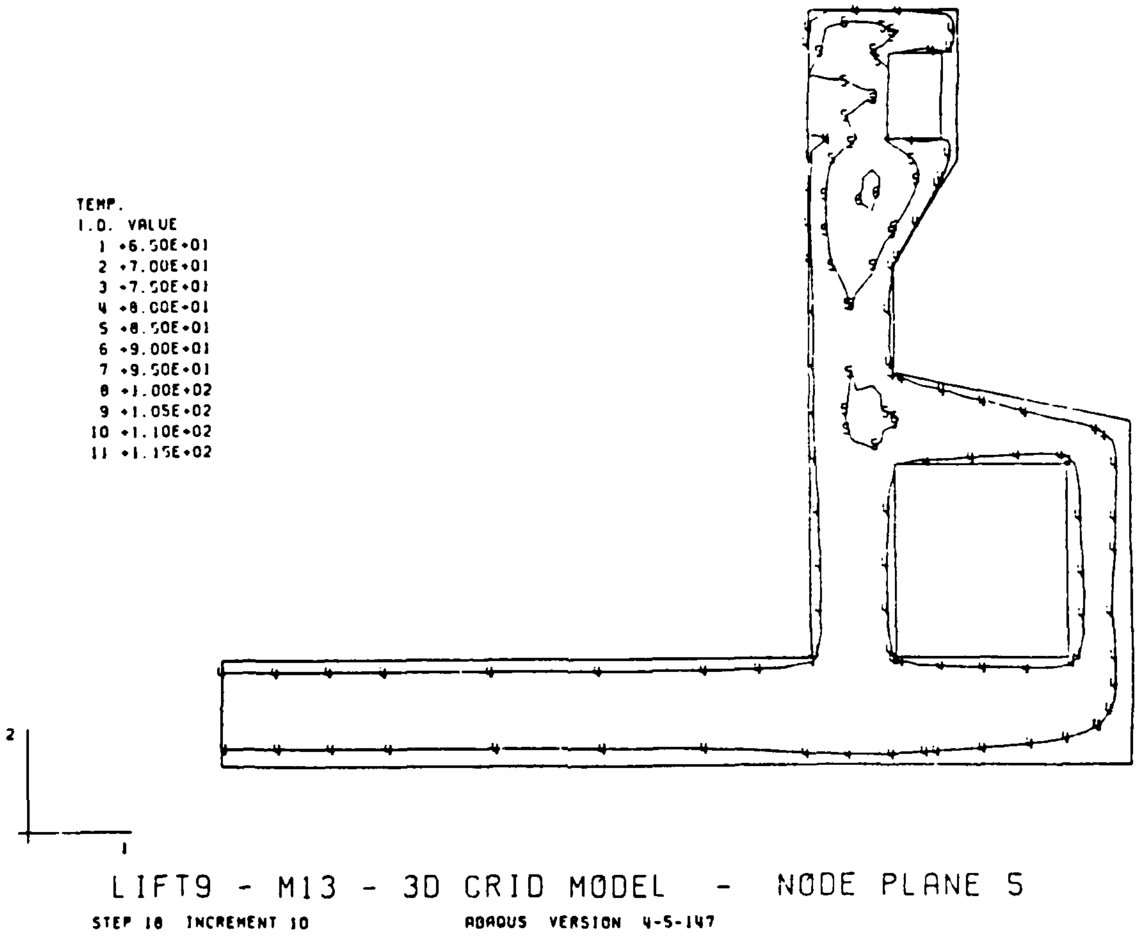


Figure 15b. Temperature distribution in node plane 5 of structure 7 days after lift 9 is placed.

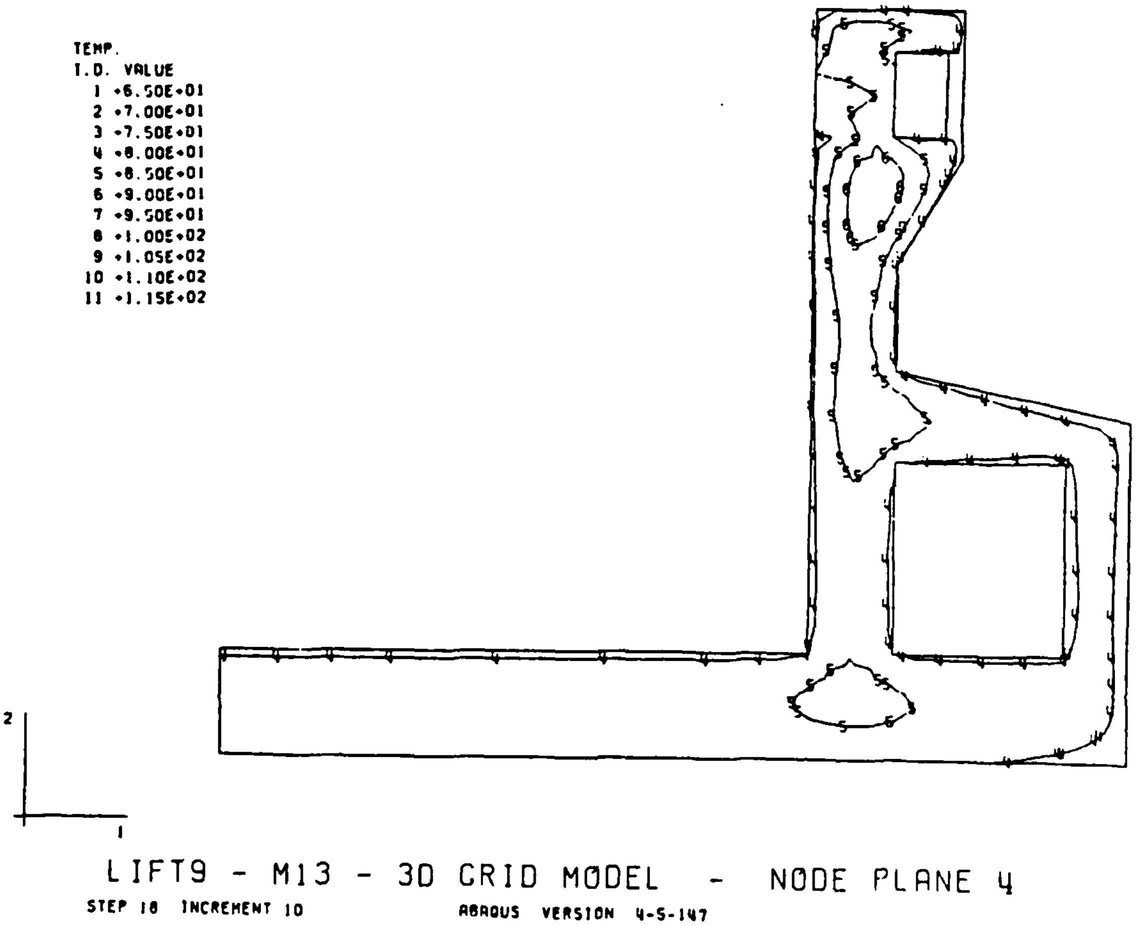


Figure 15c. Temperature distribution in node plane 4 of structure 7 days after lift 9 is placed.

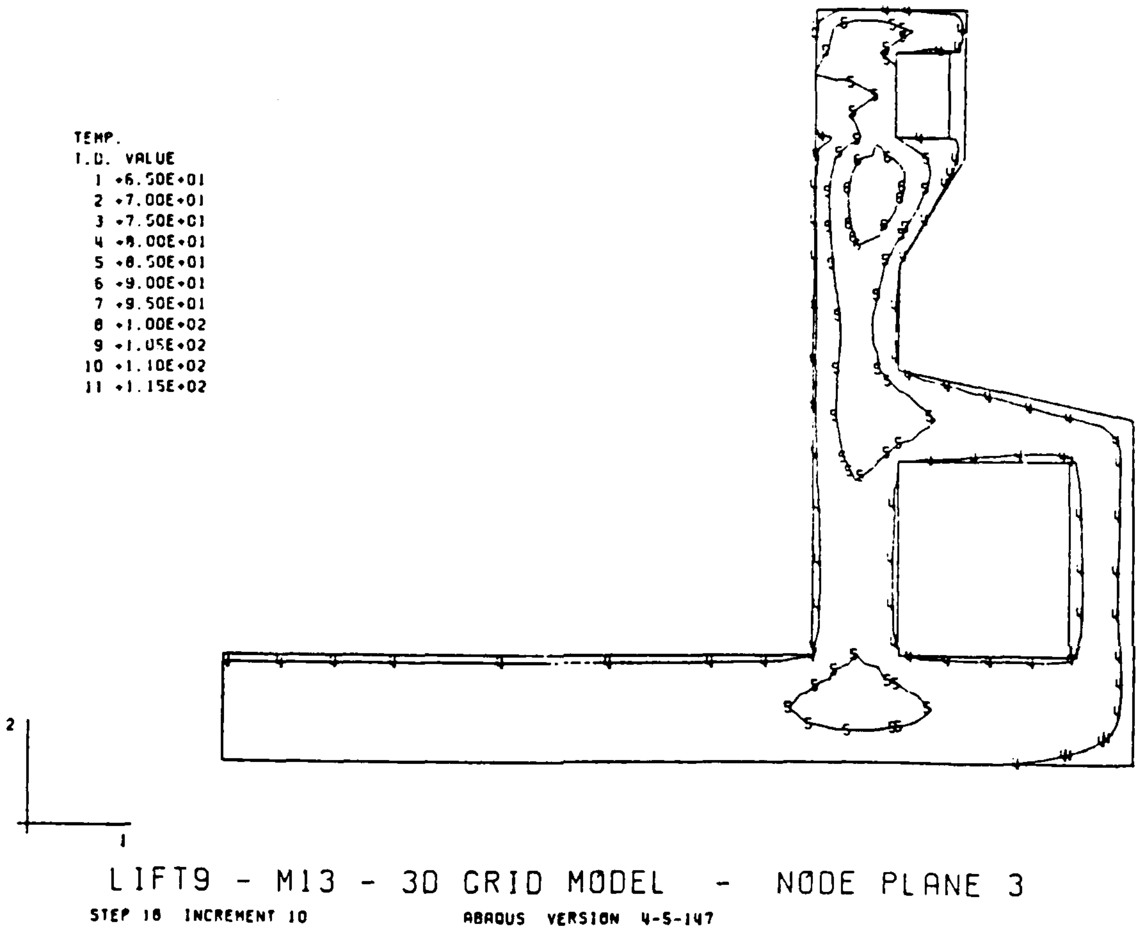


Figure 15d. Temperature distribution in node plane 3 of structure 7 days after lift 9 is placed.

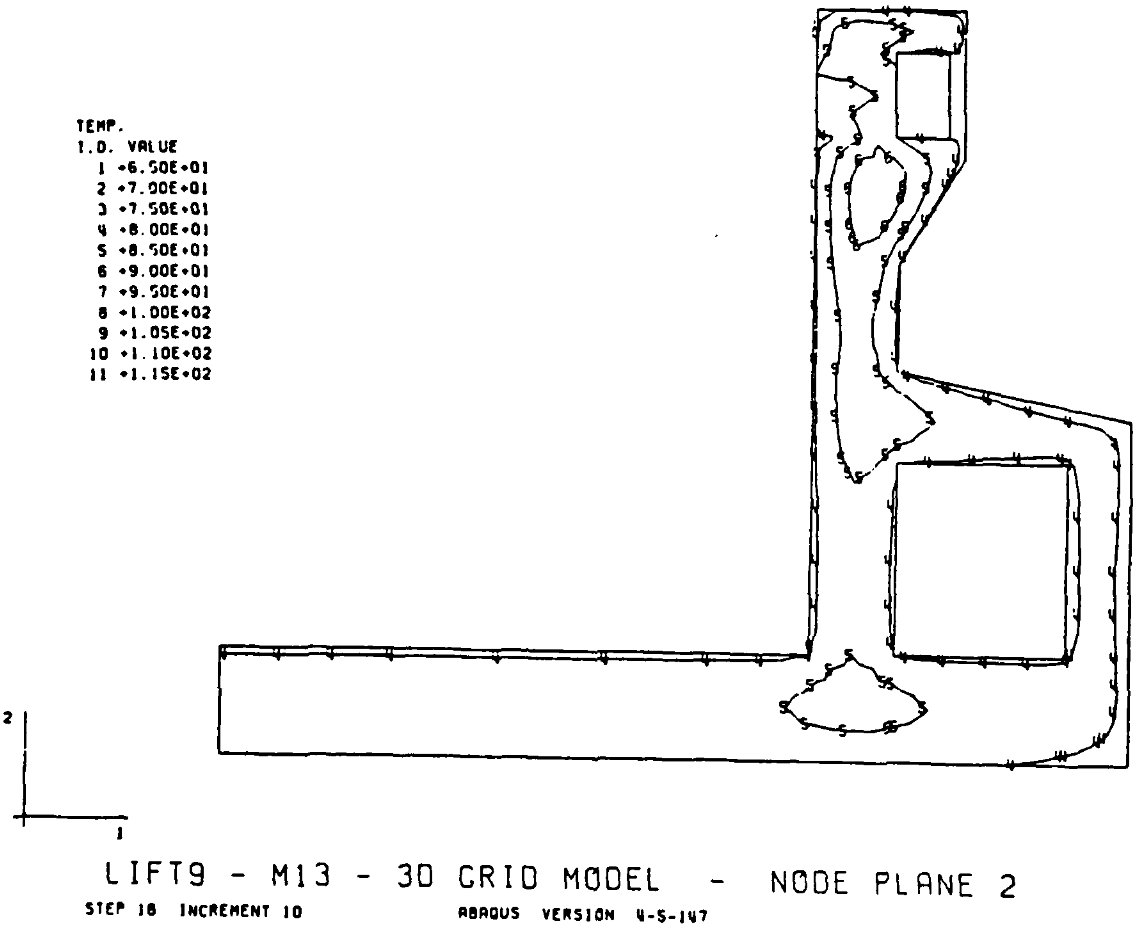


Figure 15e. Temperature distribution in node plane 2 of structure 7 days after lift 9 is placed.

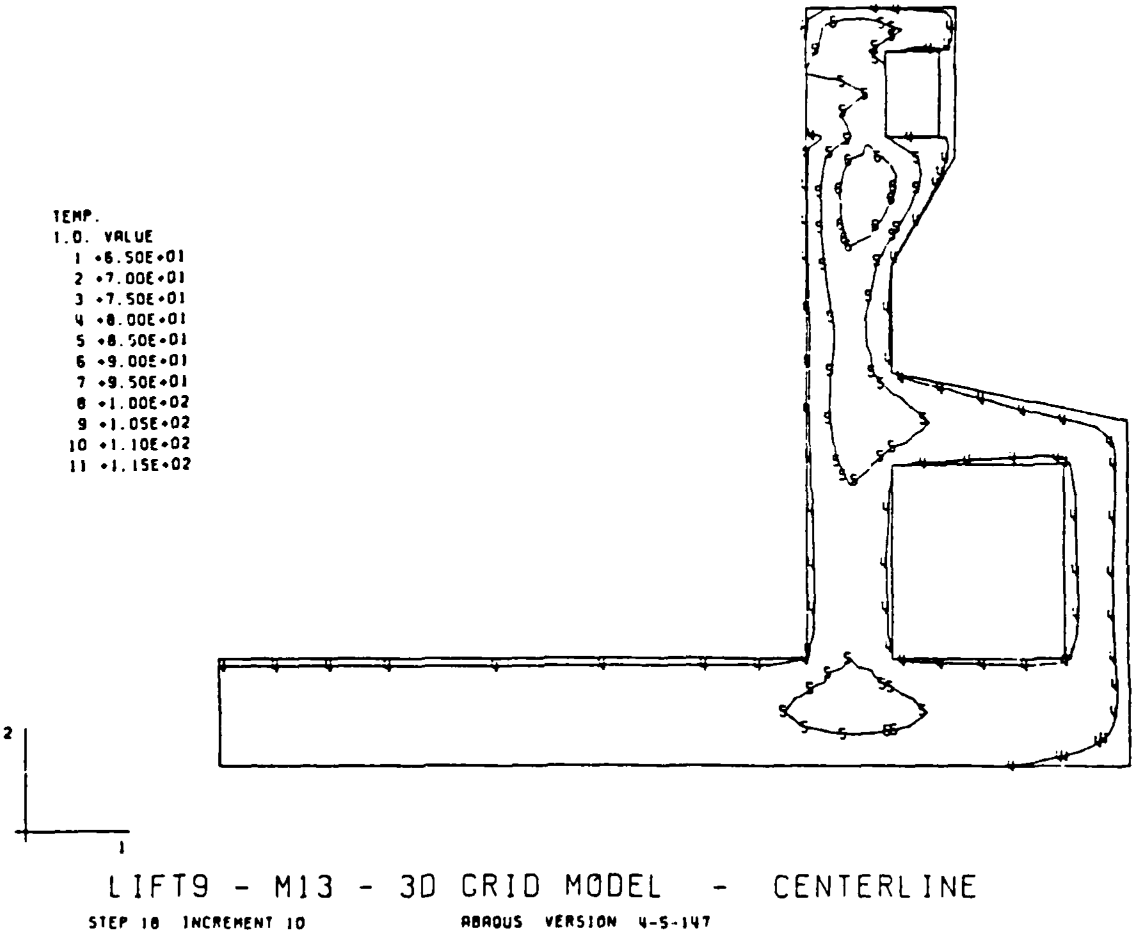


Figure 15f. Temperature distribution in the centerline of structure 7 days after lift 9 is placed.

PART VIII: STRESS ANALYSES OF MONOLITH L-13

Presentation of Results

Two-dimensional gravity loading

66. The ABAQUS program was used to perform the 2-D stress analysis of monolith L-13 for both instantaneous gravity turn-on of the entire structure and an incremental construction build-up sequence of the structure. Figures 16a and 16b show the displaced structure and maximum principal (tensile) stress contours, respectively, for the gravity turn-on analysis for a Young's Modulus (E) of 3.12×10^6 psi. Figures 17a and 17b give the same results for $E = 4.80 \times 10^6$ psi. These modulus values correspond to the ACI modified and normal compressive strength of the concrete at 28 days, respectively. Figures 18a thru 18d and 19a thru 19b show the displaced structure and maximum principal stress contours, respectively, for four four stages of construction using incremental construction sequencing. This incremental construction analysis uses the material modulus calculation routine UMAT1. WES2DT was used to make the same incremental construction analysis. Figures 20a thru 20d and 21a thru 21d show the resultant displacement vector plots and principal stress vector plots, respectively, from this analysis.

Two-dimensional gravity and thermal loading

67. The ABAQUS program was used to perform the 2-D stress analysis including gravity and temperature loading for FE grids 1 and 2 using the modulus routine UMAT1. The displaced structure plots from grids 1 and 2 are given in Figures 22a thru 22d and 24a thru 24d, respectively. The maximum principal stress contours for both grids are given in Figures 23a thru 23d and 25a thru 25d, respectively. The new modulus subroutine UMAT2 (concrete aging creep model) was used with ABAQUS with grid 1 to make the analysis when E

did not depend on temperature and E did depend on temperature. The displaced structure and maximum principal stress contours are given in Figures 26a thru 26d and 27a thru 27d for E not a function of temperature. Figures 28a thru 28d and 29a thru 29d show the displacement and maximum principal stress contours for E as a function of temperature. A WES2DT analysis was made of this same gravity and temperature loading. The resultant displacement vector plots are shown in Figures 30a thru 30d. The principal stress vector plots are shown in Figures 31a thru 31d.

Two-dimensional gravity and thermal loading including creep

68. ABAQUS was used in incremental construction analyses of the structure using FE grid 1 with the modulus subroutine UMAT2. Displaced-structure plots are shown in Figures 32a thru 32d. Maximum principal stress contours are shown in Figures 33a thru 33d. WES2DT was also used to make the same analysis. Figures 34a thru 34d show resultant displacement vectors and Figures 35a thru 35d show principal stress vectors from the WES2DT analysis.

Two-dimensional gravity and thermal loading including creep and shrinkage

69. ABAQUS was used to make this analysis using FE grid 1 and modulus subroutine UMAT2. Displaced-structure plots for this analysis are shown in Figures 36a thru 36d. Maximum principal stress contours are shown in Figures 37a thru 37b.

Three-dimensional gravity loading

70. ABAQUS was used to perform a 3-D gravity turn-on analysis of monolith L-13 using the FE grid in Figure 8a. The displaced structure at the element faces in the 5 element planes in Figure 8d are shown in Figures 38a thru 38e.

Discussion of Results

Gravity turn-on analyses

71. Comparisons of gravity turn-on analyses of monolith L-13 made with $E = 3.12 \times 10^6$ psi and $E = 4.8 \times 10^6$ psi seen in Figures 16 and 17, respectively, showed both the displacements and stresses to be in close agreement. Maximum principal stresses are slightly higher for $E = 4.8 \times 10^6$ psi as expected. Also, comparisons of displacements between these 2-D runs and the 3-D gravity turn-on run seen in Figure 38 closely agree.

Incremental construction with gravity loading only ABAQUS versus WES2DT

72. Incremental construction analyses of monolith L-13 with gravity loading only were conducted with ABAQUS and WES2DT. Comparison of displacement results in Figures 18 and 20 show the results to be very similar. The largest deflection of the base slab occurs midway between the centerline and the outer edge of the monolith after placement of two lifts (Figures 18a and 20a). This is because the loading is uniform and the pile support is weaker in this area. As concrete in the wall was placed and the loading was no longer uniform, displacements of the slab under the wall increased and maximum displacements in the slab shifted outward toward the edge of the slab (Figures 18b-c and 20b-c).

73. Stress comparisons between the ABAQUS and WES2DT programs required comparing principal stress in contour and vector plots (Figures 19 and 21), respectively, because these were the available modes of displaying principal stress from the two programs. Although comparing data from contour and vector plots was not an easy task, it did appear that maximum tensile stresses occurred in the same locations with both programs. In addition, the location of these maximum tensile stresses coincided with locations of maximum slab curvature, namely on the top of the slab at the centerline and at the bottom of

the slab directly under the vertical cantilever section of the wall. The two programs use different methods for starting the stress calculations in a new lift. The slight differences in stress distributions calculated by the two programs in some areas can be attributed to the different lift start-up methods and are amplified by rapidly increasing values of E at early ages.

Gravity turn-on versus
incremental construction

74. Comparisons between whole-structure gravity turn-on and incremental construction simulation with gravity loading only with ABAQUS showed predictable results. In gravity turn-on analyses, the maximum displacements in the slab were nearly equal under the wall and lower at the centerline of the monolith. In incremental construction analyses, maximum displacements in the slab occurred directly under the vertical cantilever section of the wall with lower displacements near the outer edge of the slab and at the centerline. The displacements in the wall were characteristically different between gravity turn-on and incremental construction analyses. During incremental construction, each successive lift is placed up to its planned elevation. Therefore, the displacement of the top of each lift decreases at higher elevations in the structure. Conversely, in the gravity turn-on analysis, the maximum displacement occurs at the top of the wall because all displacements accumulate at the highest elevation. These results have thus exhibited known modes of displacement for gravity turn-on and incremental construction analyses.

75. Stress contours resulting from ABAQUS calculations of gravity turn-on and incremental construction were very similar as expected. Stress values within the base slab were slightly higher due to use of a constant, mature E (28-day value) whereas the incremental construction analysis used aging E values which are lower at early age.

Two-dimensional gravity and thermal loading

76. When thermal effects due to heat of hydration of cement were added to the loading, the predominant changes in the response of the structure were an elongation of the base slab and a downward curvature of the outer end of the base slab. These effects were observed from the both the ABAQUS and WES2DT results. This response is illustrated by comparing Figures 22,24,26,28, and 30. Elongation of the slab is due to thermal expansion. The curvature of the base slab occurs as a result of differential thermal expansion between a new lift and previous lifts. The concrete temperature rise data shown in Figure 4a shows that a new lift can undergo thermal expansion equivalent to a potential temperature rise of 35^{o} F during the first five days after placement. The previous lift during the same time period (its second 5 days) can only experience thermal expansion equivalent to a 5^{o} F temperature rise. The differential longitudinal expansion due to the temperature rise in each lift causes the downward curvature of the outer portion of the slab. The curvature is not actually as pronounced as the temperature differential between the two lifts would indicate because the E, hence stiffness, of the newer lift is lower than that of the previous lift. Effectively, only a part of the temperature differential thus causes curvature of the slab.

77. The addition of thermal loading caused an increase in tensile stresses on the top surface of the base slab near the outer edge after placement of lift 2. Tensile stresses also increased along the vertical wall surfaces and compressive stresses developed in the center of wall masses. These stresses in the wall develop due to the differential expansion from the thermal gradients between the cooler outer surfaces and the warm interiors. In ABAQUS maximum principal stress contour plots include z-direction stresses which result from the absolute restraint to thermal expansion in its plane

strain formulation in two ways. First, z-direction compressive stresses increase x- and y- direction tensile stresses due to Poisson effect in ABAQUS. And z-direction out-of-plane stresses may be included in 2-D maximum principal stress plots. Therefore, z-direction stresses may be mixed in with x - y plane stresses in the ABAQUS principal stress plots. It is understood that subsequent ABAQUS versions will include only in-plane stresses in these plots.

78. Comparison of principal stress contours (Figures 23 and 25) using ABAQUS grids 1 and 2 (Figures 7a and 7b) showed virtually identical results. Comparisons of displacements (Figures 22 and 24) also showed very close agreement. It was concluded, based upon these results, that the coarse mesh of FE grid 1 was adequate for all subsequent analyses of monolith L-13.

79. Comparisons were also made between analyses results from ABAQUS and from WES2DT that included thermal loading. Comparisons between results from the two programs must be tempered by the realization that ABAQUS plane strain calculations effectively fully restrain z-direction expansion and WES2DT does not. Consequently, z-direction stresses develop in ABAQUS which through Poisson effect modify x- and y-direction stresses. In WES2DT, z-direction stresses are not calculated so that they are effectively zero with no resulting Poisson effect. In addition, stress plots in ABAQUS may include z-direction stresses. With these points in mind, examination of displacement plots from the two programs (Figures 22 and 30) showed very similar deflection patterns at all locations. Comparison of maximum principal stress plots (Figures 23 and 31) showed tensile stress results that compared very well in location and magnitude. When maximum principal stresses were compressive, stresses were generally lower from ABAQUS. This may be the result of the different considerations for plain strain calculations by ABAQUS and WES2DT.

80. All previously described analyses with ABAQUS employed the modulus

subroutine UMAT1 in which the E versus age function was entered as tabular input. ABAQUS modulus subroutine UMAT2 (aging creep model) enters E versus age data by a mathematical function representation. When UMAT2 was first used, several initial comparative FE analyses were run to identify any differences between UMAT1 and UMAT2 without employing creep or shrinkage to establish bases of comparisons between the two subroutines. UMAT2 incorporates E as a function of temperature as well as age. Comparative runs were made to identify the differences introduced for the temperature dependence of E for the range of temperatures encountered in these analyses. The displaced grid (Figures 26 and 28) and principal stress contour (Figures 27 and 29) plots show that temperature dependence of E does not appreciably affect the results. Comparisons of the E versus age representations used in UMAT1 and UMAT2 were made by comparing displaced grid (Figures 22 and 28) and principal stress contour (Figures 23 and 29) plots. These results show that elongation and downward curvature of the base slab (lifts 1 and 2) are slightly greater for the UMAT2. In locations of maximum tensile stresses, UMAT2 produced stresses up to 100 percent higher than those by UMAT1 after five days after placement of lift 2. These higher stresses from UMAT2 were determined to be the direct result of much higher values of E during the first day in the functional representation used in UMAT2. The method for expressing E versus time in the aging creep model will require modification in the future to better express E values for the first day or so of age. This could not be done in time to be used in this study. The remainder of the analyses were made using ABAQUS modulus subroutine UMAT2 with the realization that early-age stresses would be higher than normal.

Two-dimensional gravity and thermal loading including creep

81. Analyses of L-13 which included gravity and thermal loading with creep were conducted using both ABAQUS-UMAT2 with FE grid 1 and WESTDT

AD-A183 664 THERMAL STRESS ANALYSES OF MISSISSIPPI RIVER LOCK AND DAM 26(R)(U) ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MS STRUCTURES LAB A A BOMBICH ET AL. JUL 87 2/4

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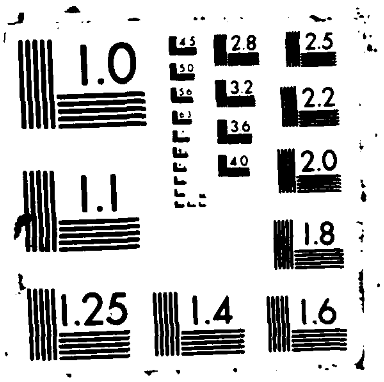
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2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

effects of creep changed the deflected response of the monolith. Although the displacement trends (Figures 32 and 34) produced by ABAQUS and WES2DT compared remarkably well, magnitudes of deflection were higher with ABAQUS.

82. When comparing the principal stress plots without creep for ABAQUS and WES2DT (Figures 23 and 31) to principal stress plots for the two programs with creep (Figures 33 and 35), the following observations were made. The relaxation of stresses due to creep with ABAQUS-UMAT2 reduced peak principal stresses in the base slab from 300 psi (Figure 29a) to 150 psi (Figure 33a) at five days after placement of lift 2. At 5 days after placement of lift 4, peak principal stresses in the base slab were reduced from 250 psi (Figure 23b) to 50 psi (Figure 33b). With WES2DT the similar comparison showed reduction of peak principal stresses due to creep in the base slab from 150 psi (Figure 31a) to 115 psi (Figure 35a) at 5 days after placement of lift 2 and from 90 psi (Figure 31b) to 50 psi (Figure 35b) at 5 days after placement of lift 4. These comparisons show that initial stresses are much higher and relaxation due to creep is much greater with ABAQUS-UMAT2 than with WES2DT. The higher initial stresses are consistent with the fact that the early-age E values are greater with UMAT2. As discussed in paragraph 28, it was known that the creep data incorporated into UMAT2 would produce slightly greater creep relief than the data used by WES2DT. Also, since the highest rate of creep occurs when these stresses are high, a proportionately larger amount of stress relief resulted with ABAQUS. At later times as the initial, high thermal gradients and the resulting thermal stresses are reduced, the excessively relaxed stresses are further reduced. This process accounts for the large decrease in stresses seen in the base slab in Figure 35b.

Two-dimensional gravity and thermal loading including creep and shrinkage

83. An ABAQUS analysis was conducted on L-13 using UMAT2 with gravity

and thermal loading including creep and shrinkage. The addition of this autogenous shrinkage caused noticeably different results. Comparison of ABAQUS analyses with creep, but with and without shrinkage showed both different displacement and principal stress response. Comparison of displaced grids (Figures 32 and 36) for analyses with and without shrinkage, respectively, shows that the addition of shrinkage cancels some of the thermal elongation of lift 2 and reduces the differential thermal expansion between lifts 1 and 2 that had produced downward curvature of the outer end of the base slab. Subsequently, further shrinkage caused deflections of the slab directly under the verticall cantilever section of the wall to increase substantially (Figures 36a - 36d). Comparison of maximum principal stresses showed that at 5 days after placement of lift 2, stresses in the base slab were greater and nearly symmetrical about the lift 1-lift 2 interface when shrinkage was applied. In fact, stresses increased in several areas of the wall. Although the creep and shrinkage data used in these ABAQUS FE analyses are not based upon the results of tests of Lock and Dam 26R concrete which may cause the results to deviate slightly, it is evident from these analyses that inclusion of creep and shrinkage are necessary for proper thermal stress evaluation.

Pile loads

84. The load in a pile is directly proportional to the deflection of the pile head, therefore, the distribution of pile loads underneath the base slab is dependent principally upon the base slab deflections. Table 6 gives the vertical pile loads from analyses using ABAQUS and WES2DT. Also included are pile loads supplied by St. Louis District. The ABAQUS results using a Young's modulus modified by ACI agree very closely with the St. Louis District values in a gravity turn-on analysis. Since the ABAQUS and WES2DT modulus values were not to be modified for the remaining analyses, an ABAQUS analysis

Table 6. Vertical Pile Loads for Monolith 13
(7 Days after placement of last lift)

	GRAVITY TURN-ON			GRAVITY ONLY		GRAVITY & THERMAL LOADS					GRAVITY & THERMAL LOADS		
Pile No.	St. Louis District	ABAQUS		ABAQUS (UMAT1)	WES2DT	ABAQUS (UMAT1)		ABAQUS (Grid #1)		WES-2DT	(W/CREEP)		(W/CREEP & SHRINK.) ABAQUS
		E1	E2			Grid #1	Grid #2	(UMAT2*)	(UMAT2)		ABAQUS	WES2DT	
1	86 2	89.6	96.1	75.0	71.0	71.9	71.4	72.4	72.4	68.9	45.3	65.6	45.0
2	88.3	91.5	97.5	78.9	75.5	75.5	75.2	74.9	74.9	73.4	50.5	70.4	50.2
3	94.2	96.9	101.7	90.2	89.0	86.2	86.1	81.8	82.2	86.6	65.8	84.7	65.3
4	103.4	105.6	108.6	107.6	111.4	102.7	102.8	92.6	93.4	108.2	92.9	108.5	92.2
5	128.1	128.1	126.6	146.5	157.0	139.2	139.7	118.3	120.1	152.2	151.8	156.5	152.0
6	155.0	153.2	147.3	181.1	191.8	171.1	171.3	144.1	146.4	185.2	208.5	192.7	211.2
7	177.8	175.5	166.6	203.7	211.9	192.0	193.0	165.8	168.2	204.1	250.4	213.2	257.5
8	190.2	189.6	180.8	208.3	211.9	197.1	197.9	179.9	181.7	204.0	257.8	212.1	270.8
9	191.1	191.1	186.6	194.2	188.8	189.5	189.9	189.3	189.3	185.2	210.9	187.4	222.3
10	189 6	189 6	188.0	185.7	177.7	187.8	187.8	197.4	196.5	179.8	184.0	177.9	189.1
11	188.8	188.8	189 8	179.4	175.6	190.8	190.8	210.3	208.5	182.6	169.5	179.0	164.3
12	189 2	190.3	193.2	176.6	179.2	200.9	199.7	230.6	228.1	195.5	178.3	189.8	155.9

NOTE - All pile loads are in KIPS/PILE

GRAVITY TURN-ON - Instantaneous placement of entire structure in one step
GRAVITY ONLY - Incremental construction of structure in lifts with only gravity applied
GRAVITY AND THERMAL LOADS - Incremental construction of structure in lifts with gravity and temperature loading
St. Louis District - Pile loads supplied by St. Louis District (E = 3,120,000 psi)
E1 - ABAQUS results using E = 3,120,000 psi (28-day strength modified by ACI code)
E2 - ABAQUS results using E = 4,800,000 psi (28-day strength)
UMAT1 - Original modulus calculation routine used with ABAQUS, only considers aging og the concrete
UMAT2 - Revised modulus routine which may include aging, creep, shrinkage and E is a function of tempreture
UMAT2* - New modulus routine which can include aging, creep, shrinkage and E as a function of temperature

was also made with the unmodified 28-day Young's modulus. The stiffer concrete slightly redistributed the pile loads with the higher loads still being located under the wall at the outer edge of the base slab. The maximum pile loads from these analyses were all less than 200 kips/pile.

85. When the wall was constructed incrementally with only gravity loads applied, the ABAQUS and WES2DT programs predicted more significant redistribution of the pile loads with maximum values of 200-210 kips/pile occurring underneath the wall.

86. As thermal loading was added, the ABAQUS-UMAT1 results for grid 1 and grid 2 were almost identical. The results of ABAQUS using the new modulus subroutine UMAT2, for both modulus as a function of temperature and constant with temperature, gave very similar results. No further analyses were made with the modulus held constant with temperature since it caused no significant change in pile loads. However the predicted pile loads using UMAT2 were redistributed from the ones using UMAT1. The larger pile loads were reduced under the wall and moved farther toward the outer edge of the base slab. Maximum pile loads were approximately 230 kips/pile for the ABAQUS-UMAT2 analysis. WES2DT results showed close agreement in magnitude and trend with the ABAQUS results using UMAT1.

87. When creep was included in the analysis, both ABAQUS and WES2DT redistributed the pile loads. Both gave lower pile loads at the centerline, lower loads at the outer edge, and higher loads under the wall. The ABAQUS results showed more extreme changes in each instant. WES2DT results ranged from 66 kips/pile at the centerline to 213 kips/pile under the wall. ABAQUS results showed 45 kips/pile at the centerline and 258 kips/pile under the wall. These ABAQUS values are 10 - 15 percent higher than WES2DT values. The higher pile loads can be attributed to higher creep occurring in ABAQUS at early times

after placement of a lift when the modulus is excessively high. The WES2DT pile loads are very similar in magnitude and distribution to those obtained earlier when only gravity loading was included in an incremental construction analysis.

88. When shrinkage was added to the ABAQUS analysis, the pile loads were slightly redistributed from those where only creep was included. Higher values were predicted under the vertical cantilever section of the wall and lower values at the outer edge of the base slab.

89. While the gravity turn-on analysis method gives adequate pile load input for use in design, the incremental construction method should give loads closer to the actual values since it more closely models the actual construction sequence. However, the incremental method will be slightly more expensive and difficult to perform since data to define the modulus as a function of time is needed and a series of solutions is performed.

Cracking potential

90. Comparisons of results were made to evaluate the potential for cracking of the concrete in the analyses that were made in this investigation. Modulus of rupture test results from Lock and Dam 26R, Phase I mixture 4c concrete yielded values of 124 psi, 280 psi, 300 psi, and 464 psi at 1-, 3-, 7-, and 28-days age, respectively. If these values are used as a simple cracking initiation limit for tensile stresses, the following conclusions can be made regarding crack potential in monolith L-13.

91. First, maximum principal stresses computed in WES2DT analyses did not exceed 150 psi in tension under any state of loading and this level was reached after 3-days age without any stress relief due to creep. With creep peak tensile stresses were 20-40 percent less. Consequently, maximum tensile stresses were less than 50 percent of modulus of rupture at any age even

without benefit of creep.

92. Secondly, maximum principal tensile stresses computed in ABAQUS analyses using UMAT1, which employed the identical modulus versus time relationship as WES2DT analyses, did not exceed 200 psi and only after 3-days age. Even without the benefit of stress relief through creep, which should relax stresses by 20-40 percent, these peak tensile stresses are only around 70 percent of modulus of rupture at 3-day.

93. Finally, maximum principal tensile stresses computed in ABAQUS analyses using UMAT2, which contained an excessively high modulus function for the first day or so of age, exceeded 300 psi at 3- to 5-days age without creep and 150 psi with creep. Considering that the computed early-age stresses were high due to the abnormally high initial modulus used in UMAT2, it is probable that values of 100 psi or less with creep at 3-days age can be expected. This reinforces the conclusion reached with the WES2DT analyses that peak tensile stresses are less than 50 percent of modulus of rupture in this structure.

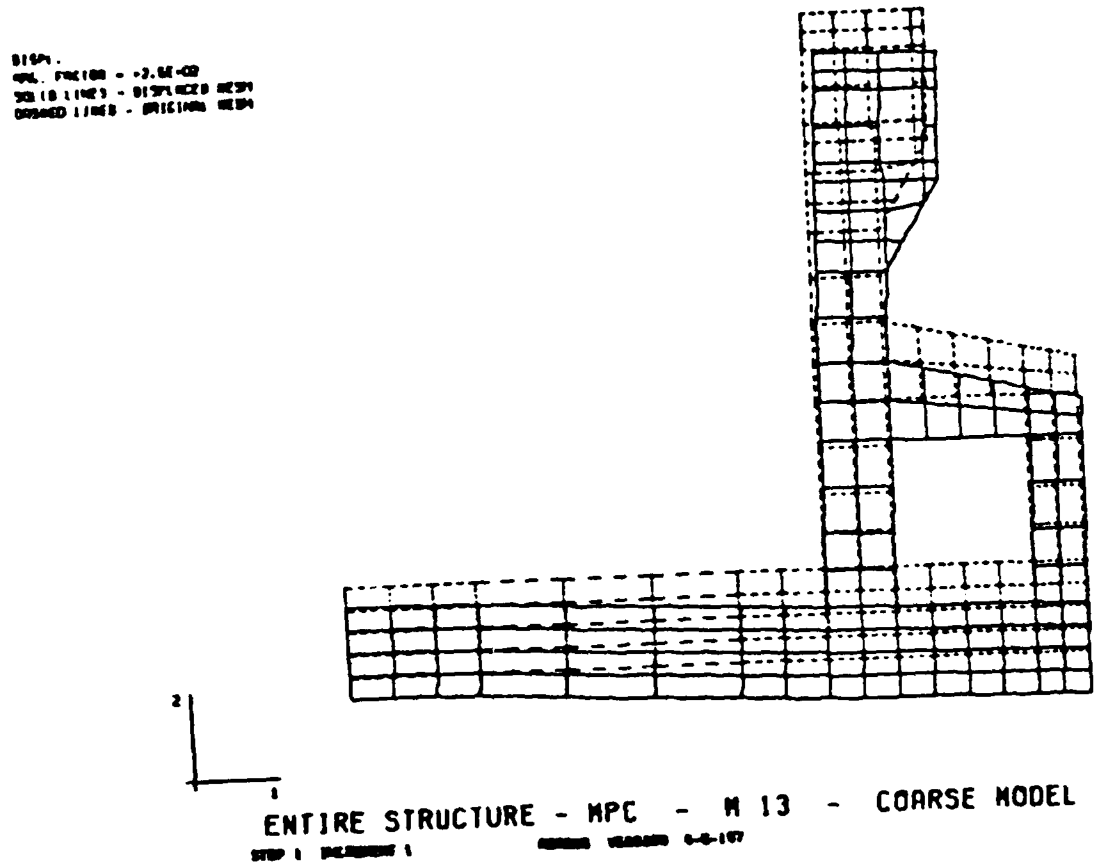


Figure 16a. Displaced structure from gravity turn-on analysis, $E = 3.12 \times 10^6$ psi

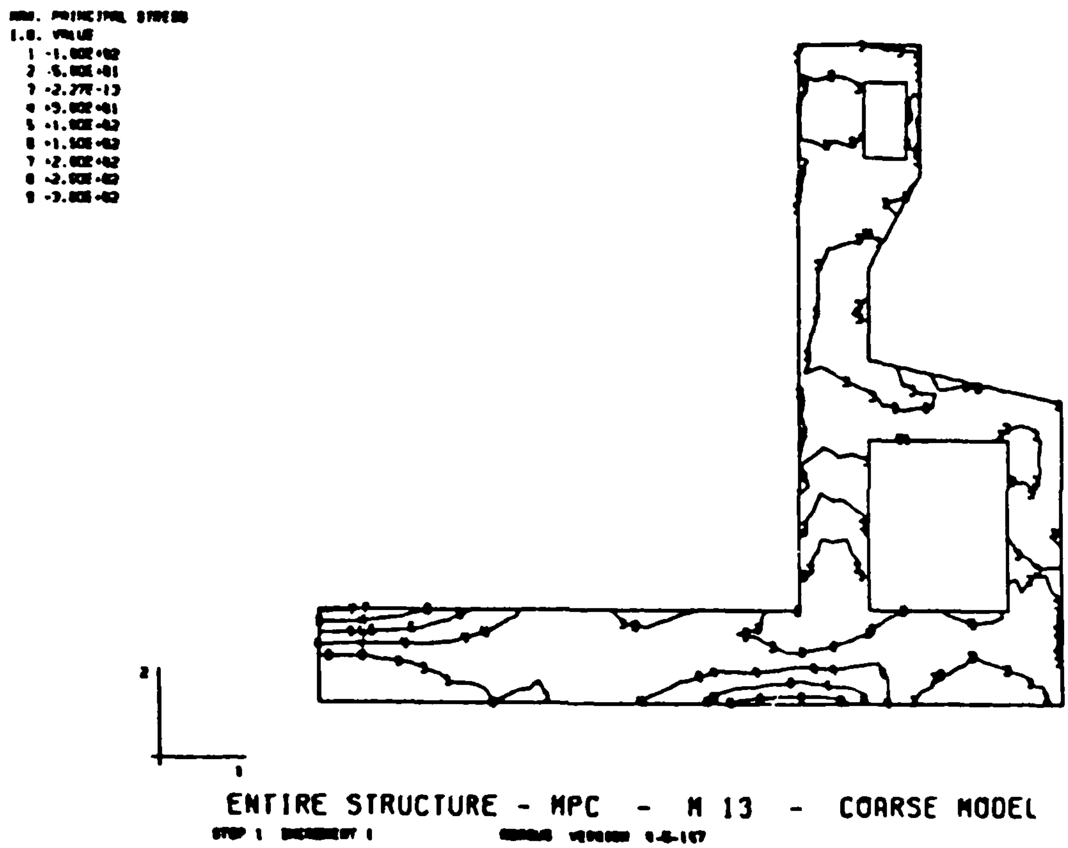


Figure 16b. Maximum principal stress contours for gravity turn-on analysis, $E = 3.12 \times 10^6$ psi

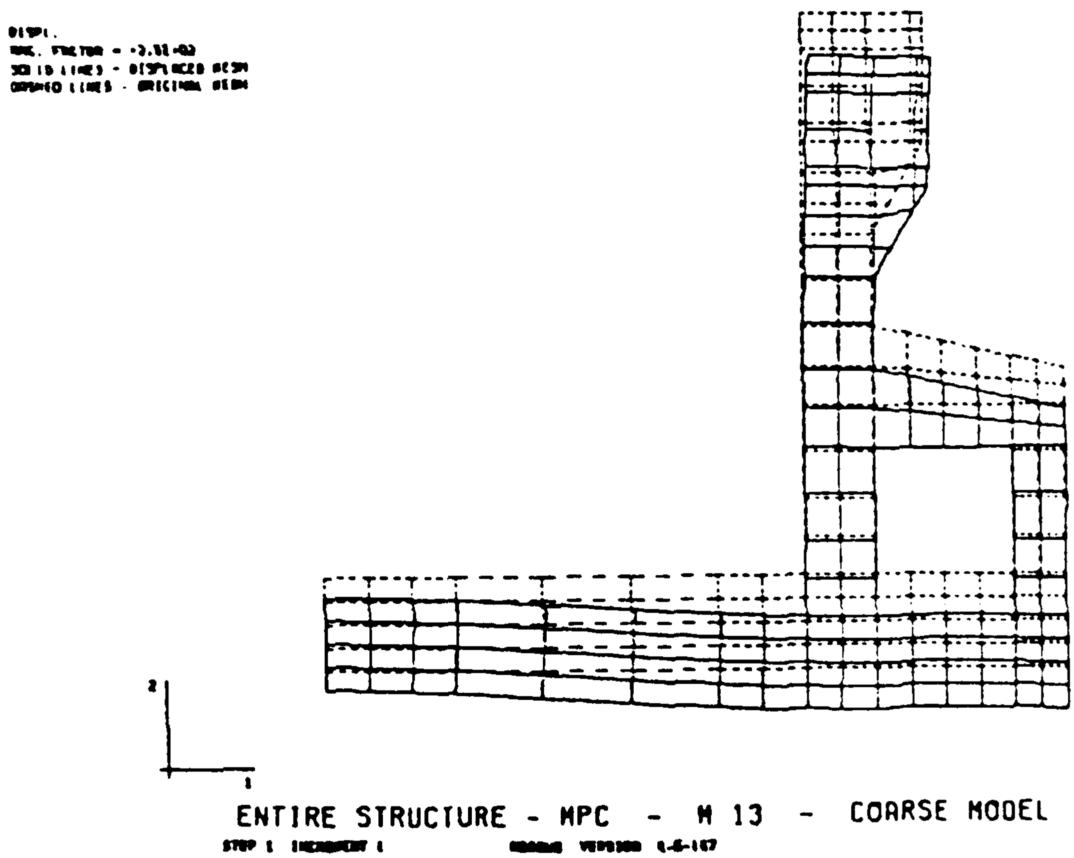


Figure 17a. Displaced structure from gravity turn-on analysis, $E = 4.8 \times 10^6$ psi

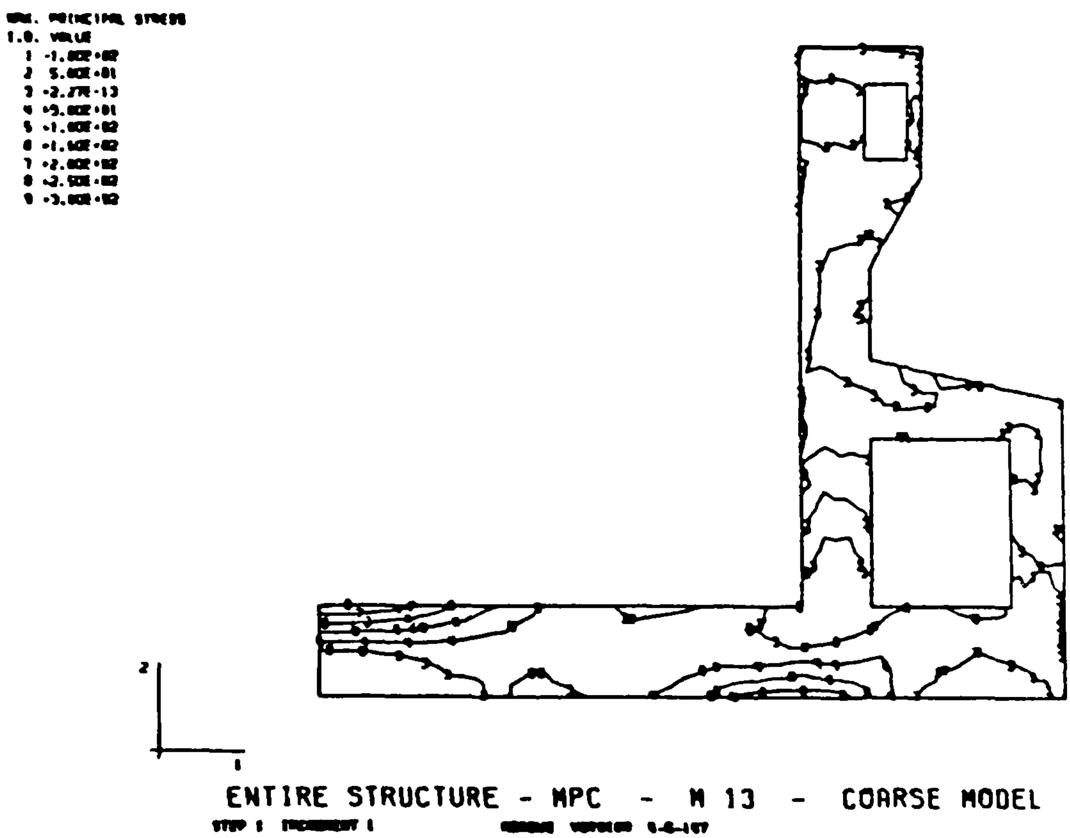


Figure 17b. Maximum principal stress contours for gravity turn-on analysis, $E = 4.8 \times 10^6$ psi

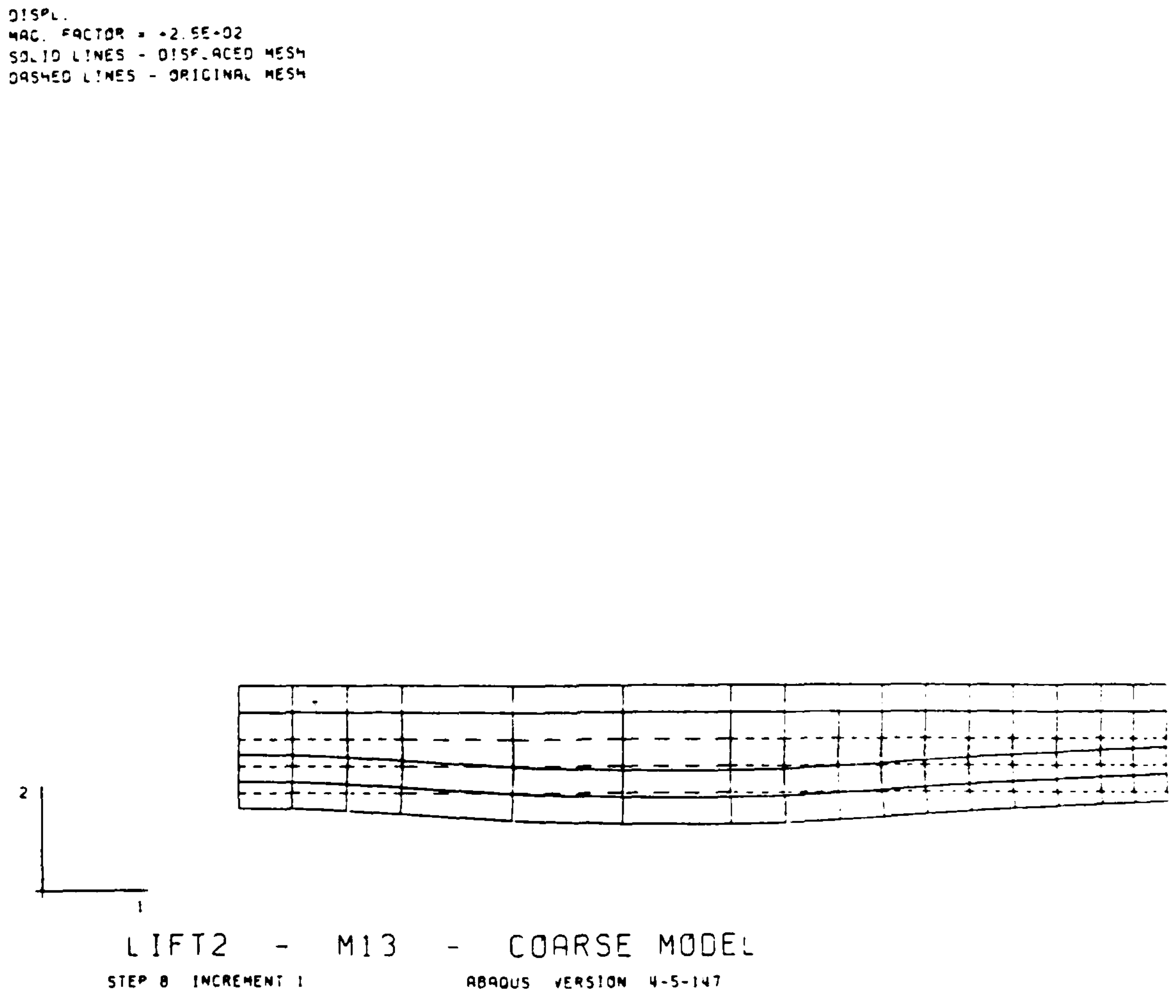


Figure 18a. Displaced structure 5 days after lift 2 is placed, gravity loading only, no creep, using program ABAQUS with first grid

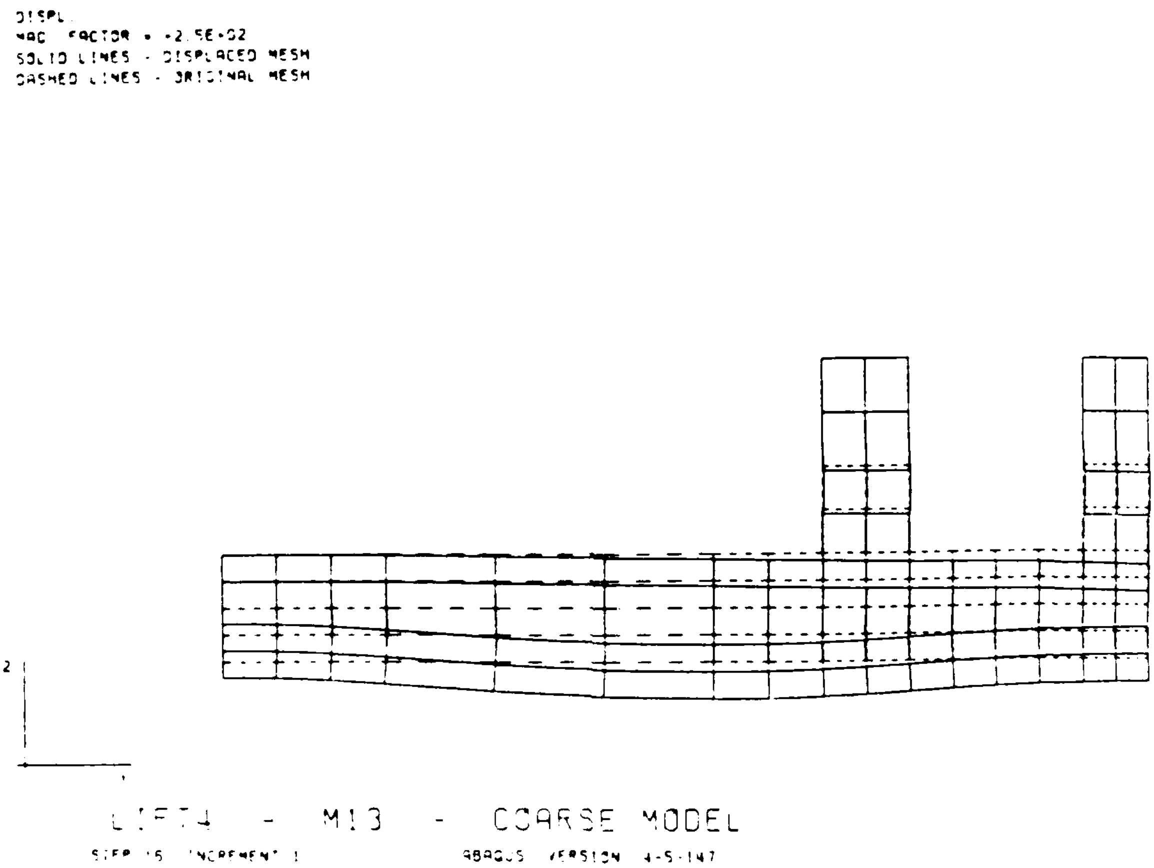


Figure 18b. Displaced structure 5 days after lift 4 is placed, gravity loading only, no creep, using program ABAQUS with first grid

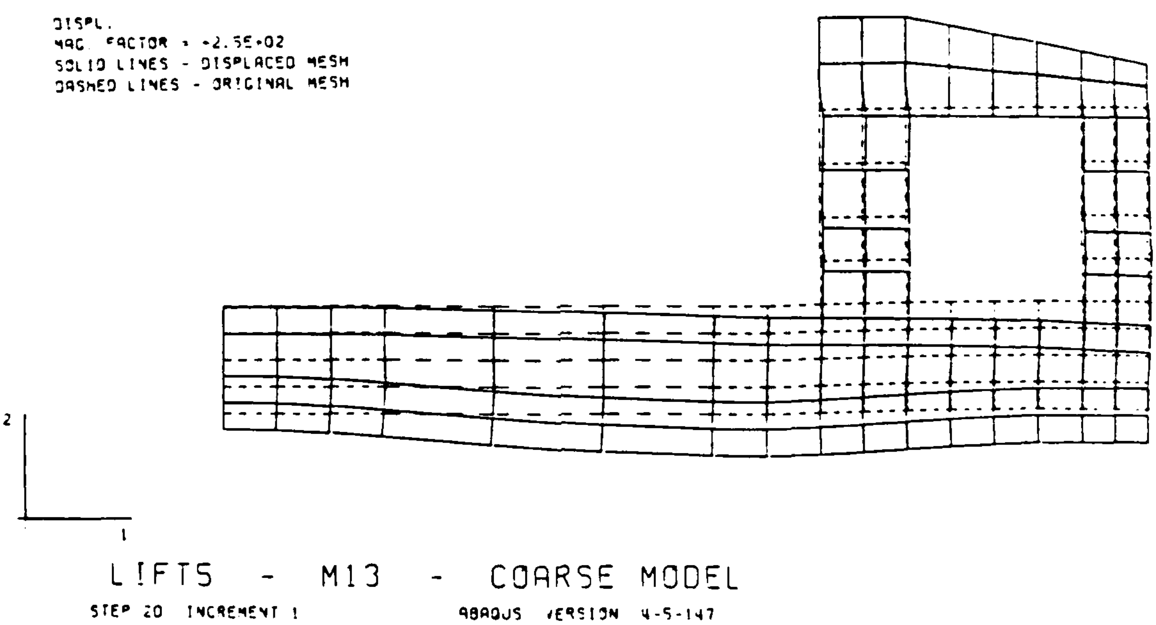


Figure 18c. Displaced structure 5 days after lift 5 is placed, gravity loading only, no creep, using program ABAQUS with first grid

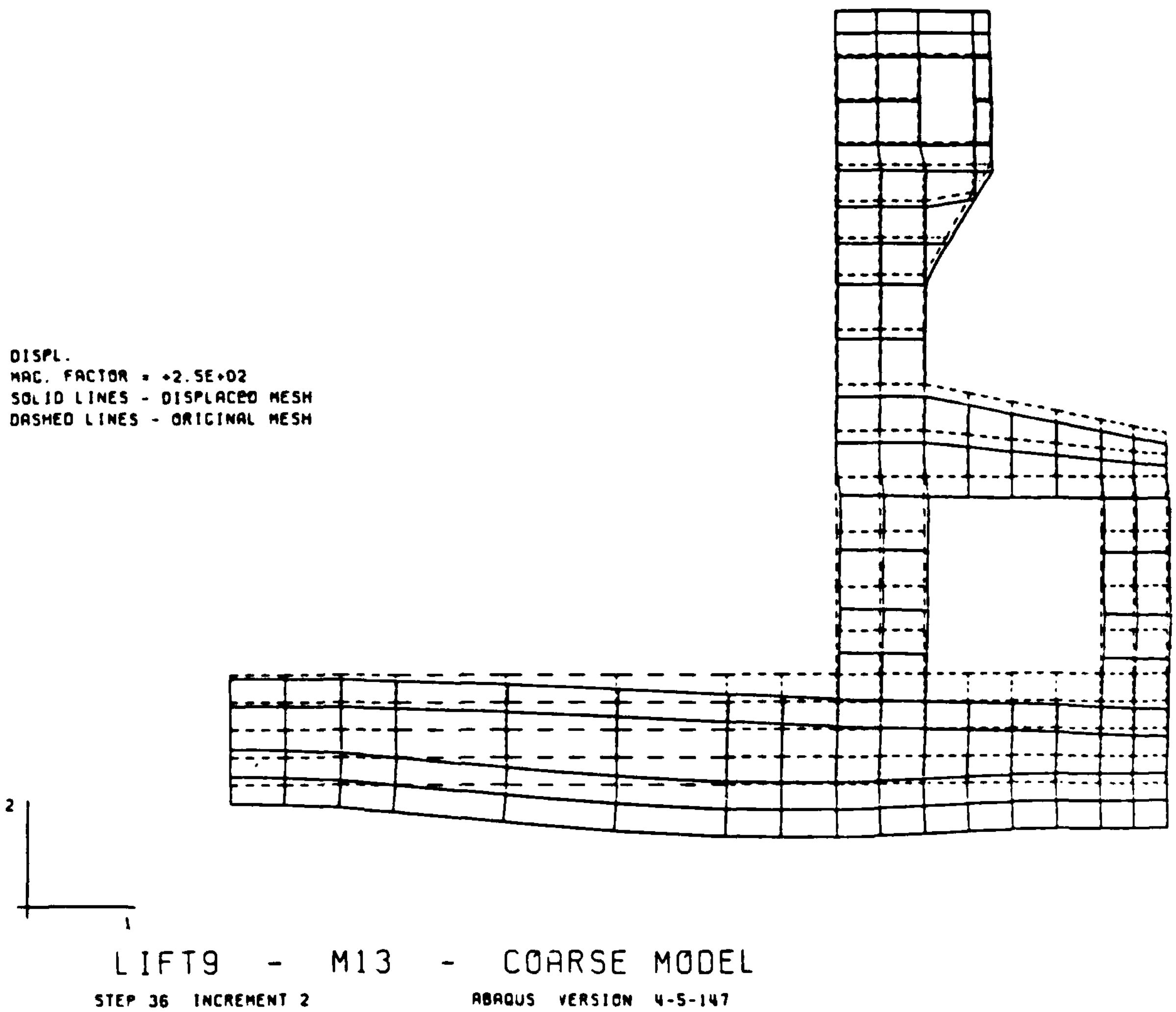


Figure 18d. Maximum principal stress (tensile) contours in structure 7 days after placement of lift 9, gravity loading only, no creep, using program ABAQUS (UMAT 1) first grid

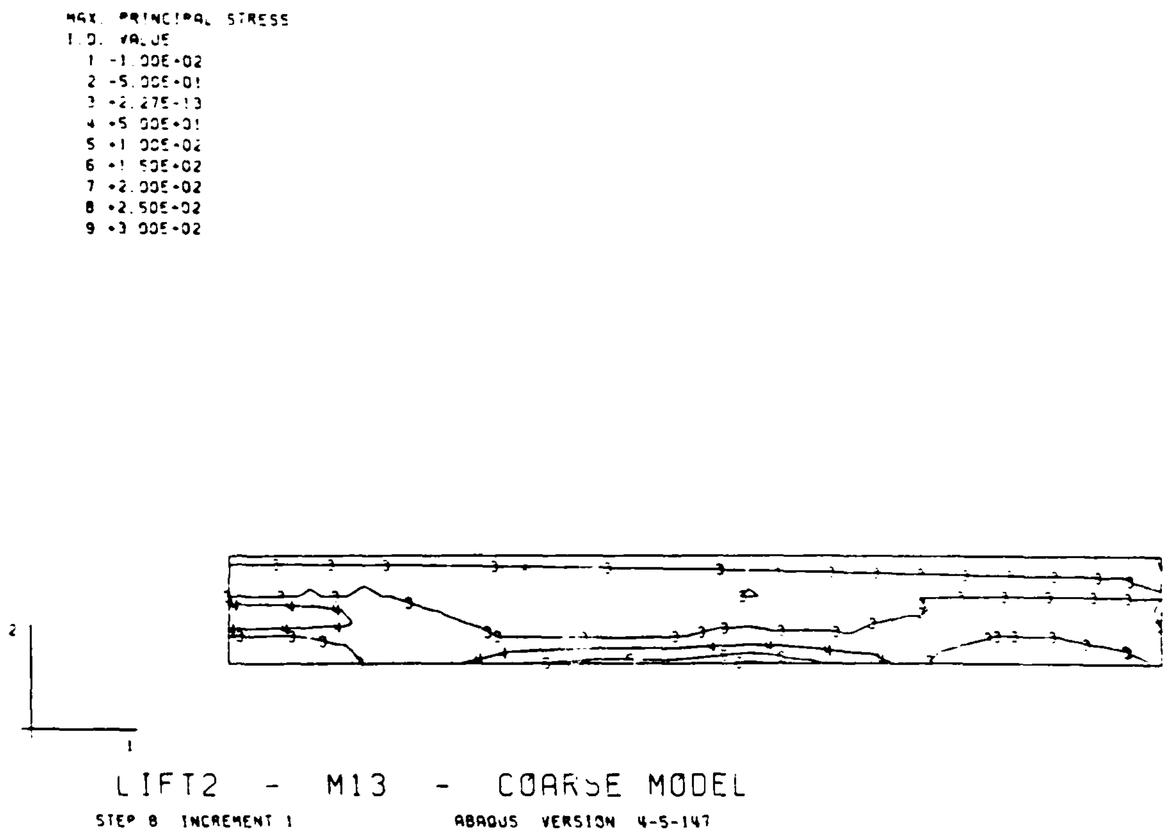


Figure 19a. Maximum principal stress (tensile) contours in structure 5 days after placement of lift 2, gravity loading only, no creep, using program ABAQUS with first grid

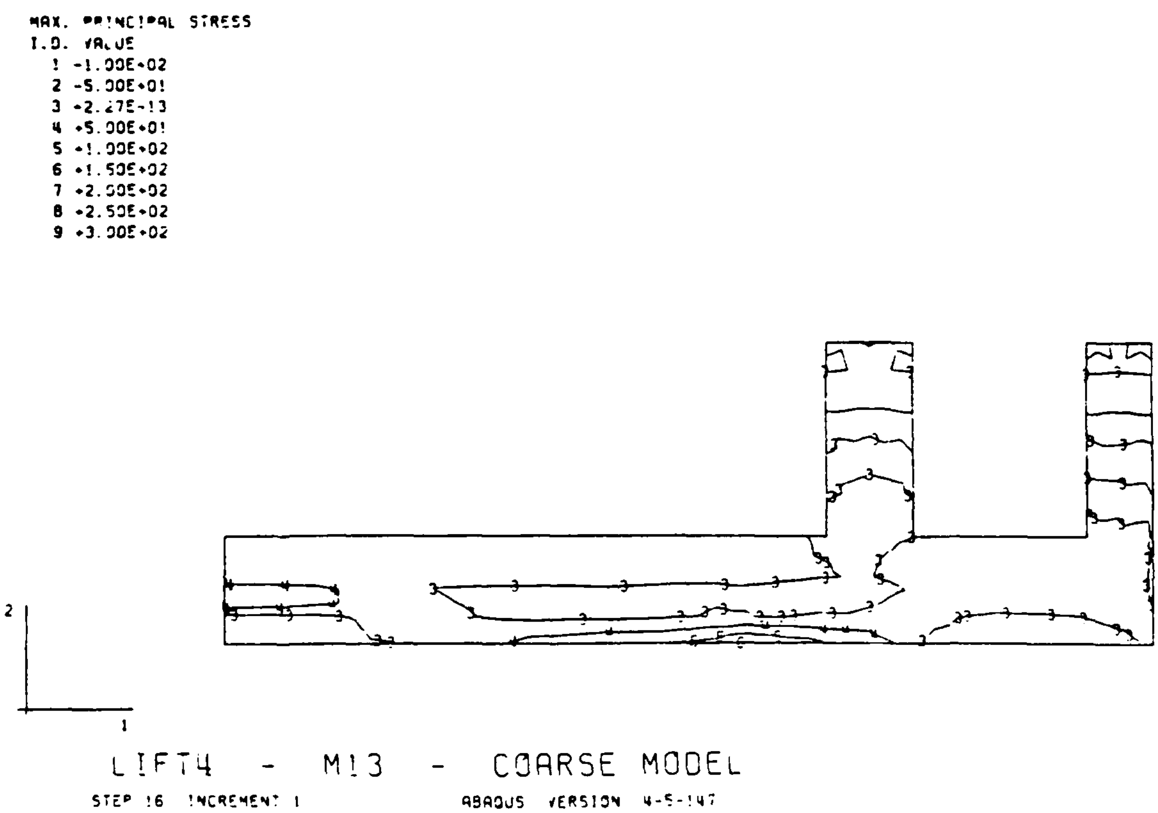


Figure 19b. Maximum principal stress (tensile) contours in structure 5 days after placement of lift 4, gravity loading only, no creep, using program ABAQUS with first grid

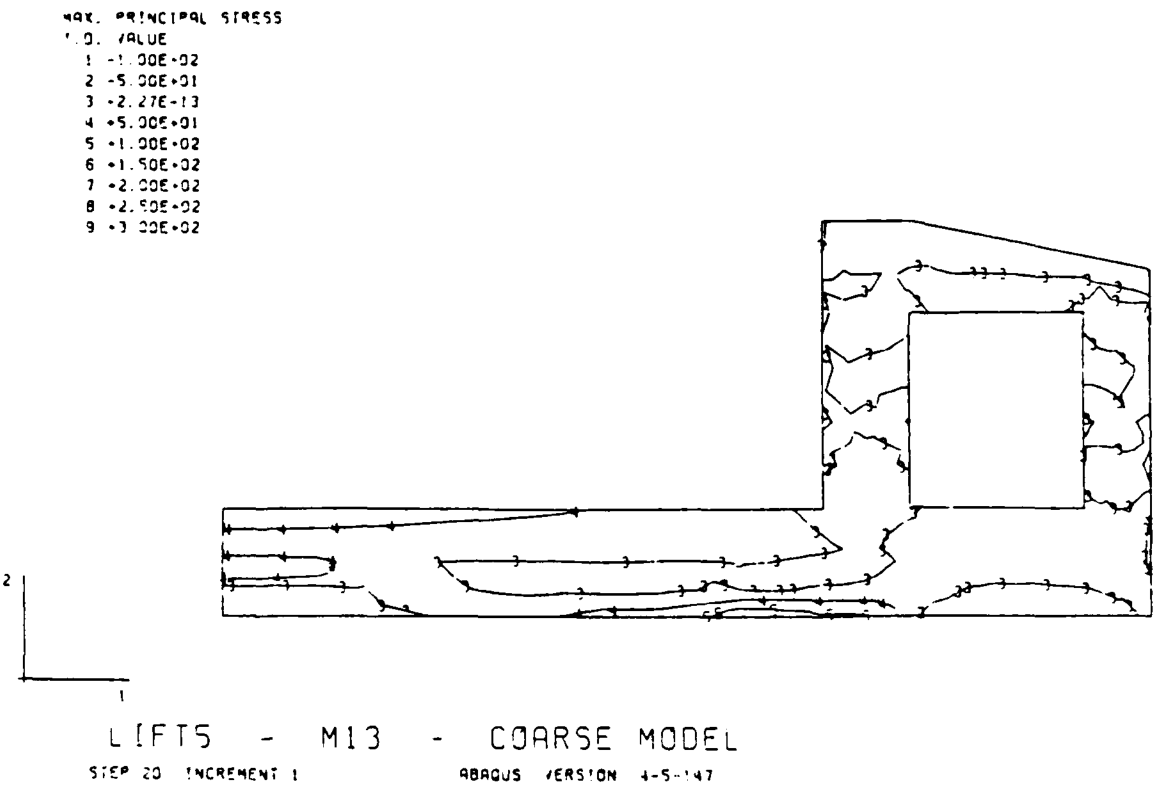


Figure 19c. Maximum principal stress (tensile) contours in structure 5 days after placement of lift 5, gravity loading only, no creep, using program ABAQUS with first grid

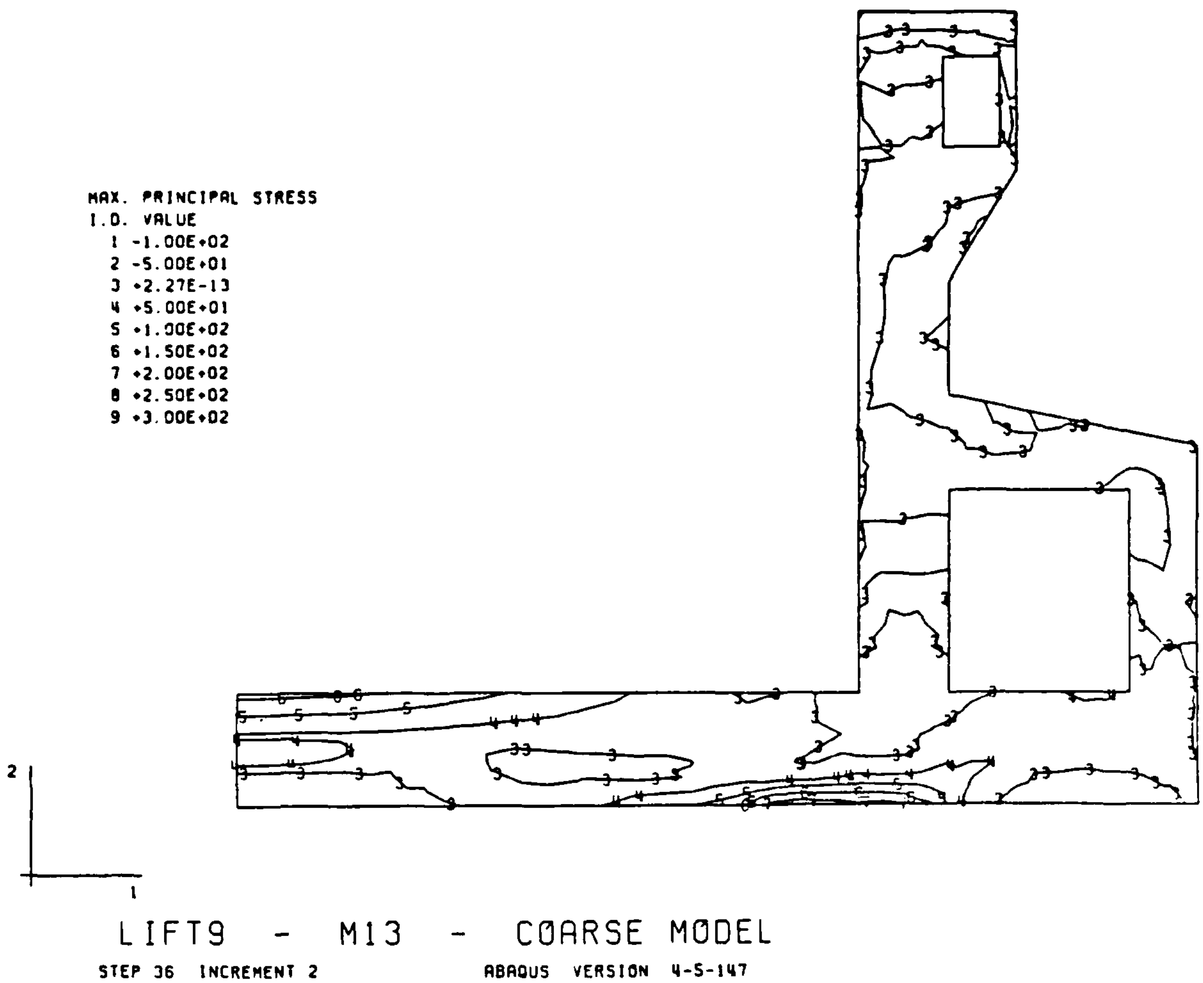


Figure 19d. Displaced structure 7 days after lift 9 is placed, gravity loading only, no creep, using program ABAQUS (UMAT 1) with first grid

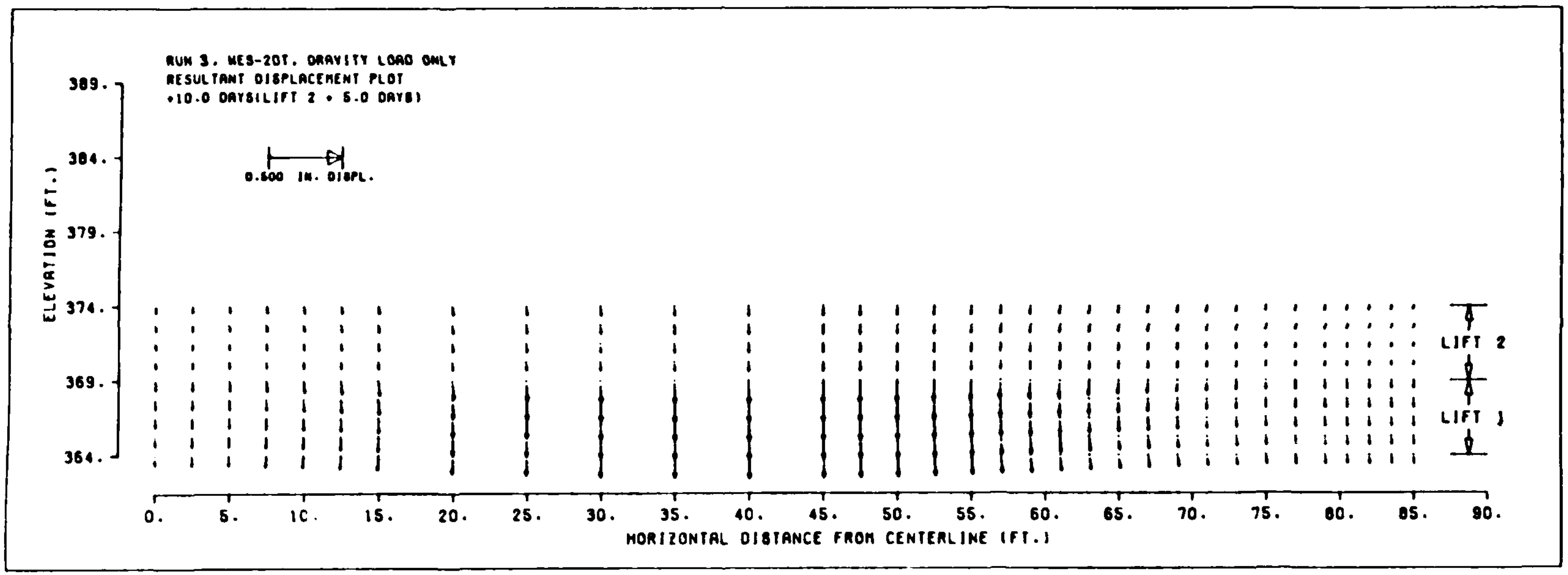


Figure 20a. Displacement of structure 5 days after lift 2 is placed, gravity load only, no creep, using WES-2DT program.

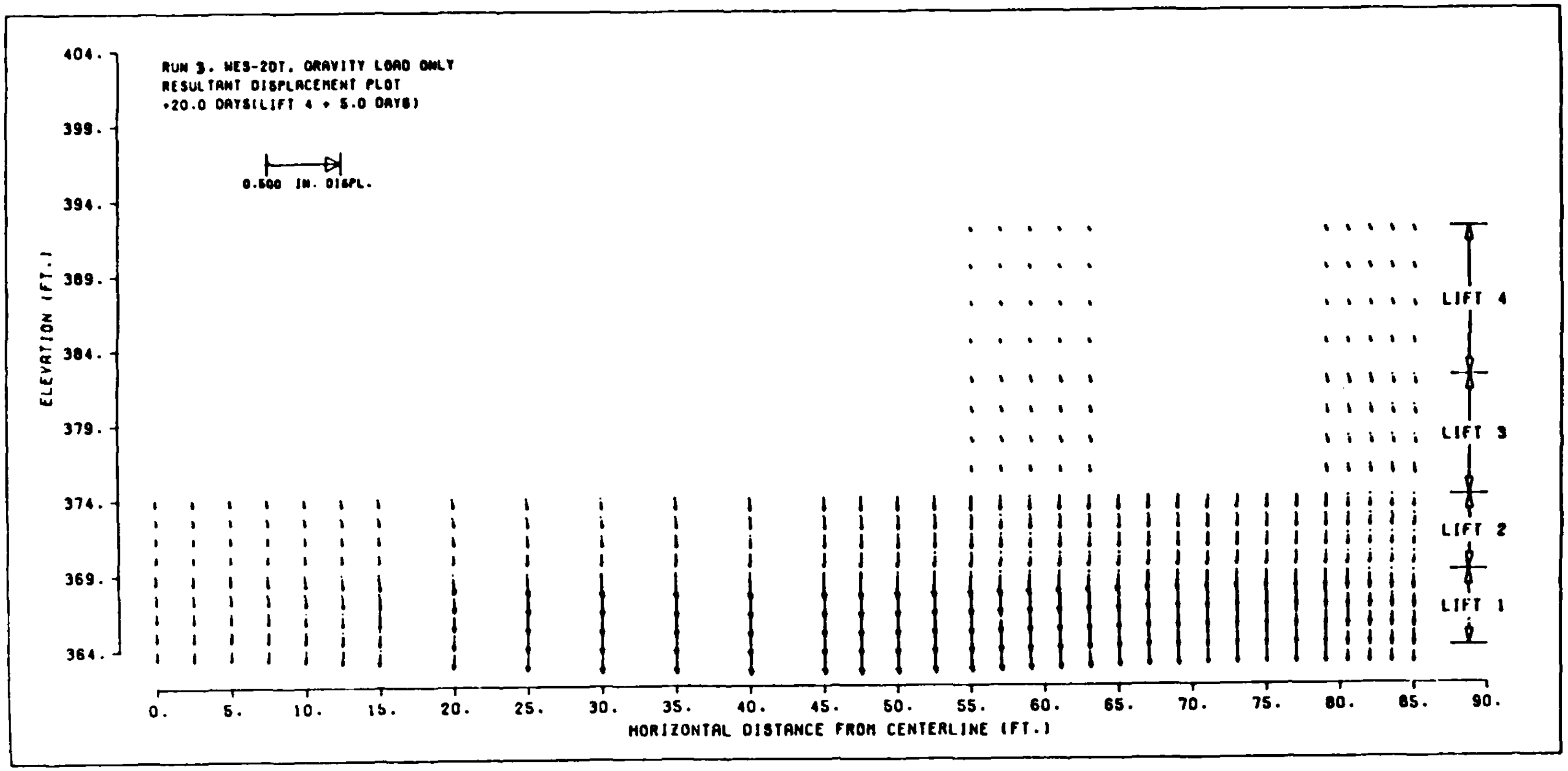


Figure 20b. Displacement of structure 5 days after lift 4 is placed, gravity load only, no creep, using WES-2DT program.

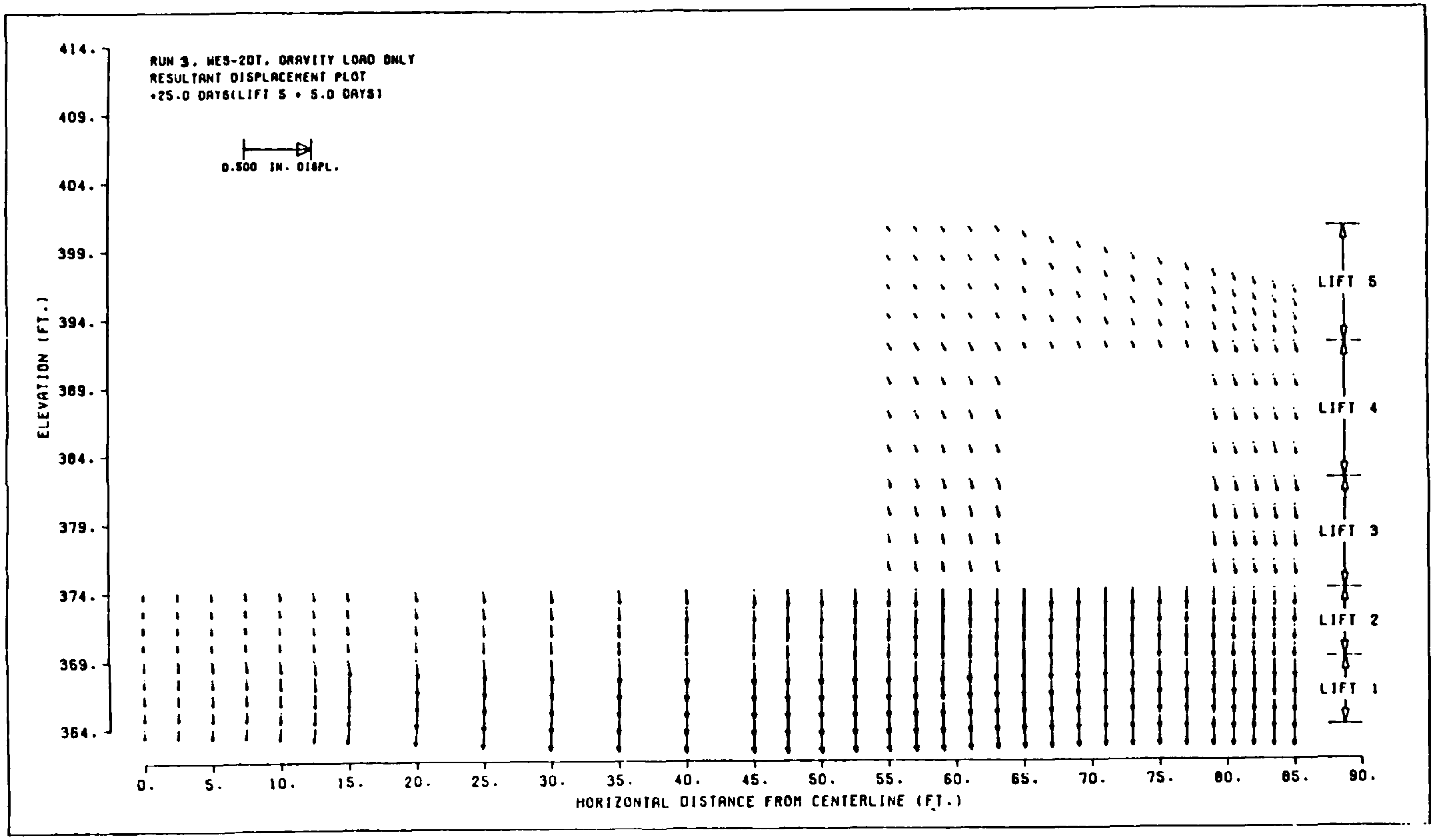


Figure 20c. Displacement of structure 5 days after lift 5 is placed, gravity load only, no creep, using WES-2DT program.

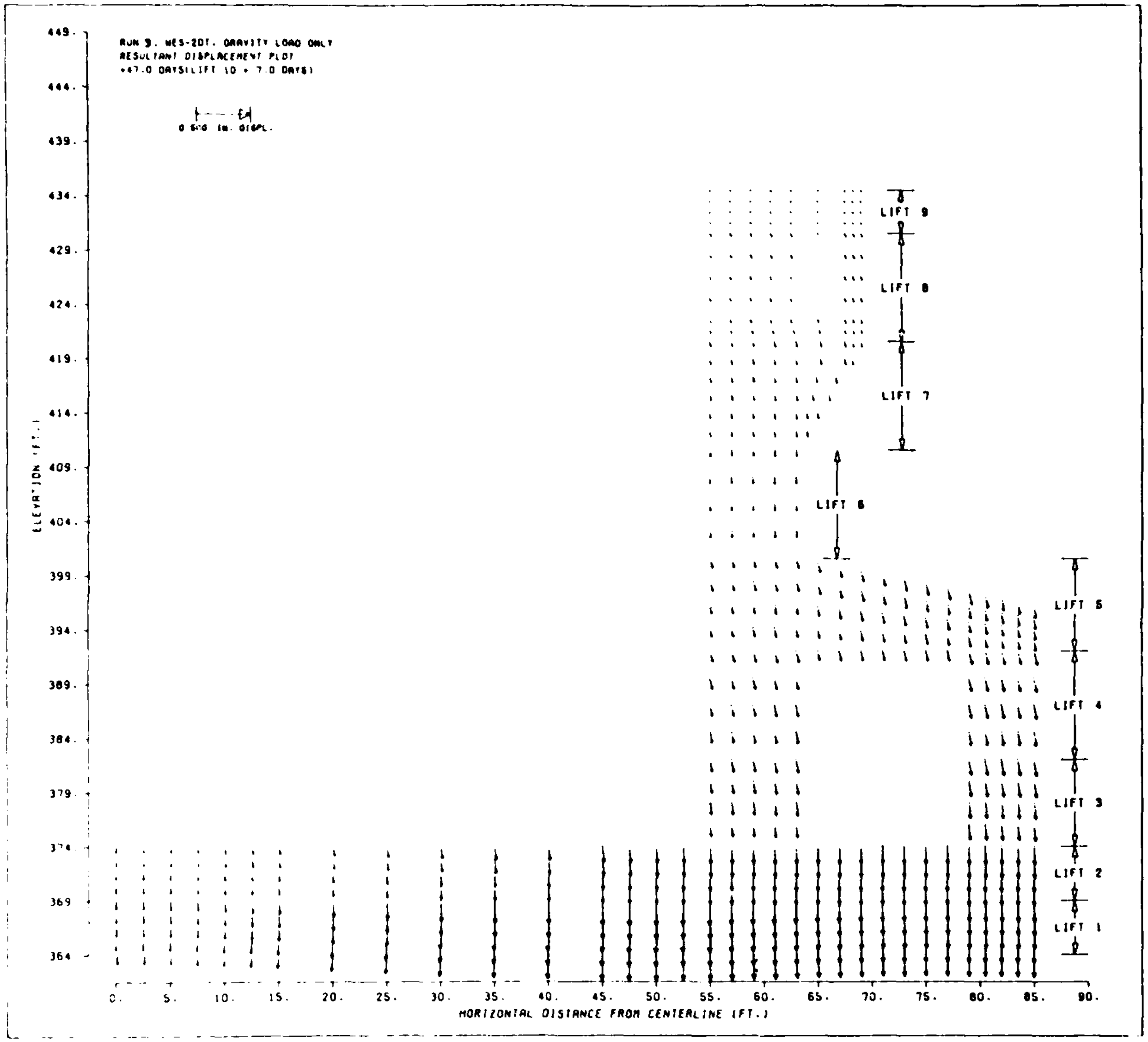


Figure 20d. Displacement of structure 7 days after lift 9 is placed, gravity load only, no creep, using WES-2DT program.

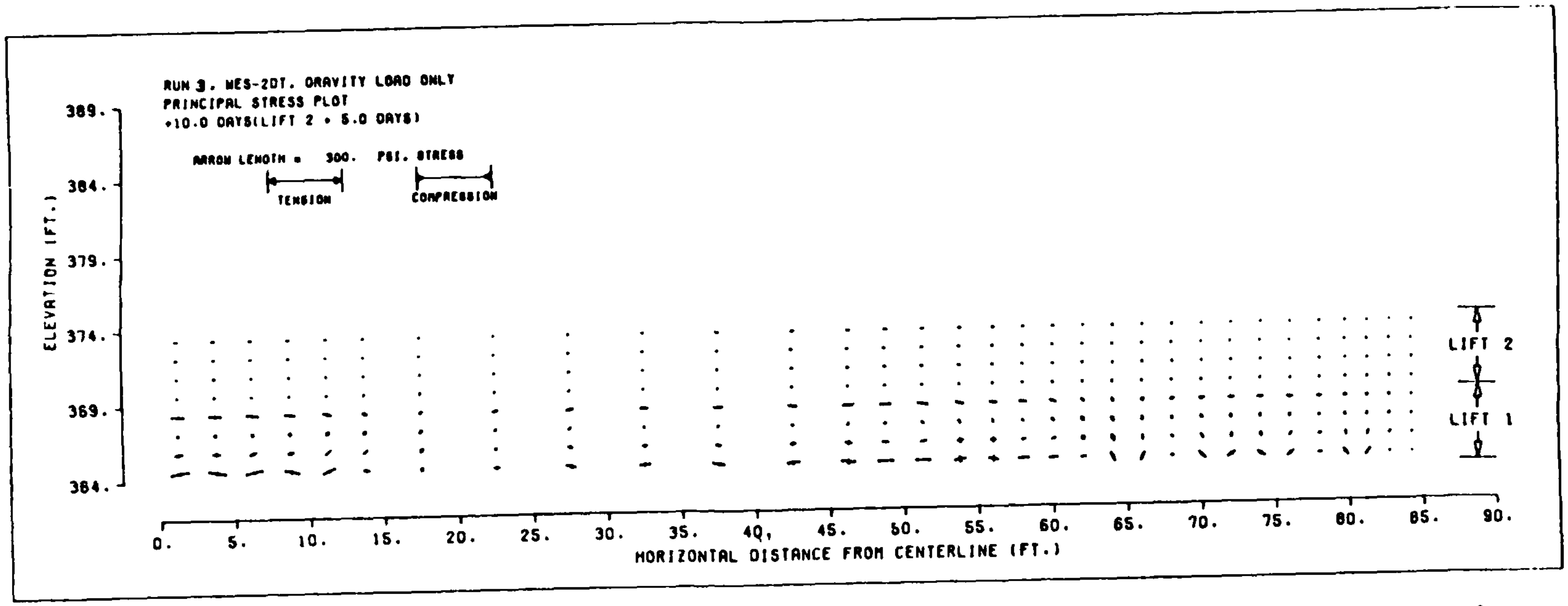


Figure 21a. Principal stress distribution in structure 5 days after lift 2 is placed, gravity loading only, no creep, using WES-2DT program.

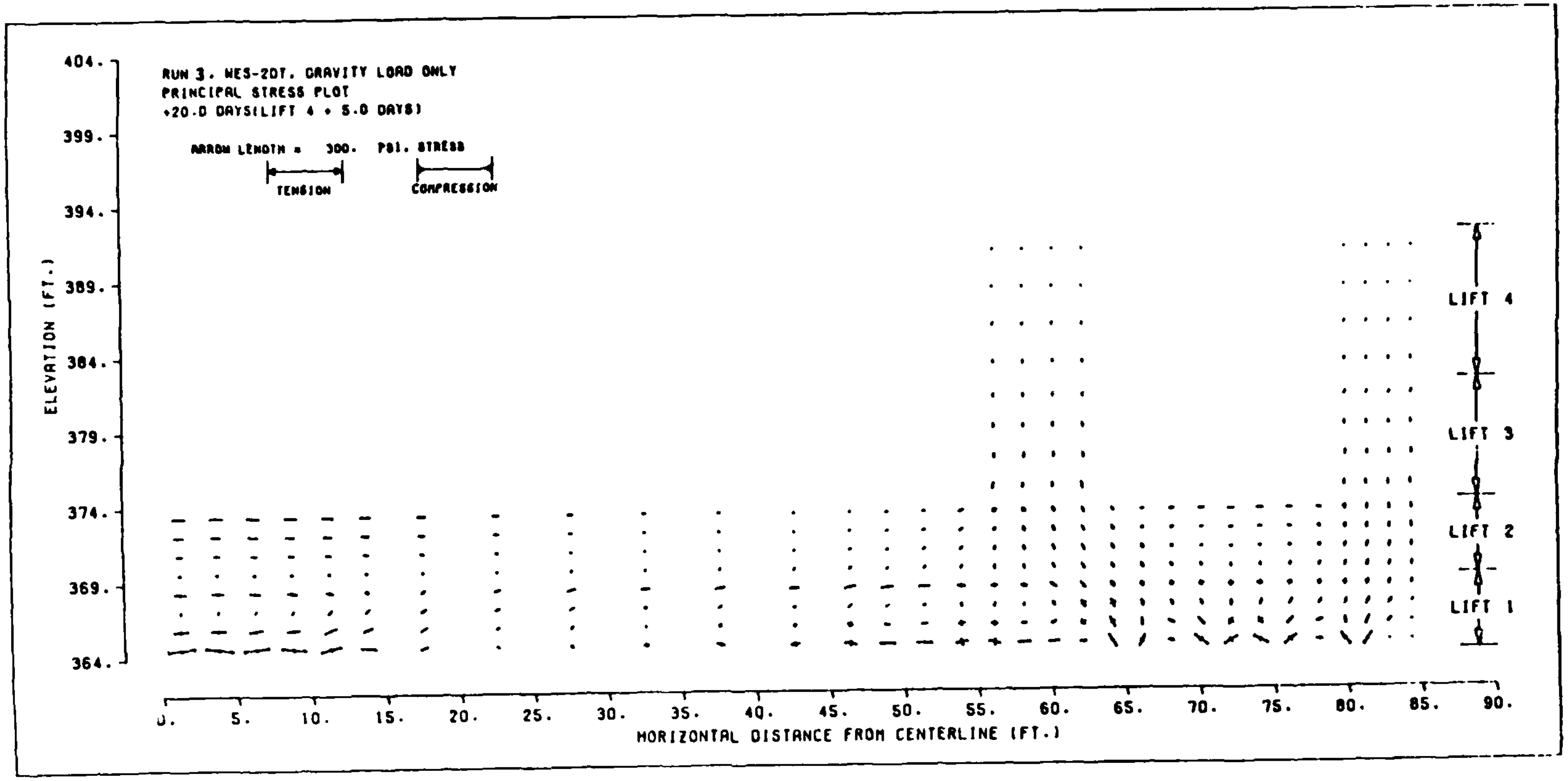


Figure 21b. Principal stress distribution in structure 5 days after lift 4 is placed, gravity loading only, no creep, using WES-2DT program.

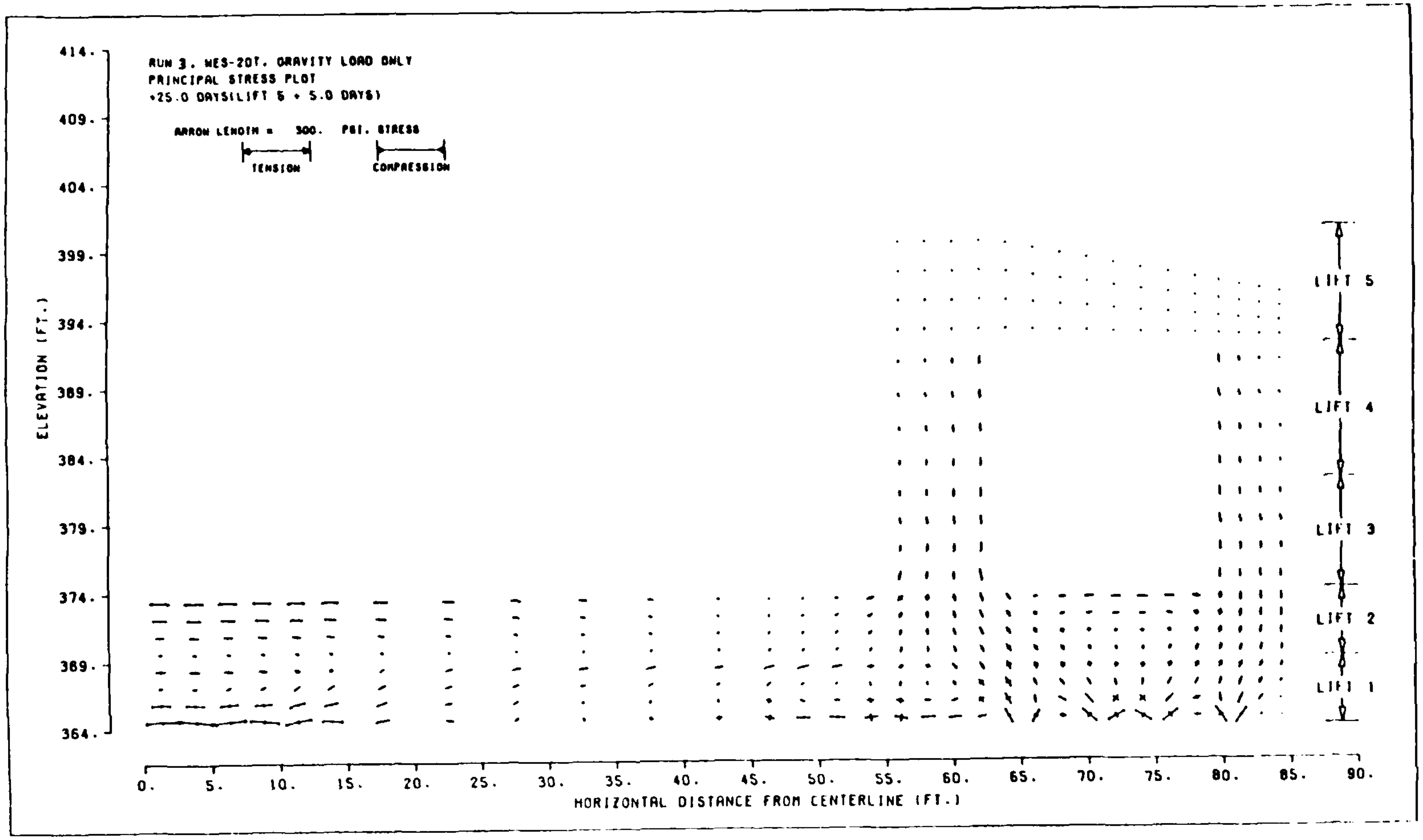


Figure 21c. Principal stress distribution in structure 5 days after lift 5 is placed, gravity loading only, no creep, using WES-2DT program.

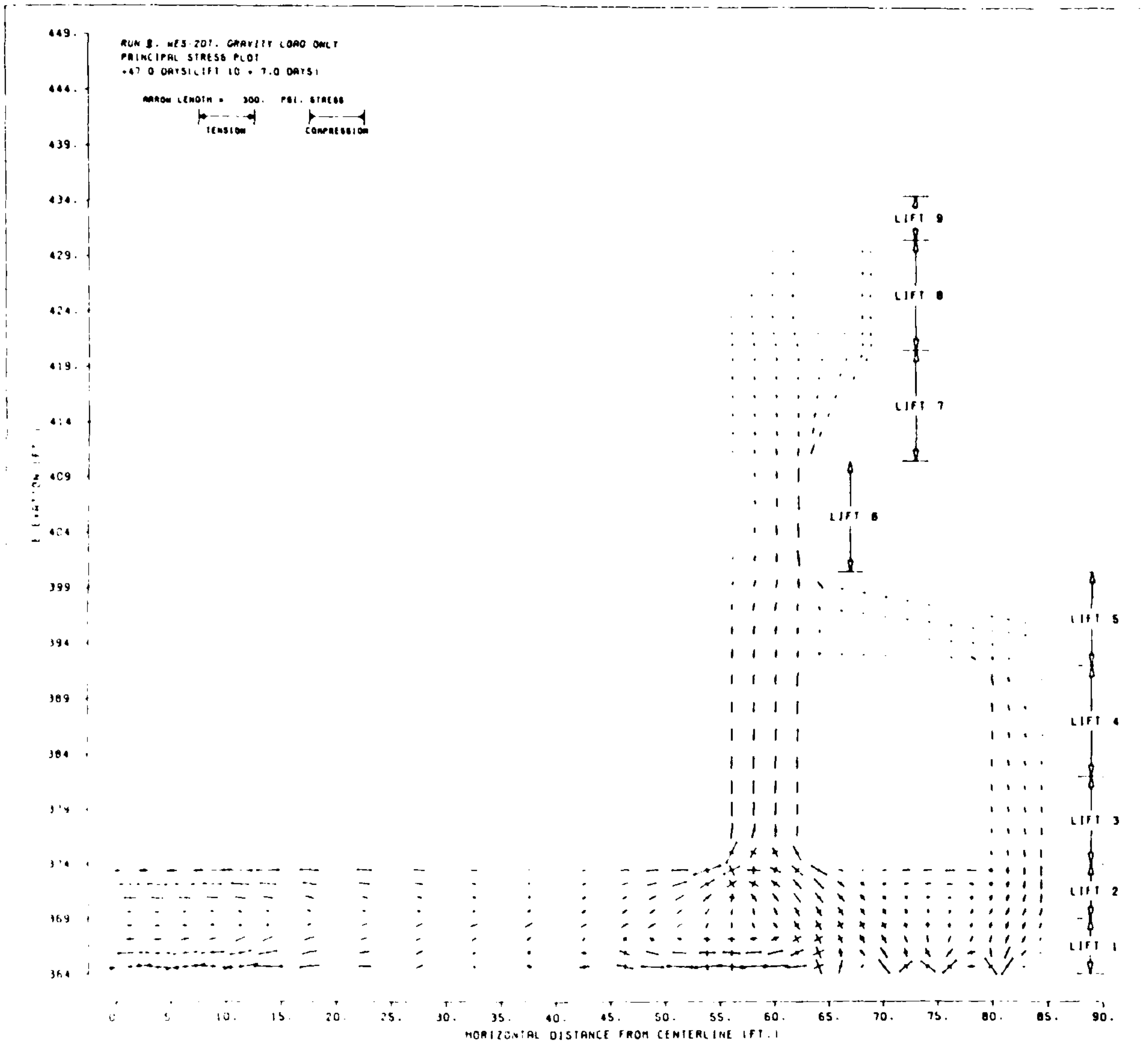


Figure 21d. Principal stress distribution in structure 7 days after lift 9 is placed, gravity loading only, no creep, using WES-2DT program.

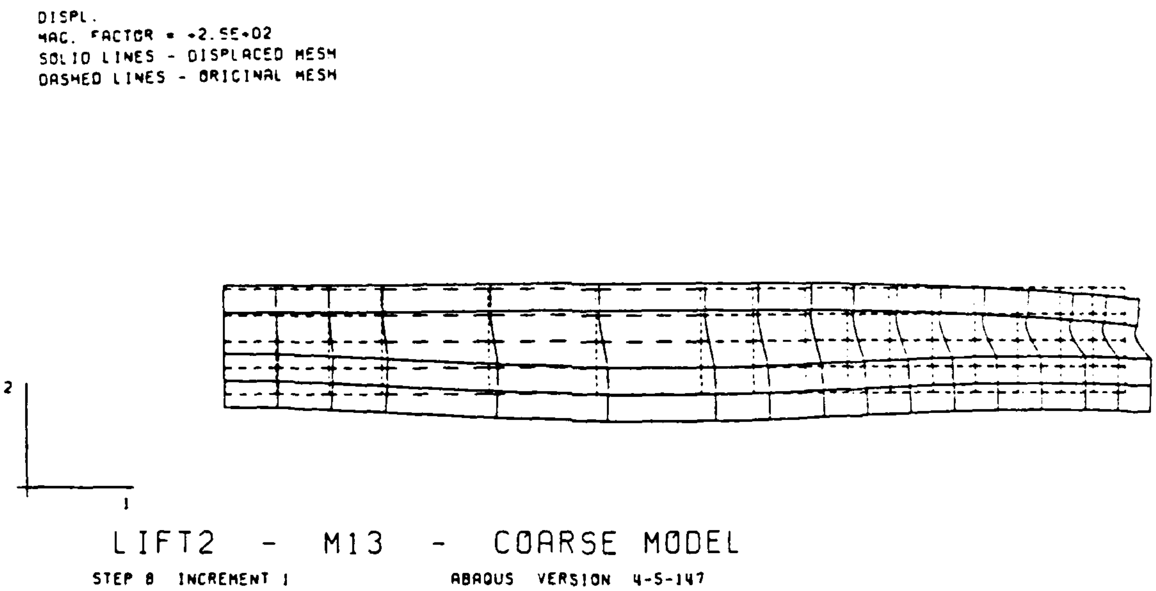


Figure 22a. Displaced structure 5 days after lift 2 is placed, thermal and gravity loading, no creep, using program ABAQUS with first grid (UMAT 1)

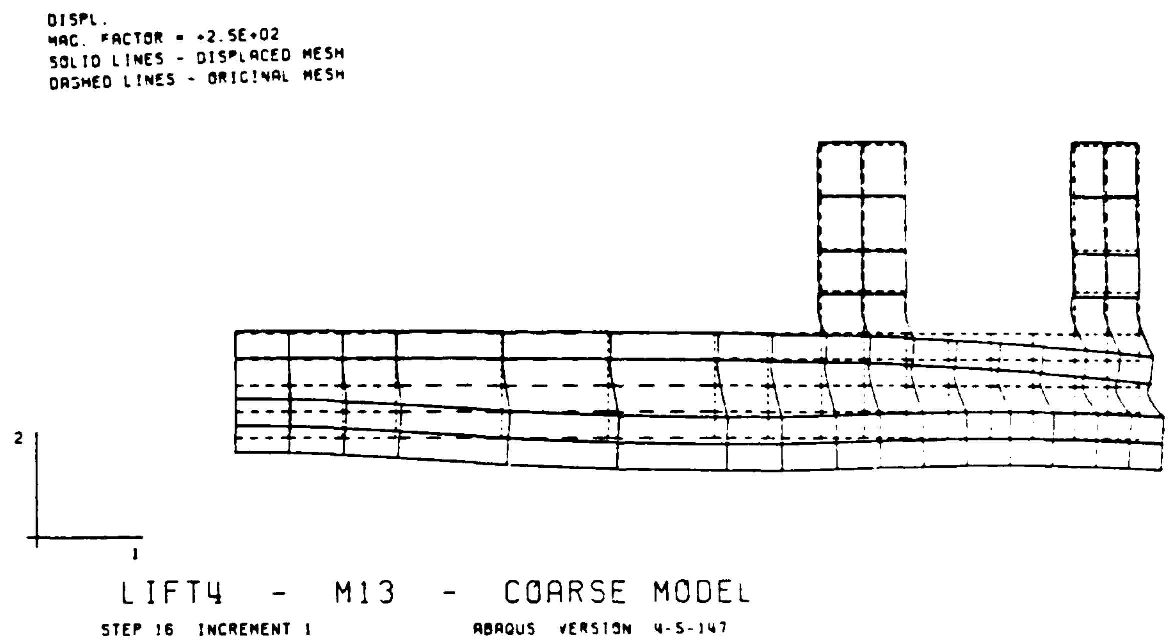


Figure 22b. Displaced structure 5 days after lift 4 is placed, thermal and gravity loading, no creep, using program ABAQUS with first grid (UMAT 1)

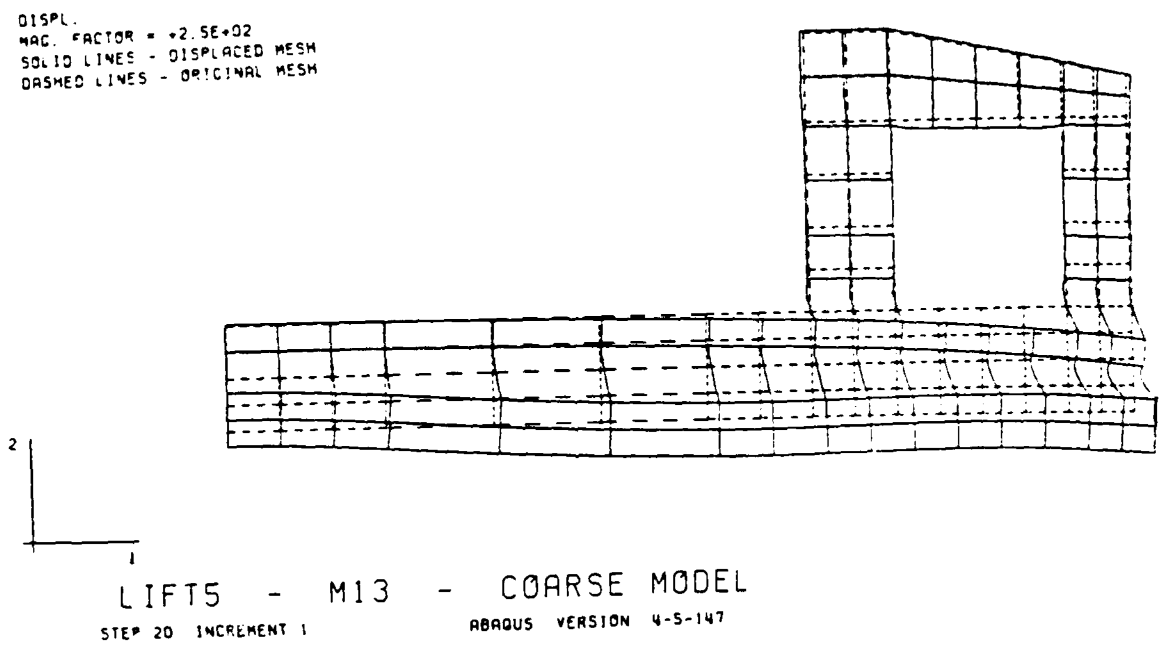


Figure 22c. Displaced structure 5 days after lift 5 is placed, thermal and gravity loading, no creep, using program ABAQUS with first grid (UMAT 1)

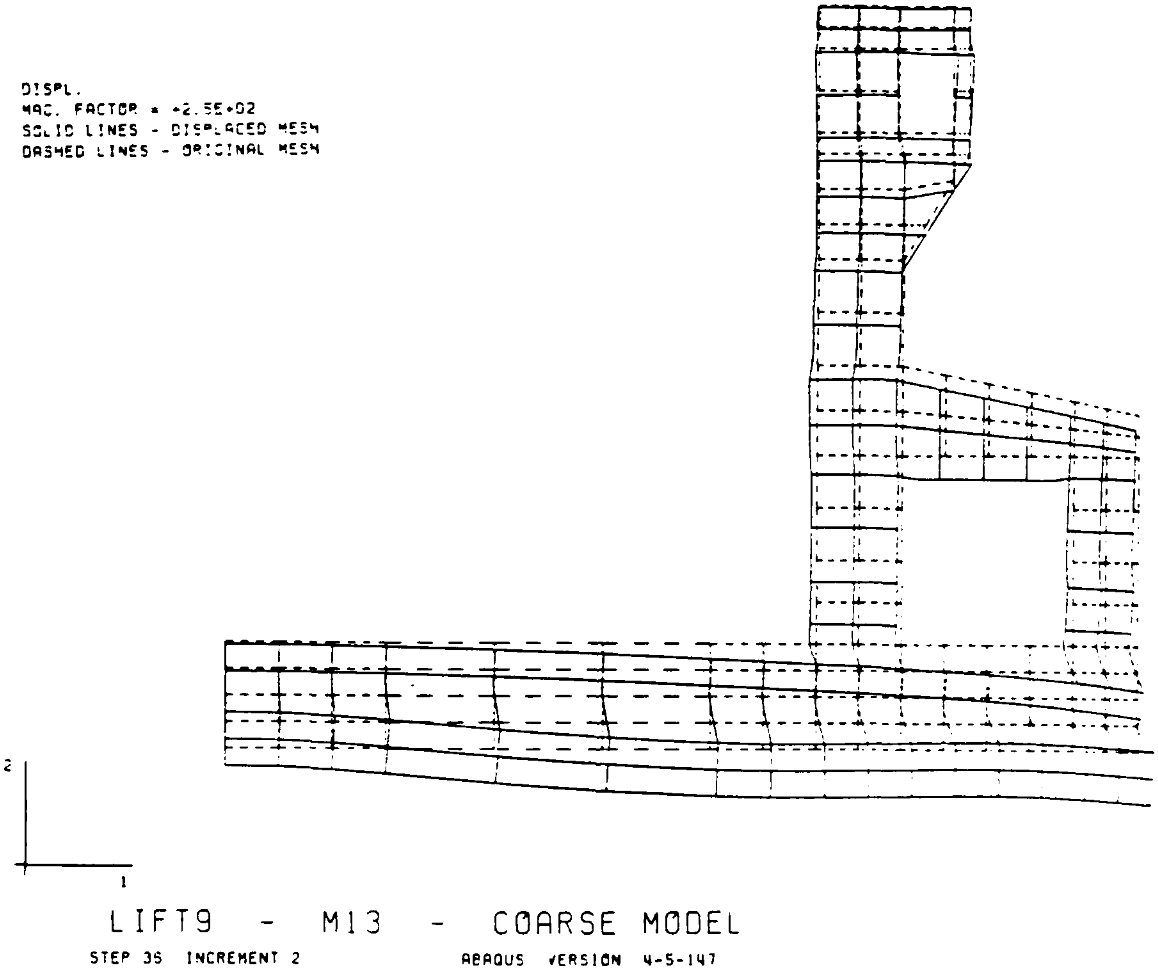


Figure 22d. Displaced structure 7 days after lift 10 is placed, thermal and gravity loading, no creep, using program ABAQUS with first grid (UMAT 1)

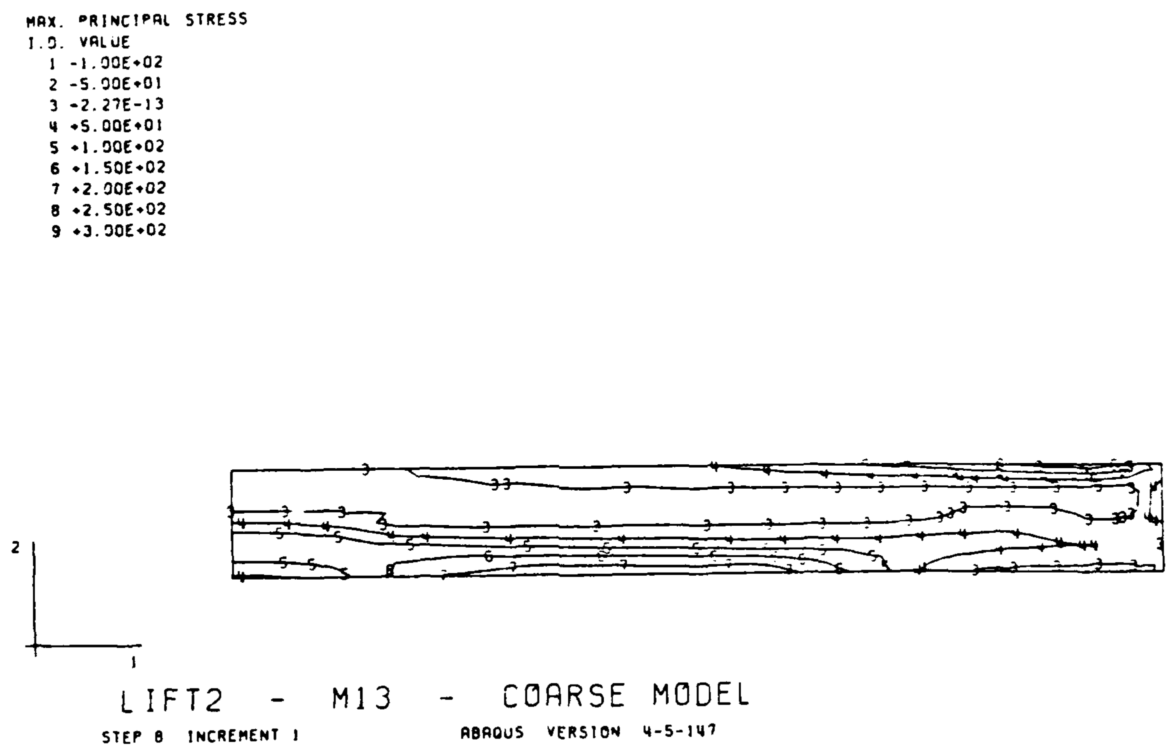


Figure 23a. Maximum principal stress (tensile) contours in structure 5 days after placement of lift 2, thermal and gravity loading, no creep, using program ABAQUS with first grid

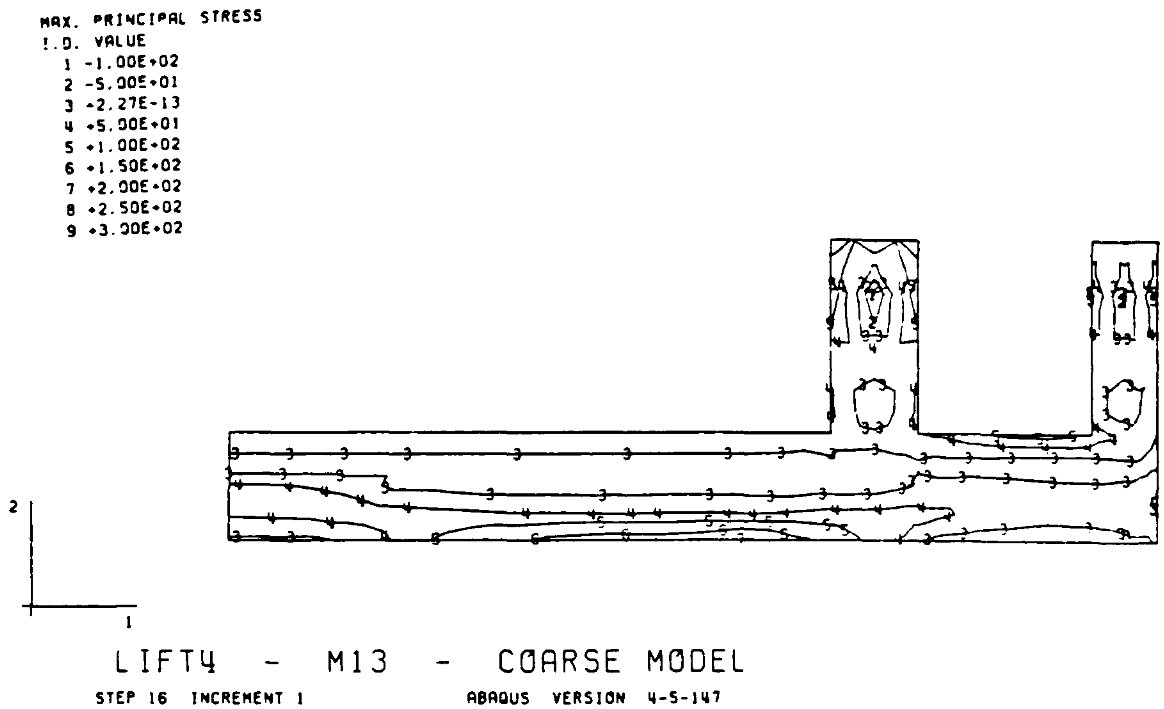


Figure 23b. Maximum principal stress (tensile) contours in structure 5 days after placement of lift 4, thermal and gravity loading, no creep, using program ABAQUS with first grid

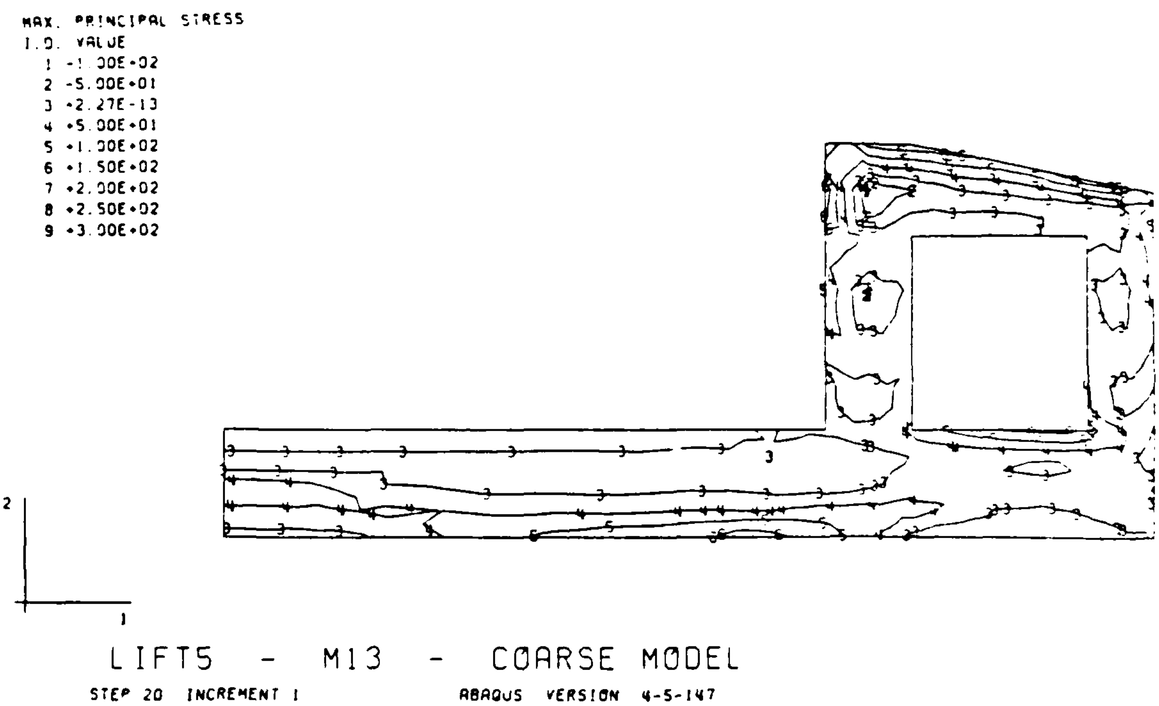


Figure 23c. Maximum principal stress (tensile) contours in structure 5 days after placement of lift 5, thermal and gravity loading, no creep, using program ABAQUS with first grid

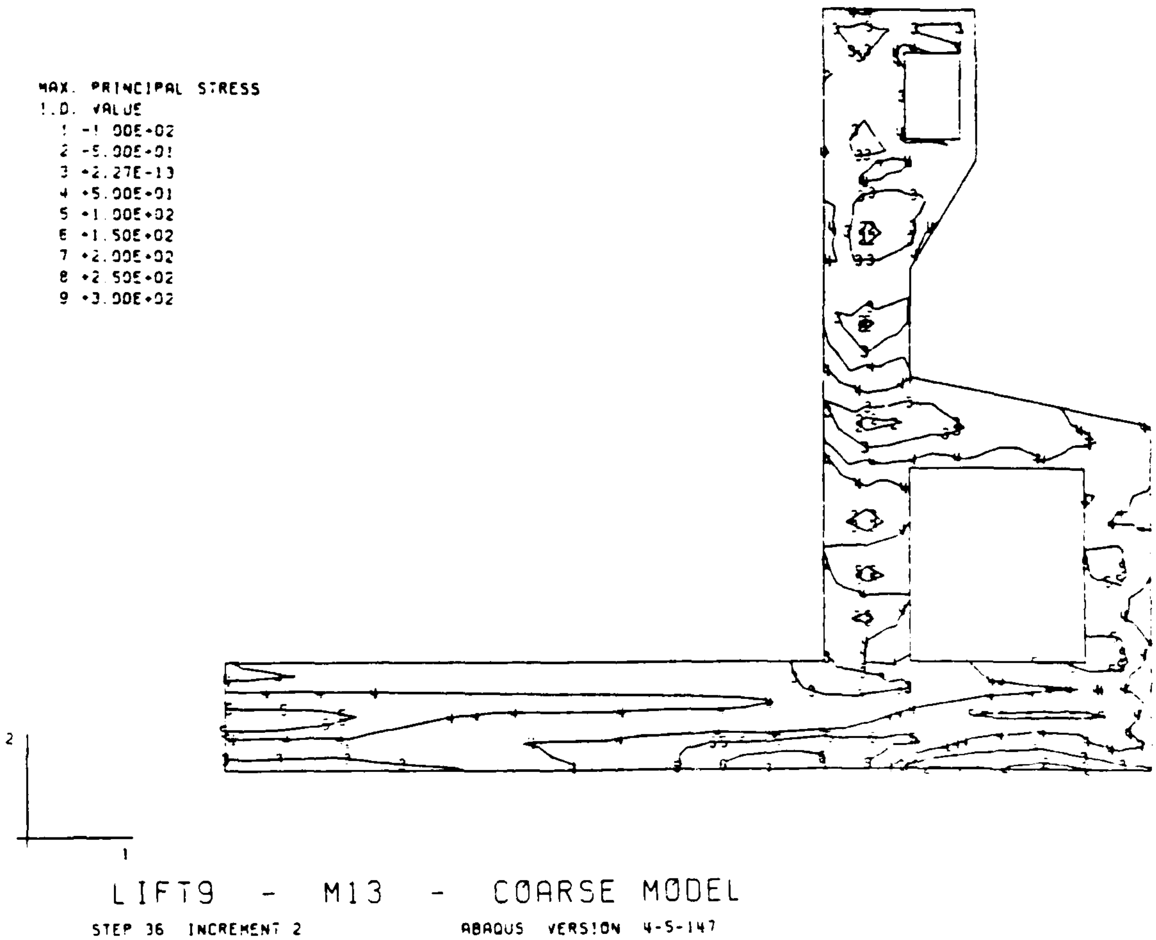


Figure 23d. Maximum principal stress (tensile) contours in structure 7 days after placement of lift 9, thermal and gravity loading, no creep, using program ABAQUS with first grid

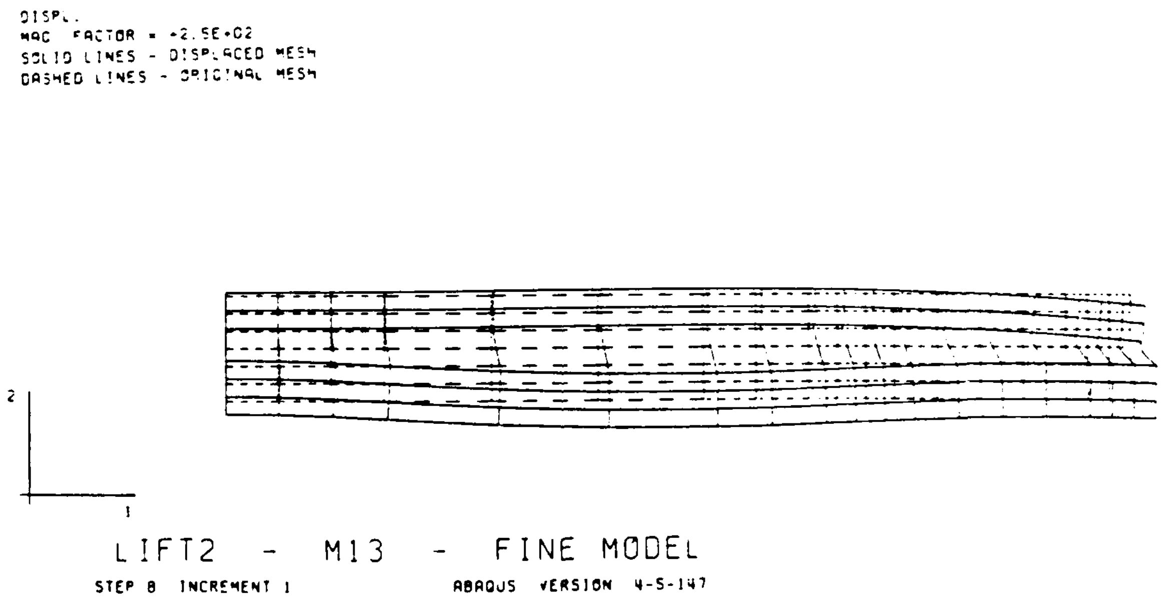


Figure 24a. Displaced structure 5 days after lift 2 is placed, thermal and gravity loading, no creep, using program ABAQUS with second grid

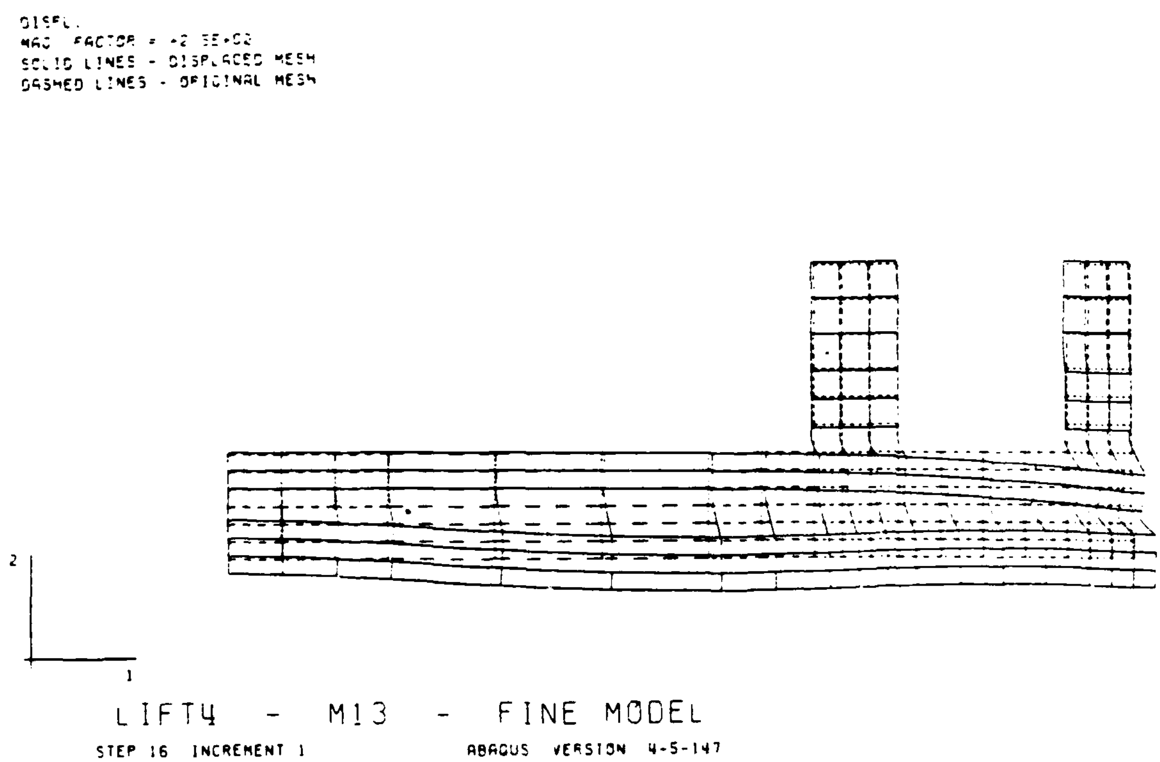


Figure 24b. Displaced structure 5 days after lift 4 is placed, thermal and gravity loading, no creep, using program ABAQUS with second grid

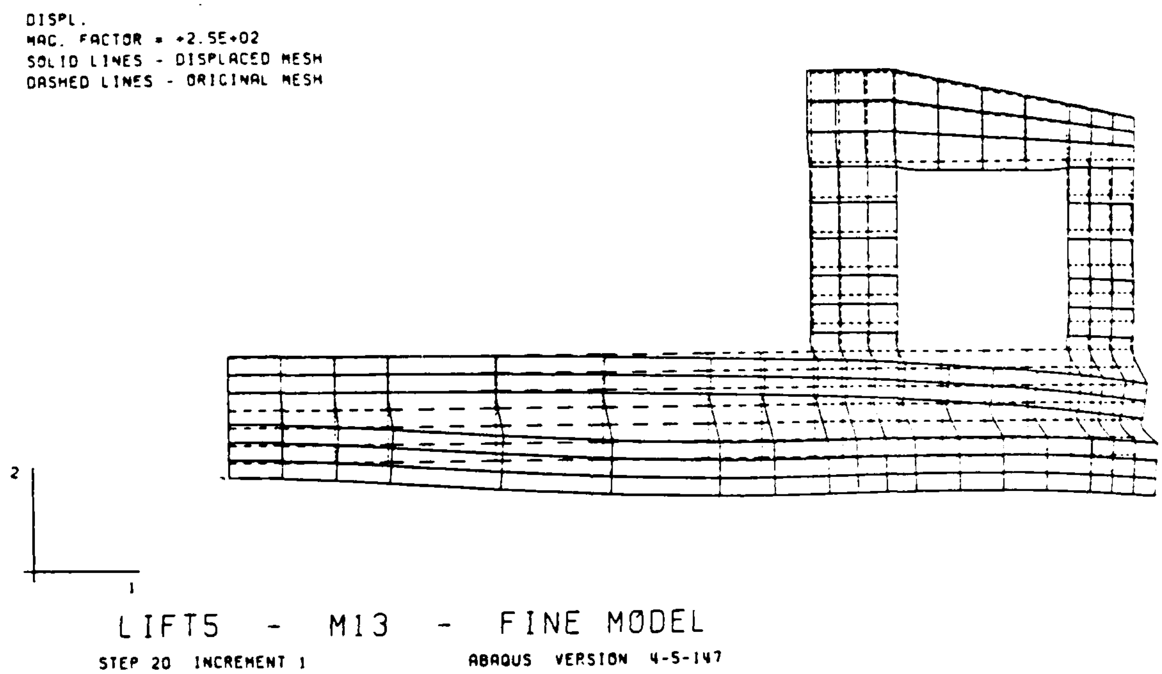


Figure 24c. Displaced structure 5 days after lift 5 is placed, thermal and gravity loading, no creep, using program ABAQUS with second grid

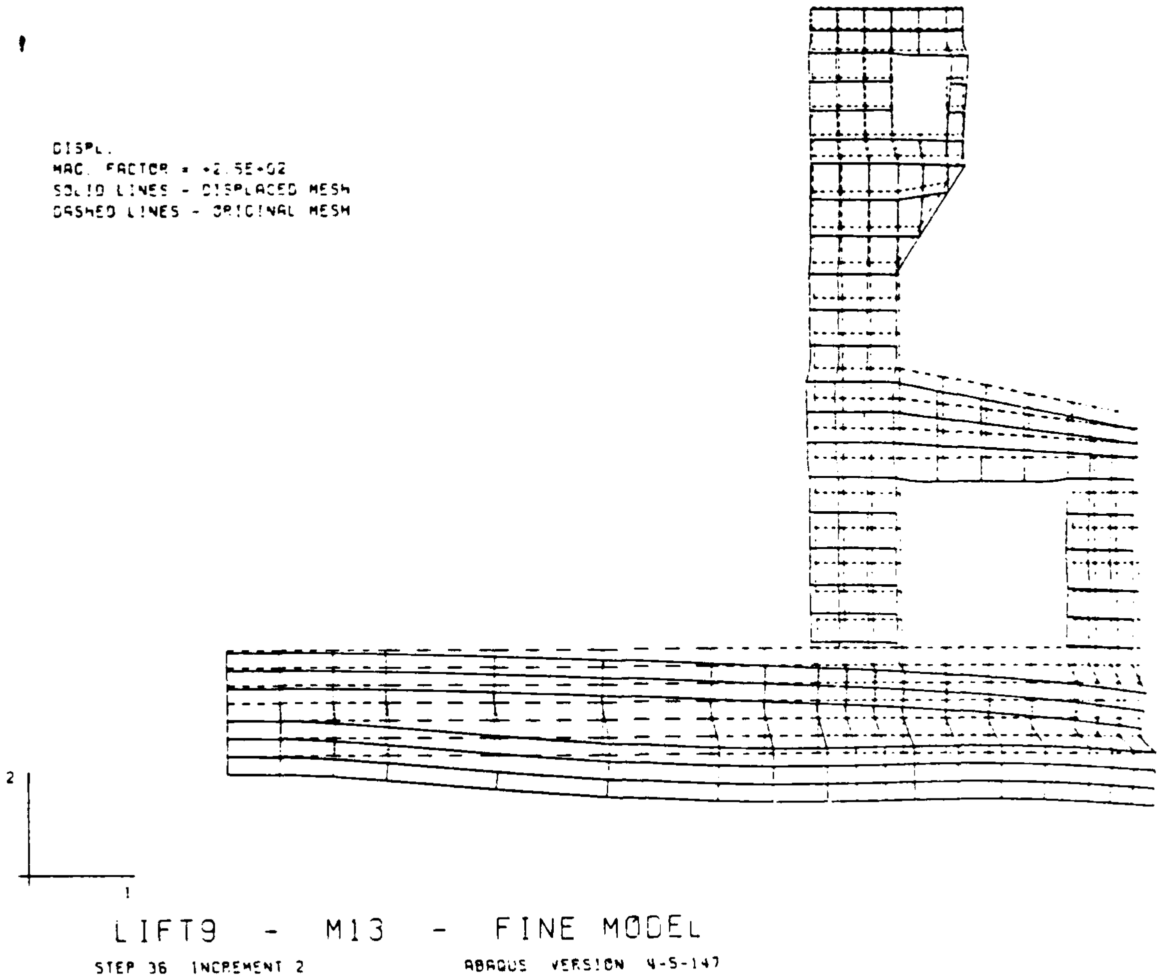


Figure 24d. Displaced structure 7 days after lift 9 is placed, thermal and gravity loading, no creep, using program ABAQUS with second grid

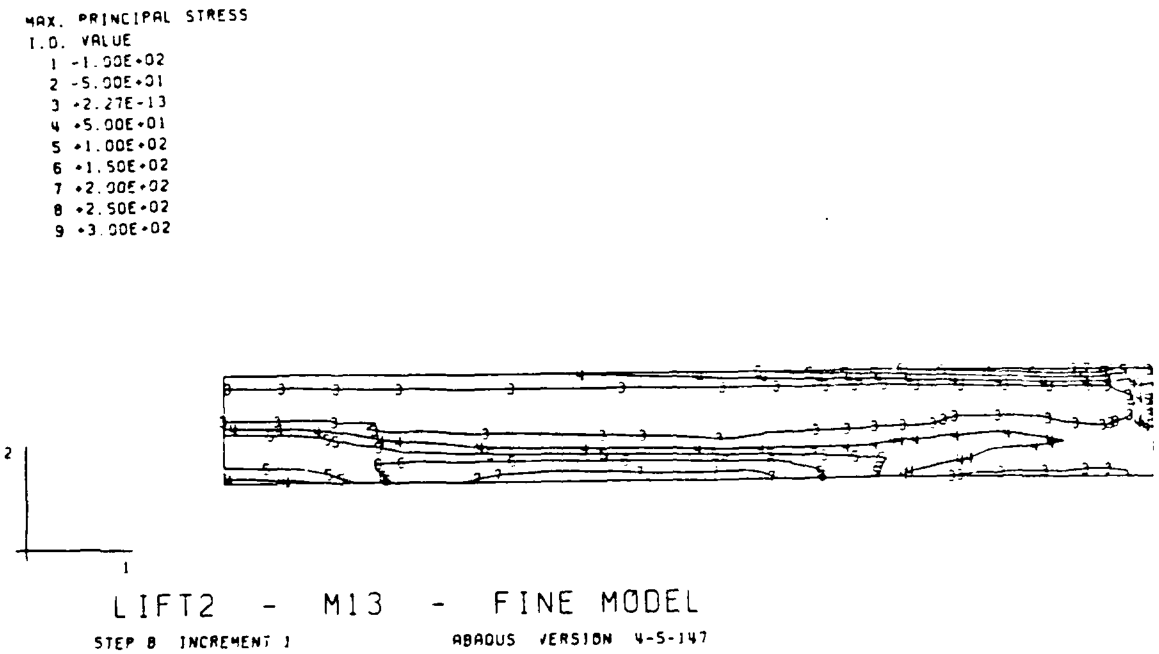


Figure 25a. Maximum principal stress (tensile) contours in structure 5 days after placement of lift 2, thermal and gravity loading, no creep, using program ABAQUS with second grid

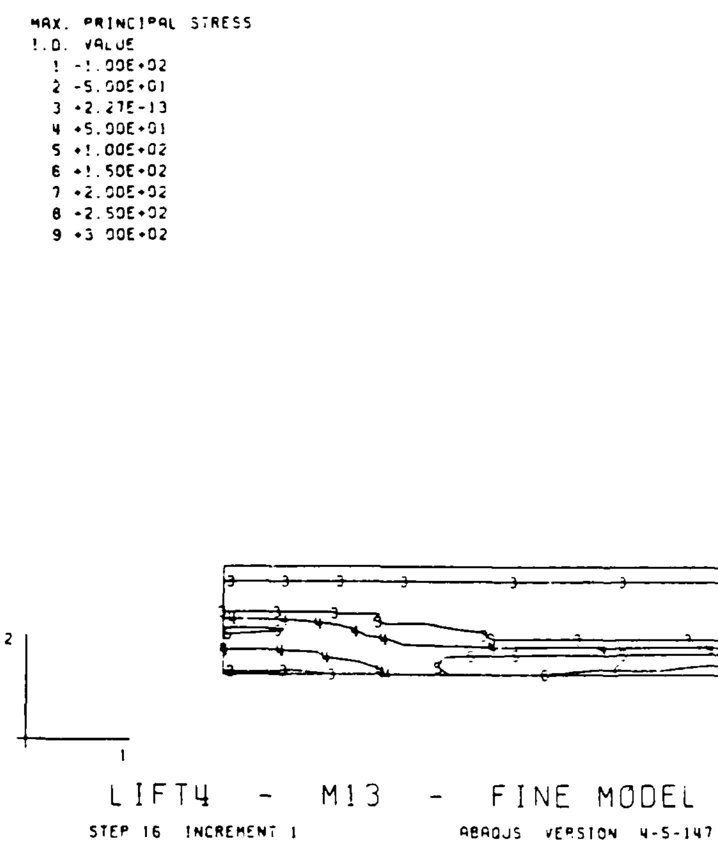


Figure 25b. Maximum principal stress (tensile) contours in structure 5 days after placement of lift 4, thermal and gravity loading, no creep, using program ABAQUS with second grid

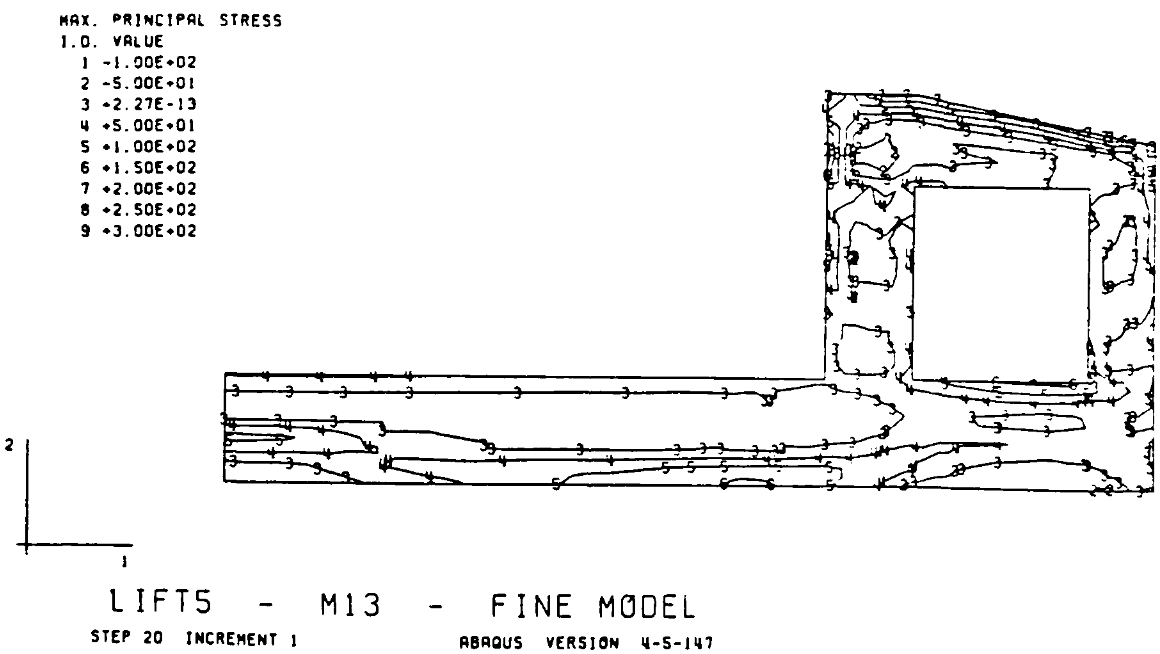


Figure 25c. Maximum principal stress (tensile) contours in structure 5 days after placement of lift 5, thermal and gravity loading, no creep, using program ABAQUS with second grid

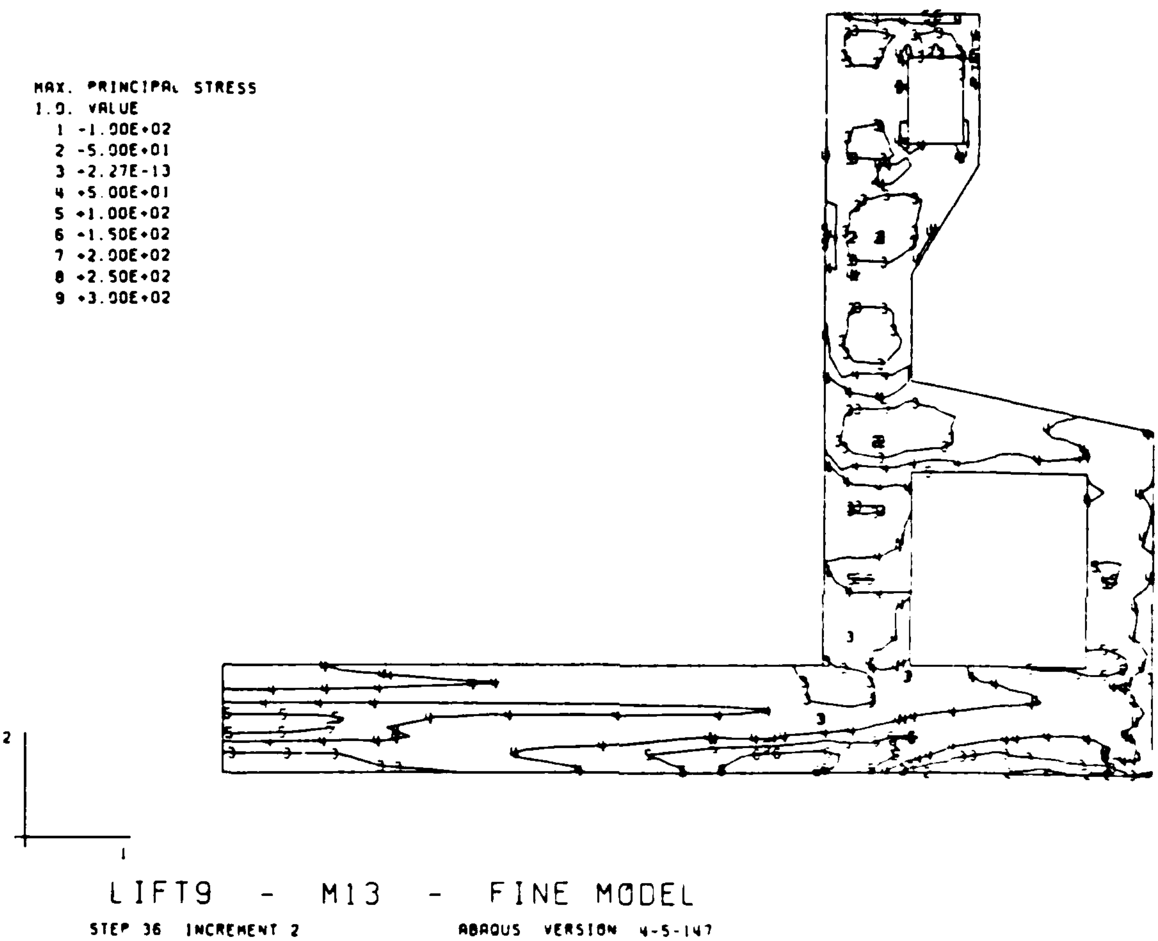


Figure 25d. Maximum principal stress (tensile) contours in structure 7 days after placement of lift 9, thermal and gravity loading, no creep, using program ABAQUS with second grid

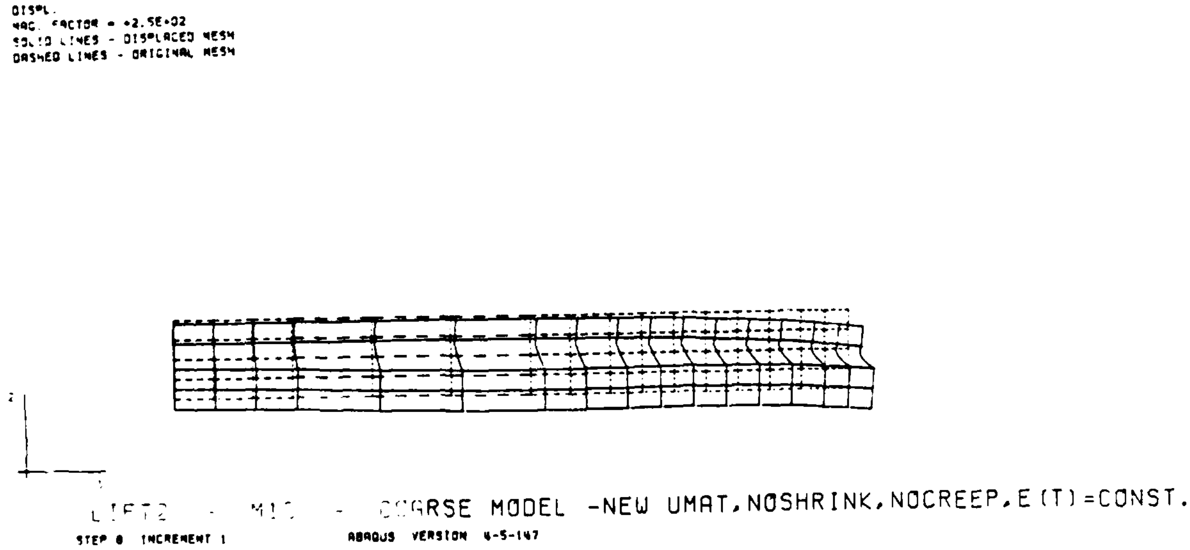


Figure 26a. Displaced structure 5 days after placement of lift 2, E constant with temperature, using ABAQUS (UMAT2).

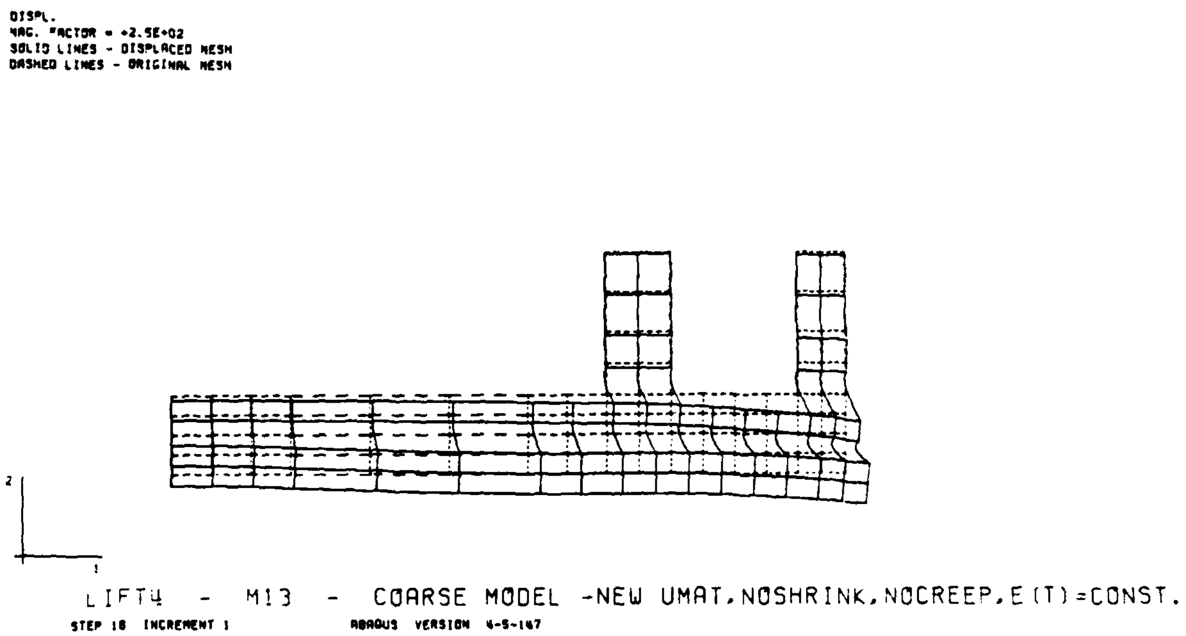


Figure 26b. Displaced structure 5 days after placement of lift 4, E constant with temperature, using ABAQUS (UMAT2).

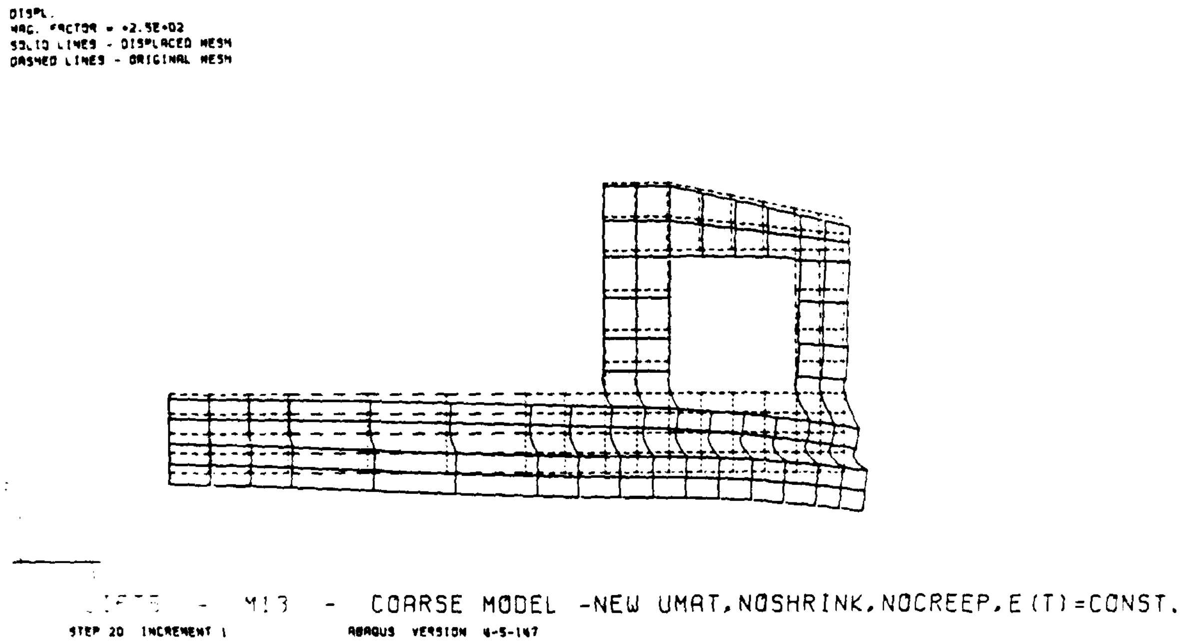


Figure 26c. Displaced structure 5 days after placement of lift 5, E constant with temperature, using ABAQUS (UMAT2).

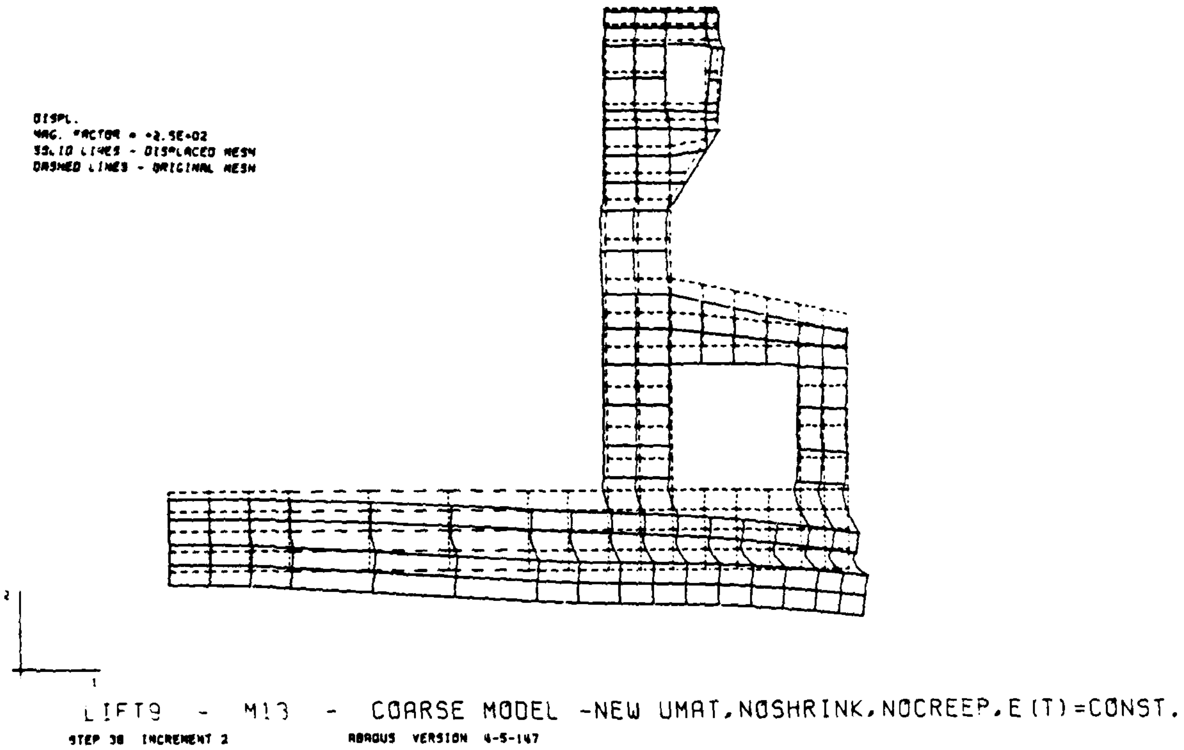


Figure 26d. Displaced structure 7 days after placement of lift 9, E constant with temperature, using ABAQUS (UMAT2).

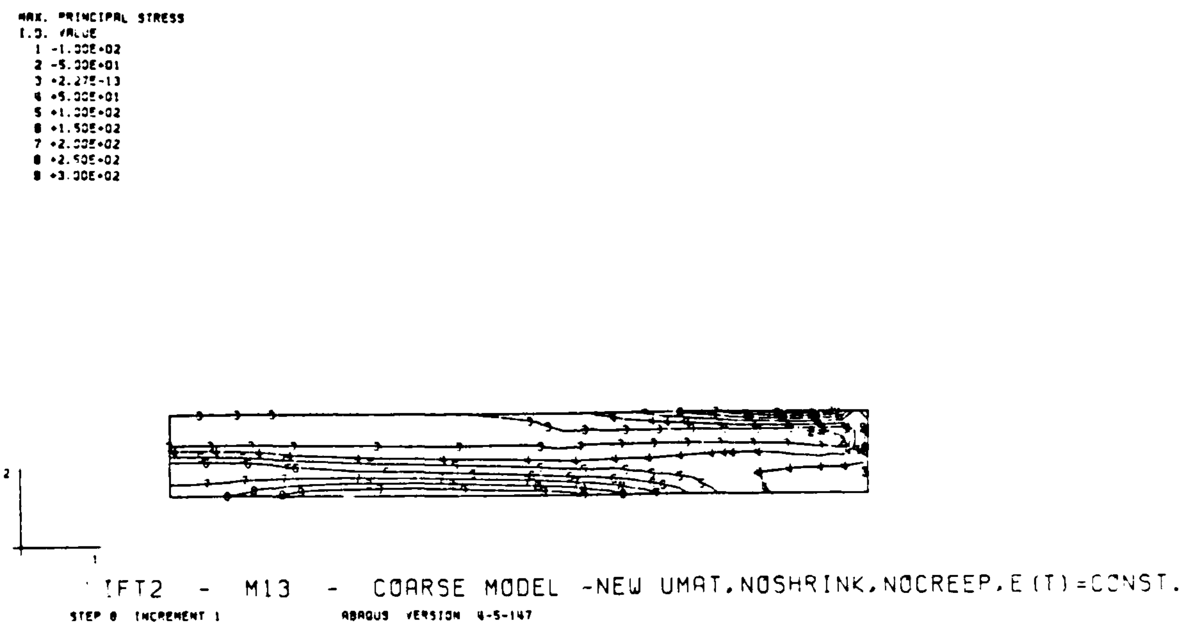


Figure 27a. Maximum principal stress contours 5 days after placement of lift 2, E constant with temperature, using ABAQUS (UMAT2).

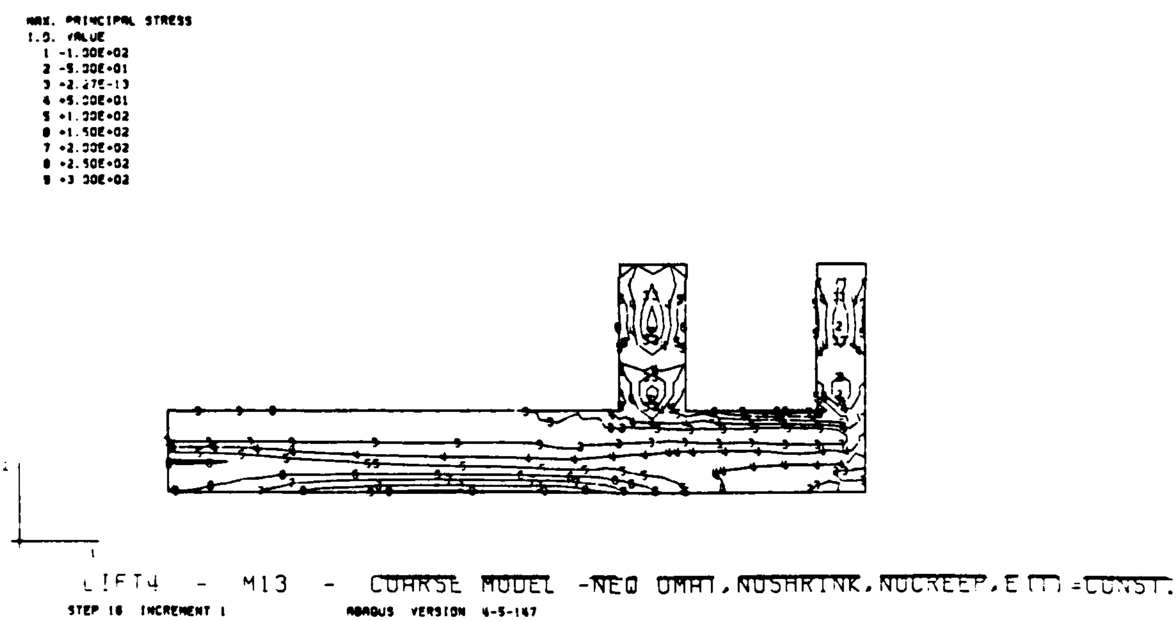


Figure 27b. Maximum principal stress contours 5 days after placement of lift 4, E constant with temperature, using ABAQUS (UMAT2).

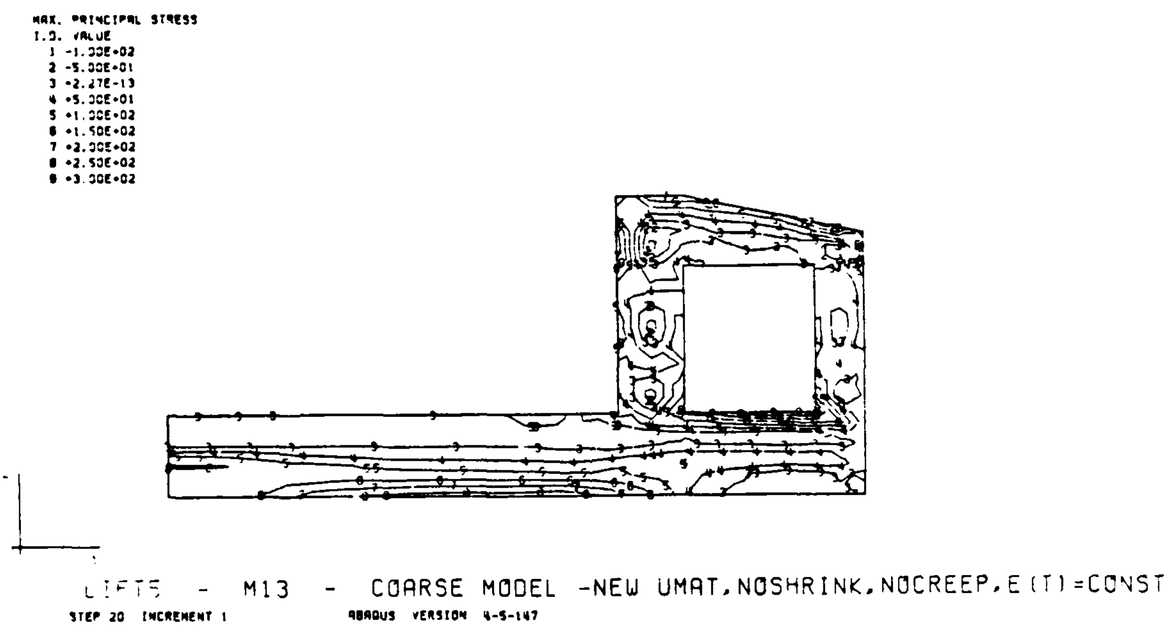


Figure 27c. Maximum principal stress contours 5 days after placement of lift 5, E constant with temperature, using ABAQUS (UMAT2).

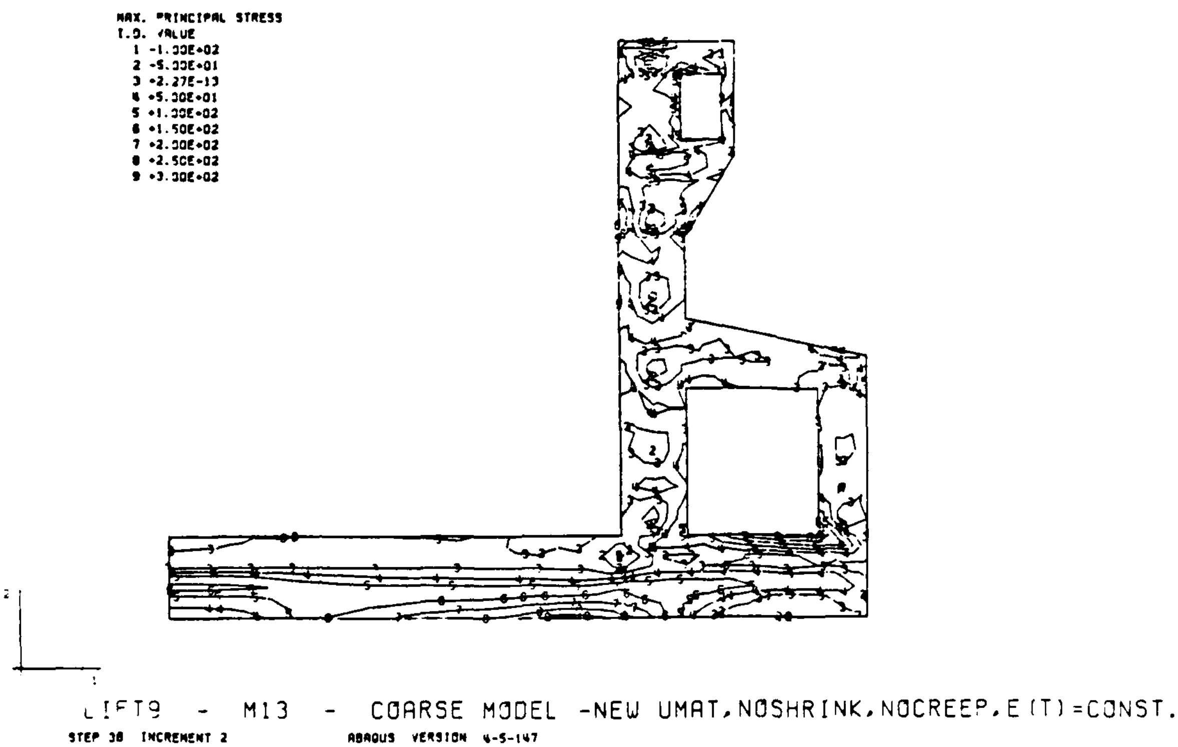


Figure 27d. Maximum principal stress contours 7 days after placement of lift 9, E constant with temperature, using ABAQUS (UMAT2).

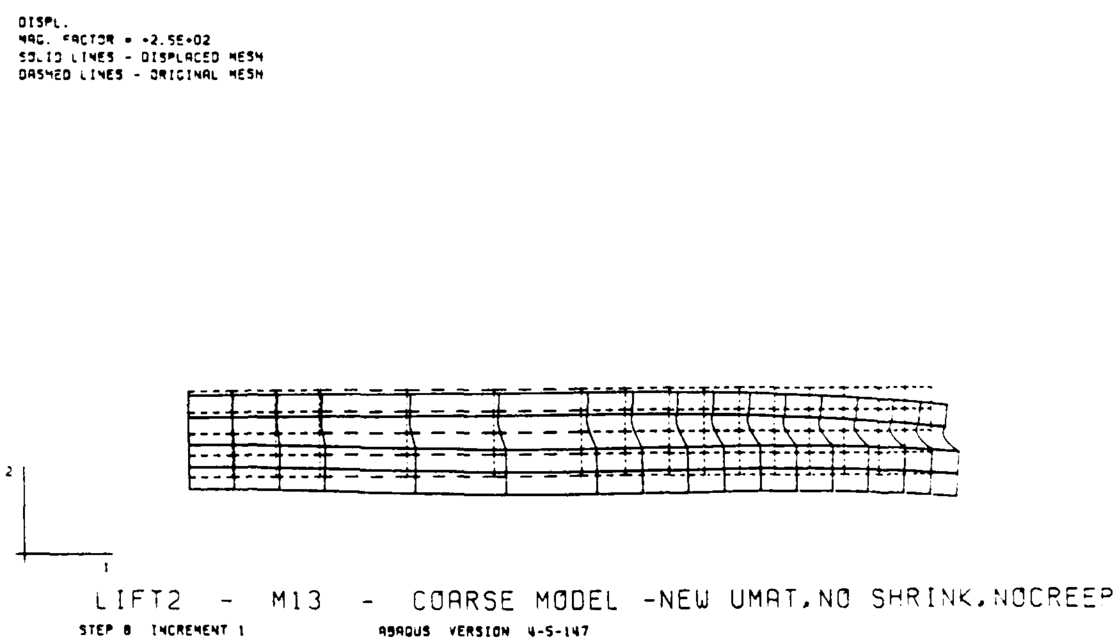


Figure 28a. Displaced structure 5 days after placement of lift 2, E is a function of temperature, using ABAQUS (UMAT2).

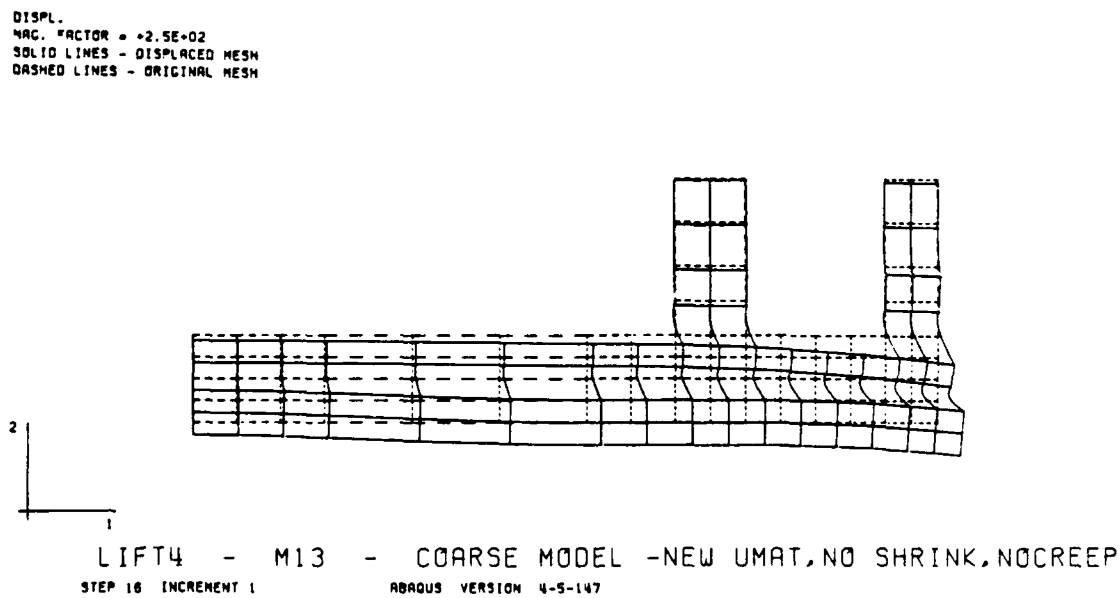


Figure 28b. Displaced structure 5 days after placement of lift 4, E is a function of temperature, using ABAQUS (UMAT2).

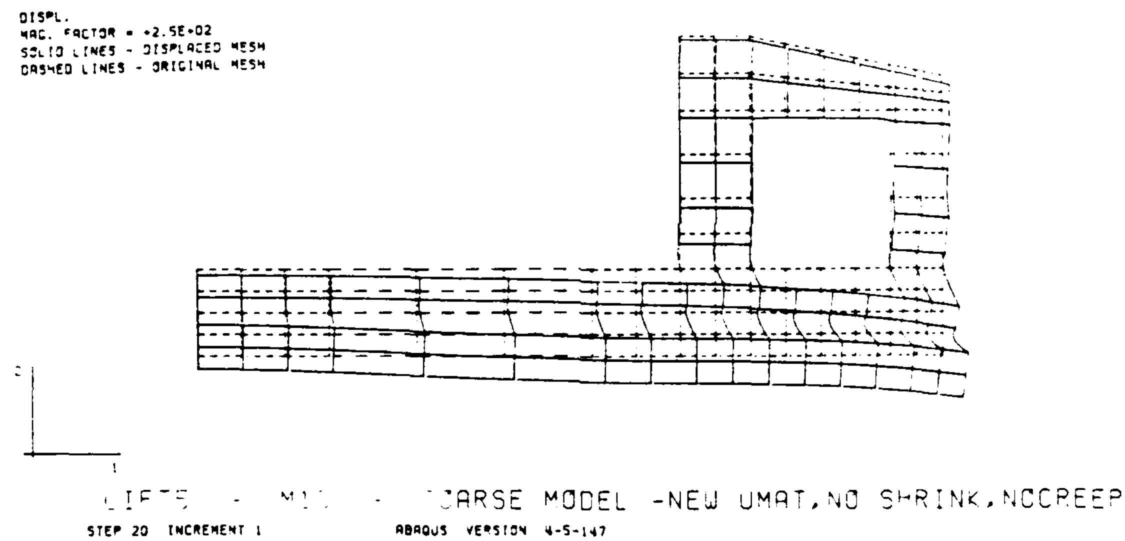


Figure 28c. Displaced structure 5 days after placement of lift 5, E is a function of temperature, using ABAQUS (UMAT2).

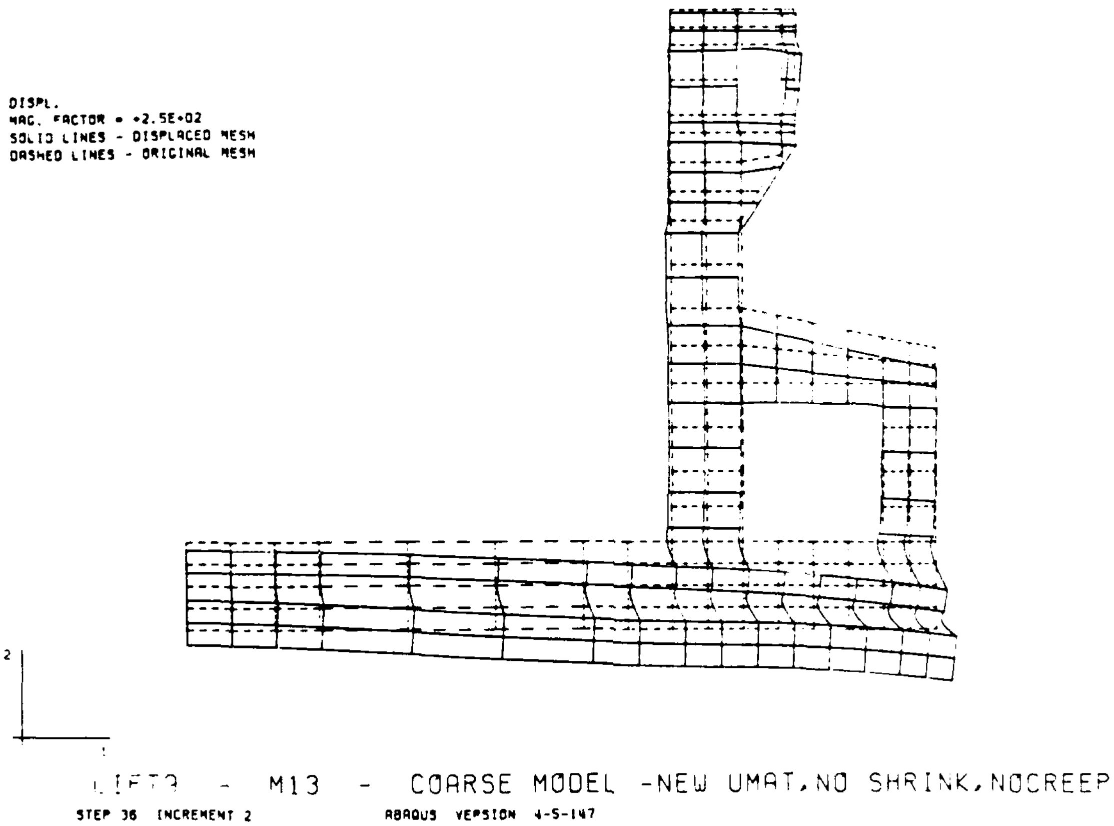


Figure 28d. Displaced structure 7 days after placement of lift 9, E is a function of temperature, using ABAQUS (UMAT2).

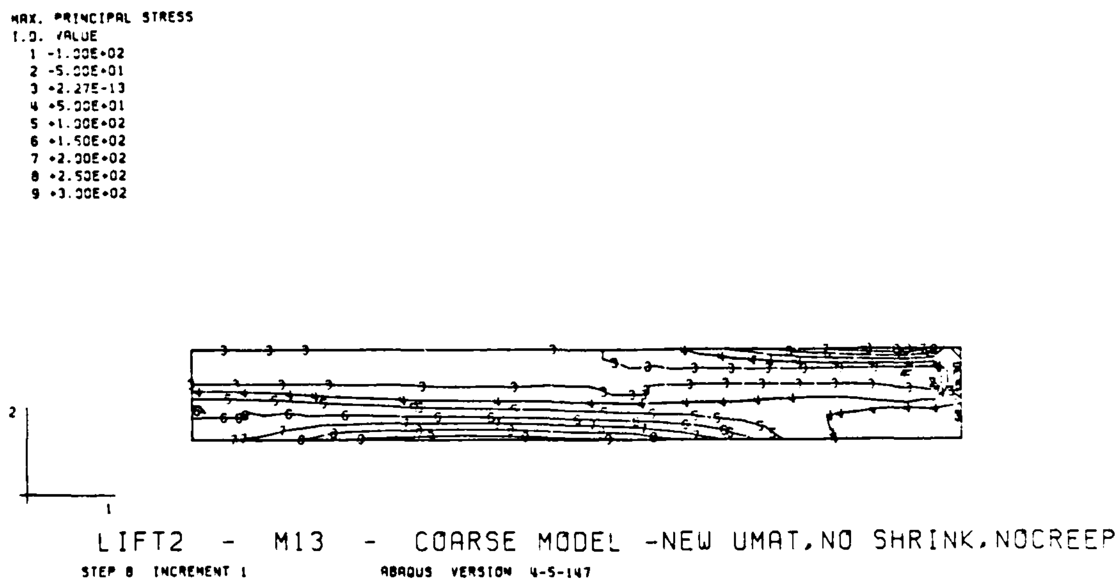


Figure 29a. Maximum principal stress contours 5 days after placement of lift 2, E is a function of temperature, using ABAQUS (UMAT2).

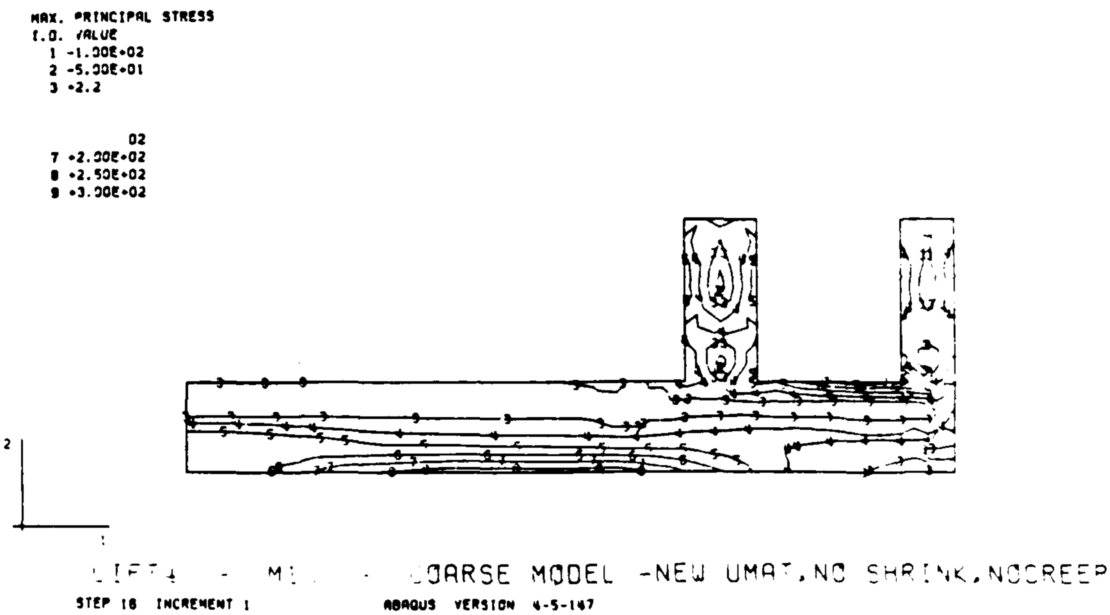


Figure 29b. Maximum principal stress contours 5 days after placement of lift 4, E is a function of temperature, using ABAQUS (UMAT2).

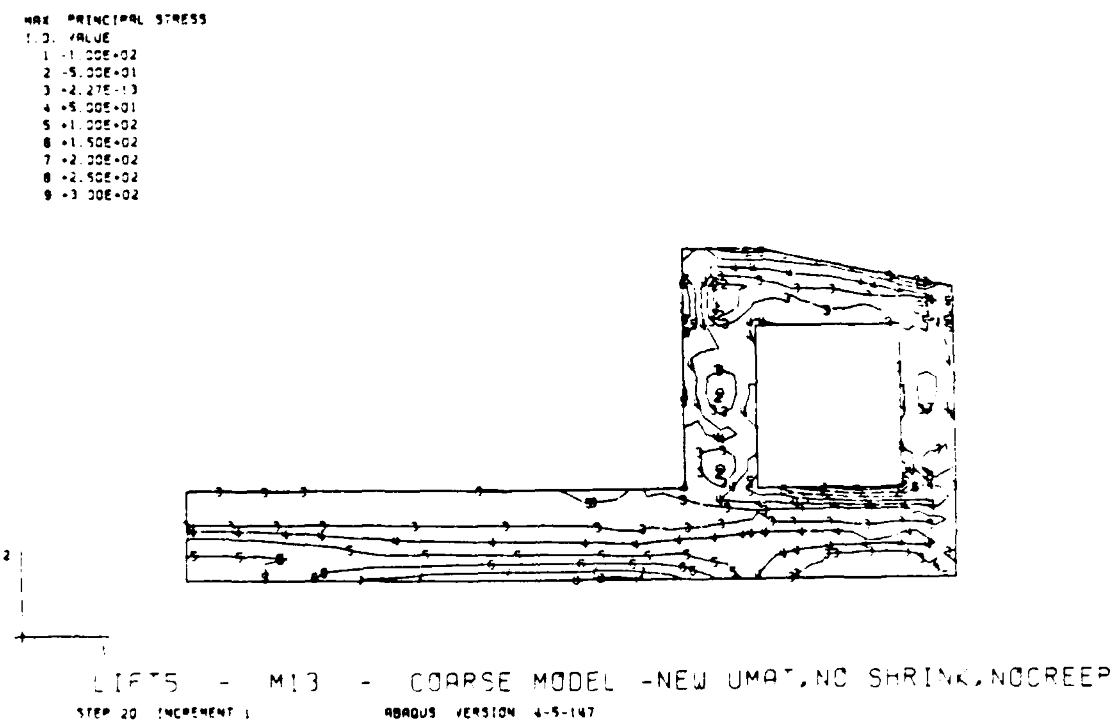


Figure 29c. Maximum principal stress contours 5 days after placement of lift 5, E is a function of temperature, using ABAQUS (UMAT2).

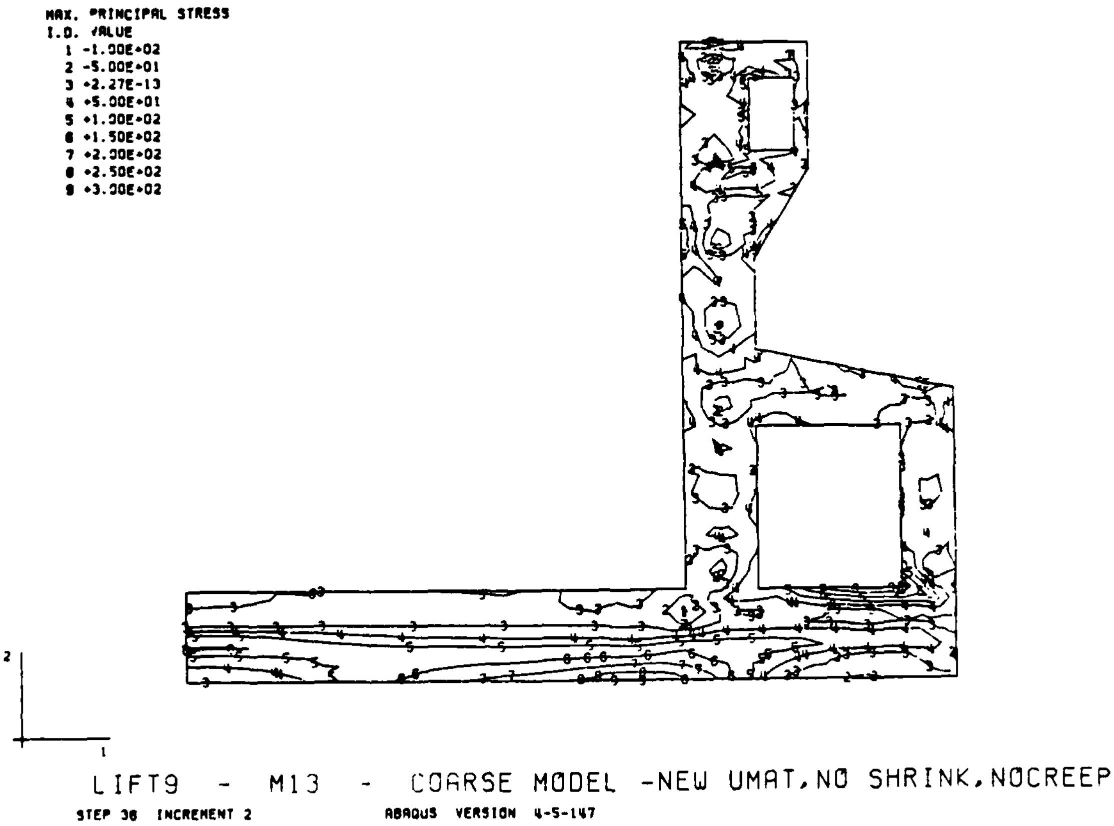


Figure 29d. Maximum principal stress contours 7 days after placement of lift 9, E is a function of temperature, using ABAQUS (UMAT2).

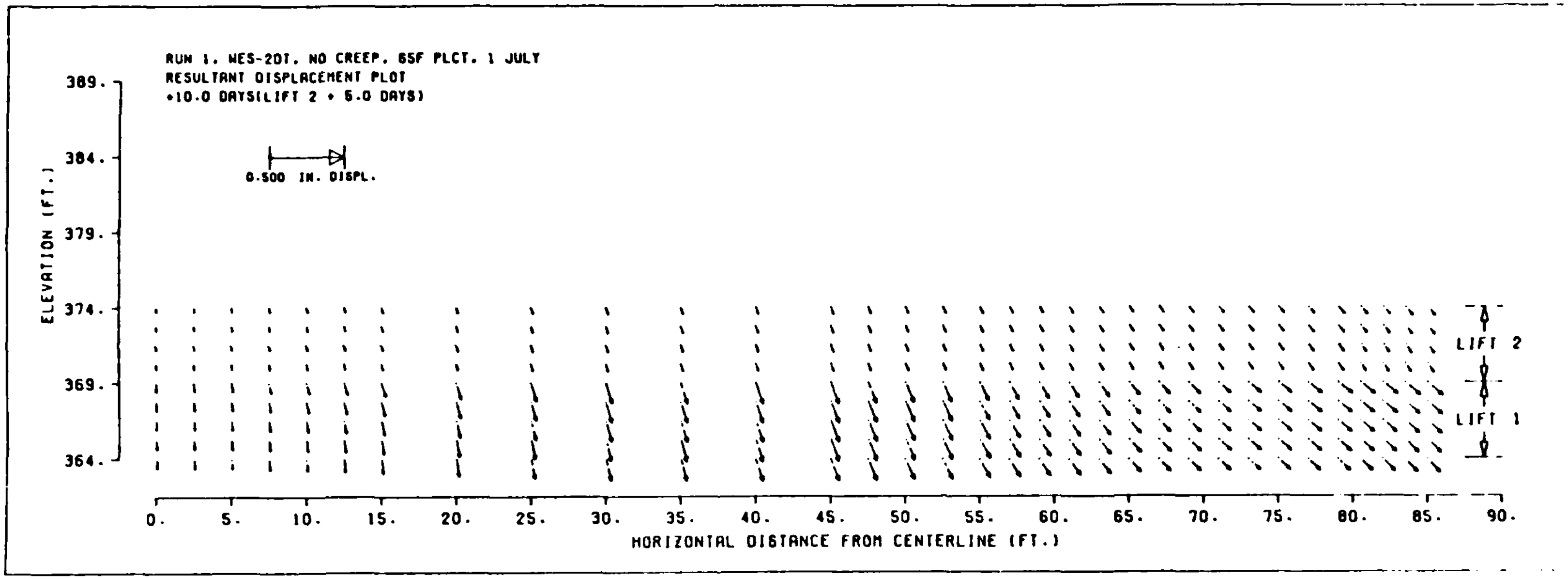


Figure 30a. Displacement of structure 5 days after lift 2 is placed thermal and gravity loading, no creep, using WES -2DT

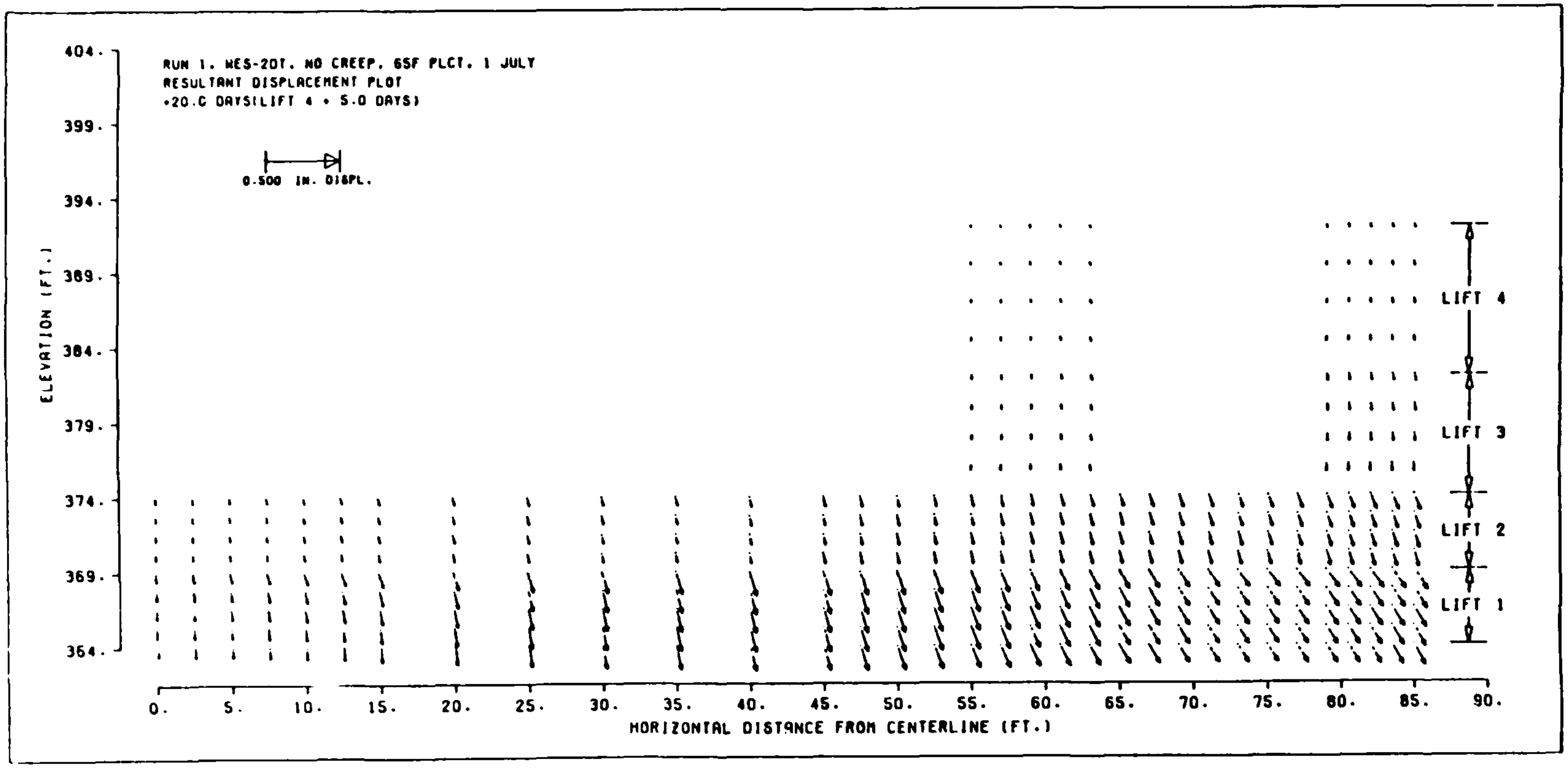


Figure 30b. Displacement of structure 5 days after lift 4 is placed thermal and gravity loading, no creep using WES-2DT program.

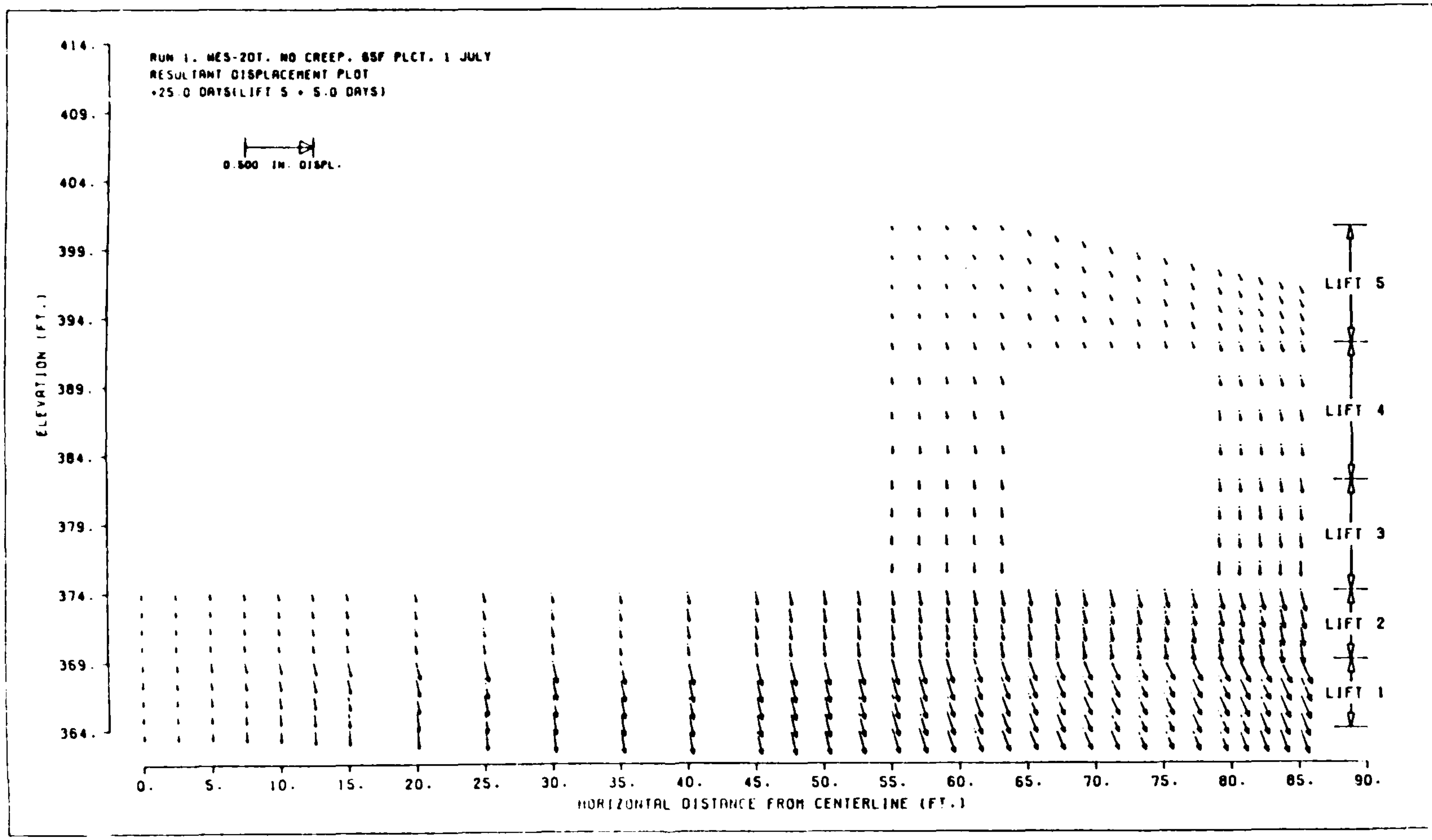


Figure 30c. Displacement of structure 5 days after lift 5 is placed, thermal and gravity loading, no creep, using WES-2DT program.

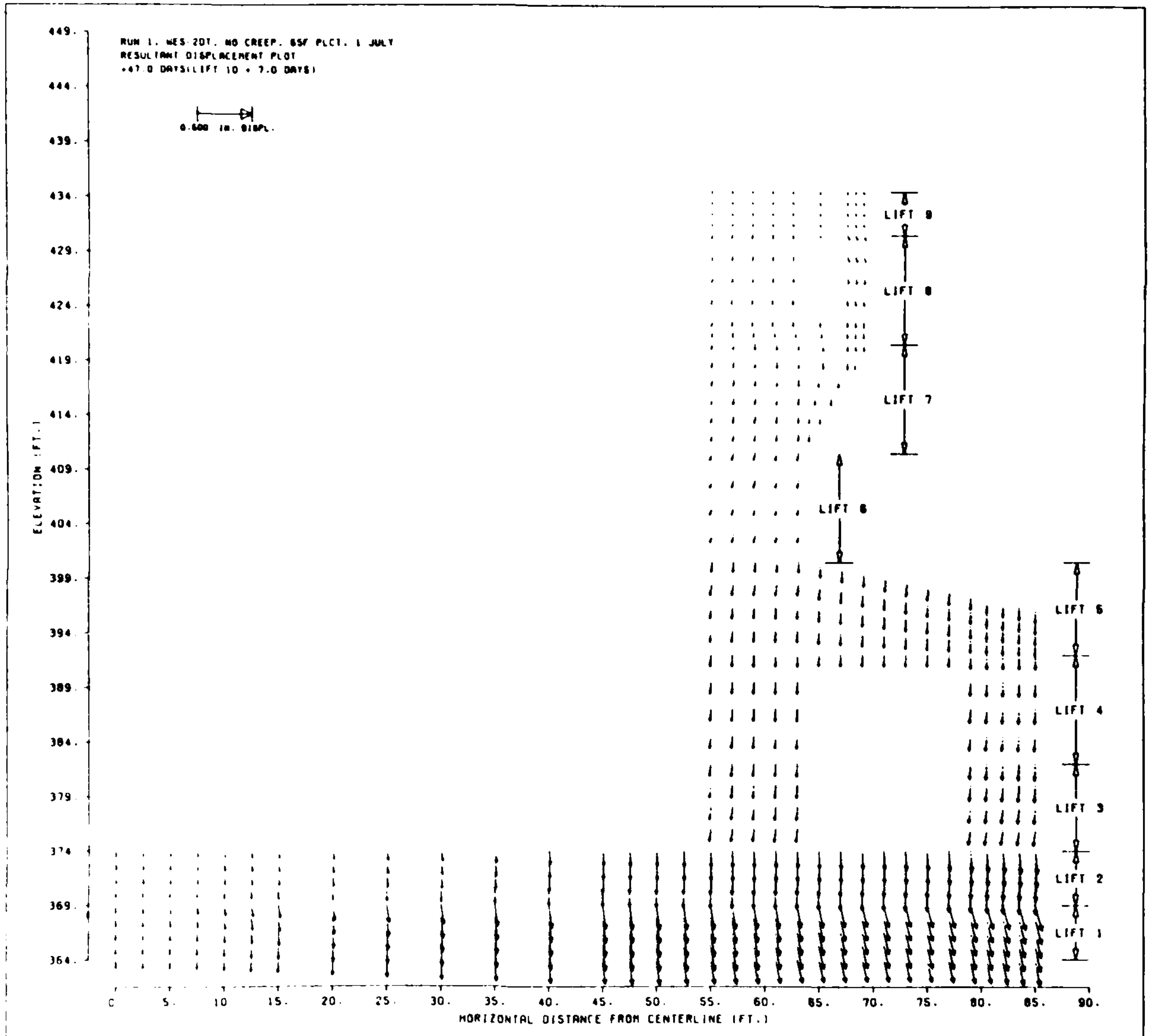


Figure 30d. Displacement of structure 7 days after lift 9 is placed thermal and gravity loading no creep using WES-2DT program.

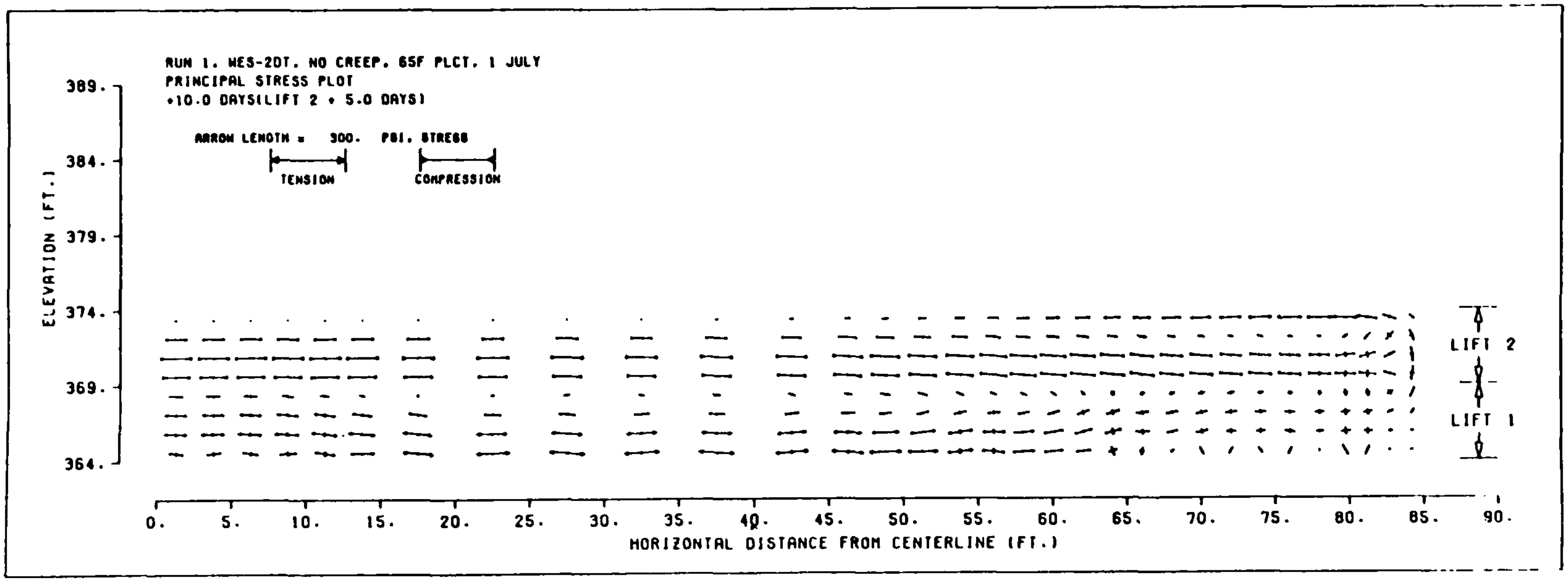


Figure 31a. Principal stress distribuion in structure 5 days after lift 2 is placed, thermal and gravity loading, no creep, using WES-2DT program.

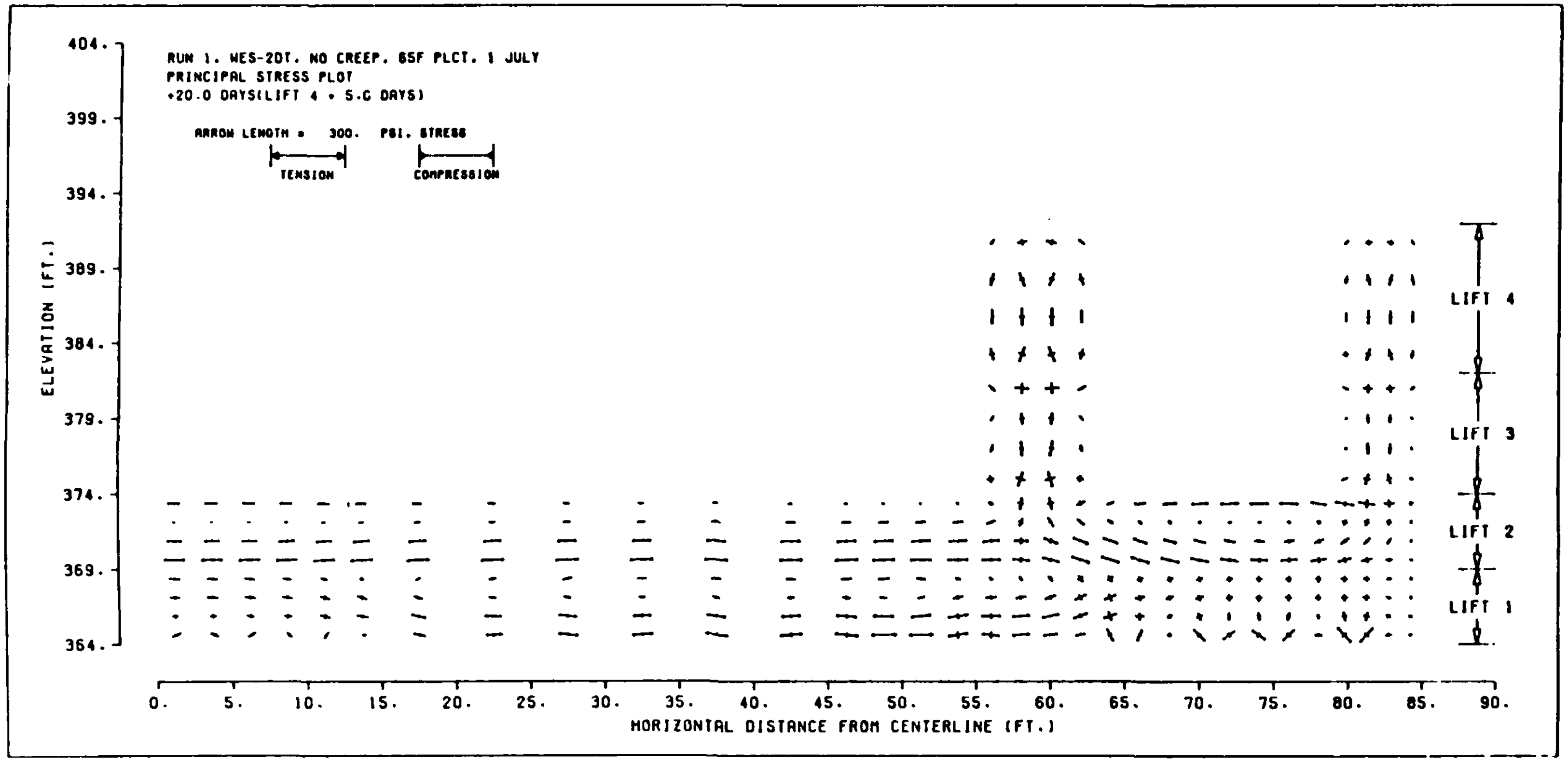


Figure 31b. Principal stress distribution in structure 5 days after lift 4 is placed, thermal and gravity loading, no creep, using WES-2DT program.

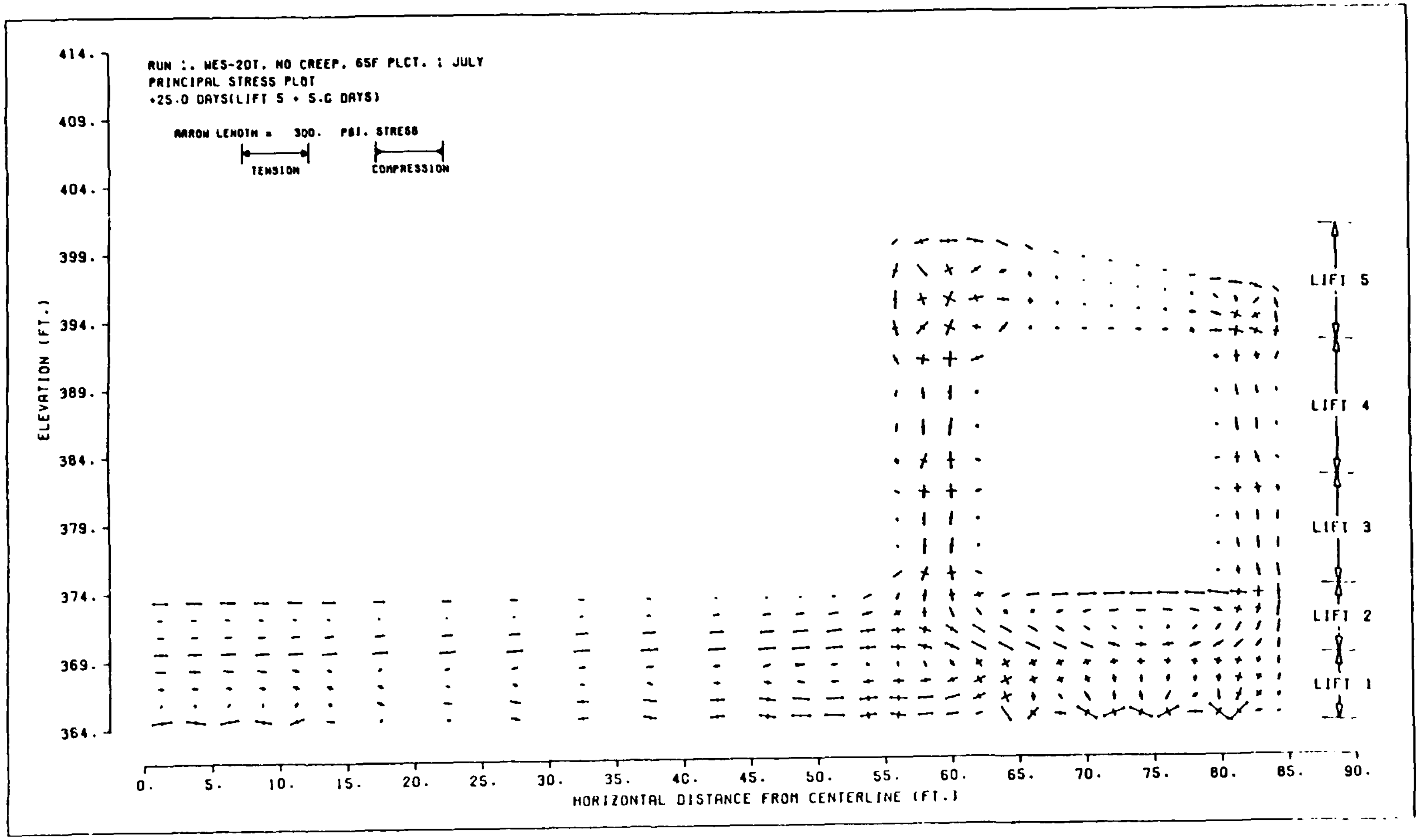


Figure 31c. Principal stress distribution in structure 5 day after lift 5 is placed, thermal and gravity loading, no creep, using WES-2DT program.

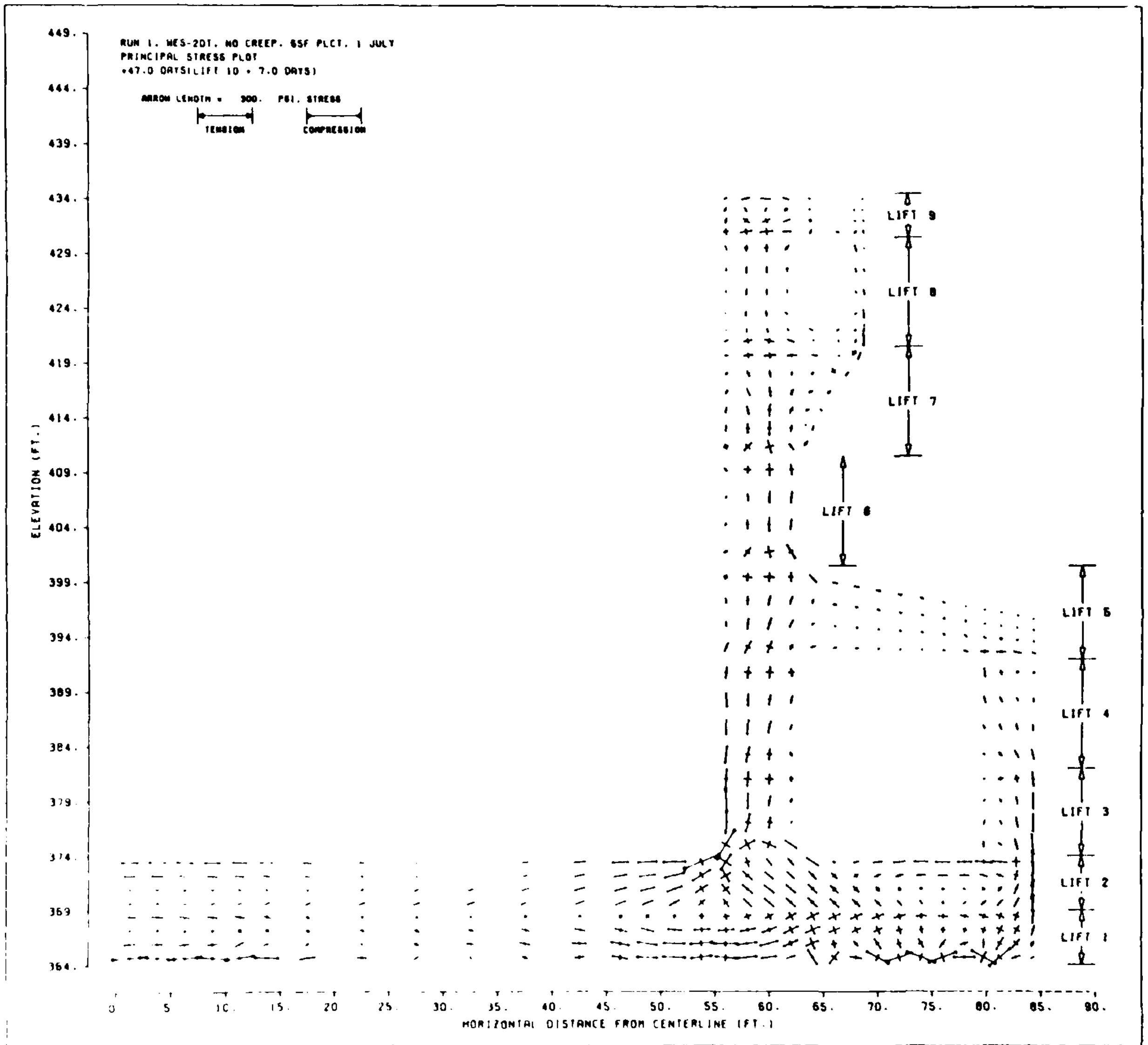


Figure 31d. Principal stress distribution in structure 7 days after lift 9 is placed, thermal and gravity loading, no creep using WES-2DT program.

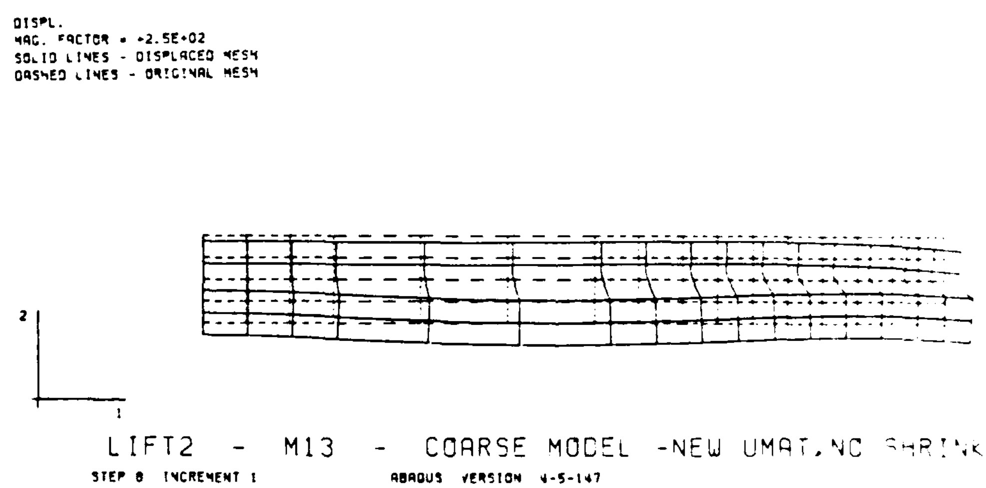


Figure 32a. Displaced structure 5 days after placement of lift 2 including creep, using ABAQUS.

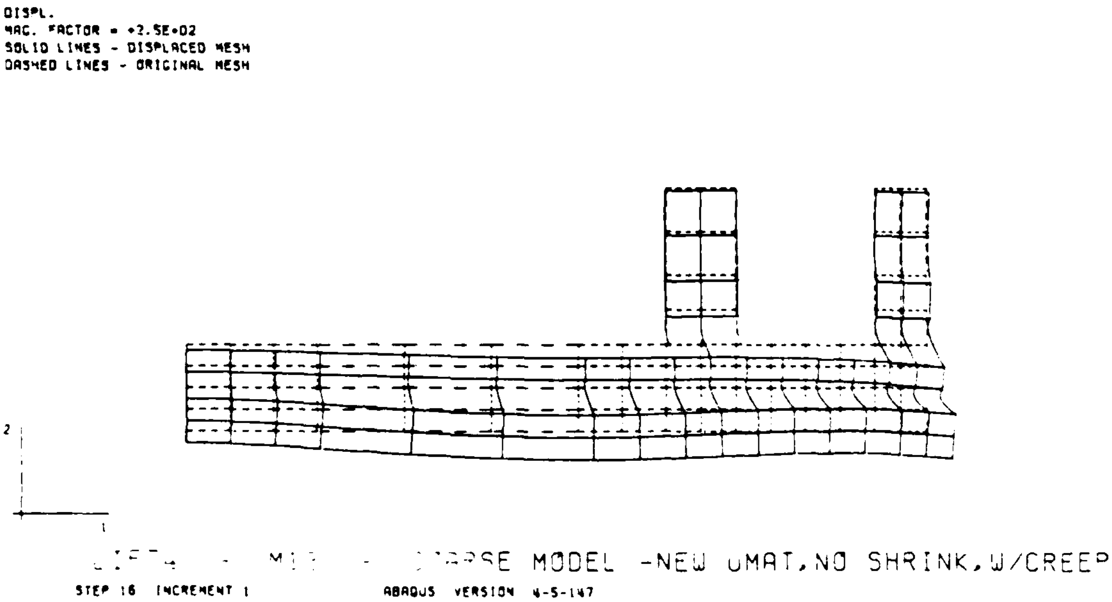


Figure 32b. Displaced structure 5 days after placement of lift 4 including creep, using ABAQUS.

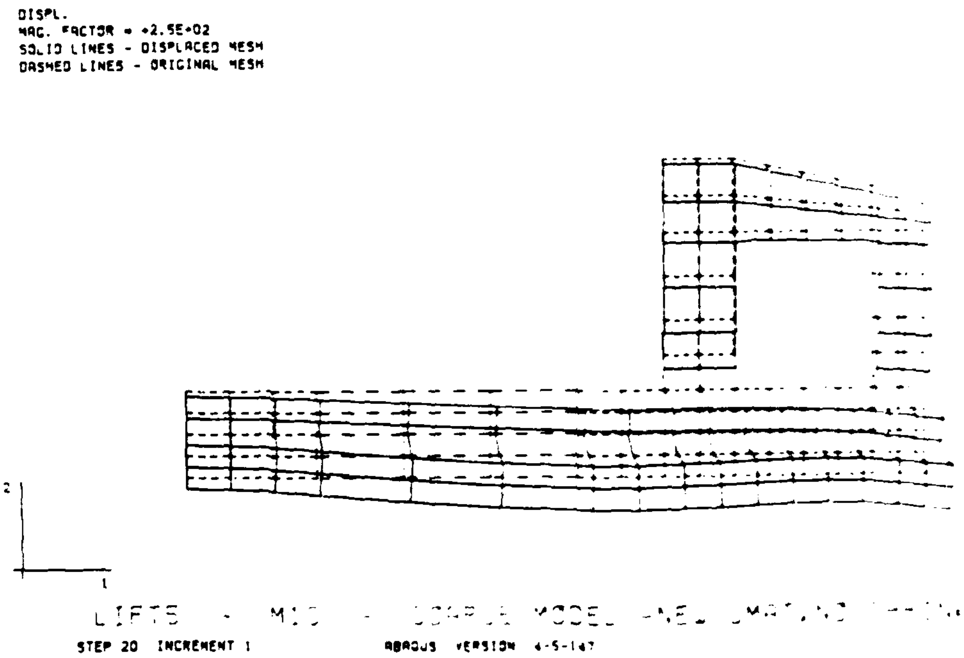
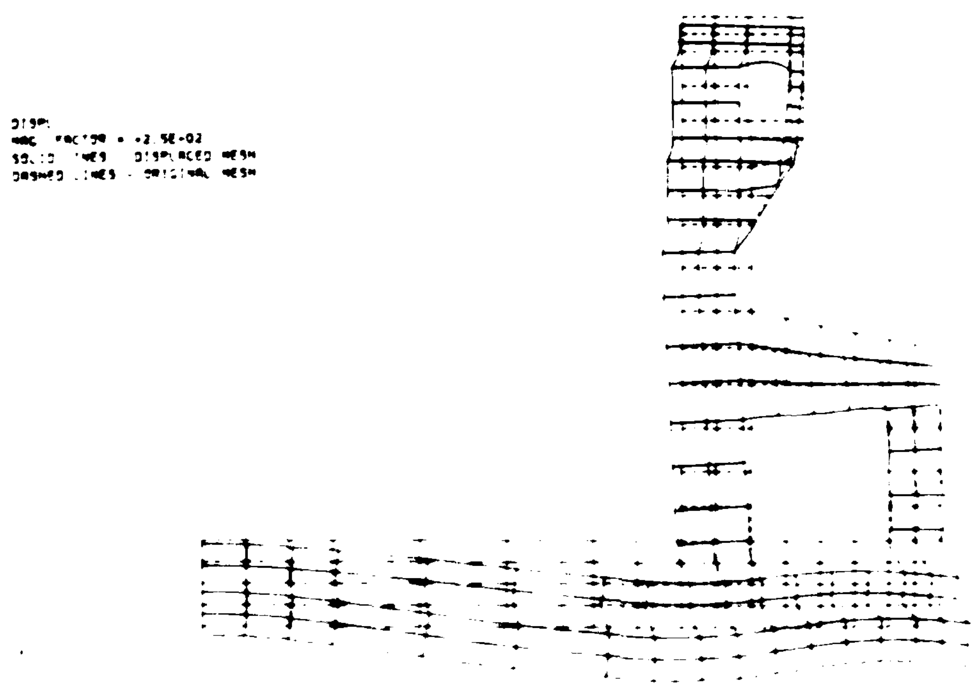


Figure 32c. Displaced structure 5 days after placement of [illegible] creep, using ABAQUS


DISPL
MAG FACTOR = +2.5E-02
SOLID LINES - DISPLACED MESH
DASHED LINES - ORIGINAL MESH

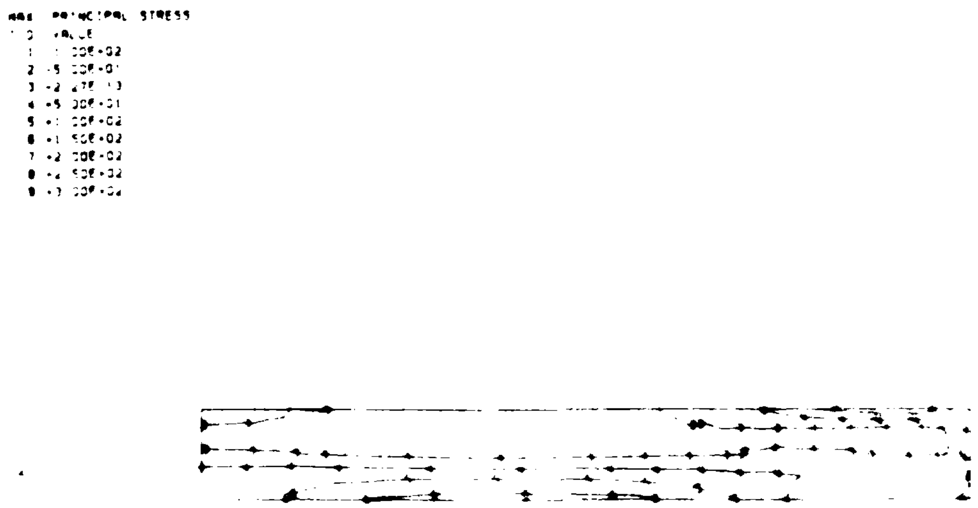


Figure [illegible] Maximum principal stress contours [illegible] days after placement [illegible] [illegible] using ABA[illegible] UMAT.

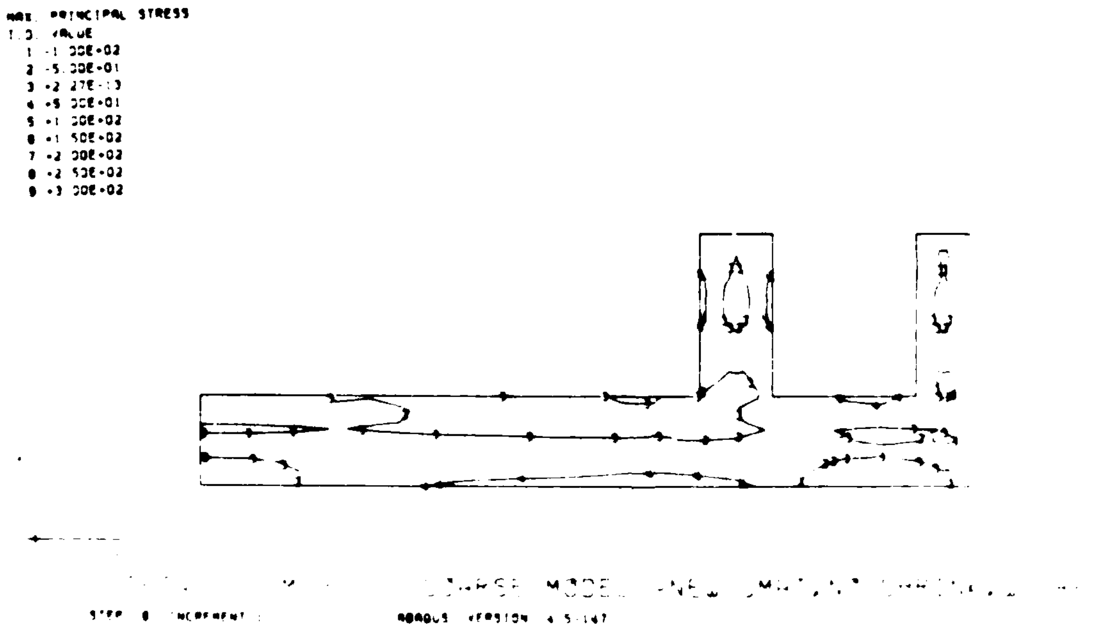


Figure 33b Maximum principal stress contours 5 days after placement of lift 4 including creep, using ABAQUS (UMAT)

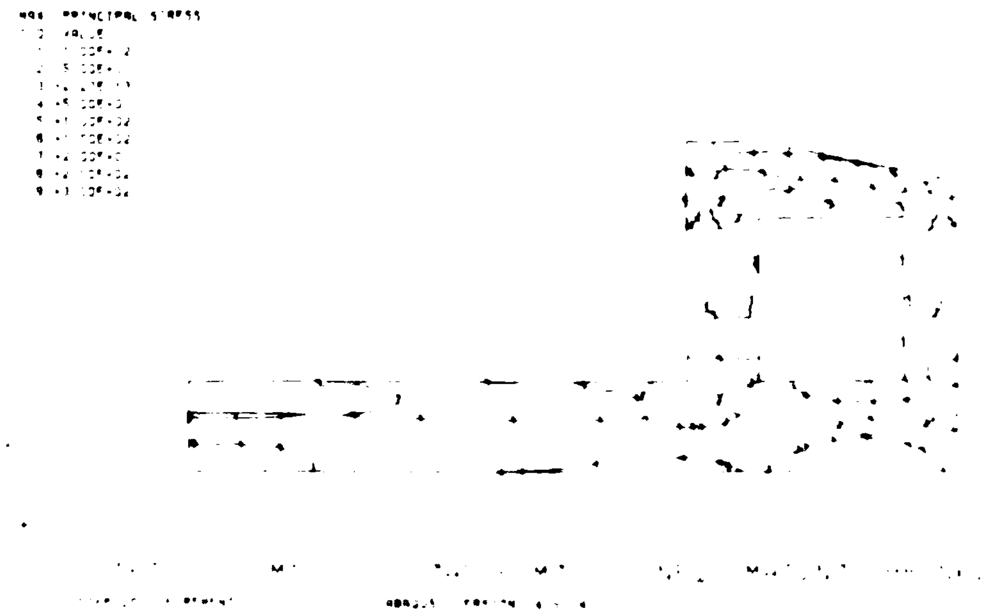
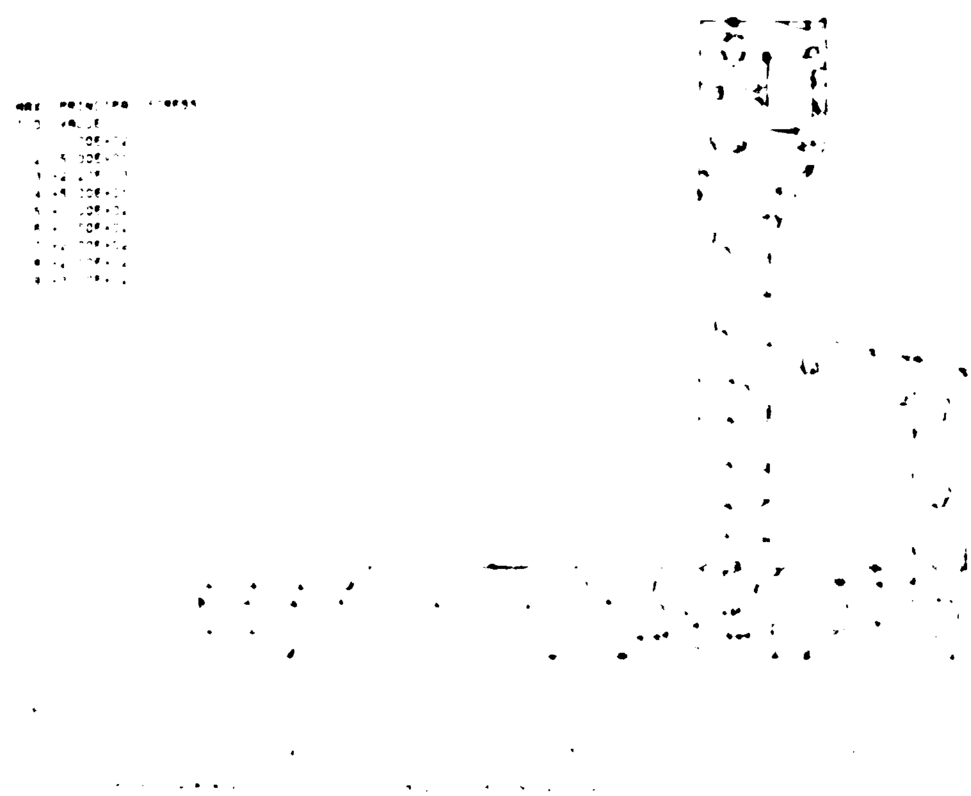
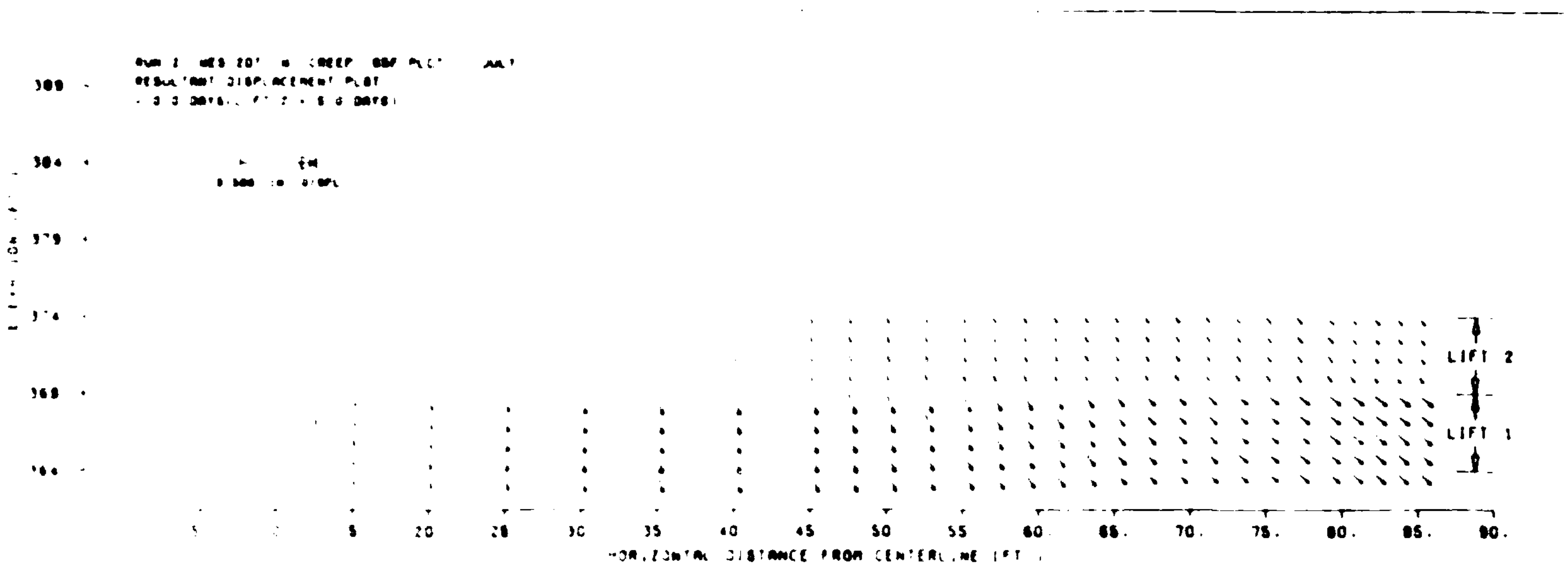


Figure [illegible]. Maximum principal stress contours [illegible] days after placement [illegible] lift [illegible] including creep [illegible]





[illegible] Displacement of structure [illegible] days after lift 2 is placed, thermal and gravity loading, creep, using WES-2DT program.

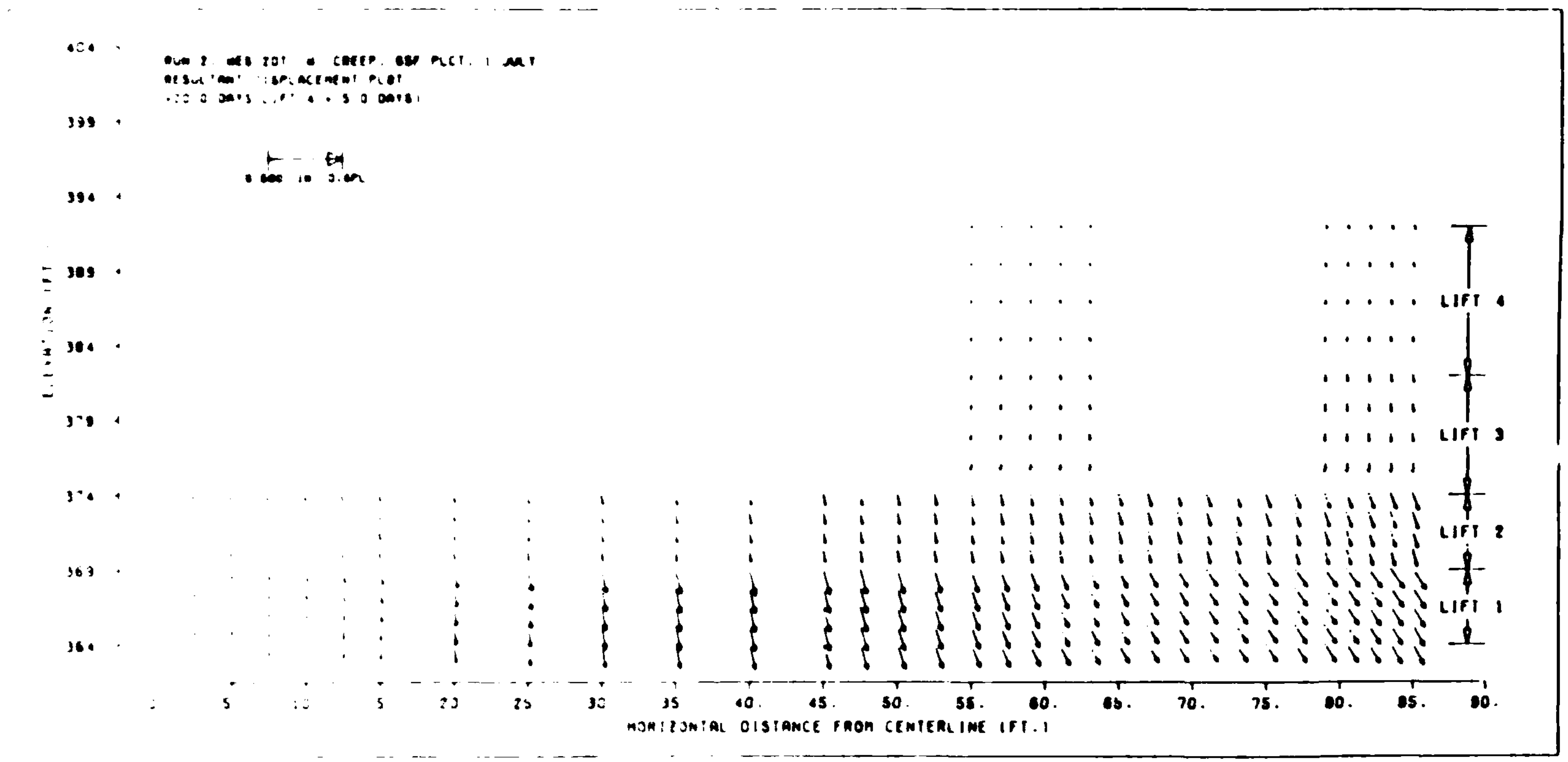


Figure [illegible]. Displacement of structure 5 days after lift 4 is placed, thermal and gravity loading, creep, using WES-2DT program

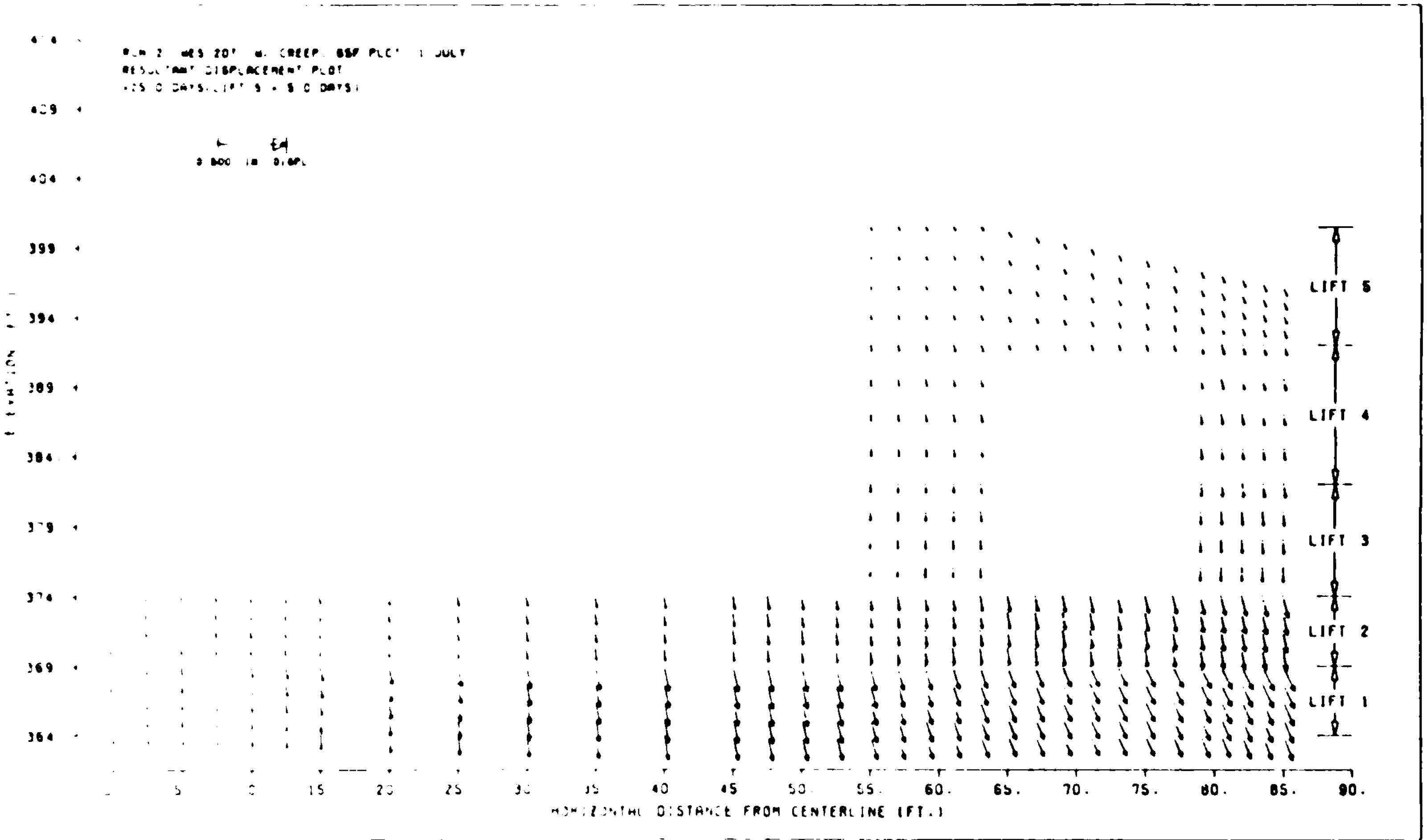


Figure . Displacement of structure 5 days after lift 5 is placed, thermal and gravity loading, creep, using WES-2DT program.

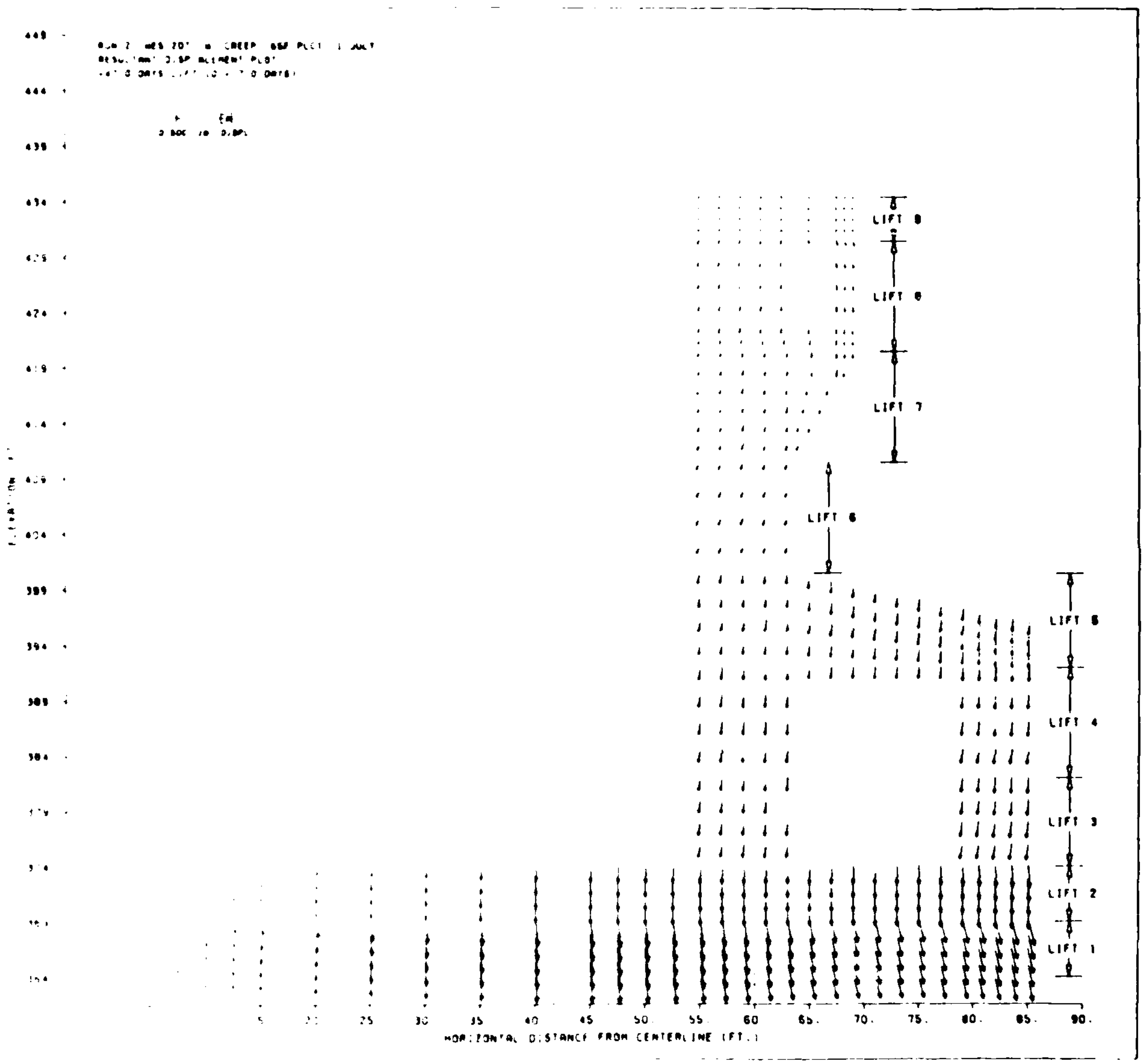


Figure [illegible]d. Displacement of structure 7 days after lift 9 is placed, thermal and gravity loading, creep, using WES-2DT program.

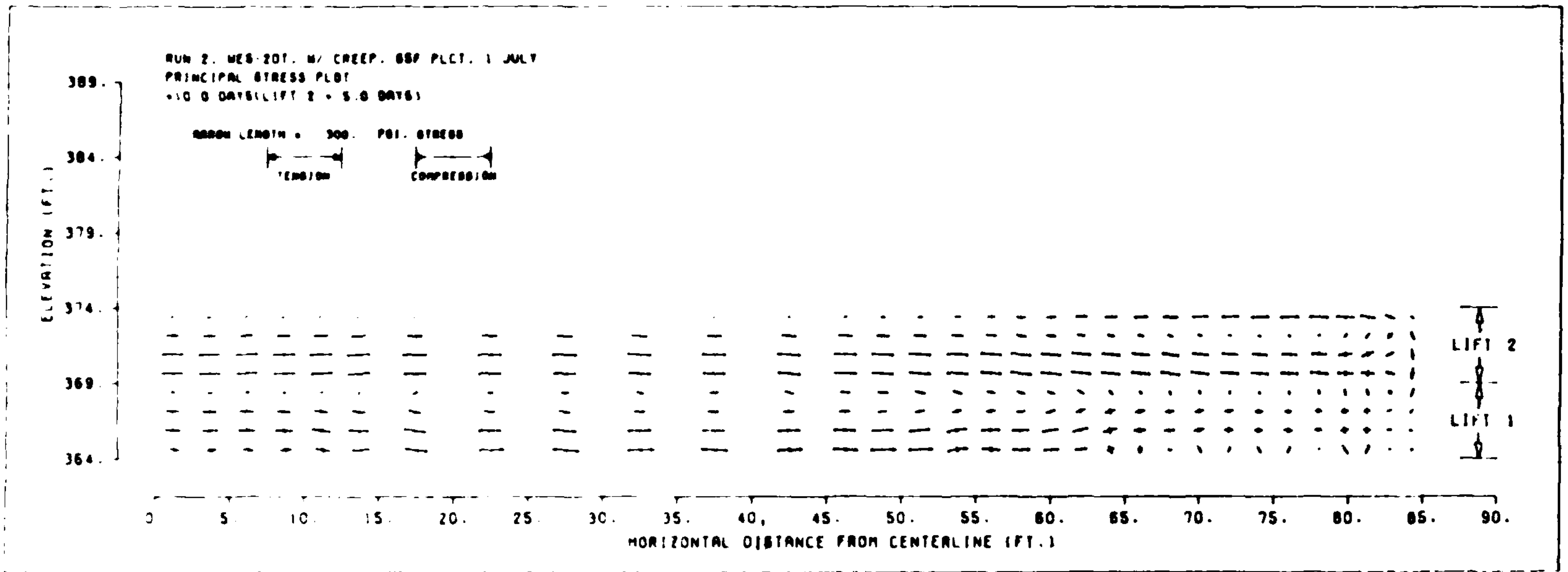


Figure 5a. Principal stress distribution in structure 5 days after lift 2 is placed, thermal and gravity loading, with creep, using WES-2DT program.

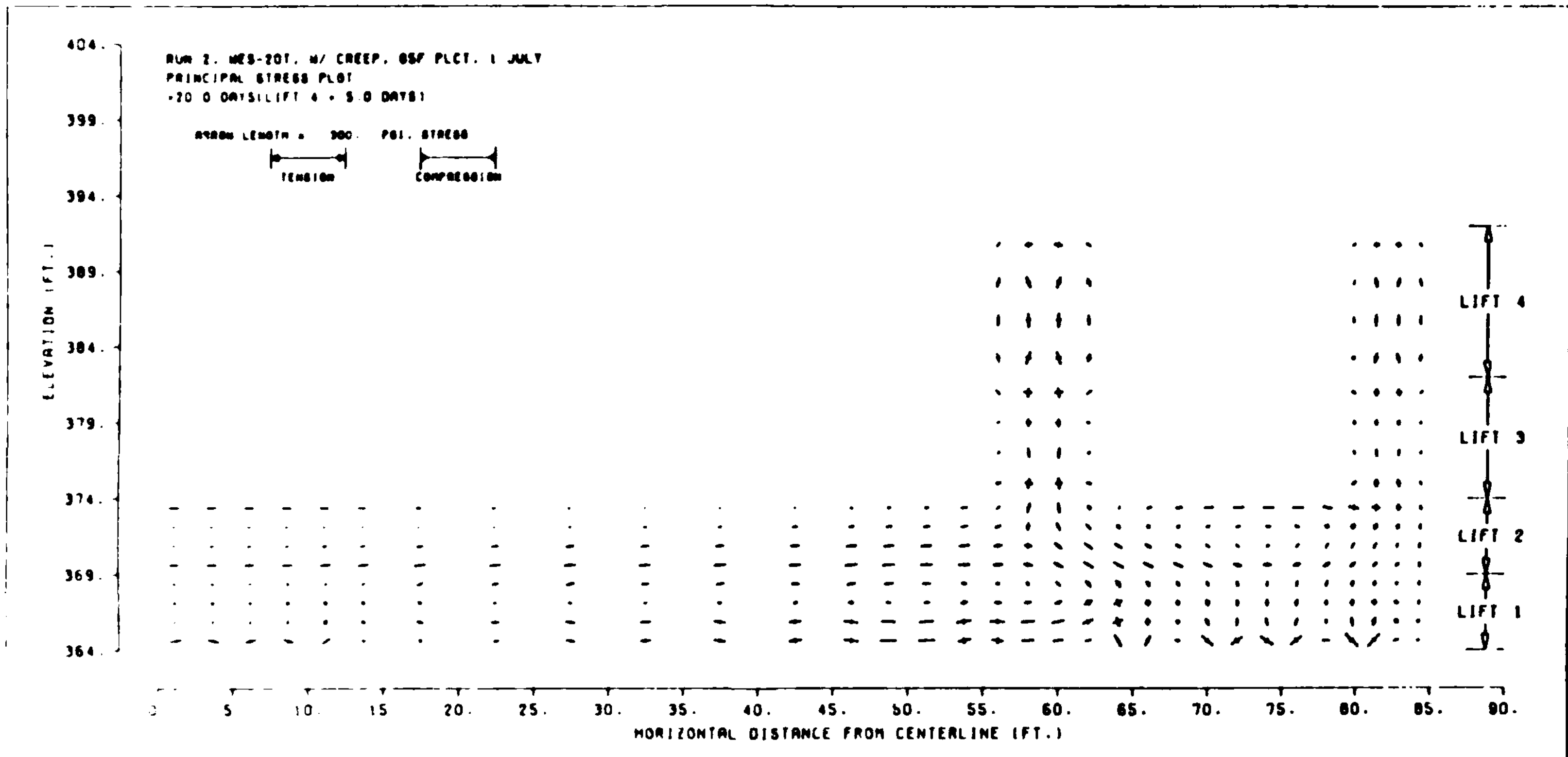
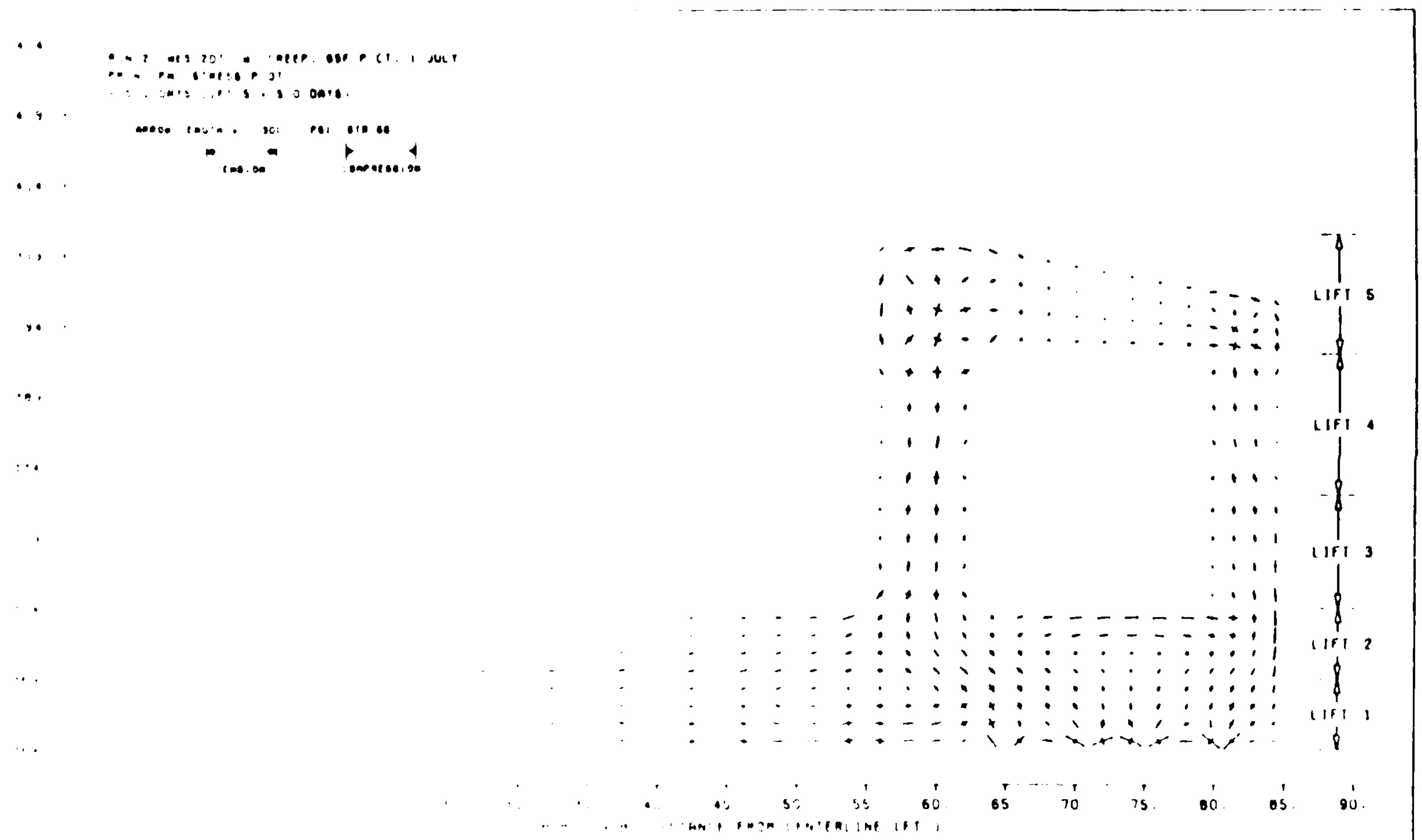


Figure 356. Principal stress distribution in structure 5 days after lift 4 is placed, thermal and gravity loading, with creep, using WES-2DT program.



... in structure 5 days after lift 5 is placed, ... with creep, using WES-2DT program.

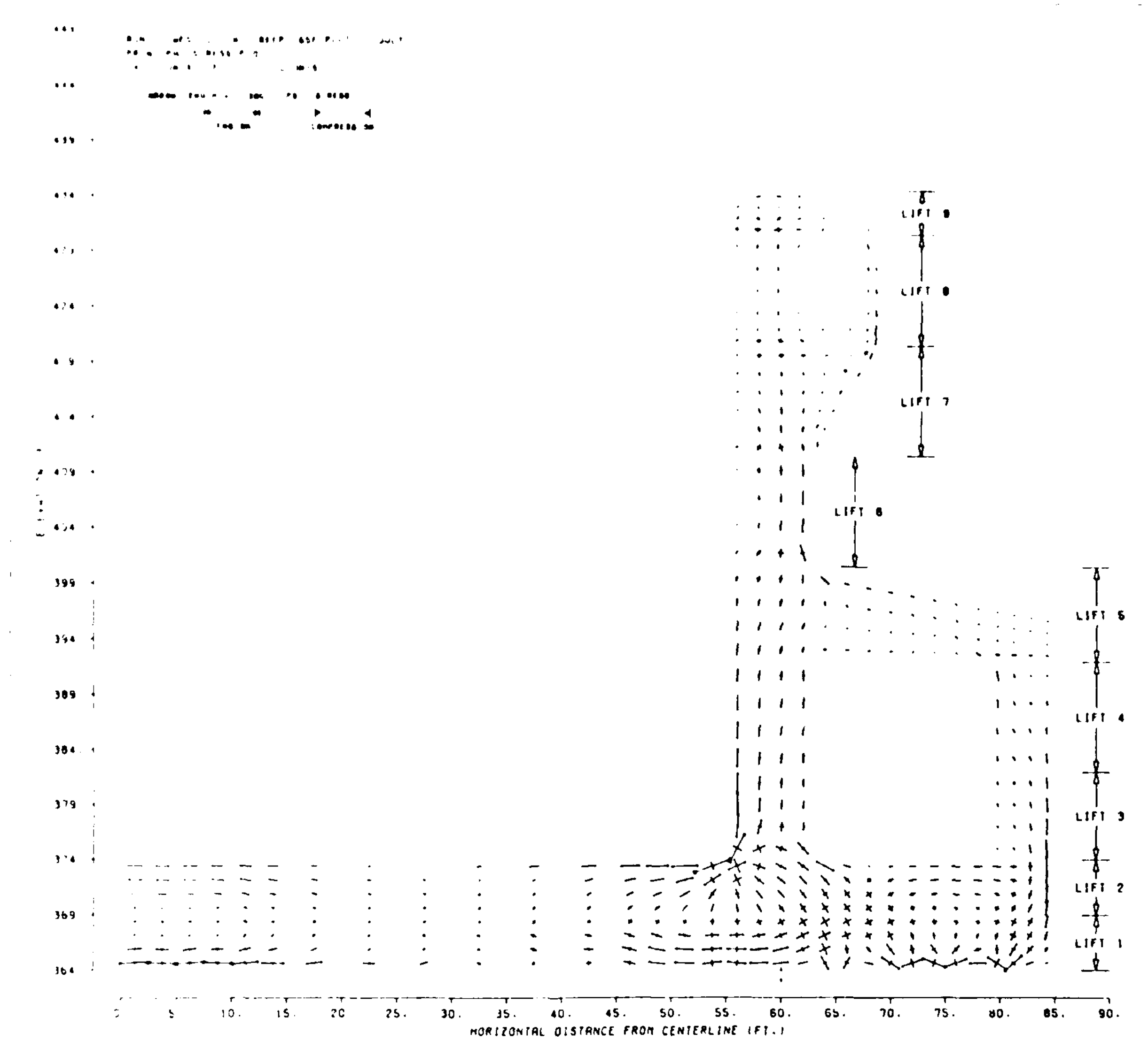


Figure 35d. Principal stress distribution in structure 7 days after lift 9 placed, thermal and gravity loading, with creep, using WES-2DT program.

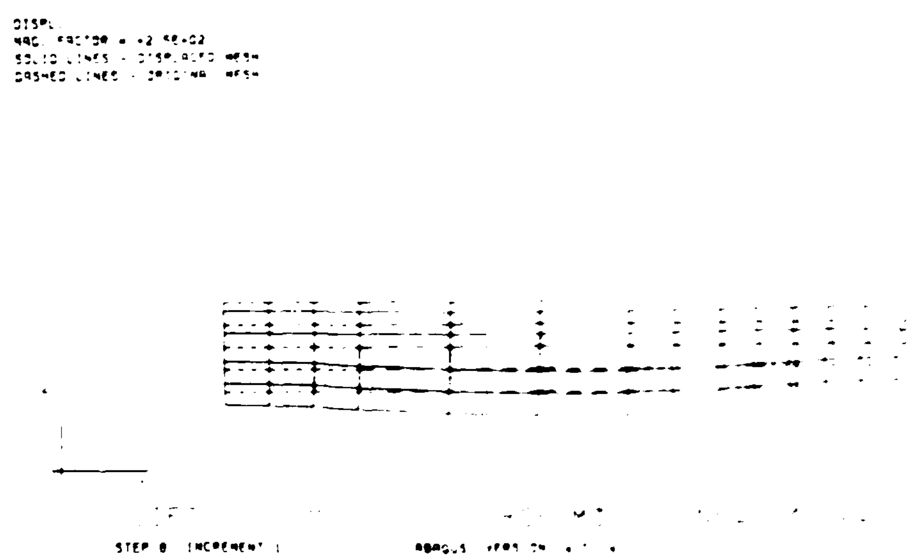


Figure 36a. Displaced [illegible] creep and [illegible]

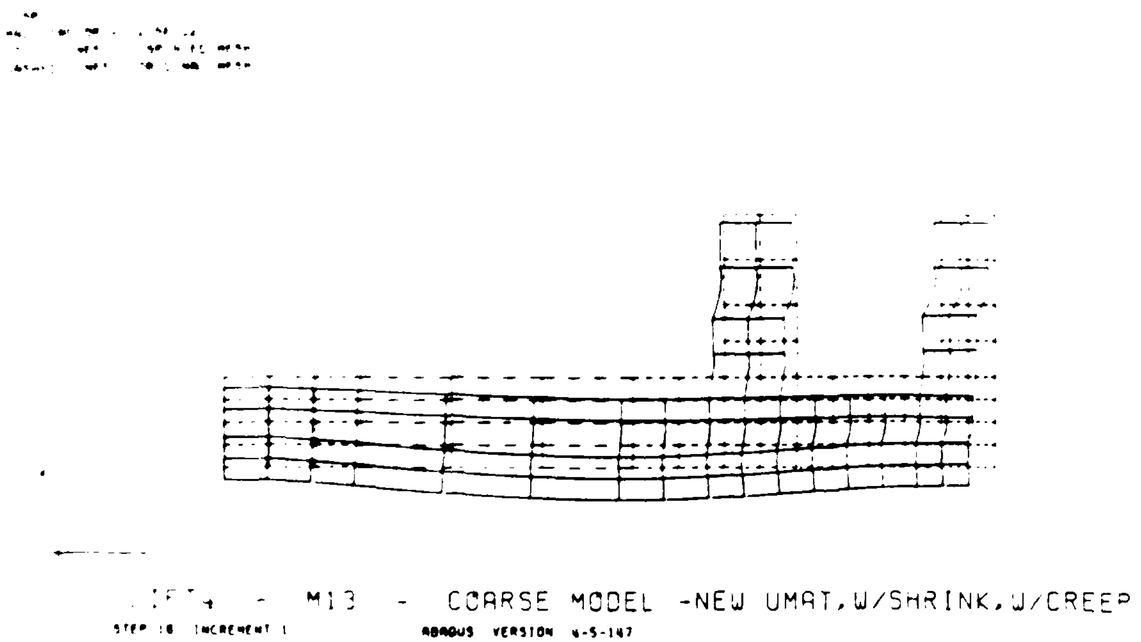


Figure 36b. Displaced structure 5 days after placement of lift 4 including creep and shrinkage, using ABAQUS.

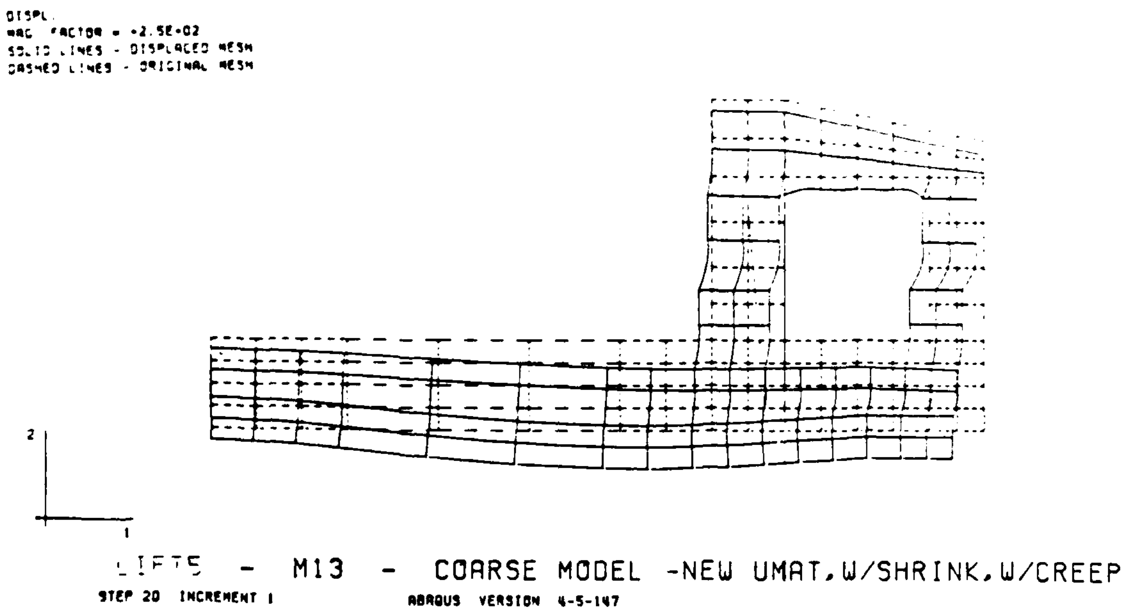


Figure 36c. Displaced structure 5 days after placement of lift 5 including creep and shrinkage, using ABAQUS.

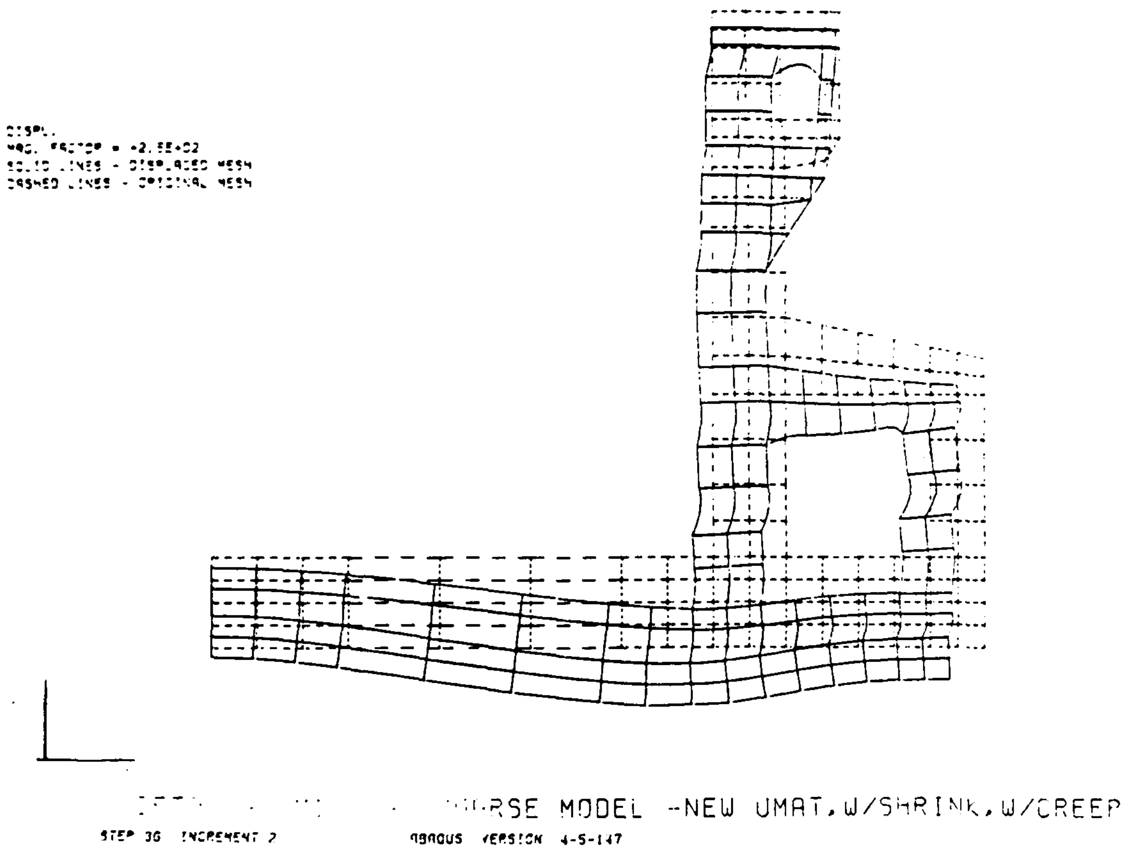


Figure 36d. Displaced structure 7 days after placement of lift 9 including creep and shrinkage, using ABAQUS.

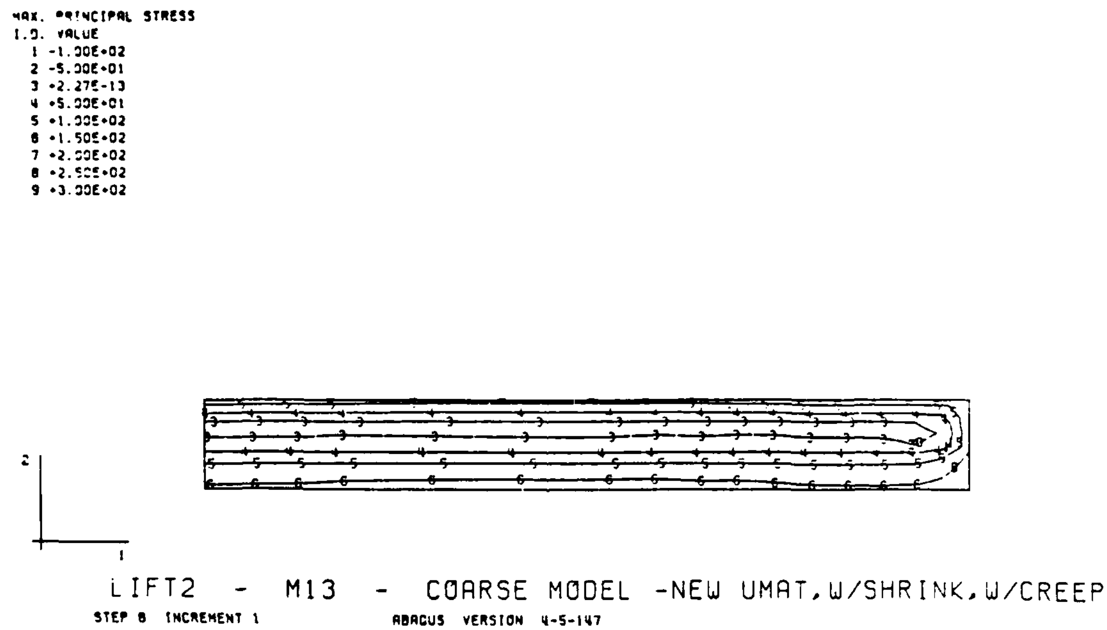


Figure 37a. Maximum principal stress contours 5 days after placement of lift 2 including creep and shrinkage, using ABAQUS (UMAT2).

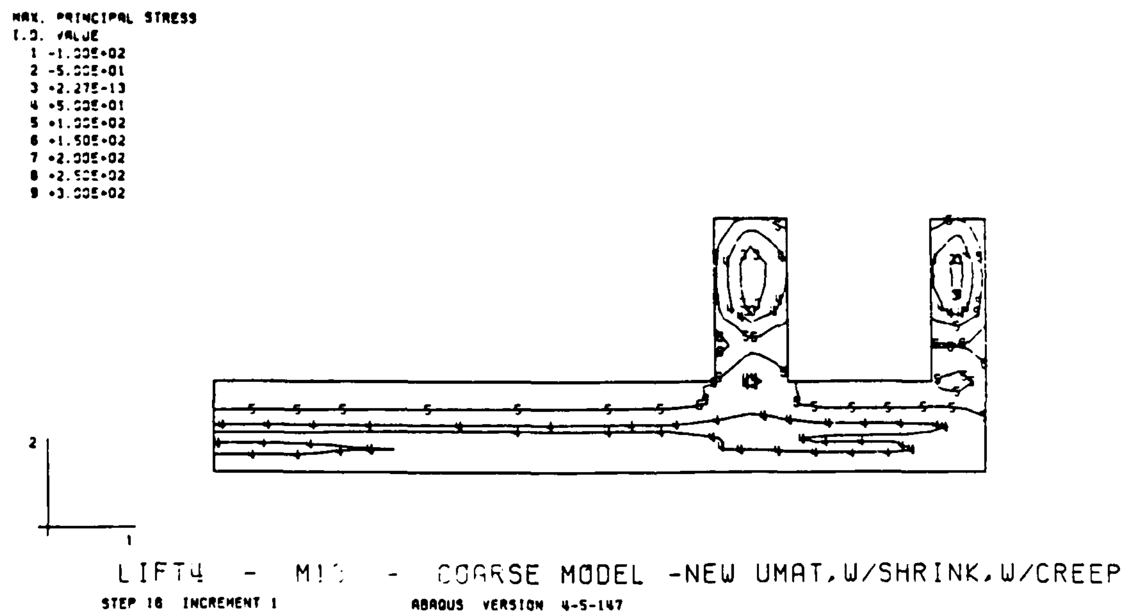


Figure 37b. Maximum principal stress contours 5 days after placement of lift 4 including creep and shrinkage, using ABAQUS (UMAT2).

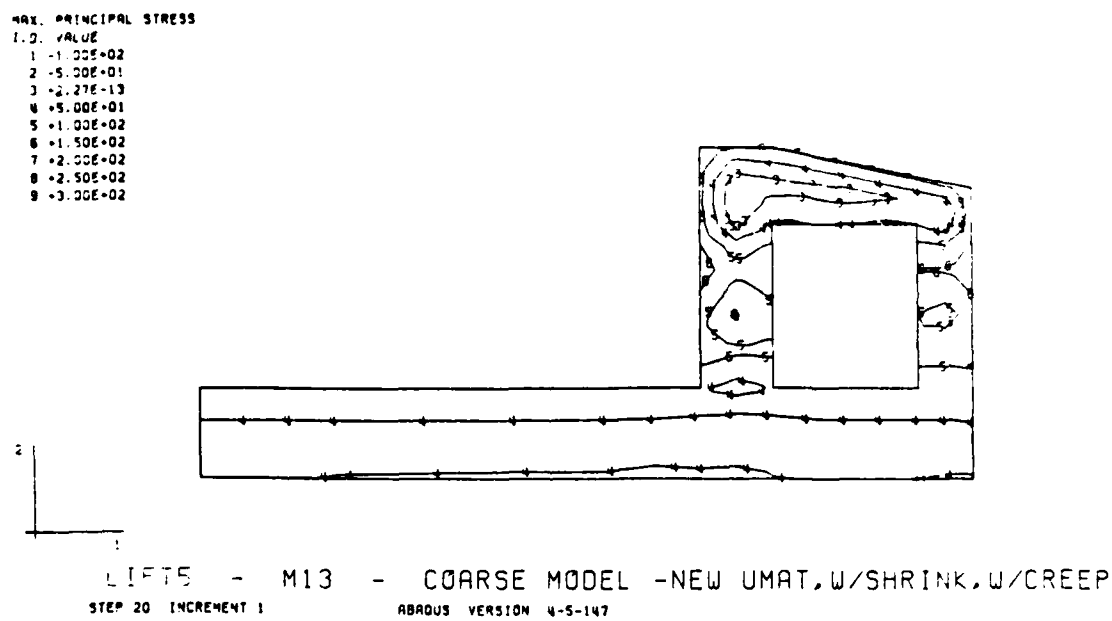


Figure 37c. Maximum principal stress contours 5 days after placement of lift 5 including creep and shrinkage, using ABAQUS (UMAT2).

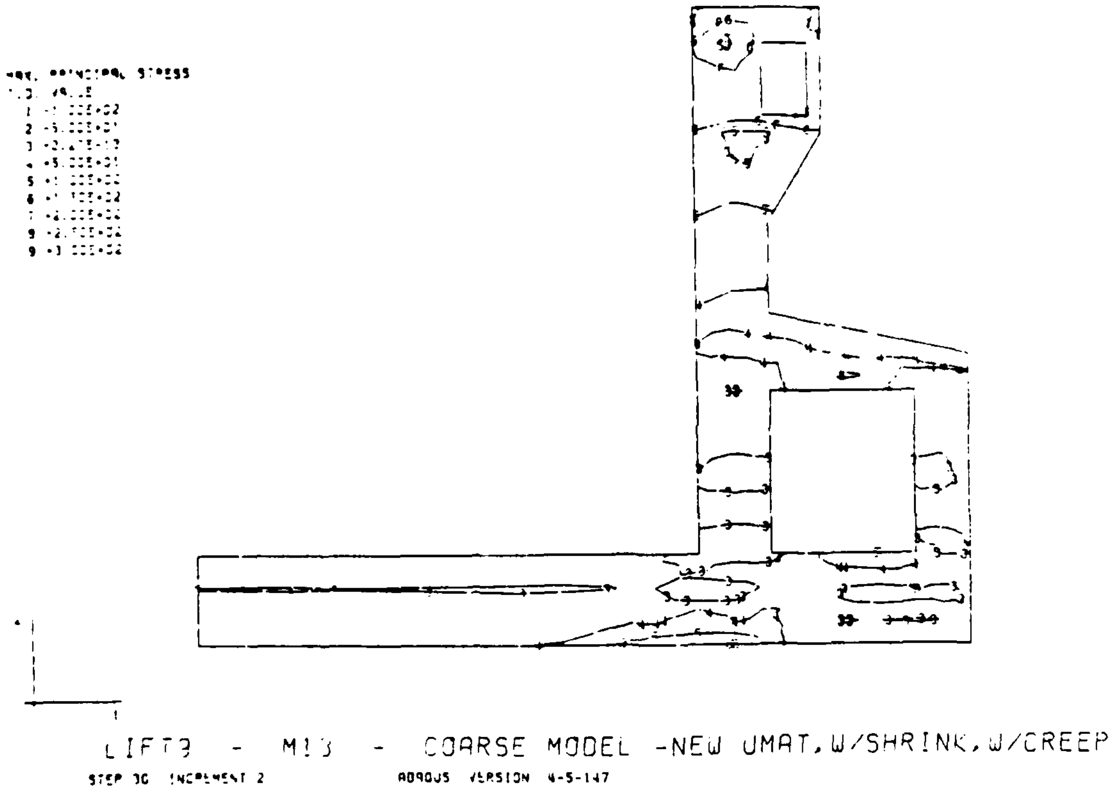


Figure 37d. Maximum principal stress contours 7 days after placement of lift 9 including creep and shrinkage, using ABAQUS (UMAT2).

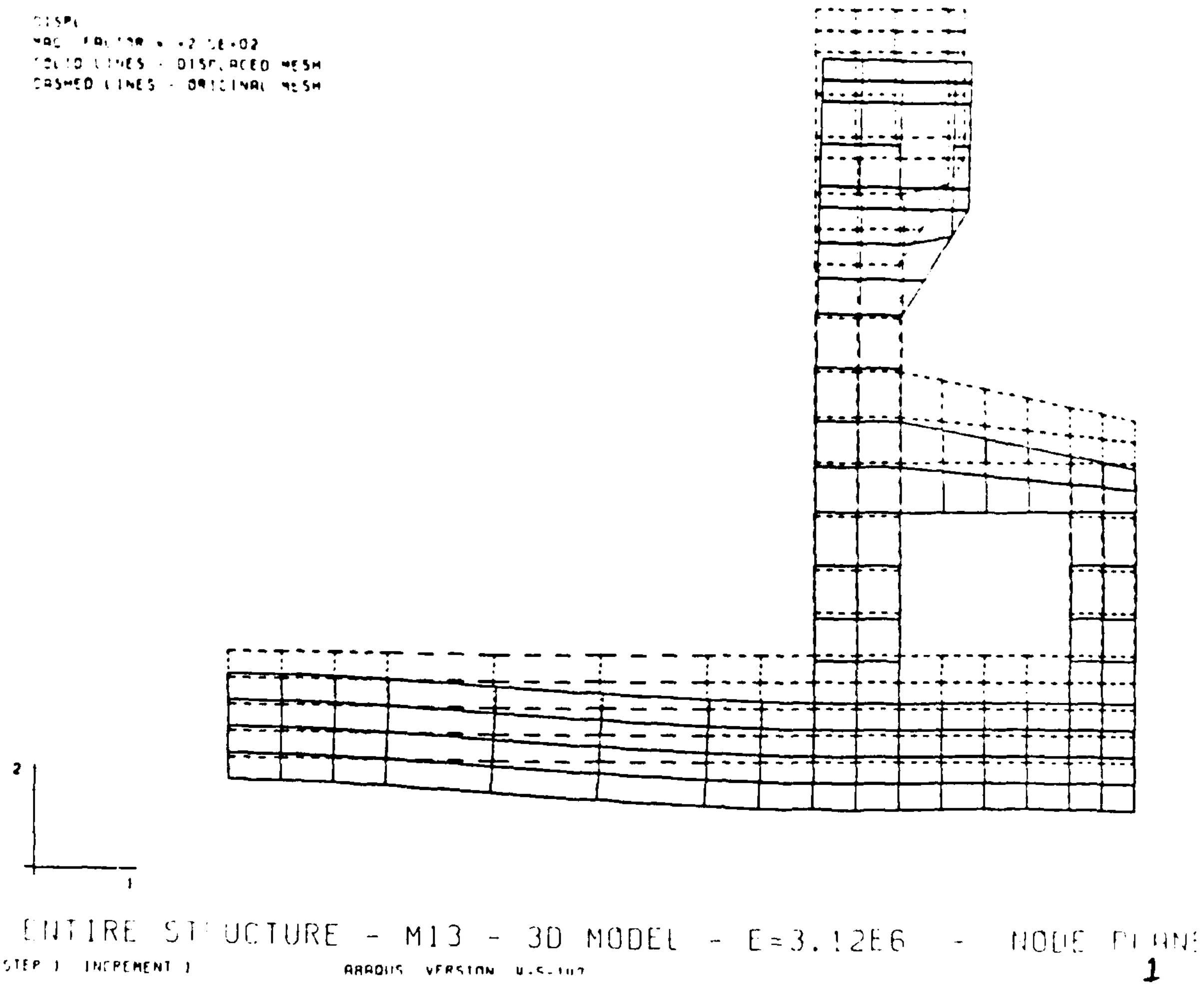


Figure 38a. Displaced structure for 3-dimensional analysis of Monolith 13 at node plane 1 (centerline).

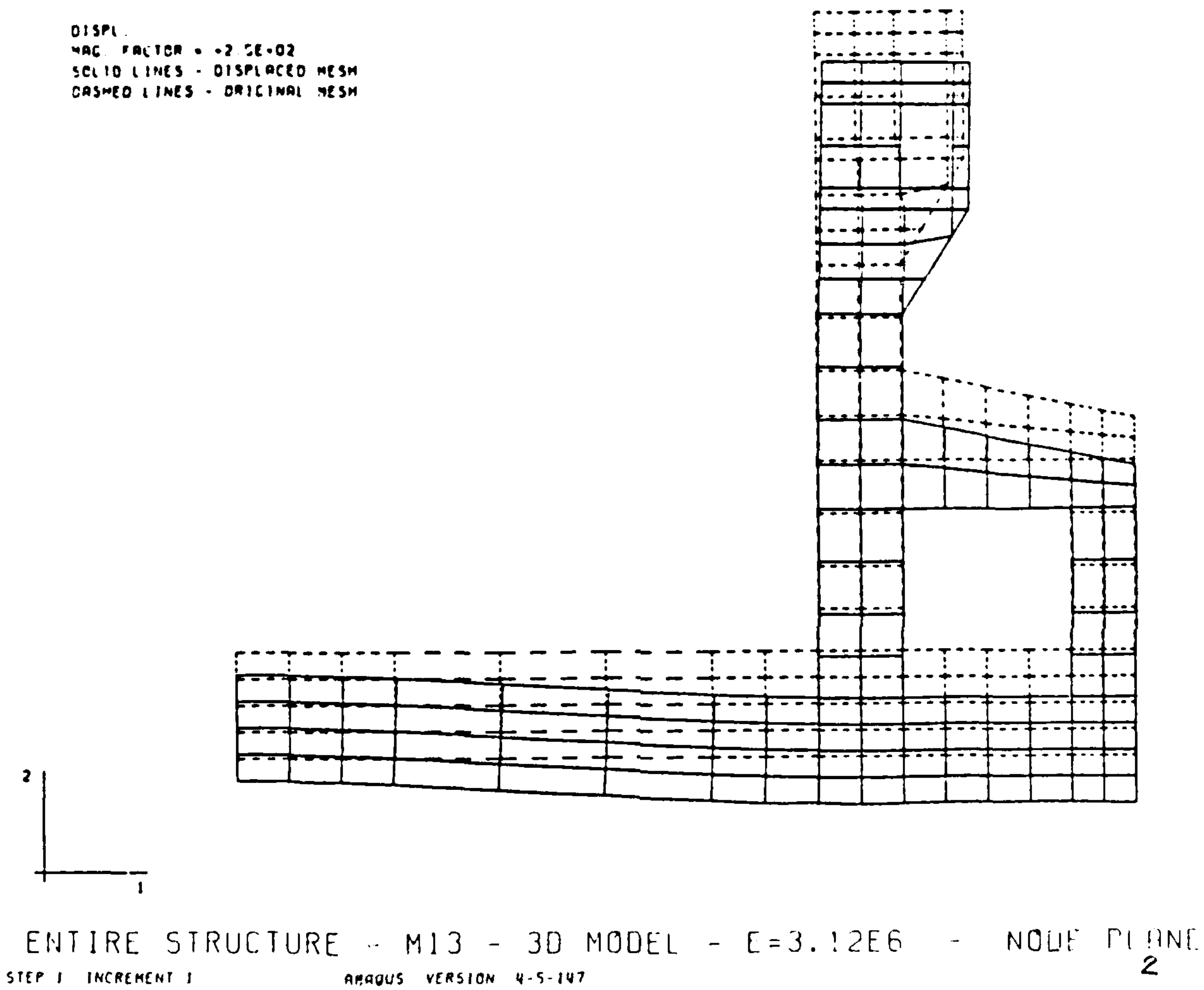


Figure 38b. Displaced structure for 3-dimensional analysis of Monolith 13 at node plane 2.

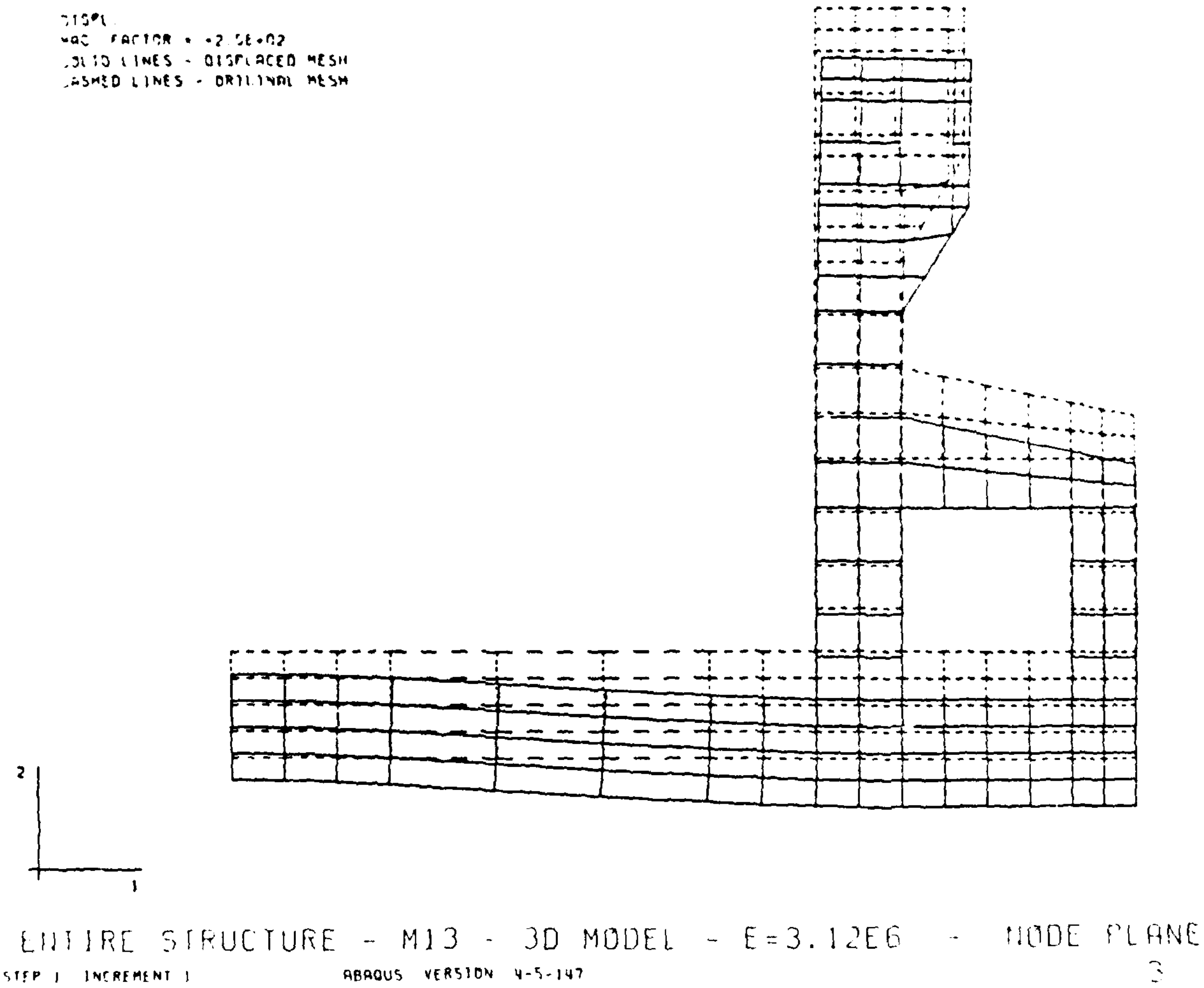


Figure 38c. Displaced structure for 3-dimensional analysis of Monolith 13 at node plane 3.

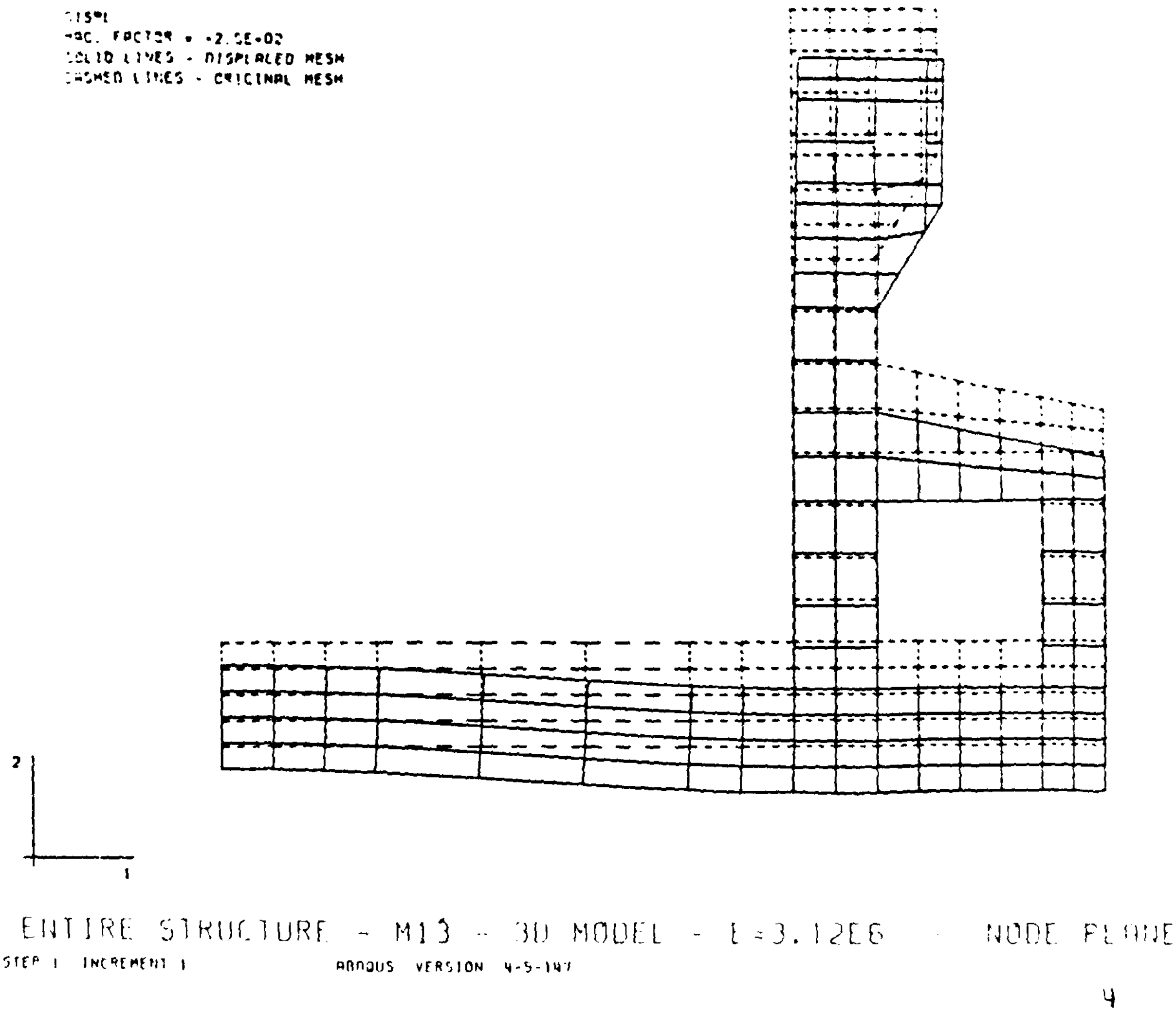


Figure 38d. Displaced structure for 3-dimensional analysis of Monolith 13 at node plane 4.

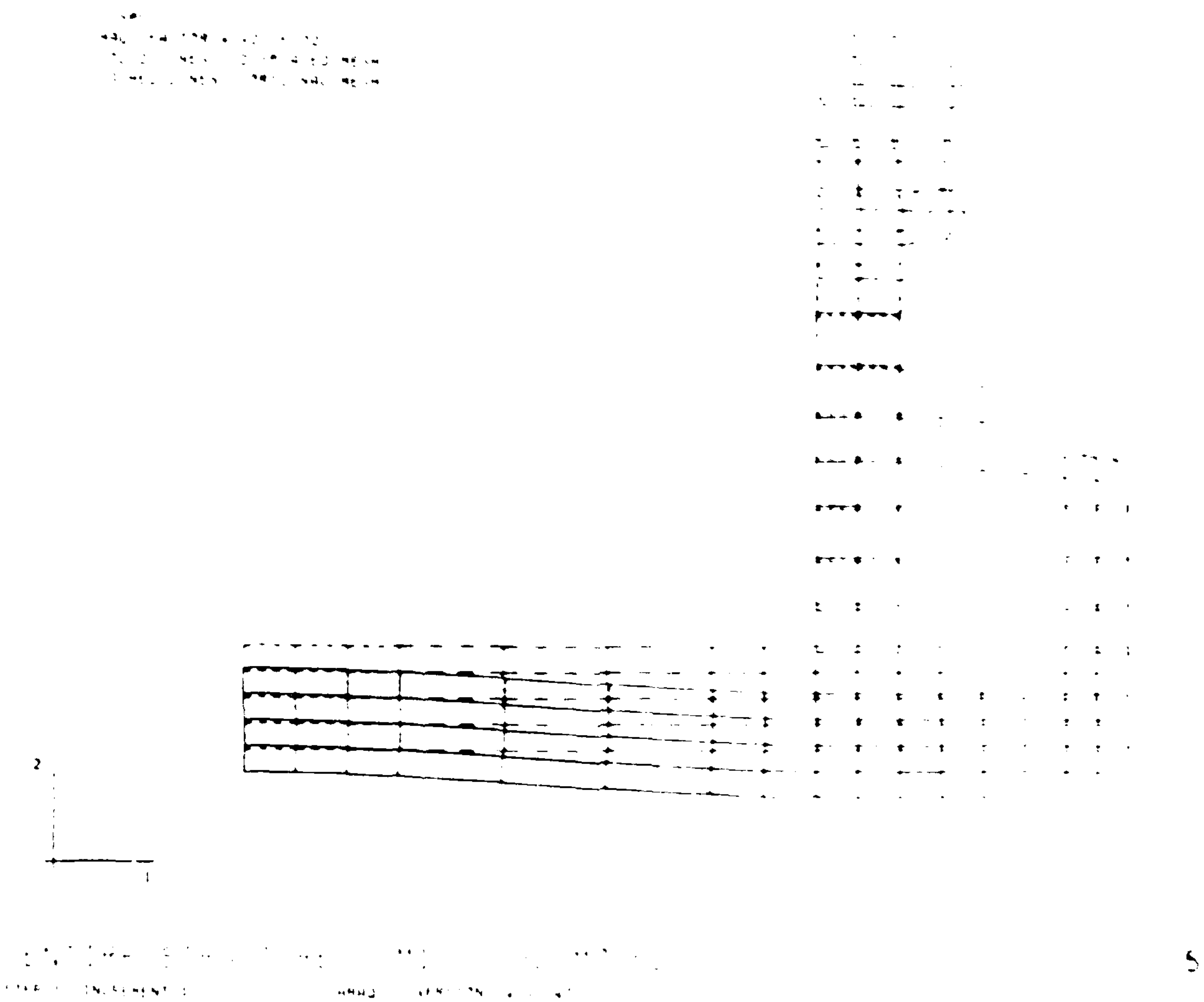


Figure 38e. Displaced structure for 3-dimensional a[illegible] at node plane 5.

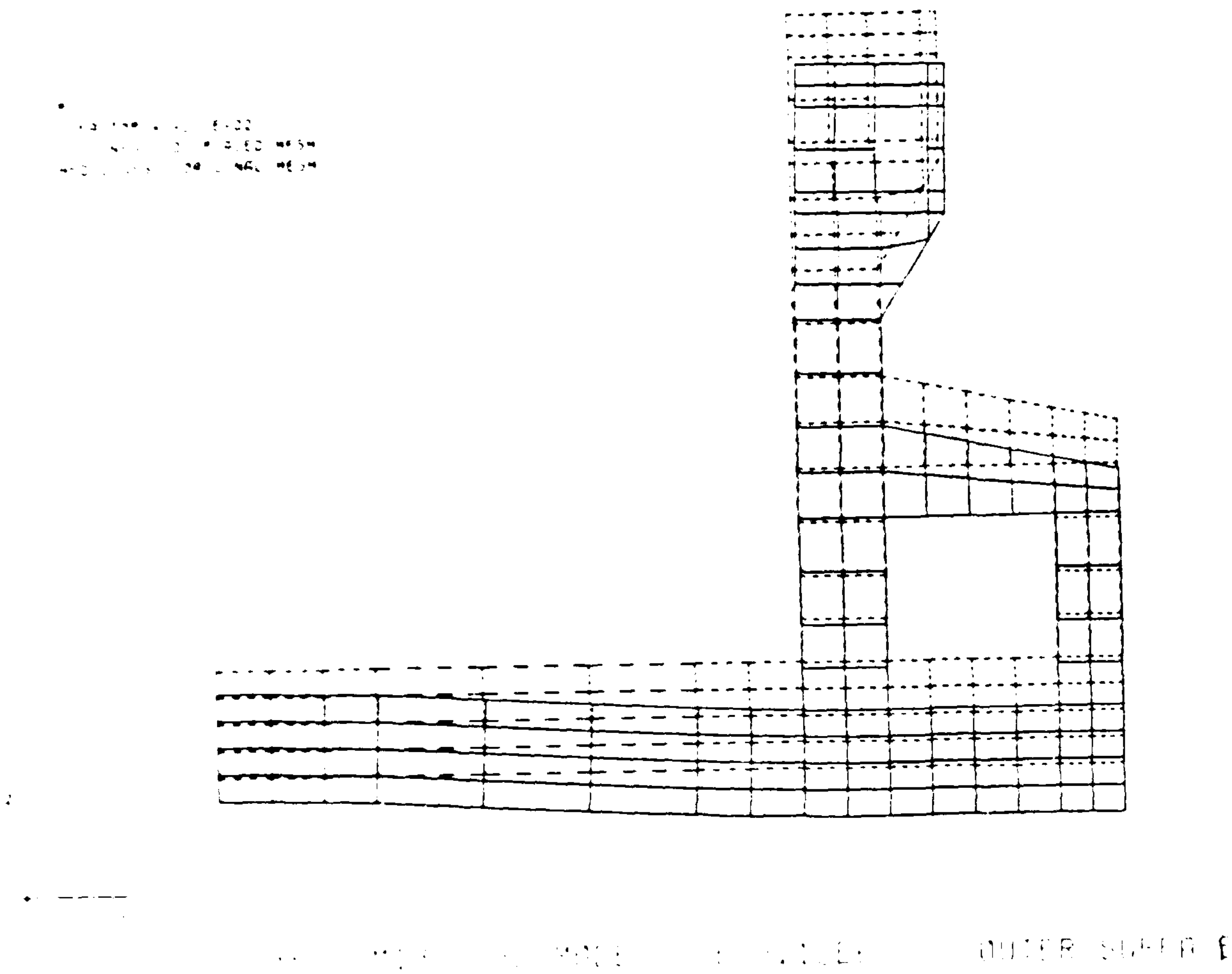
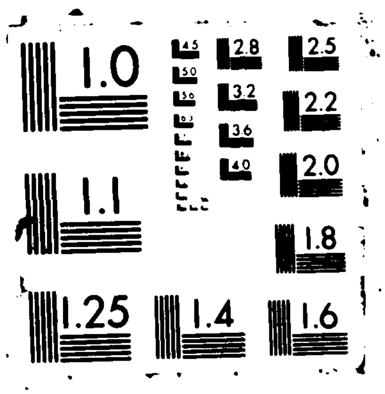


Figure [illegible] Displaced structure for 3-dimensional analysis of Monolith 13 at outer surface.

AD-A183 664 THERMAL STRESS ANALYSES OF MISSISSIPPI RIVER LOCK AND DAM 26(R)(U) ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MS STRUCTURES LAB A A BOMBICH ET AL. JUL 87 3/4

UNCLASSIFIED WES/TR/SL-87-21 F/G 13/13 NL


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0

PART IX: THERMAL ANALYSES OF MONOLITH L-17

Presentation of Results

Two-dimensional temperature analysis

94. Two-dimensional temperature analyses of monolith L-17 were also performed using both the ABAQUS and WES2DT programs. The 2-D FE models used by ABAQUS (Figure 7d) and WES2DT (Figure 7e) were based upon a cross-section taken at Station 26 + 13 which contained the smallest amount of internal voids. This cross-section was expected to experience the largest temperature rise in the monolith. The WES2DT grid only modeled the structure through lift 13. During the temperature analysis, the top surface of lift 13 was insulated after the time of placement of lift 14 to simulate the effects of the additional concrete. The gravity loading effects past lift 14 were modeled with pressure loads applied to the top of lift 13 to simulate placement of lifts 14 through 16 during the incremental construction stress analysis. Figures 39a thru 39e show results from the ABAQUS program at five stages of construction. Results from the WES2DT program are shown in Figures 40a thru 40d for the same first four of five stages of construction used for presenting ABAQUS data. The presentation of WES2DT temperature results beyond the time of placing lift 13 was omitted.

Three dimensional temperature analysis

95. Although a 3-D FE model of L-17 (Figure 7e) for use with the ABAQUS program was completed, the analysis could not be run. The temperature analysis was not made due to problems with the ABAQUS program in handling the required number of element sets and the excessive costs of making the computer runs.

Discussion of Results

Two-dimensional temperature analysis

96. The results from ABAQUS and WES2DT show very good agreement. The temperature contours, Figures 39 and 40, give the same trends and are in the identical locations for times through placement of lift 13. Slightly larger areas are shown for the 100° F contours from ABAQUS in Figures 39b and 39d that from WES2DT in Figures 40b and 40d. The ABAQUS analysis shows the maximum temperature of 105° - 110° F occurs after placement of lift 16 in the center of the massive wall section. Since the WES2DT model only extended through lift 13 the corresponding value is not given.

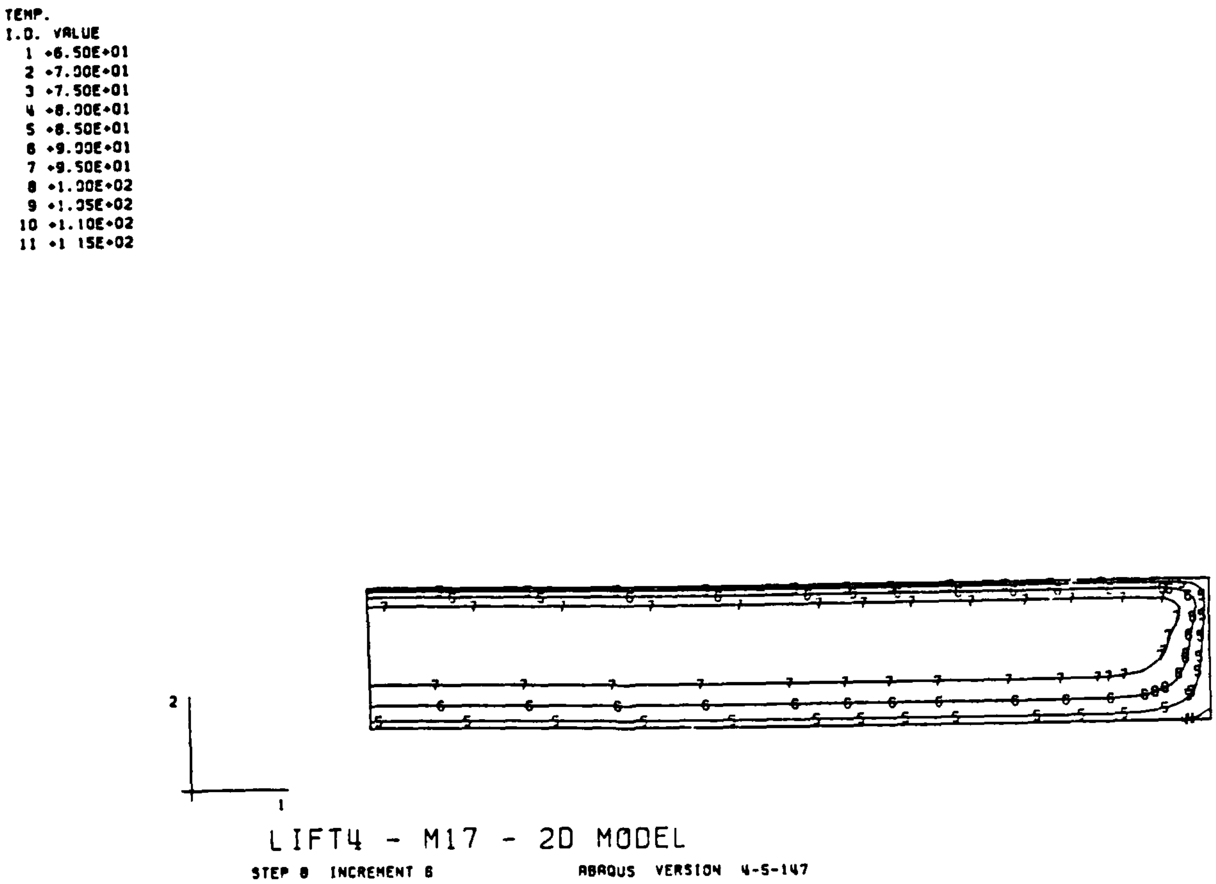


Figure 39a. Temperature contours calculated using ABAQUS in Monolith 17 at 5 days after placement of lift 4.

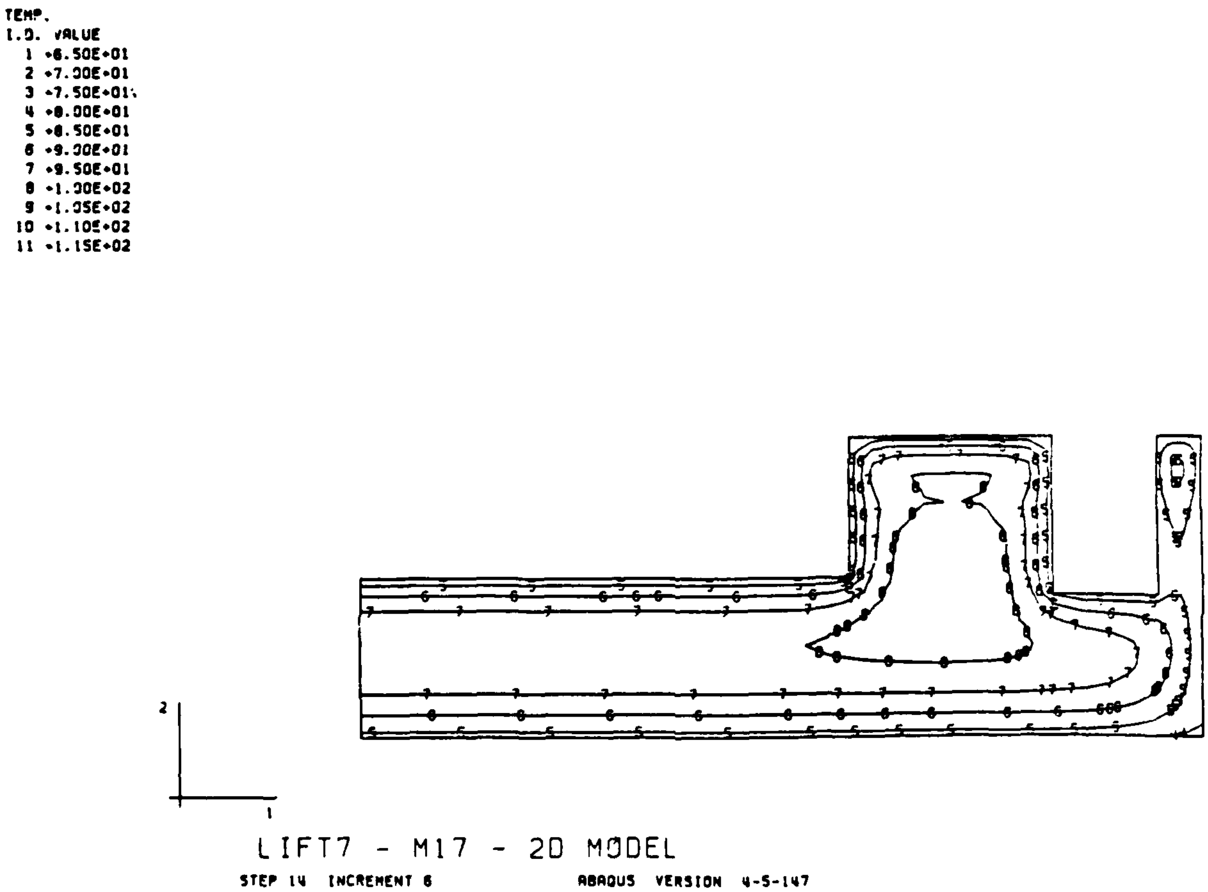


Figure 39b. Temperature contours calculated using ABAQUS in Monolith 17 at 5 days after placement of lift 7.

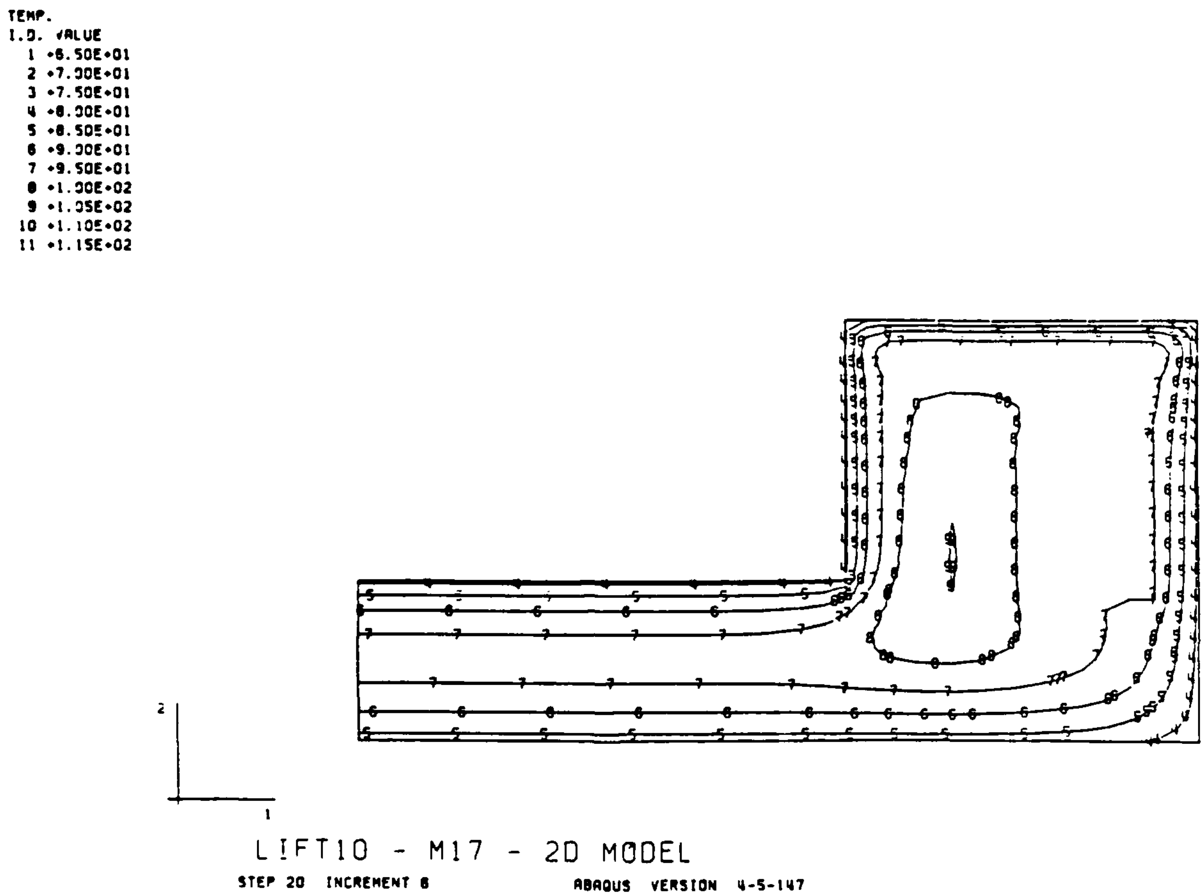


Figure 39c. Temperature contours calculated using ABAQUS in Monolith 17 at 5 days after placement of lift 10.

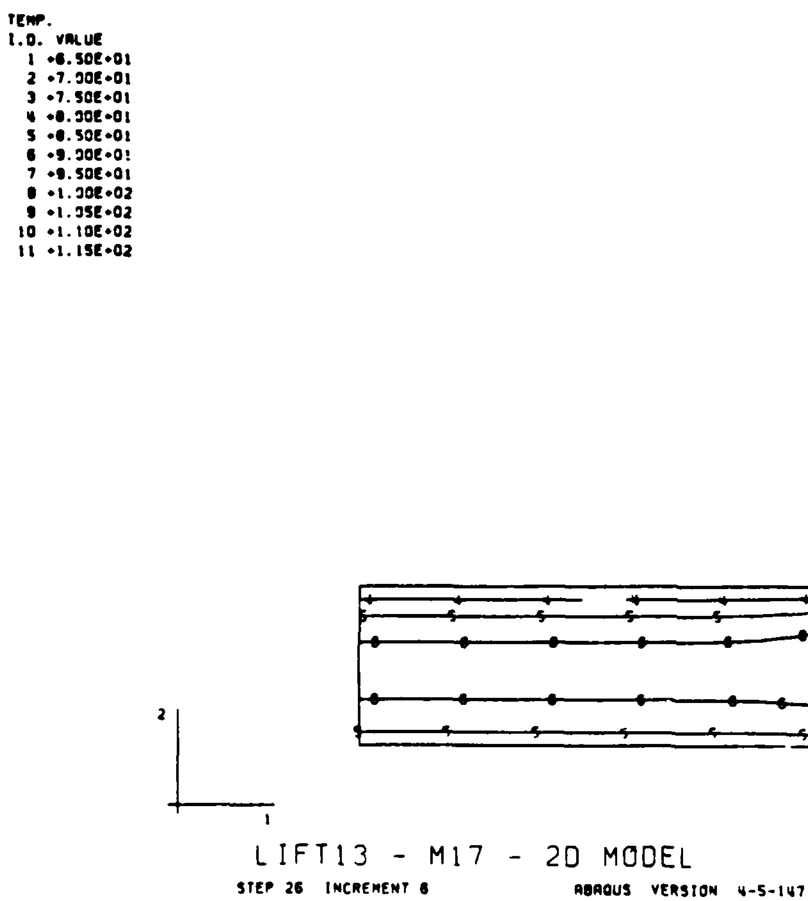


Figure 39d. Temperature contours calculated using ABAQUS in Monolith 17 at 5 days after placement of lift 13.

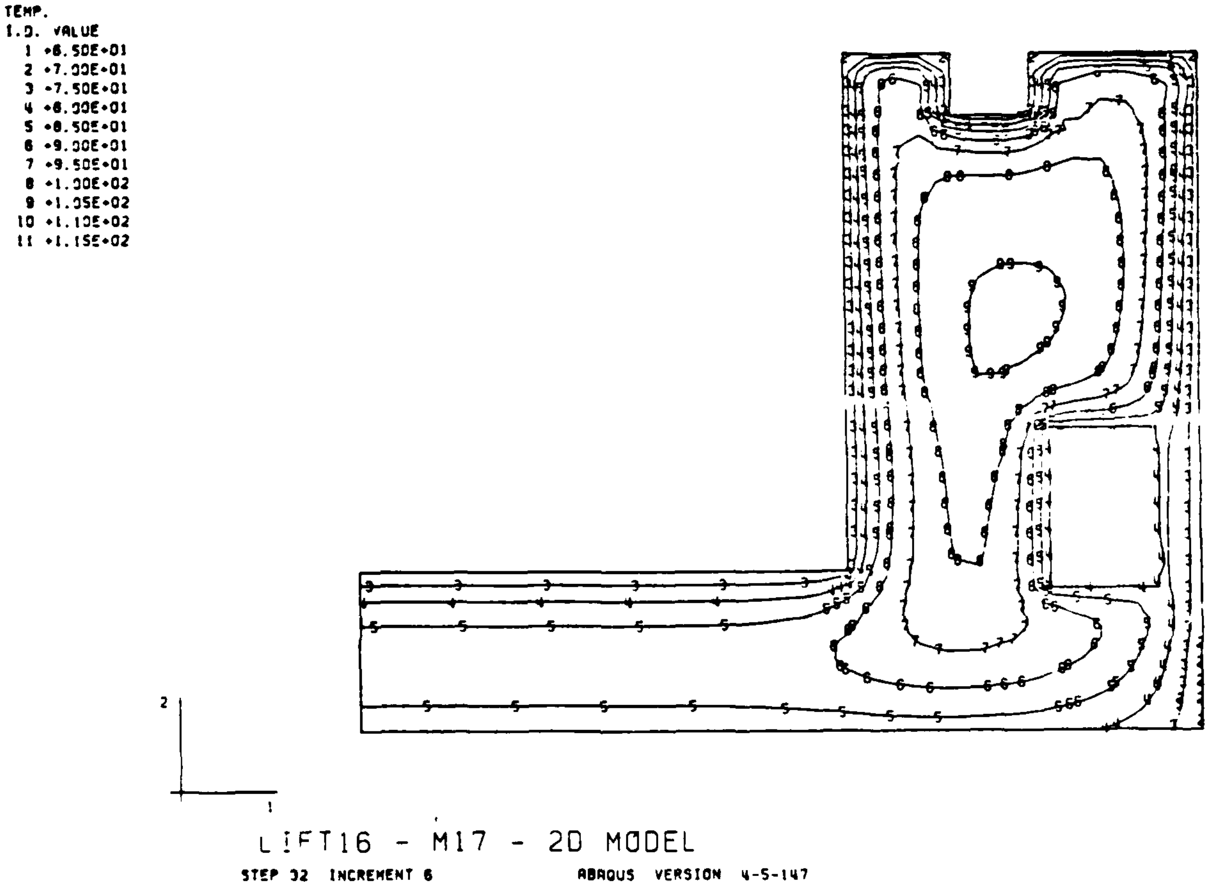


Figure 39e. Temperature contours calculated using ABAQUS in Monolith 17 at 5 days after placement of lift 16.

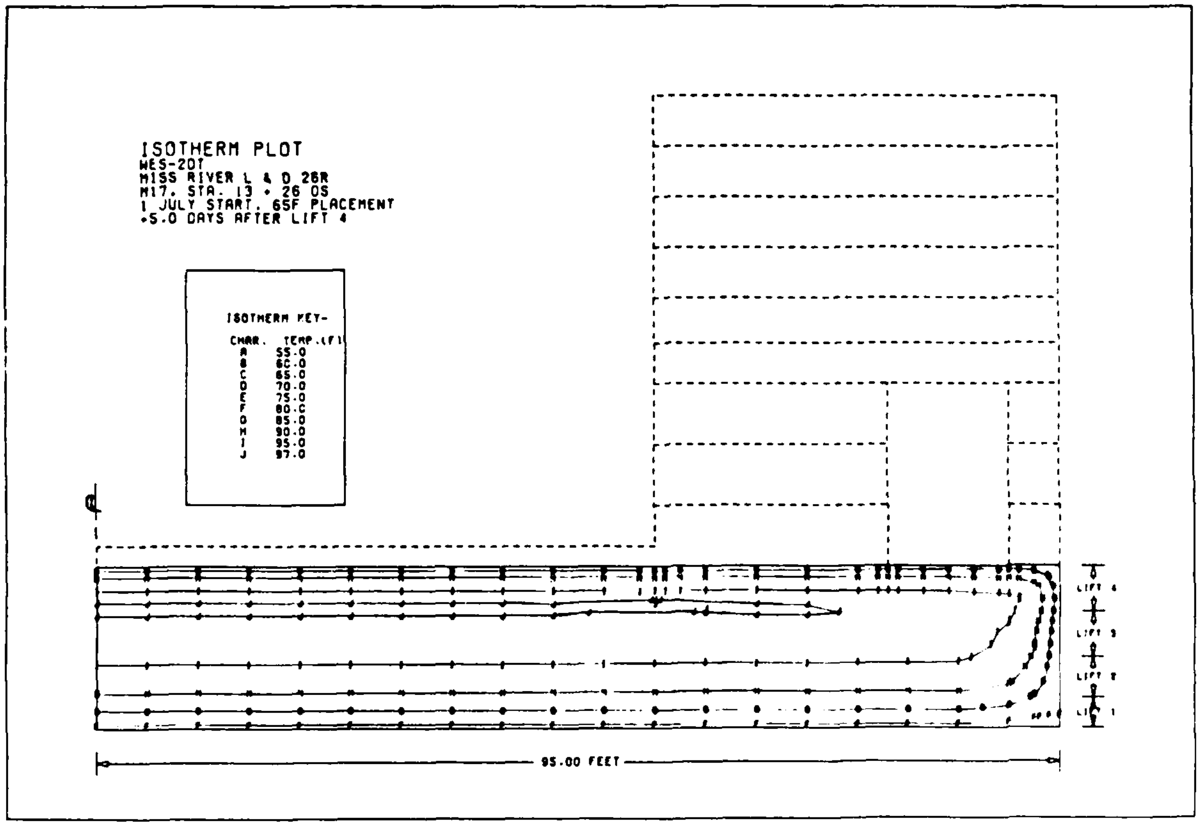


Figure 40a. Temperature contours calculated using WES2DT in Monolith 17 at 5 days after placement of lift 4.

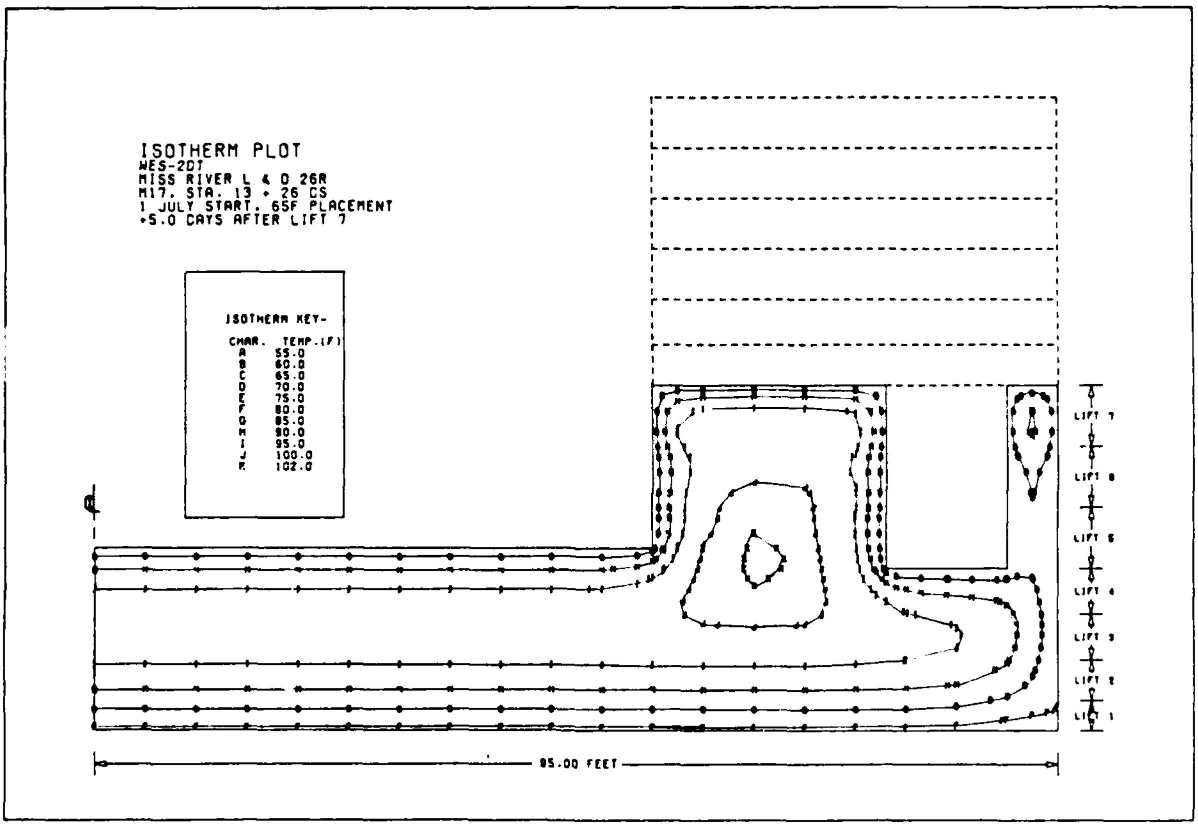


Figure 40b. Temperature contours calculated using WES2DT in Monolith 17 at 5 days after placement of lift 7.

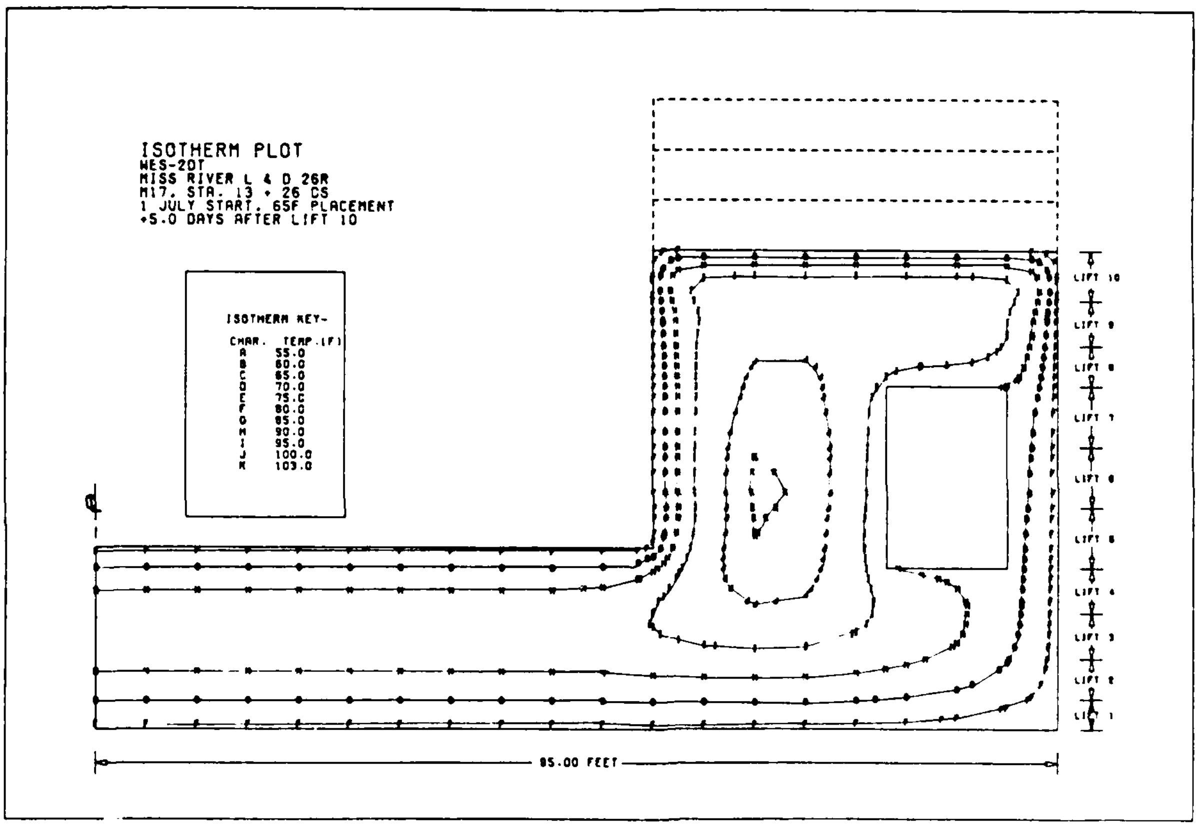


Figure 40c. Temperature contours calculated using WES2DT in Monolith 17 at 5 days after placement of lift 10.

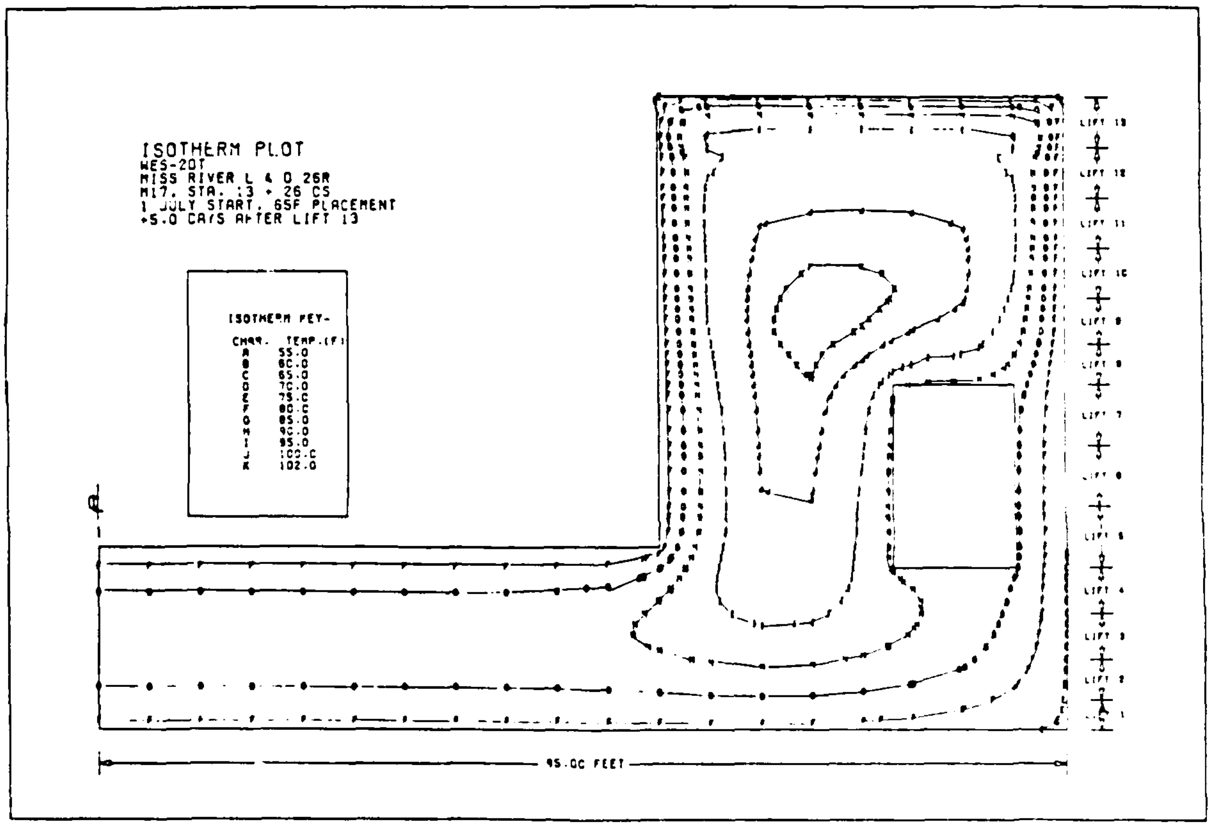


Figure 40d. Temperature contours calculated using WES2DT in Monolith 17 at 5 days after placement of lift 13.

PART X: STRESS ANALYSES OF MONOLITH L-17

Presentation of Results

Two-dimensional gravity loading

97. The ABAQUS program was used to perform the 2-D stress analysis of monolith L-17 for both instantaneous gravity turn-on of the entire structure and an incremental construction build-up sequence of the structure. Figures 41a and 41b show the displaced structure and maximum principal (tensile) stress contours, respectively, for the gravity turn-on analysis for a Young's Modulus (E) of 3.12×10^6 psi. Figures 42a and 42b give the same results for $E = 4.80 \times 10^6$ psi. These modulus values correspond to the ACI modified and normal compressive strength of the concrete at 28 days, respectively. Figures 43a thru 43c and 44a thru 44c show the displaced structure and maximum principal stress contours, respectively, for three stages of construction using incremental construction sequencing. This incremental construction analysis uses the material modulus calculation routine UMAT1.

98. WES2DT was used to make an incremental construction analysis. As described in paragraph 94, a FE model was prepared through lift 13. Gravity loads for lifts 14 through 17 were simulated by applying appropriate surface pressures to the top of lift 13. Figures 45a thru 45c and 46a thru 46c show the displacement vector plots and principal stress vector plots, respectively, from this analysis. Figures 45c and 46c represent the conditions at 5 days after lift 16 is placed which corresponds to ABAQUS analyses output in Figures 43c and 44c. All subsequent plots of WES2DT results will be similarly shown.

Two-dimensional gravity and thermal loading

99. The ABAQUS program was used to perform the 2-D stress analysis including gravity and temperature loading using the modulus routine UMAT1. The

displaced structure plots are given in Figures 47a thru 47c. The maximum principal stress contours are given in Figures 48a thru 48c. The modulus subroutine UMAT2 (concrete aging creep model) was used with ABAQUS to make an analysis with gravity and thermal loading. The displaced structure and maximum principal stress contours are given in Figures 49a thru 49c and 50a thru 50c, respectively. A WES2DT analysis was not made for this same gravity and temperature loading only.

Two-dimensional gravity and thermal loading including creep

100. ABAQUS was used in incremental construction analyses of the structure with the modulus subroutine UMAT2 including creep. Displaced-structure plots are shown in Figures 51a thru 51c. Maximum principal stress contours are shown in Figures 52a thru 52c. WES2DT was also used to make the same analysis. Figures 53a thru 53c show resultant displacement vectors and Figures 54a thru 54c show principal stress vectors from the WES2DT analysis.

Two-dimensional gravity and thermal loading including creep and shrinkage

101. ABAQUS was used to make this analysis also with modulus subroutine UMAT2. Displaced-structure plots for this analysis are shown in Figures 55a thru 55c. Maximum principal stress contours are shown in Figures 56a thru 56c.

Discussion of Results

Gravity turn-on analyses

102. Comparisons of gravity turn-on analyses of monolith L-17 made with $E = 3.12 \times 10^6$ psi and $E = 4.8 \times 10^6$ psi seen in Figures 41and 42, respectively, showed both the displacements and stresses to be in close agreement. Maximum principal stresses are slightly higher for $E = 4.8 \times 10^6$ psi as expected especially in the top, center of the base slab.

Incremental construction
with gravity loading only
ABAQUS versus WES2DT

103. Incremental construction analyses of monolith L-17 with gravity loading only were conducted with ABAQUS and WES2DT. Comparison of displacement results in Figures 43 and 45 show the results to be very similar. The largest deflections in the base slab occur all along its entire length except near the center of the wall zone after placement of the first four lifts (Figures 43a and 45a). This is because the loading is uniform and the pile support is stronger under the wall. As concrete in the lower wall region was placed, deflections in the base slab became more uniform (Figures 43b and 45b). As wall placement continued, displacements of the slab under the wall increased and maximum displacements in the slab shifted outward toward the edge of the monolith (Figures 43c and 45c).

104. Stress comparisons between the ABAQUS and WES2DT programs required comparing principal stress in contour and vector plots (Figures 44 and 46), respectively, as was described earlier in discussion of L-13. Maximum tensile stresses were generally in the same locations of the models with both programs.

Gravity turn-on versus
incremental construction

105. Comparisons between whole-structure gravity turn-on and incremental construction simulation with gravity loading only with ABAQUS showed predictable results. In both analyses, the maximum displacements of the base occurred after the simulation reached full height. Displacements were less at the centerline of the slab and greatest near the outer edge ofthe monolith under the wall. Actually, displacements at the outer edge were greater in the incremental construction analysis. As was demonstrated in the L-13 analyses, the displacements within the base slab and wall were characteristically different in gravity turn-on and incremental construction analyses. During increme-

ntal construction, each successive lift is placed up to its planned elevation. Therefore, the displacement of the top of each lift decreases at higher elevations in the structure. Conversely, in the gravity turn-on analysis, the maximum displacement occurs at the top of the wall because all displacements accumulate at the highest elevation. These results have thus exhibited known modes of displacement for gravity turn-on and incremental construction analyses.

106. Stress contours resulting from ABAQUS calculations of gravity turn-on and incremental construction were very similar as expected. Stress values within the base slab were slightly higher for the gravity turn-on analysis which used $E = 4.8 \times 10^6$ psi and for incremental construction analysis because E values were more similar while the wall was placed.

Two-dimensional
gravity and thermal loading

107. When thermal effects due to heat of hydration of cement were added to the loading, the predominant changes in the response of the structure were, as with L-13 analyses, an elongation of the base slab and a downward curvature of the outer end of the base slab. However, in L-17 the curvature phenomenon continued into the wall. These effects were observed from the both the ABAQUS and WES2DT results. This response is illustrated by comparing Figures 47, 49, 51, and 53. Elongation of the slab is due to thermal expansion relative to the centerline. As described in paragraph 76, the curvature occurs as a result of differential thermal expansion between a new lift and previous lifts. In FE analyses of monolith L-13, the differential expansion phenomenon only occurred in the two lifts of the base slab. None of the higher lifts was sufficiently long for any observable curvature to result. In monolith L-17, however, there are four full and one partial full-width lifts in the base and nine full-width lifts in the wall. The differential thermal expansion of all these lifts

contributes to a curvature in both the base slab and wall.

108. The addition of thermal loading caused an increase in maximum principal (tensile) stresses along the bottom of the base slab near the centerline and on the top surface of the base slab near the outer edge through placement of lift 4. The maximum principal stress response was similar up to this stage of simulated construction from use of both modulus subroutines UMAT1 and UMAT2 (Figures 48a and 50a). The increases in tensile stresses due to thermal loading in the areas cited above were more than 300 psi and 100 psi, respectively. Results from use of UMAT1 and UMAT2 began to differ by the time lift 16 in the wall was placed. With UMAT1, the zone of maximum tensile stress continued to be located along the bottom of the base slab near the centerline. With UMAT2, however, the zone of maximum tensile stress shifted to the top of the base slab near the centerline. This difference in maximum principal stress response is again attributed to the higher values of E within the first day with UMAT2.

109. The addition of thermal loading also increased the level of maximum principal (tensile) stresses in the wall. Tensile stresses increased from near zero with gravity loading only to about 200 psi on the top surface of lift 8 with both UMAT1 and UMAT2. As lifts 9 through 16 were added, maximum principal stresses in the upper, massive portion of the wall appeared to coincide with lift interfaces in a vertically, alternating pattern of higher and lower stress contours (Figures 48c and 50c). It is believed that the higher tensile stress levels that exist on the top surface of each new lift are "locked in" as a result of placement of the successive lift. Lower levels of maximum tensile stresses in these areas were generated in the UMAT2 analysis. This situation may be attributed to the higher, early-age E values used by the subroutine UMAT2. It is believed that different stress fields are developed when the values of E change during the same time that a temperature change is ongoing

in the concrete. The higher initial E in UMAT2 prevents this same reaction. A comparable WES2DT analysis with gravity and thermal loading, but without creep was not conducted.

Two-dimensional gravity and thermal loading including creep

110. Analyses of L-17 which included gravity and thermal loading with creep were conducted using both ABAQUS-UMAT2 and WES2DT. The effects of creep, as on monolith L-13, changed the displaced response of the monolith. When ABAQUS results using UMAT2 with creep were compared with those without creep, it was seen that creep decreases the curvature of the outer, bottom of the base (Figures 49 and 51). Outward expansion of the base slab and wall increased with creep, the direct result of displaced relaxation of the lower lifts to the elongating force supplied by the thermally expanding subsequent lifts. It seems reasonable certain that this effect is exaggerated due to the higher, early-age E values used by UMAT2. With creep, the concrete appeared to displace in an exaggerated manner in certain locations. This was the case for the increased vertical displacement of the outer edge of the floor slab (Figures 49c and 51c).

111. The displacement trends produced by ABAQUS and WES2DT did not compare (Figures 51 and 53) as well as was seen earlier with results from L-13. Again this may be partially due to the different plane strain formulations used in the two programs that was discussed earlier. The larger mass of this monolith increased internal temperatures. Therefore, increased potential existed for differential expansion. It has been seen that this differential caused generalized curvature of the monolith. However, the combined effects of high early-age E , higher creep potential than used by WES2DT, increased member stiffness due to size, and higher temperature rise caused larger lateral expansion. Actually, the displacements from the WES2DT analysis more closely

matched the ABAQUS-UMAT2 analysis without creep. This may indicate that the amount of creep in the ABAQUS-UMAT2 analysis is excessive.

112. When comparing the ABAQUS-UMAT2 maximum principal stress plots without creep (Figures 50) to maximum principal stress plots with creep (Figure 52), the following observations were made. The relaxation of stresses due to creep with ABAQUS-UMAT2 reduced peak principal stresses in the base slab from 300 psi (Figure 50a) to 100 psi (Figure 52a) at five days after placement of lift 4. At 5 days after placement of lift 7, peak principal stresses in the base slab were reduced from around 300 psi (Figure 50b) without creep to 50 psi with creep (Figure 52b). Maximum principal stresses in the vicinity of lift 13 at 5 days after placement of lift 16 were 100 psi without creep and near zero psi with creep. In contrast, maximum principal stresses in the base slab from WES2DT with creep were about 225 psi at 5 days after placement of lift 4, and approximately 175 psi at 5 days after placement of lift 7. Although WES2DT was not run without creep for L-17, the very large relaxation of stresses due to creep with ABAQUS-UMAT2 and the higher stresses with creep from WES2DT act to confirm the apparent excessive creep from UMAT2. This is the same conclusion as reached in paragraph 82 for the analyses of L-13. It is expected that incorporating into UMAT2 a corrected E versus time modulus model that better represents the 1- to 2-day values and comparable creep data as were used in the WES2DT analysis, lower initial stress levels and less creep relaxation would result from ABAQUS analyses.

Two-dimensional gravity and thermal loading including creep and shrinkage

113. An ABAQUS analysis was conducted on L-17 using UMAT2 with gravity and thermal loading including creep and shrinkage. The addition of this autogenous shrinkage caused similar, noticeably different results as was seem earlier in L-13. Comparison of ABAQUS analyses with creep, but with and with-

out shrinkage showed both different displacement and principal stress response. Comparison of displaced grids (Figures 51 and 55) for analyses with and without shrinkage, respectively, shows that the addition of shrinkage greatly reduced the thermal elongation of successive lifts in the base slab and reduced the differential thermal expansion between these lifts. The result was greatly reduced downward curvature of the outer end of the base slab and a general shortening of the slab. Shrinkage did cause the wall to attain a curvature vertically along both the inner and outer surfaces (Figure 55c).

114. Comparison of maximum principal stresses showed that at 5 days after placement of lift 4, peak values were nearly the same as without shrinkage. However, the location of maximum stresses changed from the bottom of the base slab without shrinkage to the top of the slab with shrinkage applied. Maximum principal stresses also increased in the wall, especially at times shortly after placement. This is seen in comparisons of maximum principal stresses in Figures 52b - 52c and 56b - 56c . Stresses in the last two lifts placed with shrinkage are clearly higher. Shrinkage provides an additive effect to thermal stresses that result from internal restraint.

Pile loads

115. As stated earlier, the distribution of the pile loads along the bottom of the base slab is principally dependent upon the base slab deflections. Table 9 gives the vertical pile loads from the different ABAQUS and WES2DT analyses and those supplied by the St. Louis District.

116. The ABAQUS results for a gravity turn-on analysis using an ACI-modified modulus value is in close agreement with the St. Louis District results. The discrepancies can be attributed to minor cross-sectional differences in the two cases. An ABAQUS analysis was also made using the unmodified modulus value since the remaining incremental analysis would also

Table 7. Vertical Pile Loads for Monolith 17
(5 Days after placement of last lift)

GRAVITY TURN-ON				GRAVITY ONLY		GRAVITY & THERMAL LOADS		GRAVITY & THERMAL LOADS		
Pile No	St Louis District	ABAQUS		ABAQUS (UMAT1)	WES2DT	ABAQUS		(W/CREEP)		(W/CREEP & SHRINK.) ABAQUS
		E1	E2			(UMAT1)	(UMAT2)	ABAQUS	WES2DT	
1	92.0	94.2	100.6	99.6	92.8	85.9	86.2	62.4	78.9	67.2
2	92.5	95.8	101.8	102.2	94.5	88.3	87.6	78.7	79.3	82.3
3	92.8	97.3	103.3	105.8	99.0	91.2	88.6	76.8	80.3	79.2
4	151.1	162.5	171.2	177.4	165.0	152.2	144.9	147.3	165.1	146.7
5	158.2	167.7	176.4	182.9	171.9	155.4	145.0	131.7	170.1	128.1
6	168.6	178.0	185.4	192.6	180.9	162.1	147.7	171.8	176.3	161.2
7	172.6	186.8	193.6	201.1	192.0	167.3	148.1	160.2	183.6	146.4
8	185.8	200.9	205.9	214.5	205.0	176.4	151.2	211.6	191.8	194.6
9	192.8	212.5	216.6	225.9	219.5	183.9	152.0	201.8	200.8	187.8
10	207.3	229.8	231.4	241.7	235.3	195.4	156.4	258.0	210.0	254.6
11	216.2	243.8	244.5	254.2	251.6	204.4	160.3	249.4	219.3	256.1
12	231.7	261.2	260.0	267.9	267.6	214.7	169.3	274.0	228.0	293.0
13	241.3	278.9	276.1	279.3	281.9	225.5	184.1	292.1	378.0	323.1
14	256.0	295.7	291.7	287.4	293.1	239.0	208.2	297.5	402.0	337.1
15	266.9	313.6	308.1	295.4	301.3	263.3	250.0	319.4	219.0	360.0
16	279.0	324.5	320.0	302.4	313.9	301.2	309.1	280.6	245.4	303.5
17	291.1	340.4	335.2	320.0	332.1	366.2	399.8	304.0	282.5	309.5
18	303.2	359.8	352.7	348.9	359.4	460.0	523.4	376.1	332.4	348.8
19	315.3	255.2	247.9	260.1	265.8	388.2	453.2	367.9	265.3	302.3

NOTE - All pile loads are in KIPS/PILE

GRAVITY TURN-ON	- Instantaneous placement of entire structure in one step
GRAVITY ONLY	- Incremental construction of structure in lifts with only gravity applied
GRAVITY AND THERMAL LOADS	- Incremental construction of structure in lifts with gravity and temperature loading
St. Louis District	- Pile loads supplied by St. Louis District (E = 3,120,000 psi)
E1	- ABAQUS results using E = 3,120,000 psi (28-day strength modified by ACI code)
E2	- ABAQUS results using E = 4,800,000 psi (28-day strength)
UMAT1	- Origional modulus calculation routine modified for use with ABAQUS in this study, only considers aging of the concrete
UMAT2	- New modulus routine which can include aging, creep, shrinkage and E as a function of temperature

use unmodified values. As in the L-13 runs, this stiffer concrete slightly redistributed the pile loads with the higher values being located under the wall. Maximum loads were approximately 350 kips/pile.

117. When the lock was constructed incrementally using ABAQUS and WES2DT with only gravity loading, a slight redistribution of pile loads took place. Smaller loads were located under the wall and larger loads were located under the chamber section of the slab. These shifts in loads were less than 20 kips/pile with very good agreement between ABAQUS and WES2DT. The maximum pile loads occurred at the same location with only a slight decrease in magnitude when compared with gravity turn-on analyses.

118. As thermal loading was added, the pile loads shifted more to the wall area with both UMAT1 and UMAT2 modulus subroutines. With UMAT1 the maximum pile load was 460 kips/pile while with UMAT2 it was 520 kips/pile. These maximum loads occurred at the second pile in from the outer edge of the monolith in both cases.

119. When creep was considered in the analysis, the ABAQUS and WES2DT programs gave similar results except for piles 10 - 15. This is principally due to the WES2DT analysis using a smeared pile stiffness over a given are while ABAQUS used discrete piles. ABAQUS and WES2DT produced larger pile loads under the inner wall area while having lower values under the wall toward the outer edge. The maximum values from ABAQUS was 376 kips/pile and again occurred at the second pile from the outer edge of the monolith. The WES2DT results gave the maximum load in pile 14 under the inner wall. However, this is misleading since an artificially high stiffness was used at this location because it was at the intersection of two zones of the smeared pile stiffnesses.

120. When shrinkage was added to the analysis with ABAQUS, the loads were redistributed. There was a slight increase in loads under the chamber

area, a significant increase in loads under the wall, and a decrease in loads at the outer edge. The maximum pile load occurred under the wall with a value of 360 kips/pile. However, the previous location of maximum pile load still carried a load of 350 kips/pile. Therefore, other locations can be considered critical.

Cracking potential

121. Comparisons of results were also made to evaluate the potential for cracking of concrete in the L-17 analyses reported herein. Modulus of rupture test results cited in paragraph 90 were again used as a simple cracking threshold for tensile stress. As a review, the modulus rupture values used were 124 psi, 280 psi, 320 psi, and 464 psi at 1-, 3-, 7-, and 28-days age, respectively. The following conclusions are made regarding cracking potential in monolith L-17.

122. First, maximum principal stresses computed in WES2DT analyses which included gravity and thermal loading with creep reached 225 psi in the bottom of the base slab (lift 1). These stresses developed over a period of more than 21 days as a reaction to thermal expansion of lifts 2 through 5. Consequently, the peak value was not reach until the concrete in lift 1 was more than 21 days old and had attained a modulus of rupture of about 425 psi. Thus the maximum tensile stress was less than 55 percent of tensile stress capacity.

123. Secondly, maximum principal tensile stresses computed in ABAQUS analyses using UMAT1, which employed the identical modulus versus time relationship as WES2DT analyses, reached 300 psi in the top of the base slab by 5 days after placement of lift 7 and 250 psi in several locations in the wall (Figure 48). The 300 psi level occurred in concrete that was at least 15 days old and the 250 psi values developed around 5 days after placement. Even

without the benefit of creep stress relief, which should relax stresses by 20-40 percent, these peak tensile stresses are only around 80 percent of modulus of rupture attained at the concrete age when maximum tensile stresses occurred.

124. Finally, maximum principal tensile stresses computed in ABAQUS analyses using UMAT2, which contained an excessively high modulus function for the first day or so of age, reached 300 psi in the bottom of the base slab by 21 days after placement of lift 1. Stresses were only about 100 psi in the same location and time when creep was applied. Stresses in the wall without creep reached around 200 psi and with creep were about 100 psi (Figures 50 and 52). Considering that the computed early-age stresses were probably high due to the higher initial modulus used in UMAT2, it is probable that stress values generated by ABAQUS will be less than shown here. This reinforces the conclusion reached with the WES2DT analyses that peak tensile stresses are less than 55 percent of modulus of rupture in this structure.

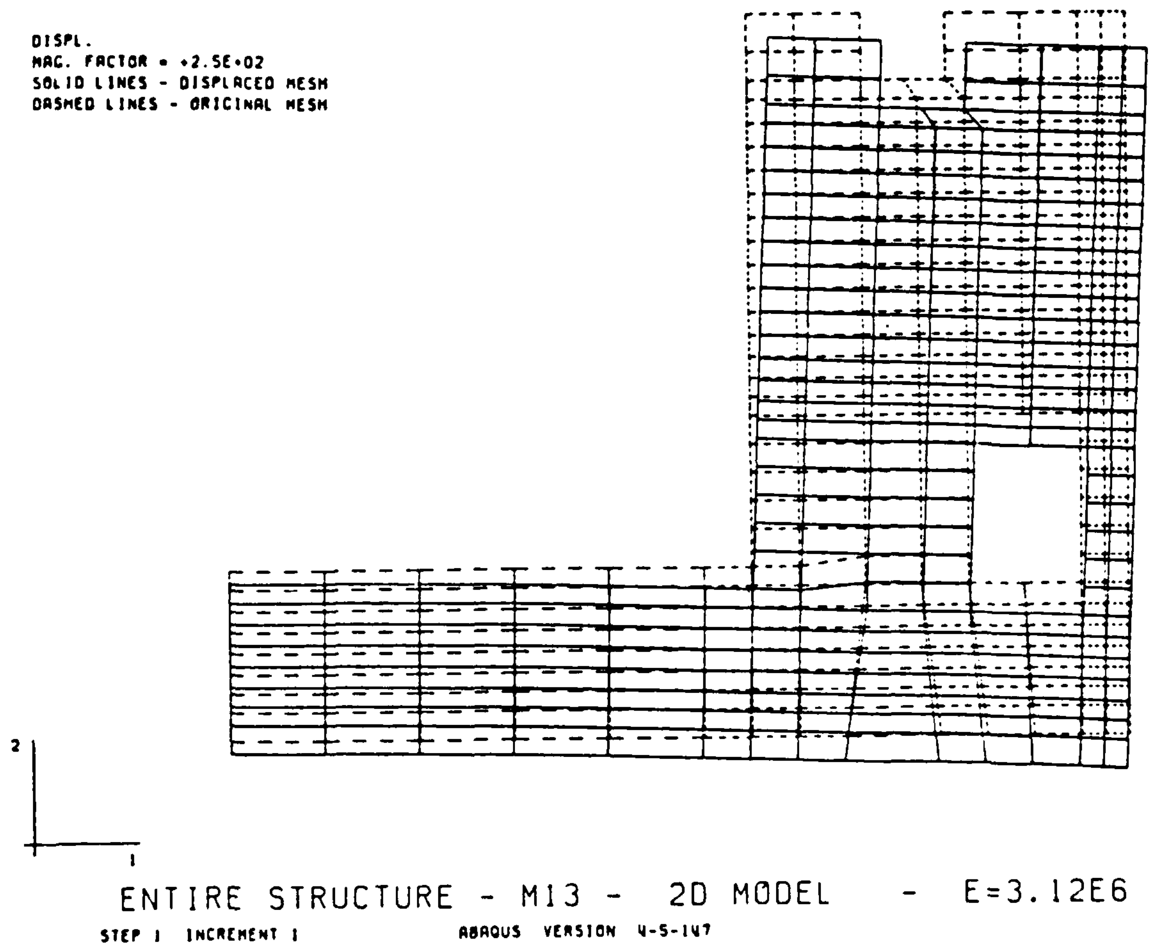


Figure 41a. Displaced structure from gravity turn-on analysis, $E = 3.12 \times 10^6$ psi

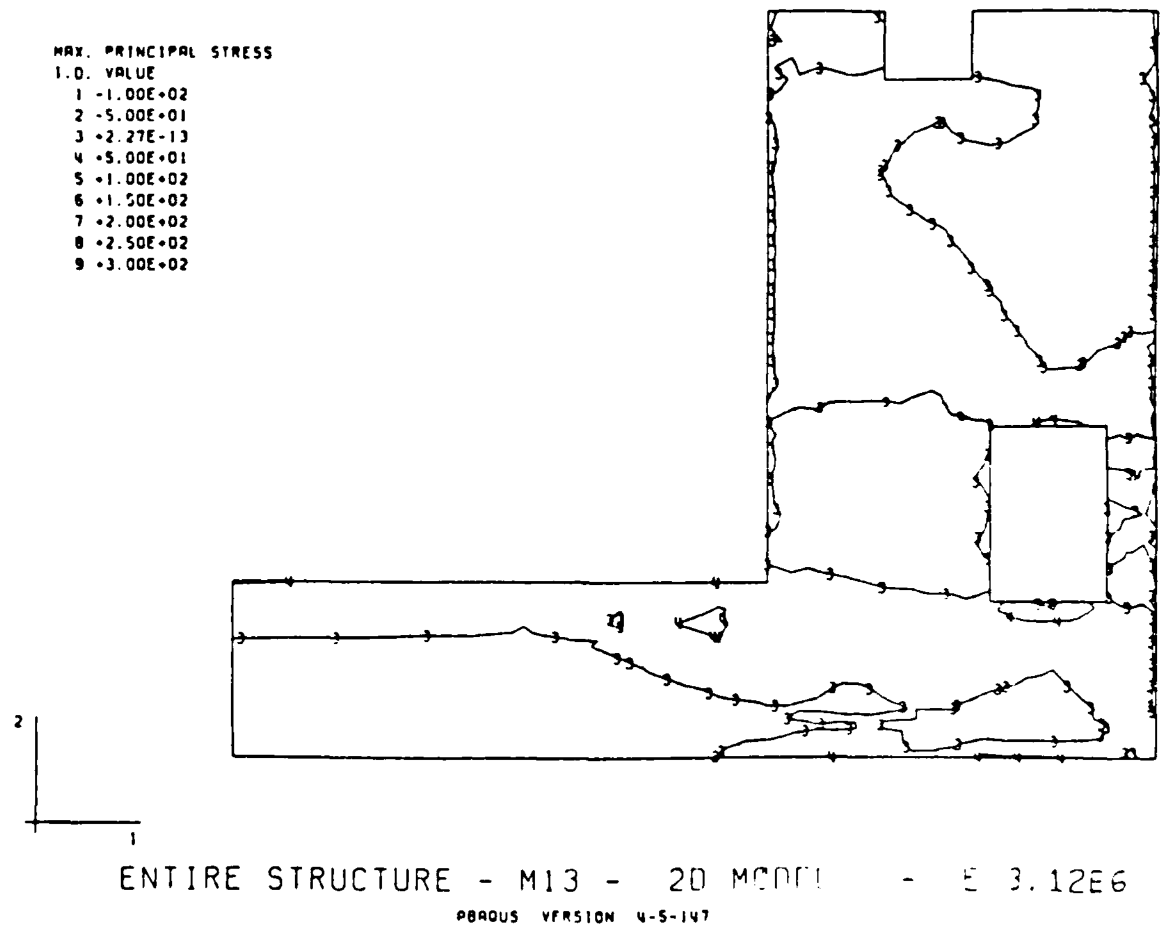


Figure 41b. Maximum principal stress contours for gravity turn-on analysis, E = 3.12×10^6 psi

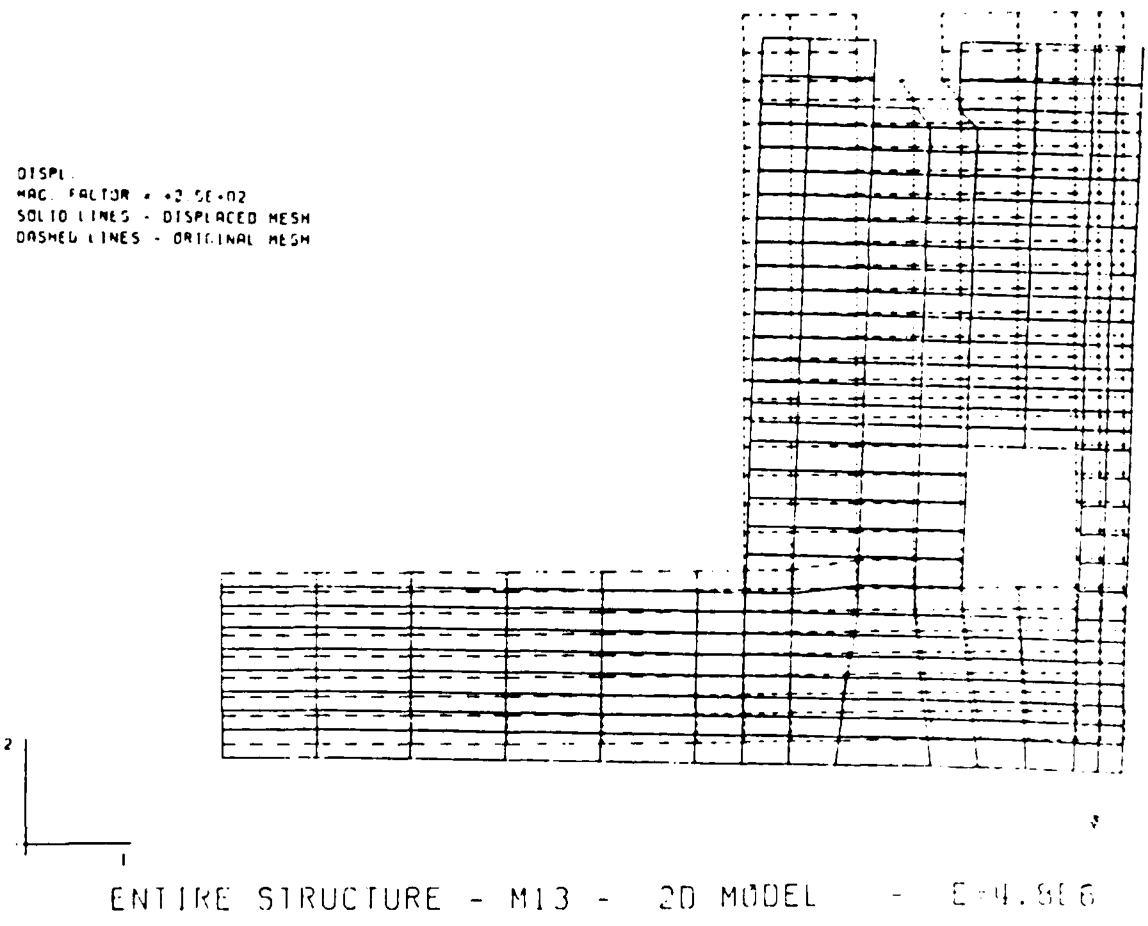


Figure 42a. Displaced structure from gravity turn-on analysis.
$E = 4.8 \times 10^6$ psi

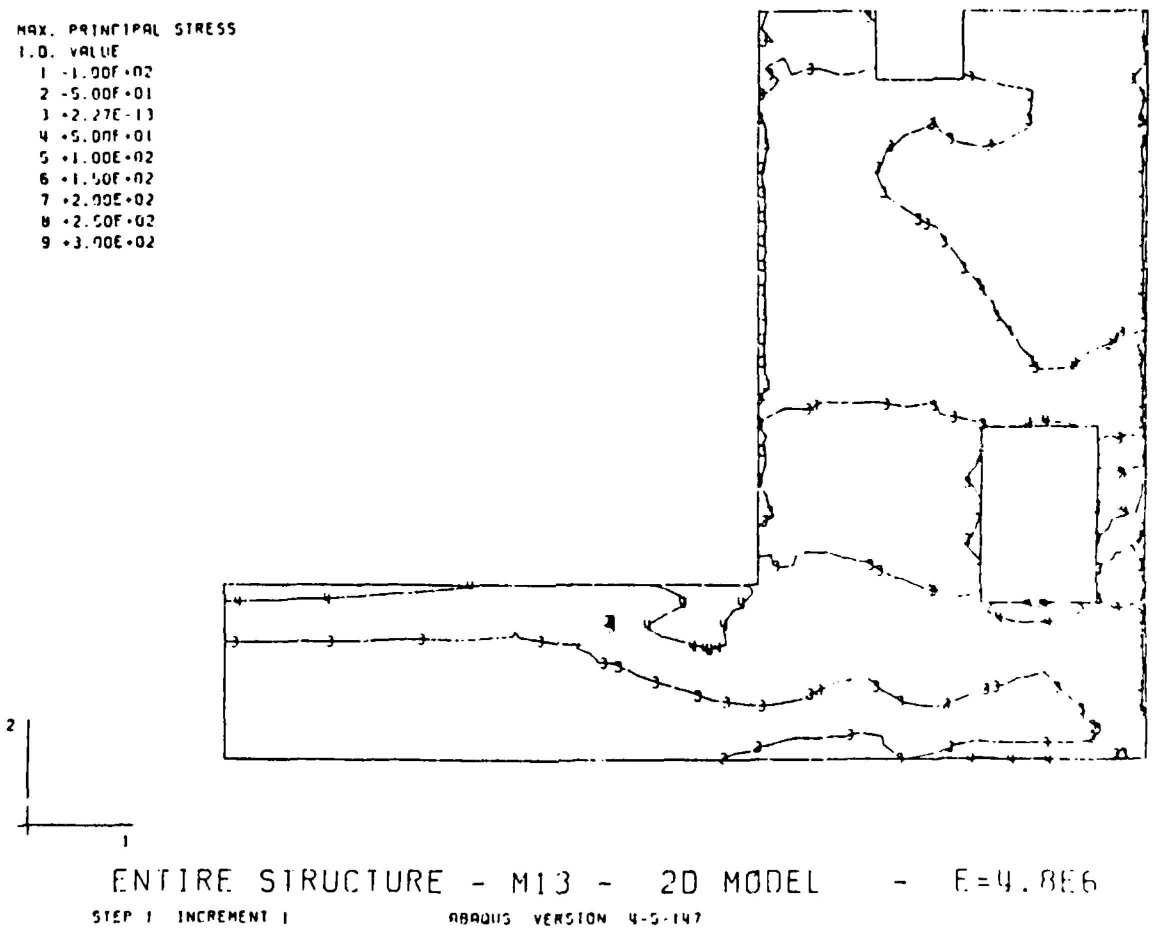


Figure 42b. Maximum principal stress contours for gravity turn-on analysis, $E = 4.8 \times 10^6$ psi

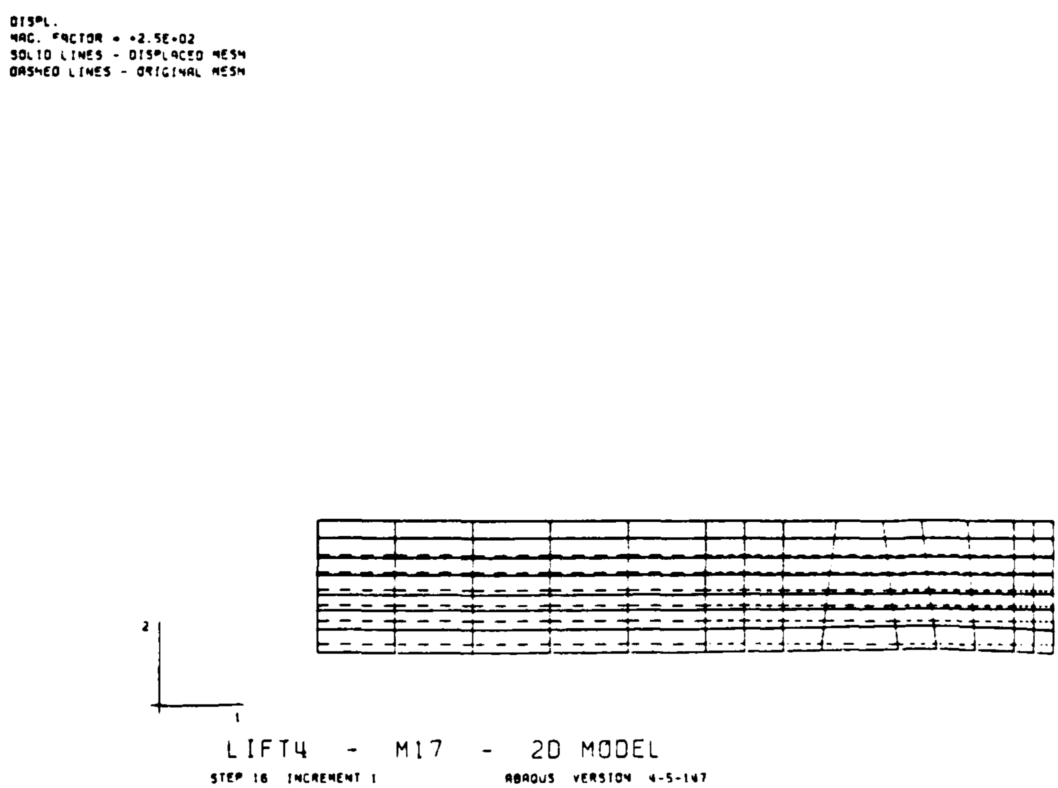


Figure 43a. Displaced structure 5 days after placement of lift 4, gravity loading only, using ABAQUS.

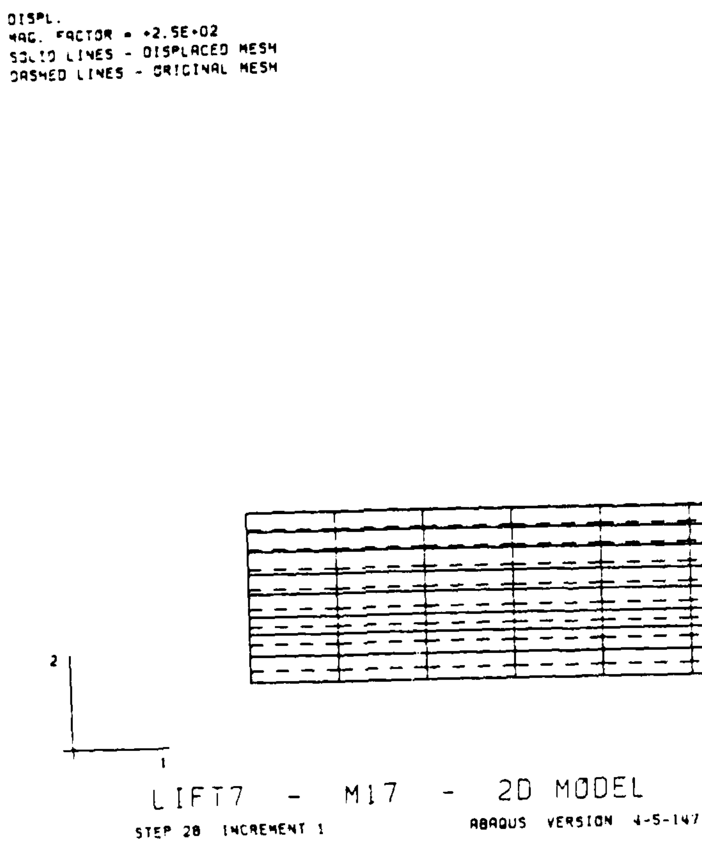


Figure 43b. Displaced structure 5 days after placement of lift 7, gravity loading only, using ABAQUS.

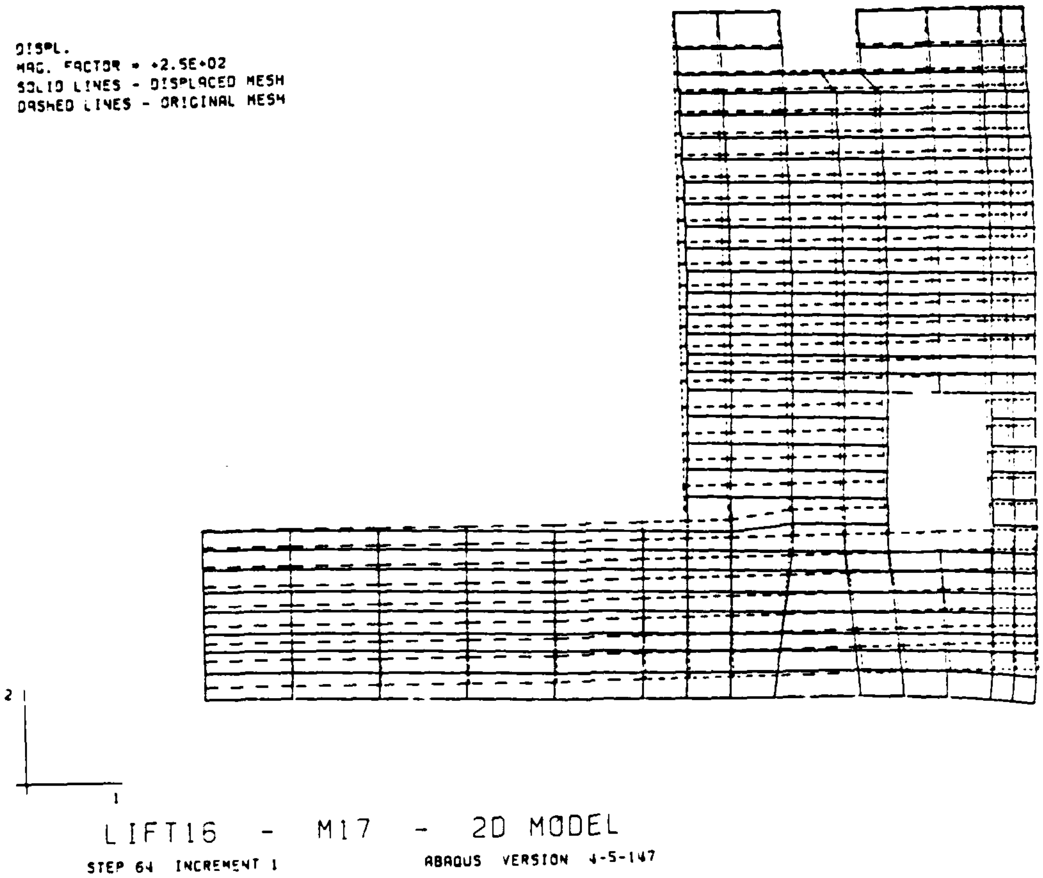


Figure 43c. Displaced structure 5 days after placement of lift 16, gravity loading only, using ABAQUS.

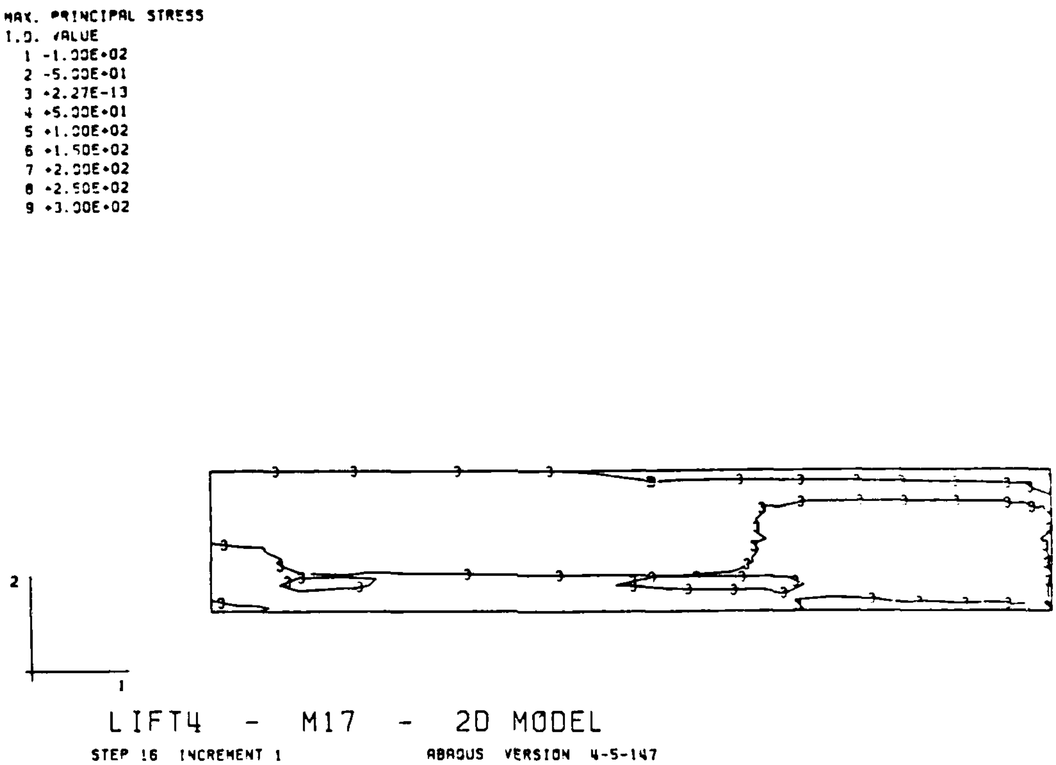


Figure 44a. Maximum principal stress contours 5 days after placement of lift 4, gravity loading only, using ABAQUS.

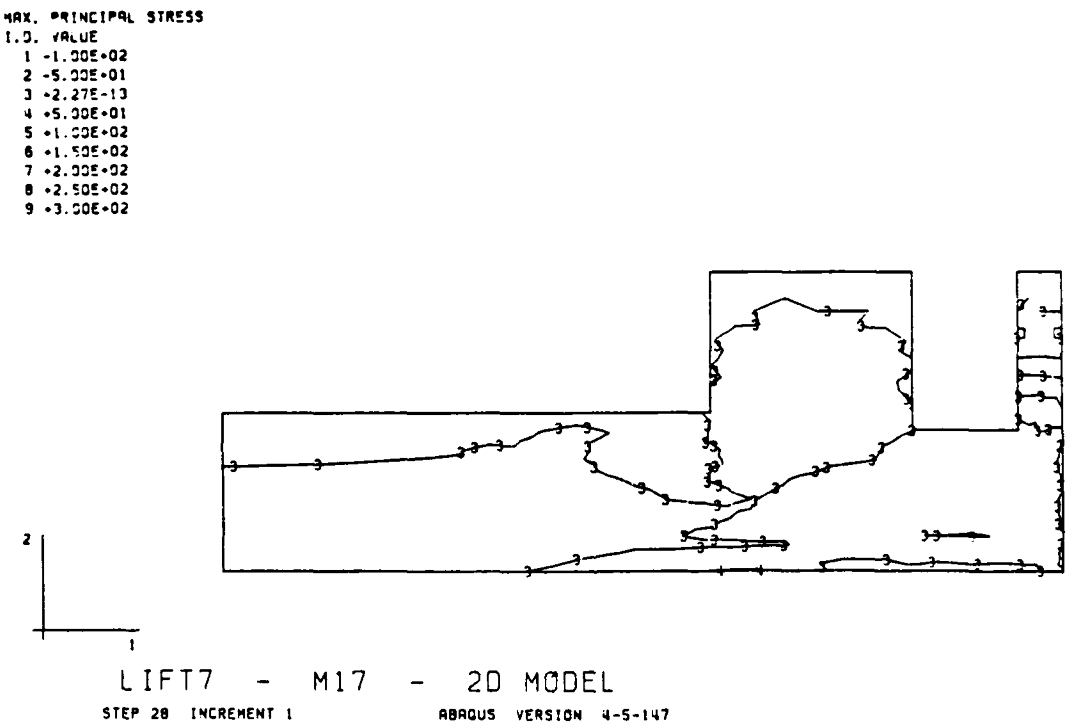


Figure 44b. Maximum principal stress contours 5 days after placement of lift 7, gravity loading only, using ABAQUS.

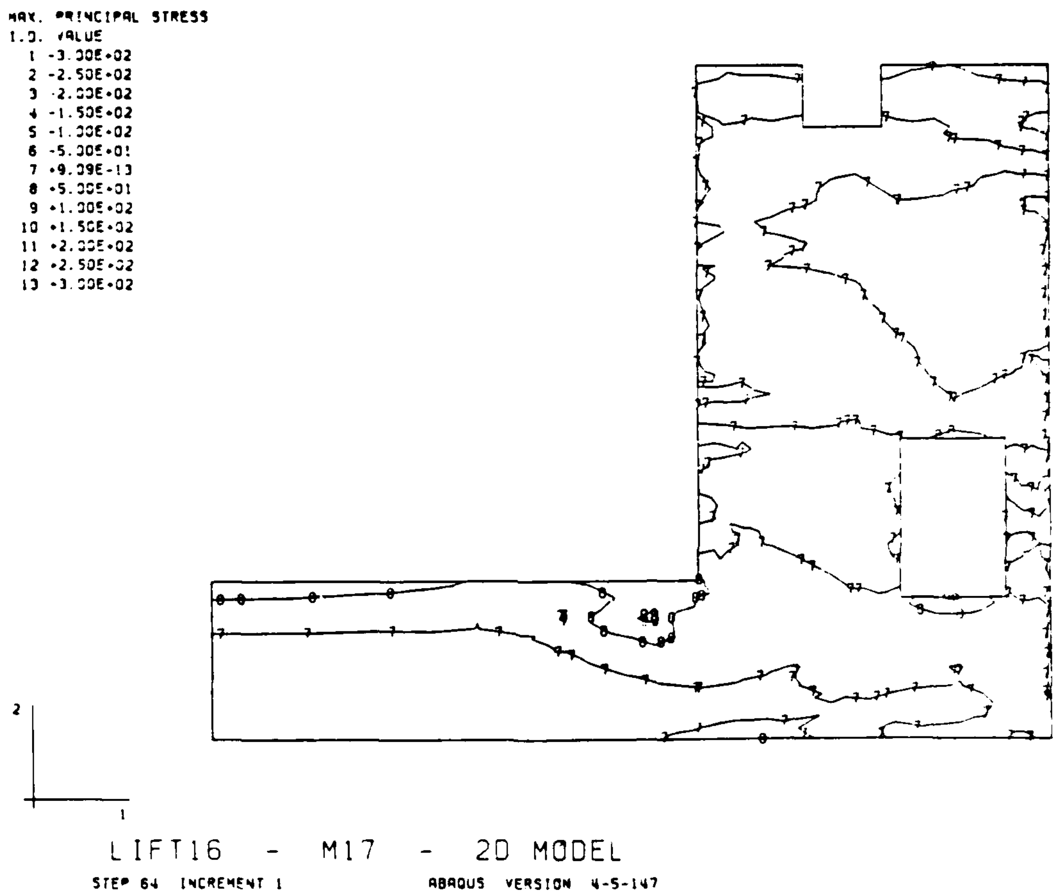


Figure 44c. Maximum principal stress contours 5 days after placement of lift 16, gravity loading only, using ABAQUS.

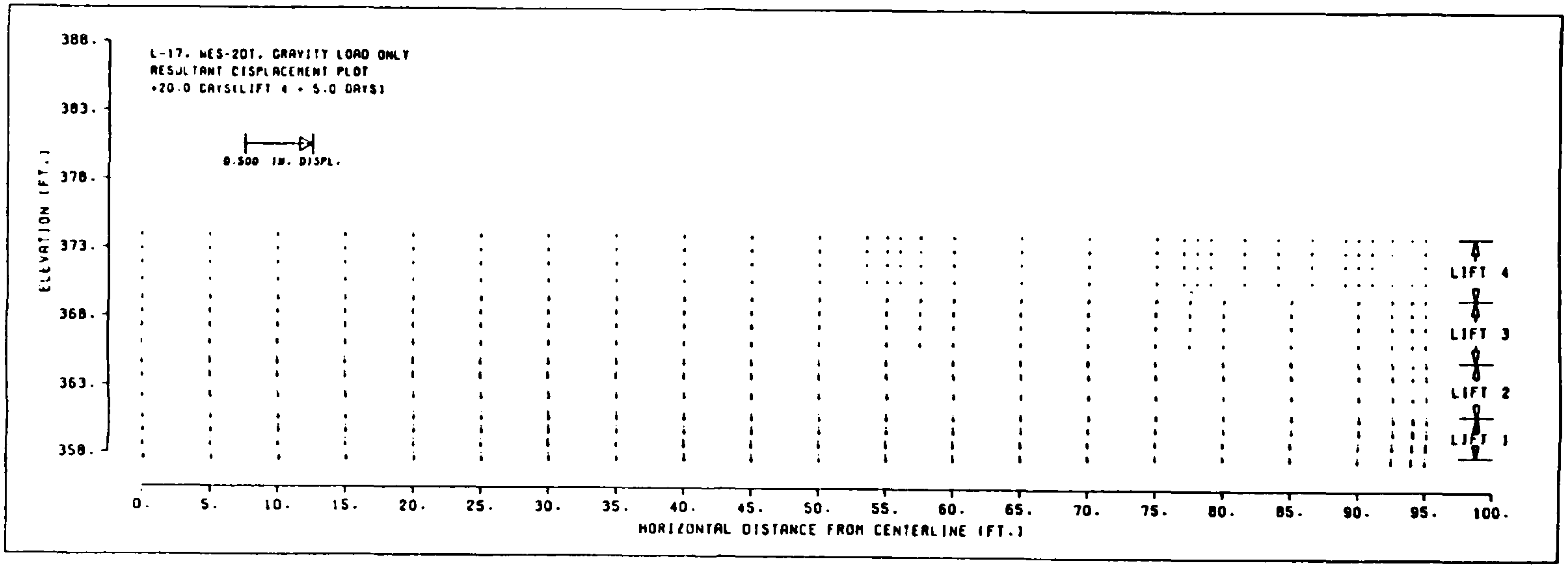


Figure 45a. Resultant displacement vector plot of structure 5 days after lift 4 is placed, gravity only, using WES2DT.

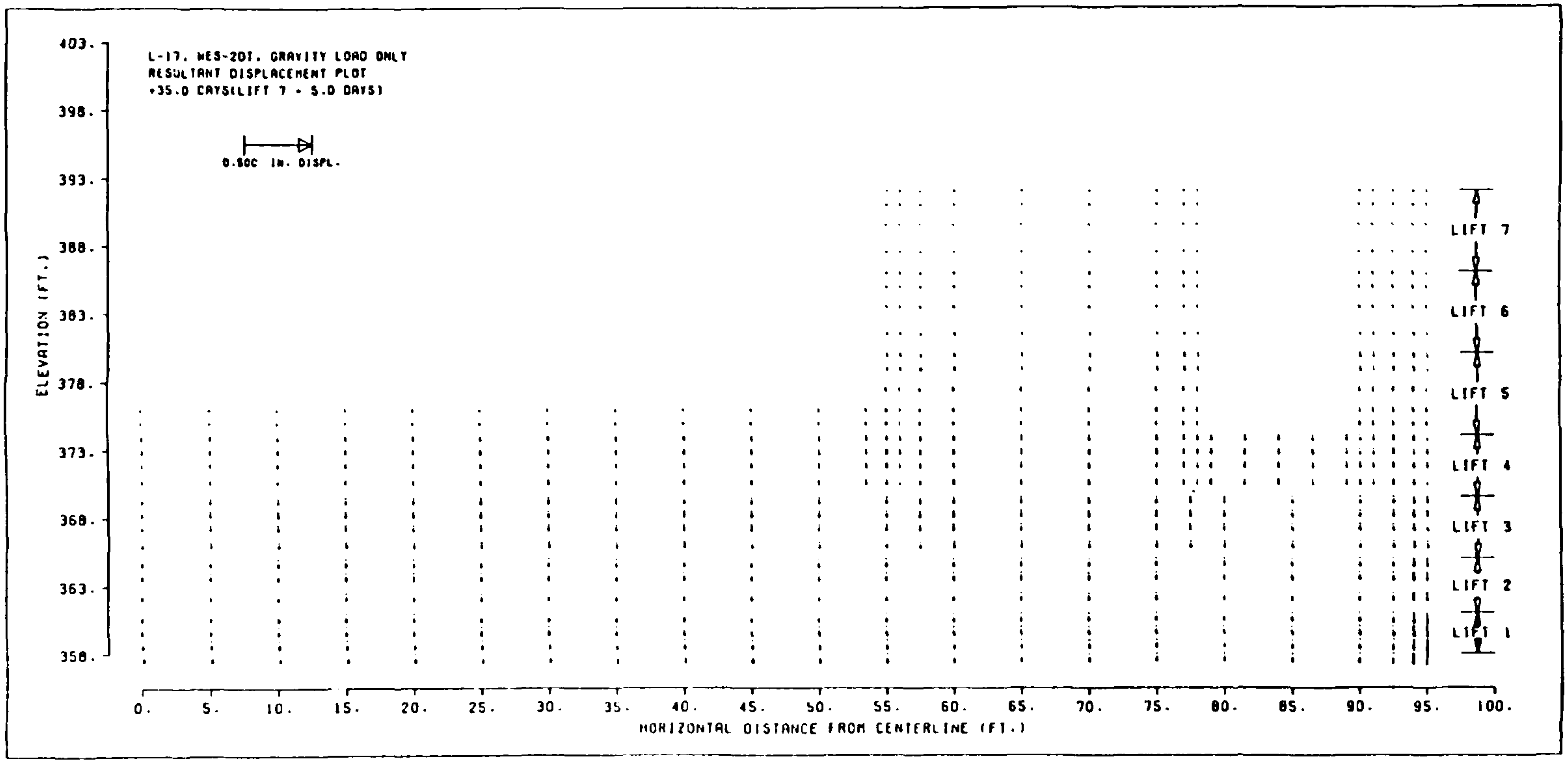


Figure 45b. Resultant displacement vector plot of structure 5 days after lift 7 is placed, gravity only, using WES2DT.

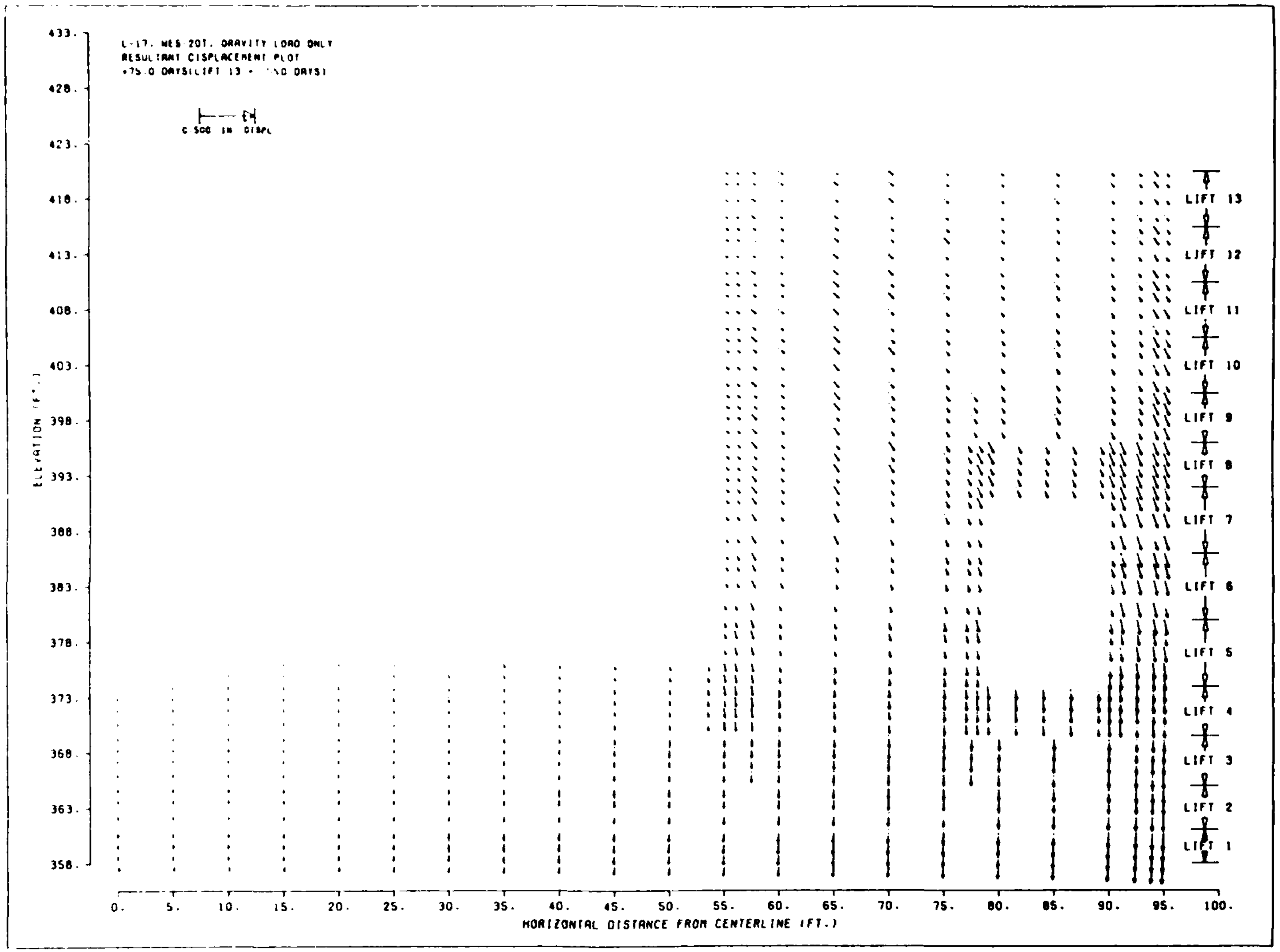


Figure 45c. Resultant displacement vector plot of structure 20 days after lift 13 is placed, gravity only, using WES2DT. (This corresponds to 5 days after lift 16 is placed).

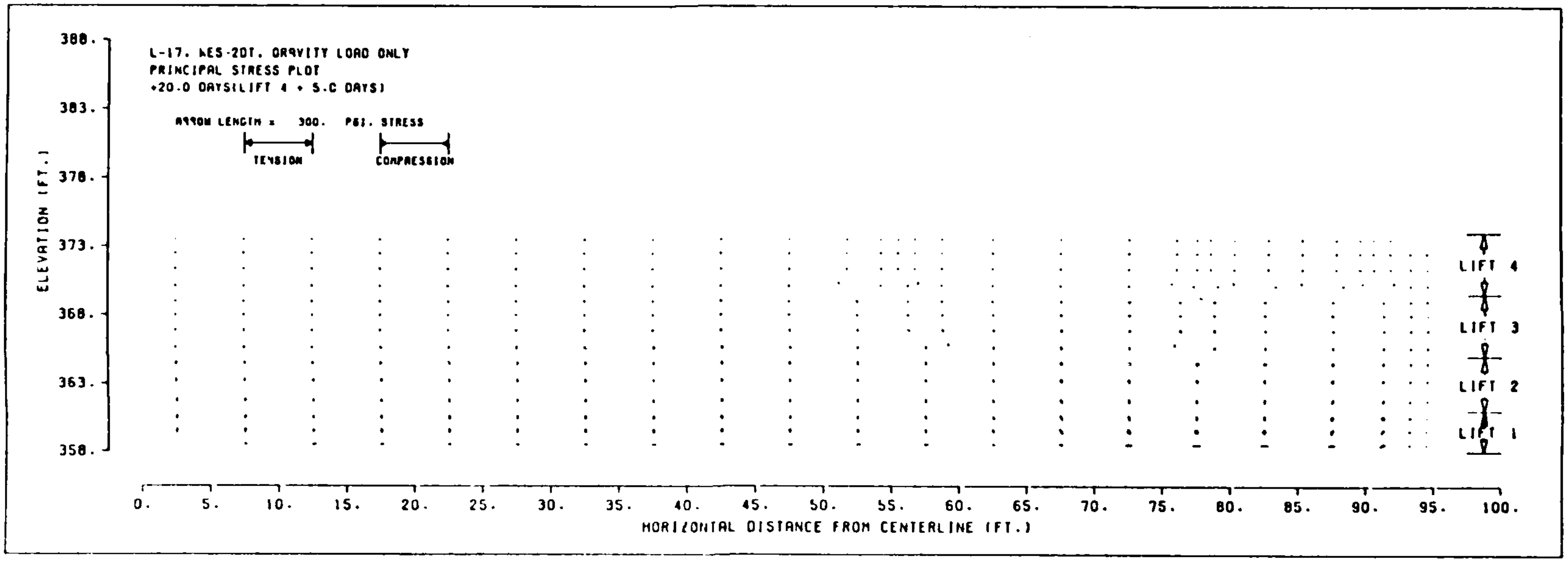


Figure 46a. Principal stress contours of structures 5 days after lift 4 is placed, gravity loading only, using WES2DT.

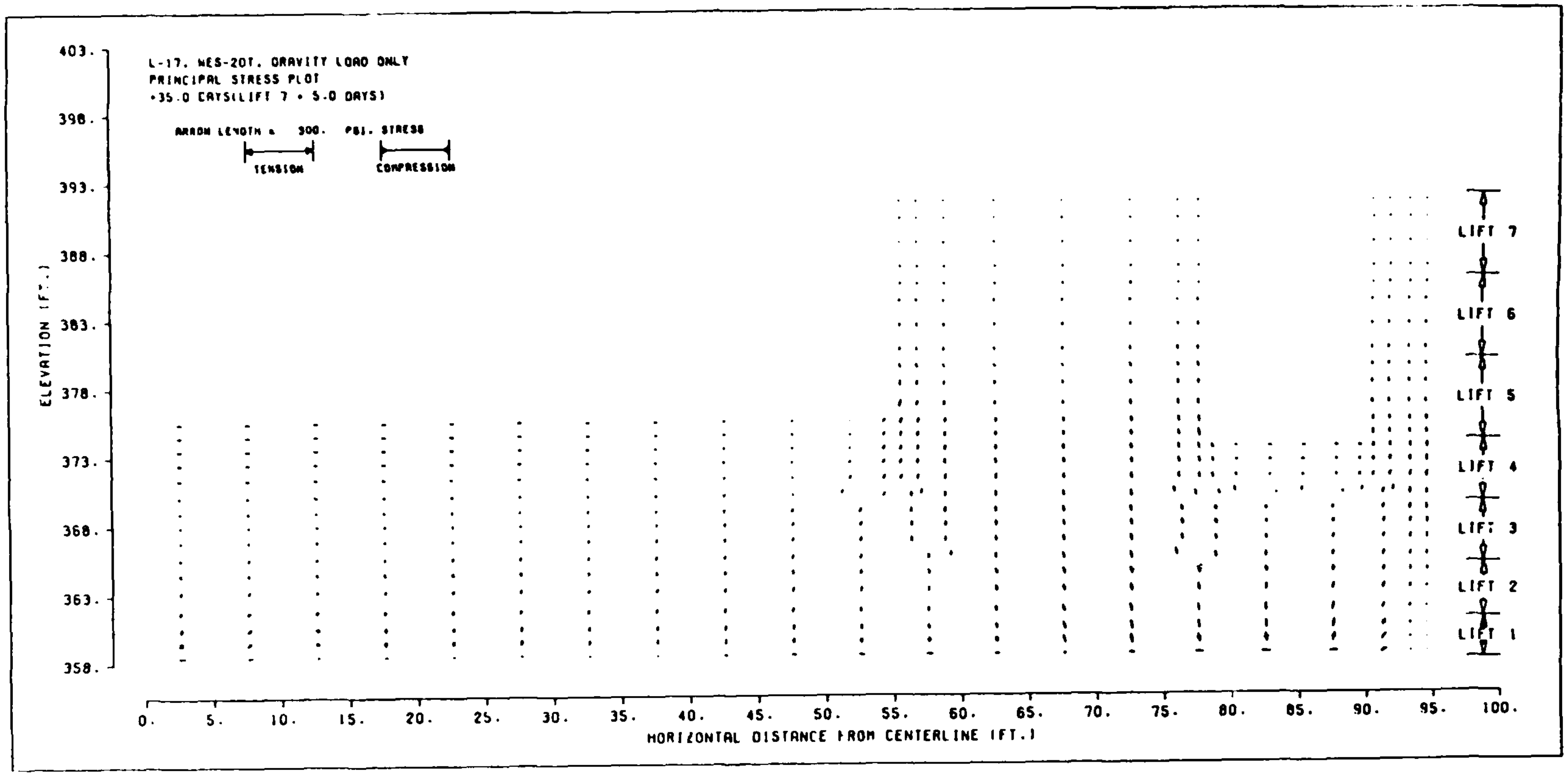


Figure 46b. Principal stress contours of structure 5 days after lift 7 is placed, gravity loading only, using WES2DT.

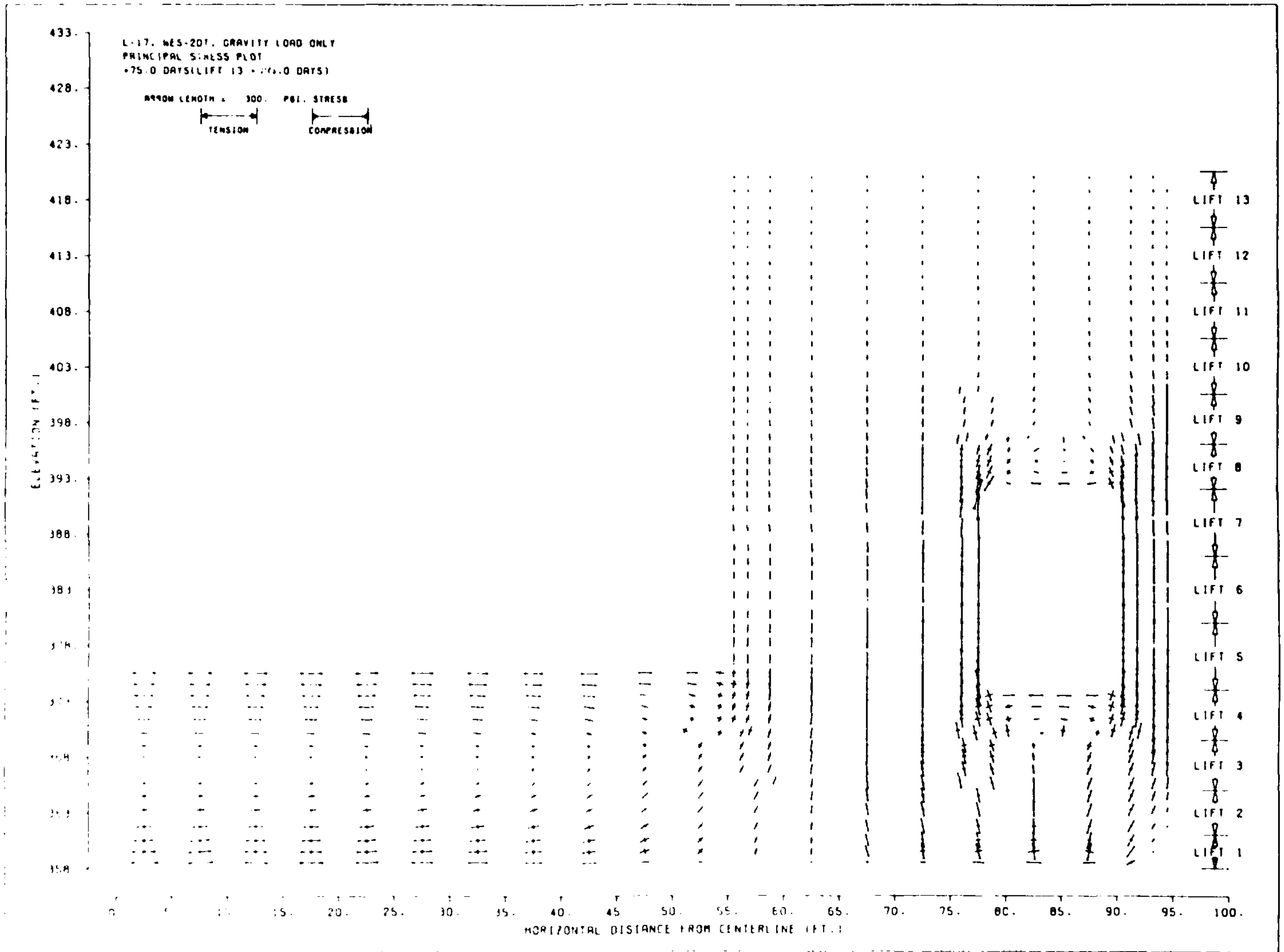


Figure 46c. Principal stress contours of structure 20 days after lift 13 is placed, gravity loading only, using WES2DT. (This corresponds to 5 days after lift 16 is placed).

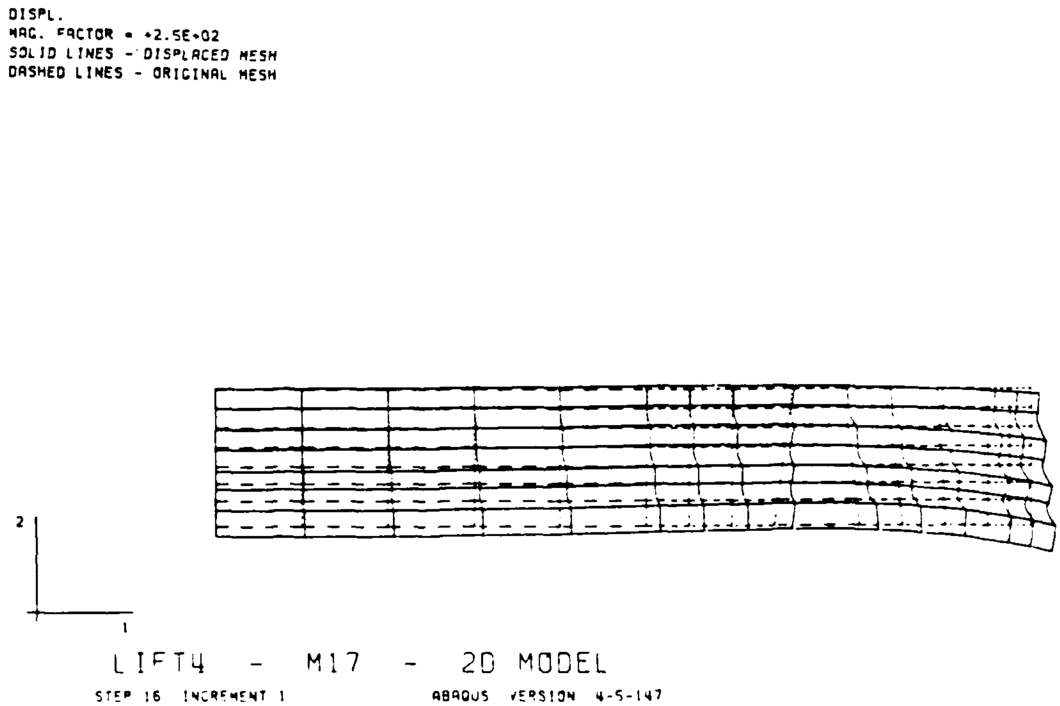


Figure 47a. Displaced structure 5 days after placement of lift 4, gravity and temperature loading, using ABAQUS (UMAT1).

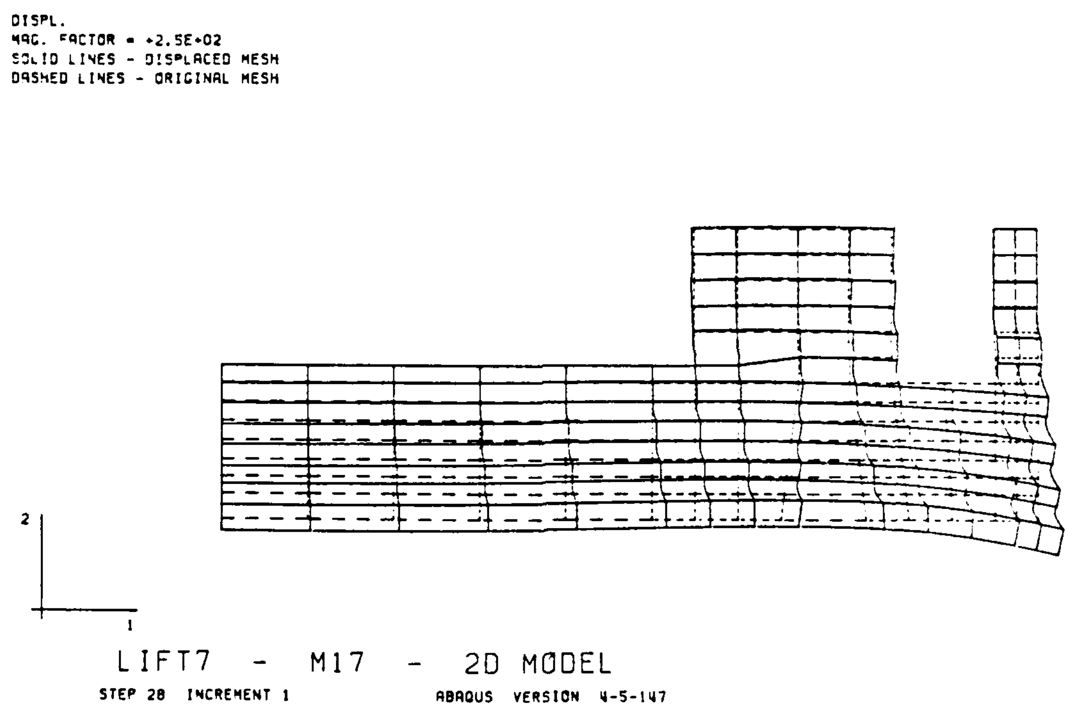


Figure 47b. Displaced structure 5 days after placement of lift 7, gravity and temperature loading, using ABAQUS (UMAT1).

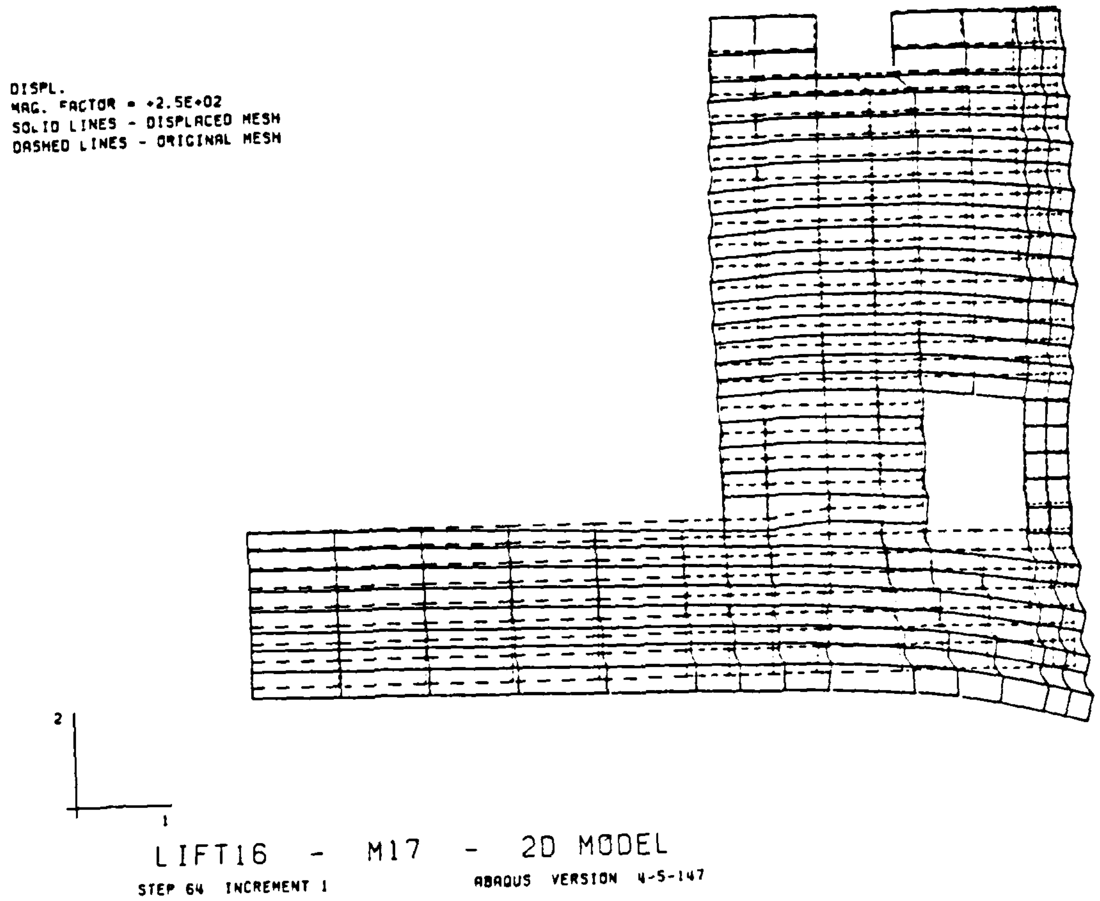


Figure 47c. Displaced structure 5 days after placement of lift 16, gravity and temperature loading, using ABAQUS (UMAT1).

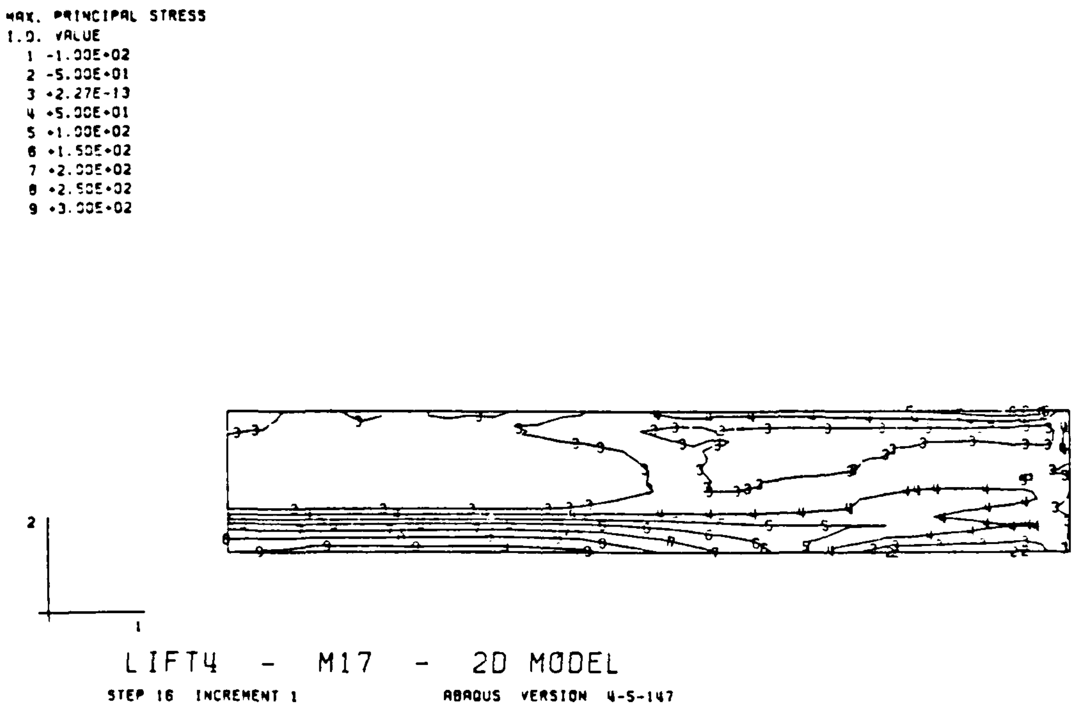


Figure 48a. Maximum principal stress contours 5 days after placement of lift 4, gravity and temperature loading, using ABAQUS (UMAT1).

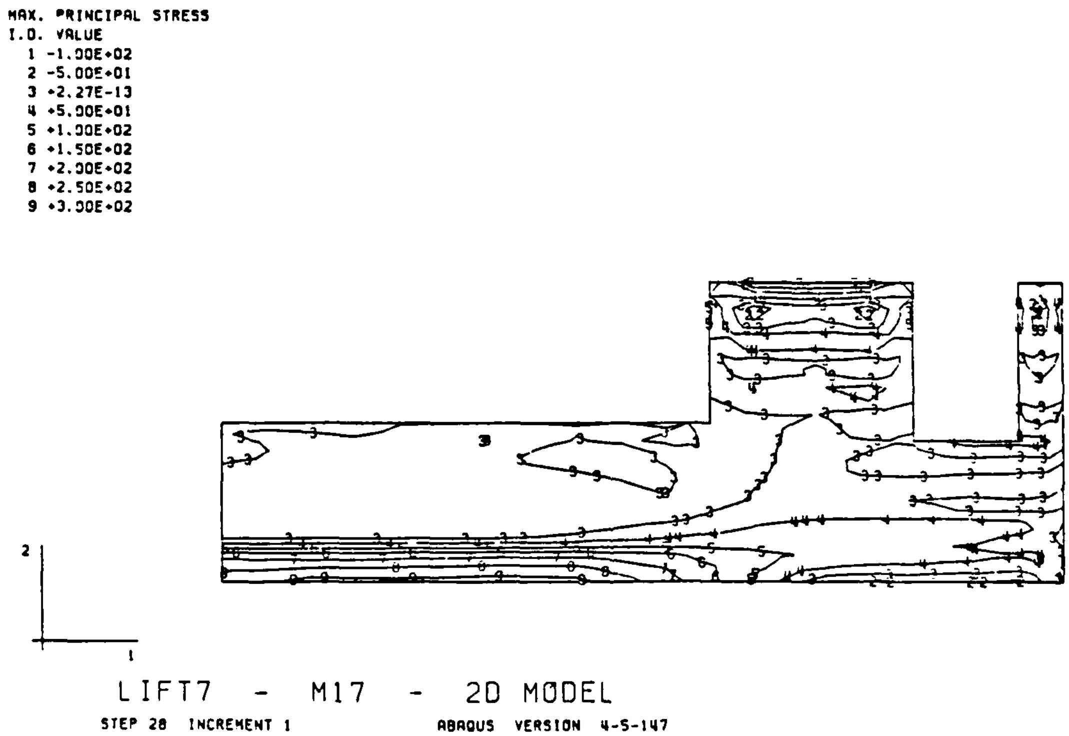


Figure 48b. Maximum principal stress contours 5 days after placement of lift 7, gravity and temperature loading, using ABAQUS (UMAT1).

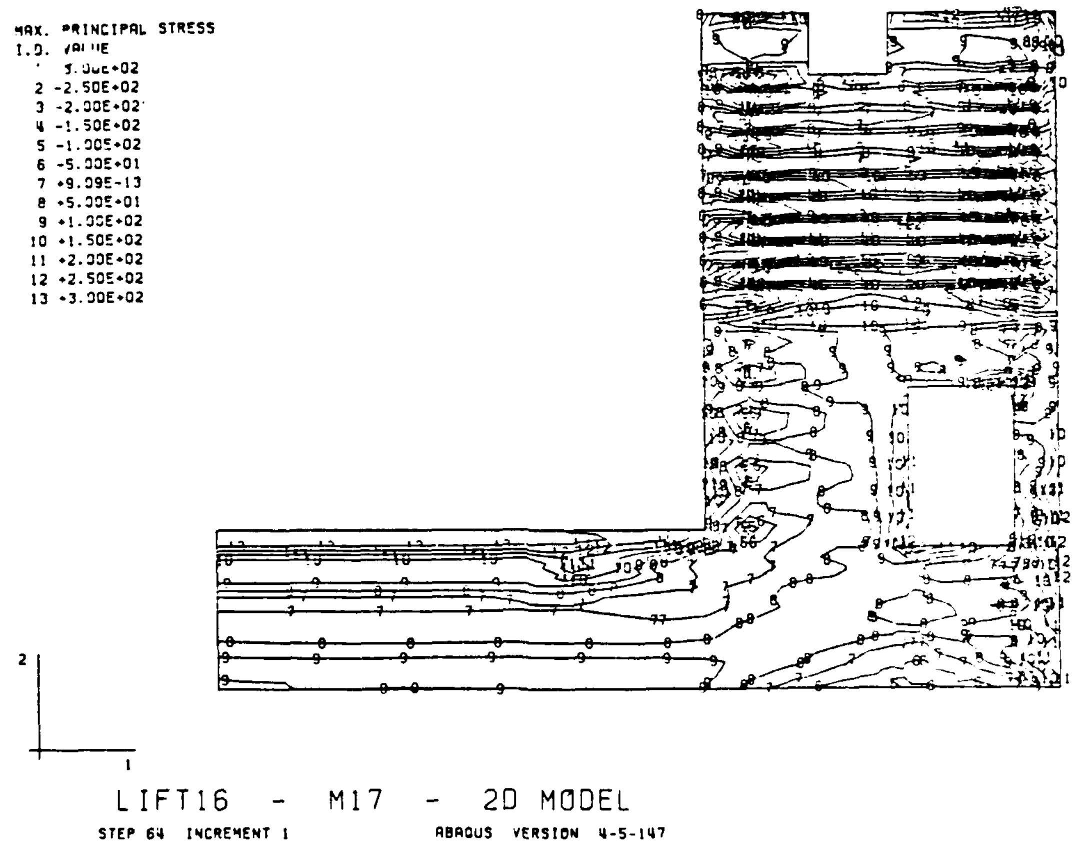


Figure 48c. Maximum principal stress contours 5 days after placement of lift 16, gravity and temperature loading, using ABAQUS (UMAT1).

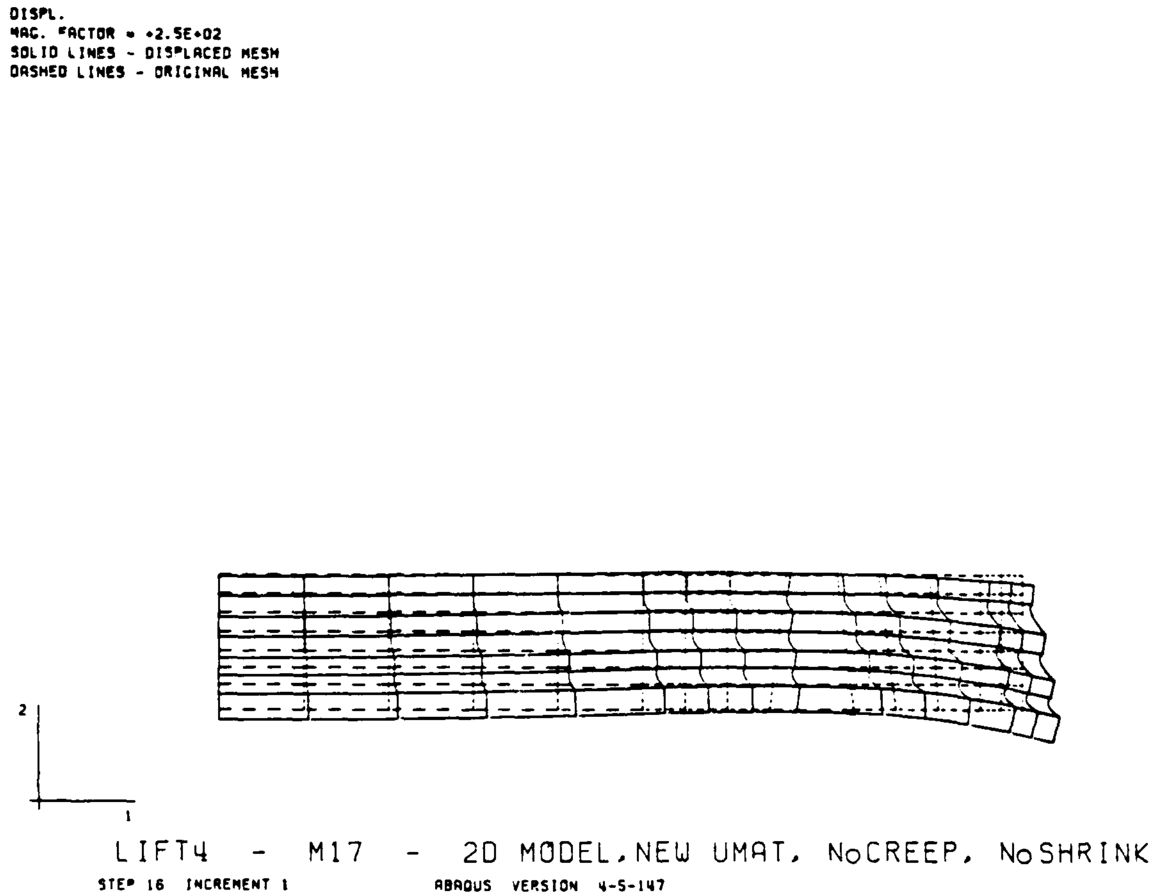


Figure 49a. Displaced structure 5 days after placement of lift 4, gravity and temperature loading, using ABAQUS (UMAT2).

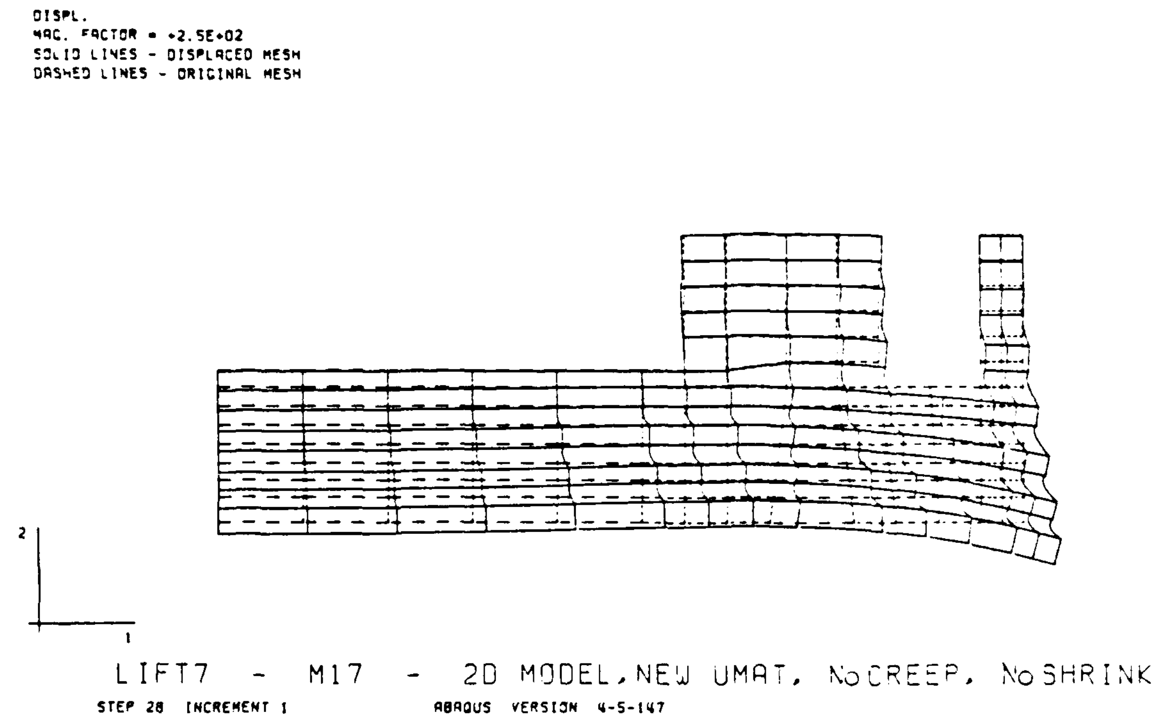


Figure 49b. Displaced structure 5 days after placement of lift 7, gravity and temperature loading, using ABAQUS (UMAT2).

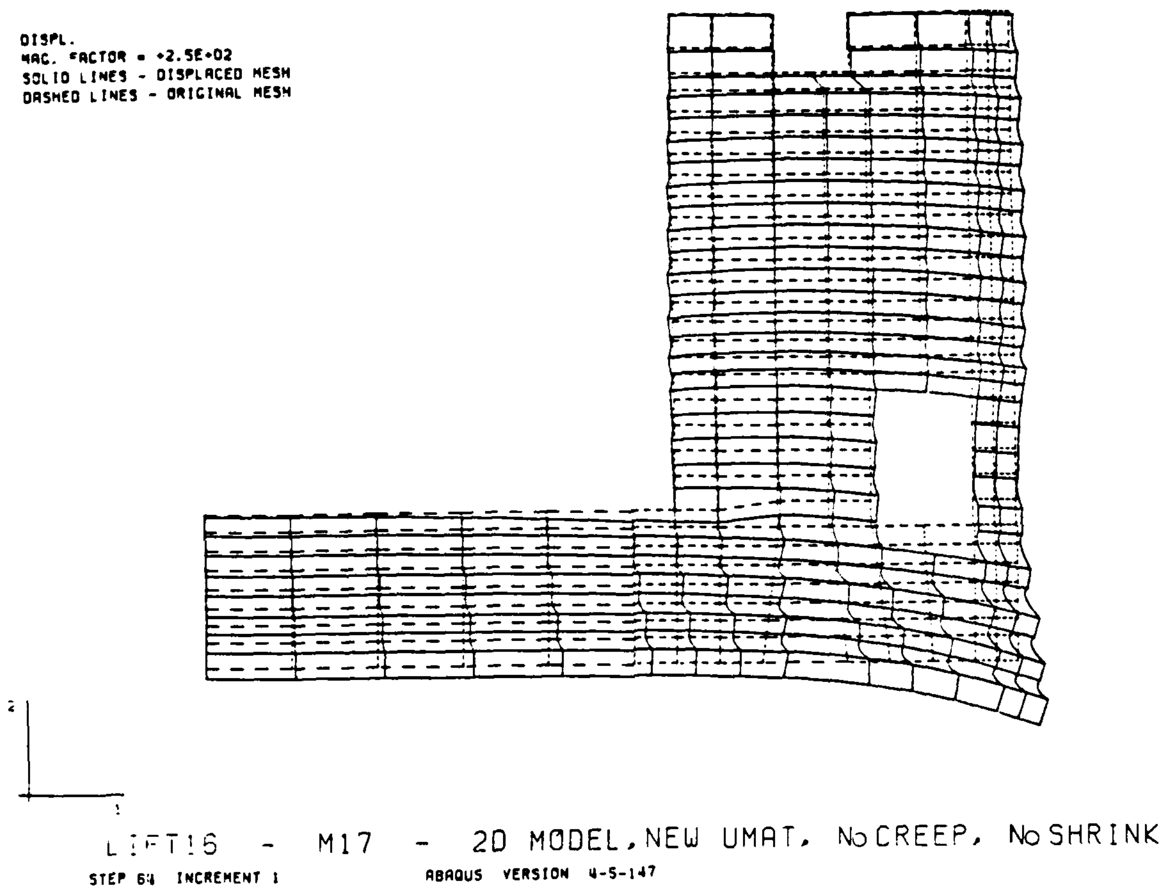


Figure 49c. Displaced structure 5 days after placement of lift 16, gravity and temperature loading, using ABAQUS (UMAT2).

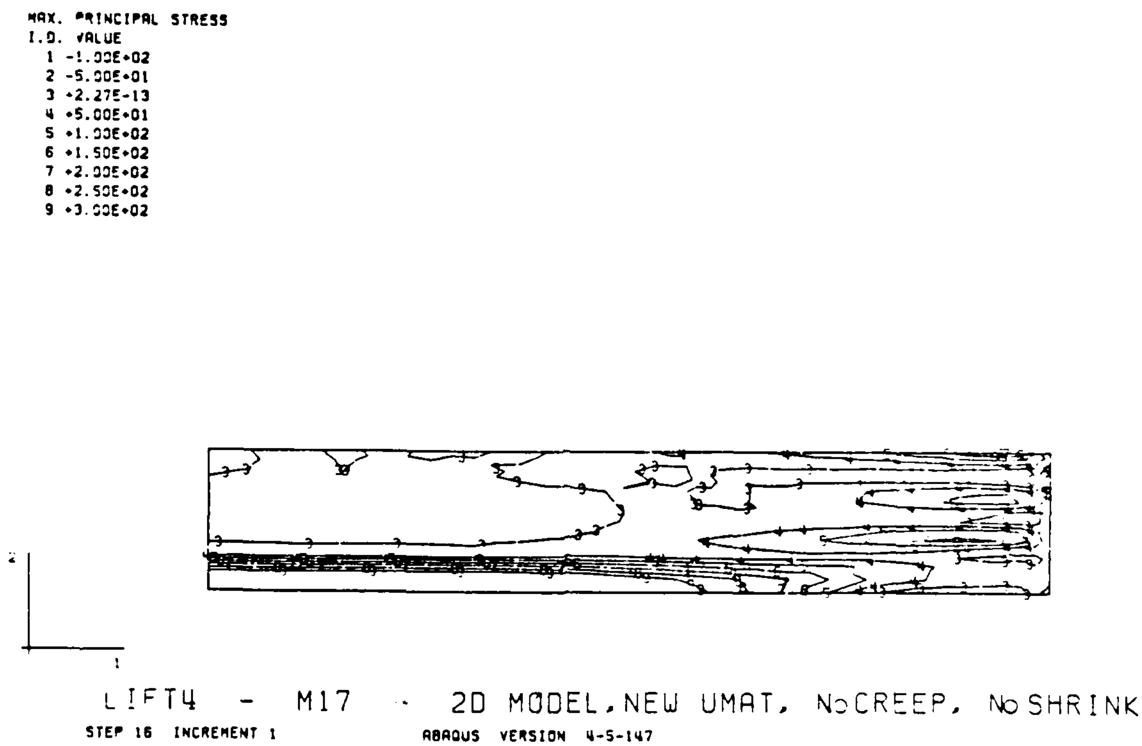


Figure 50a. Maximum principal stress contours 5 days after placement of lift 4, gravity and temperature loading, using ABAQUS (UMAT2).

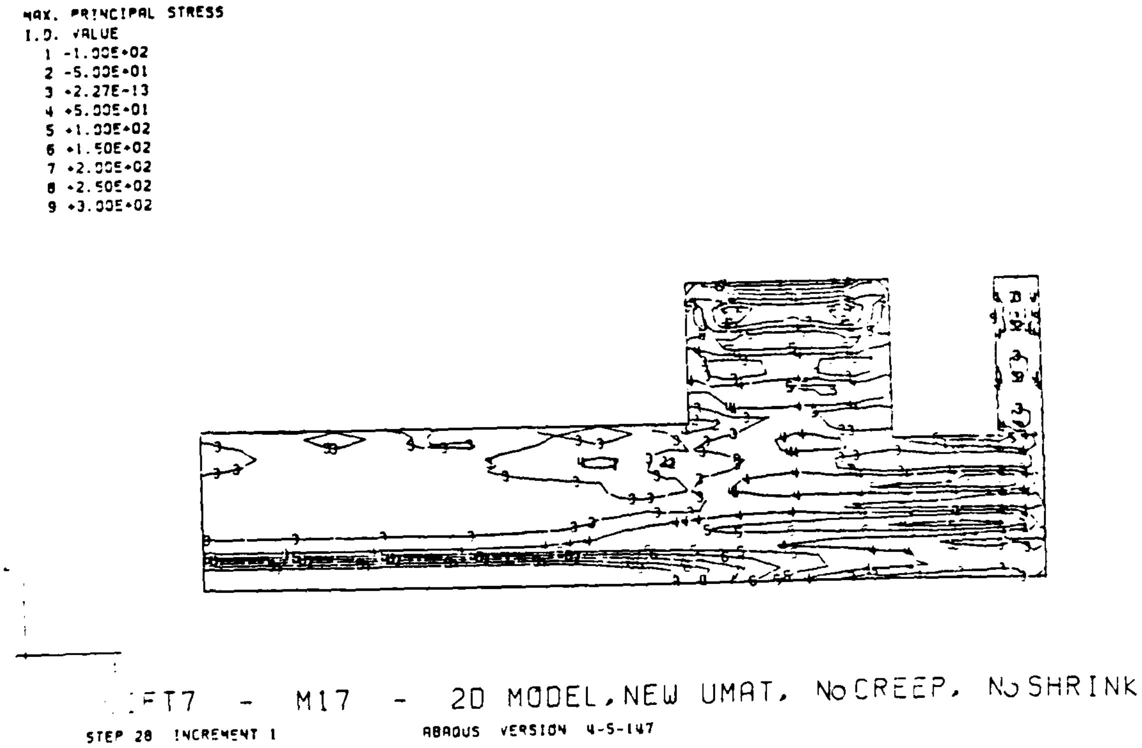


Figure 50b. Maximum principal stress contours 5 days after placement of lift 7, gravity and temperature loading, using ABAQUS (UMAT2).

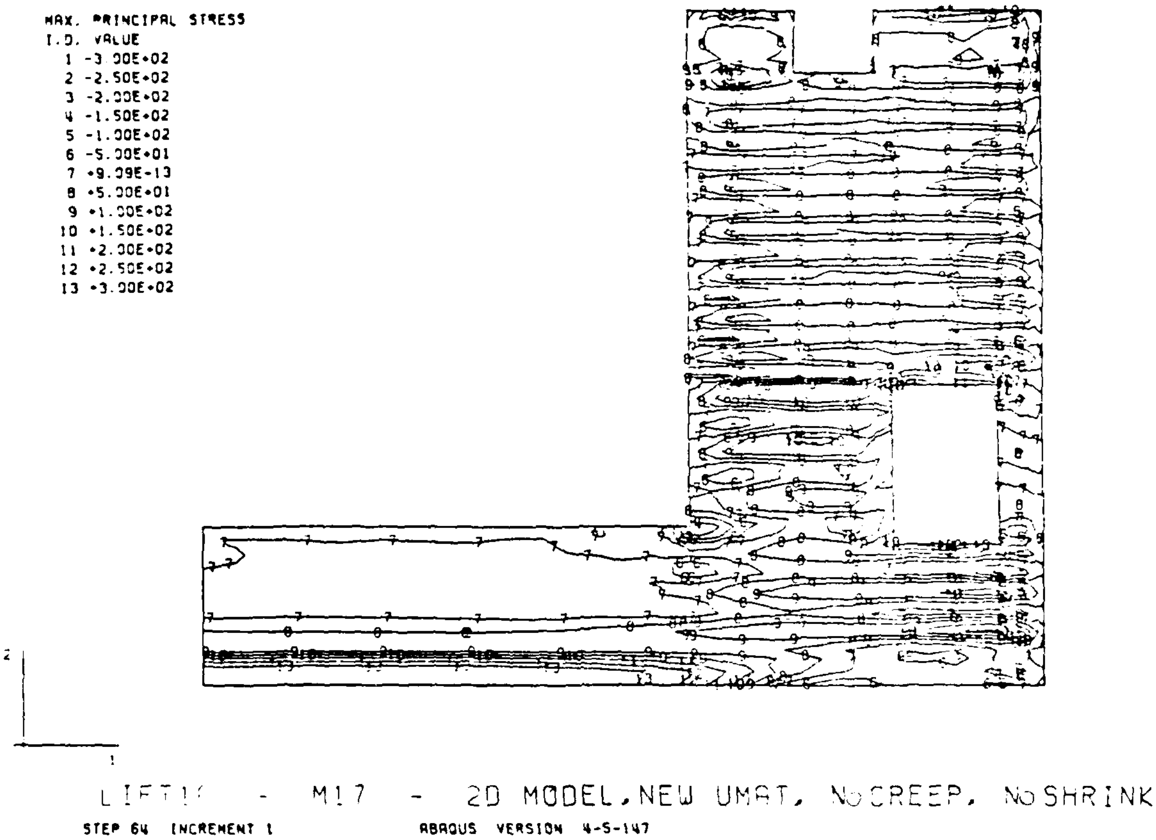


Figure 50c. Maximum principal stress contours 5 days after placement of lift 16, gravity and temperature loading, using ABAQUS (UMAT2).

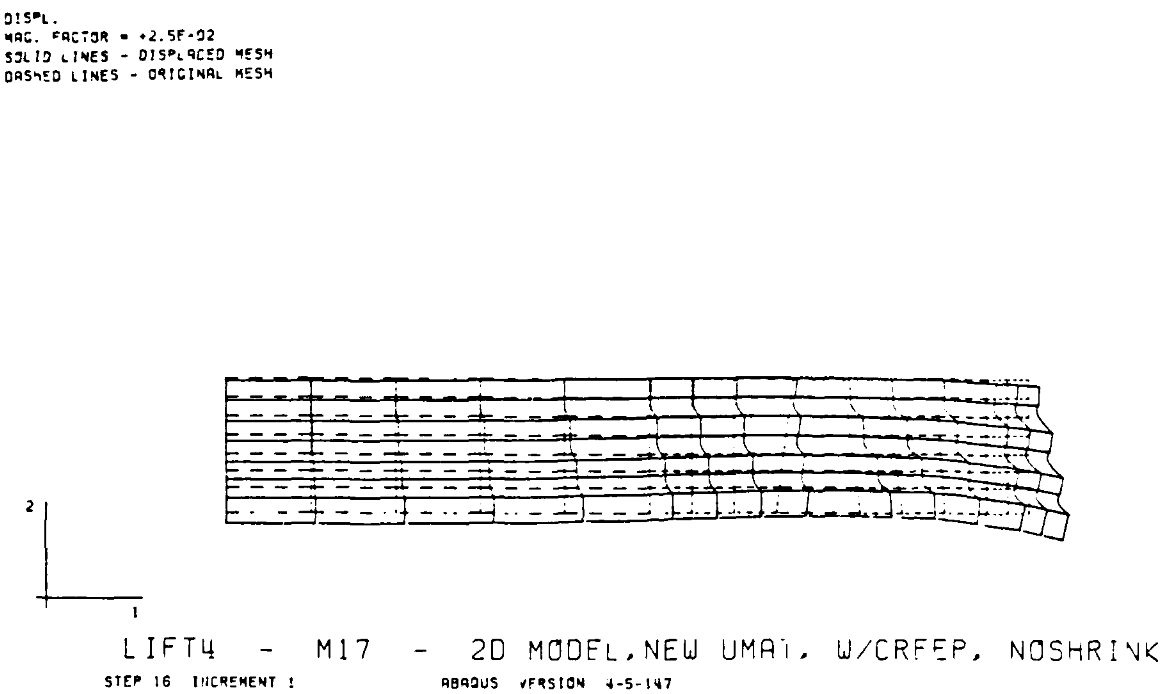


Figure 51a. Displaced structure 5 days after placement of lift 4, gravity and temperature loading with creep, using ABAQUS (UMAT2).

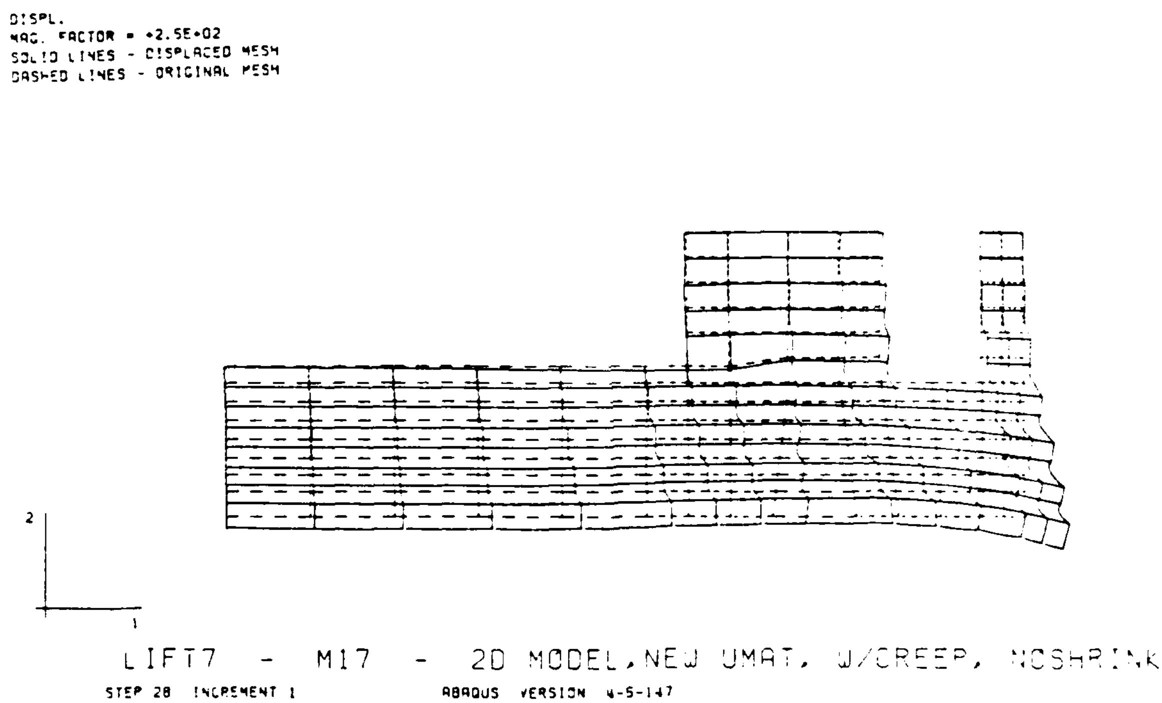


Figure 51b. Displaced structure 5 days after placement of lift 7, gravity and temperature loading with creep, using ABAQUS (UMAT2).

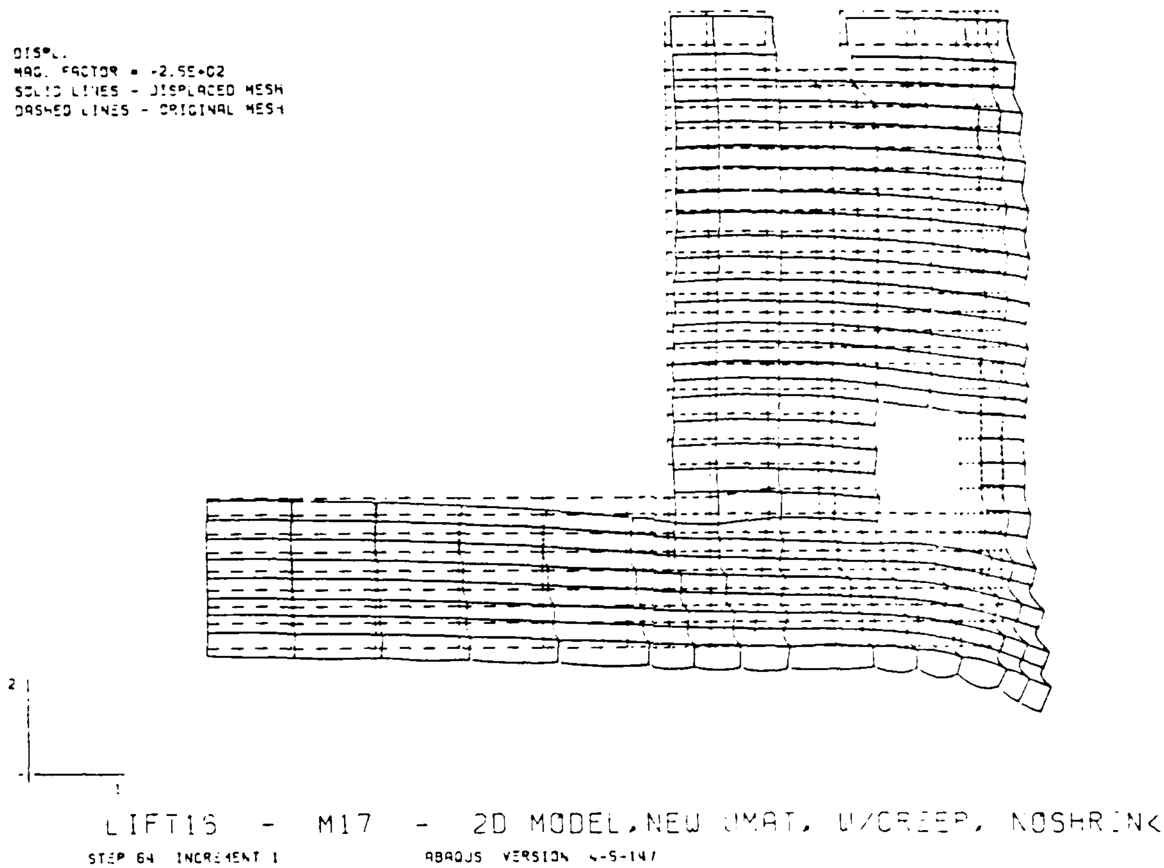


Figure 51c. Displaced structure 5 days after placement of lift 16, gravity and temperature loading with creep, using ABAQUS (UMAT2).

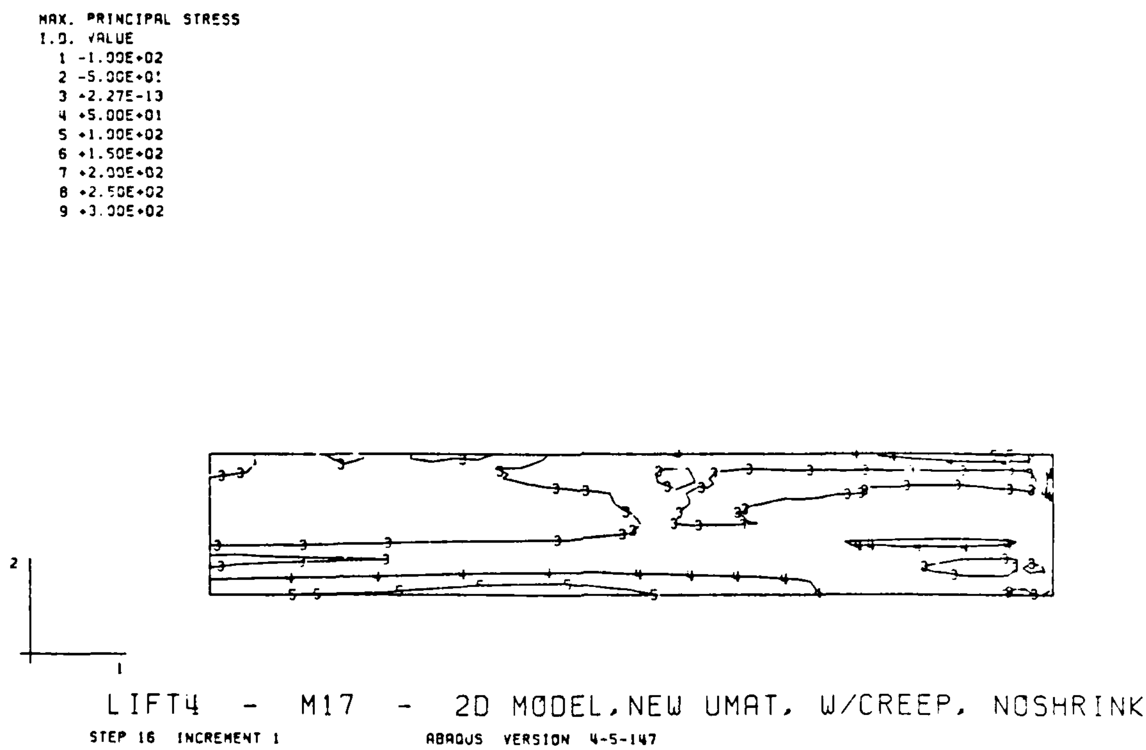


Figure 52a. Maximum principal stress contours 5 days after placement of lift 4, gravity and temperature loading with creep, using ABAQUS (UMAT2).

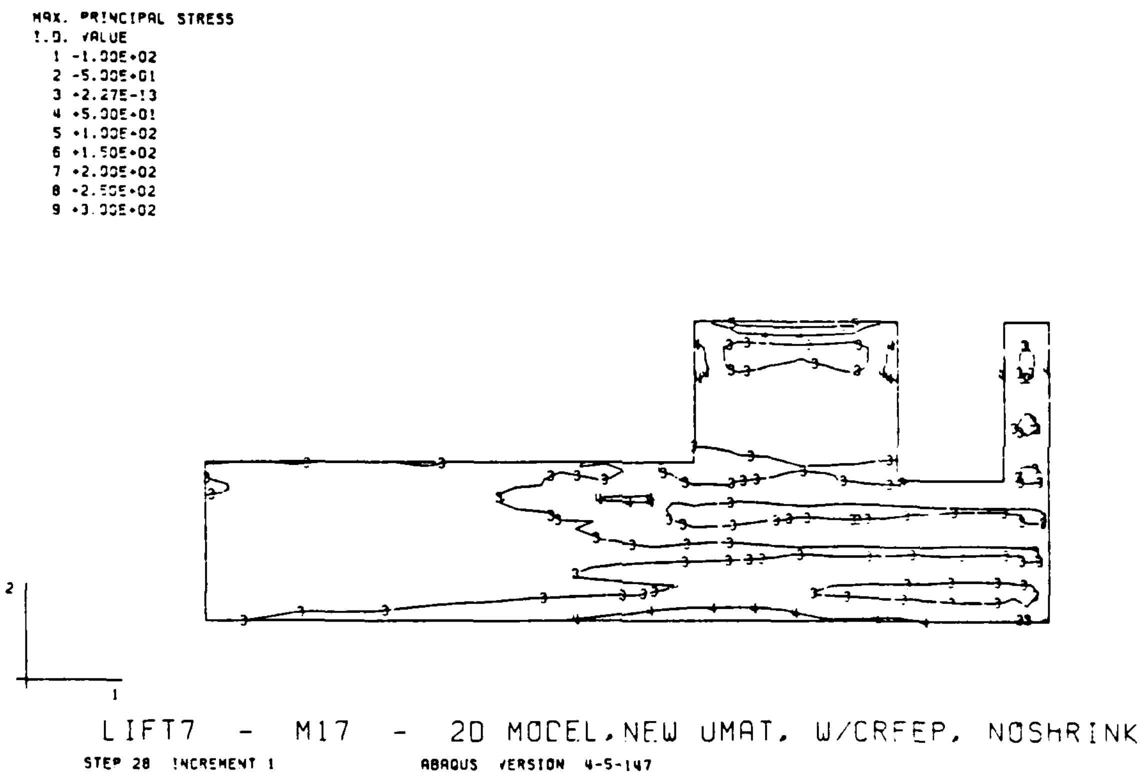


Figure 52b. Maximum principal stress contours 5 days after placement of lift 7, gravity and temperature loading with creep, using ABAQUS (UMAT2).

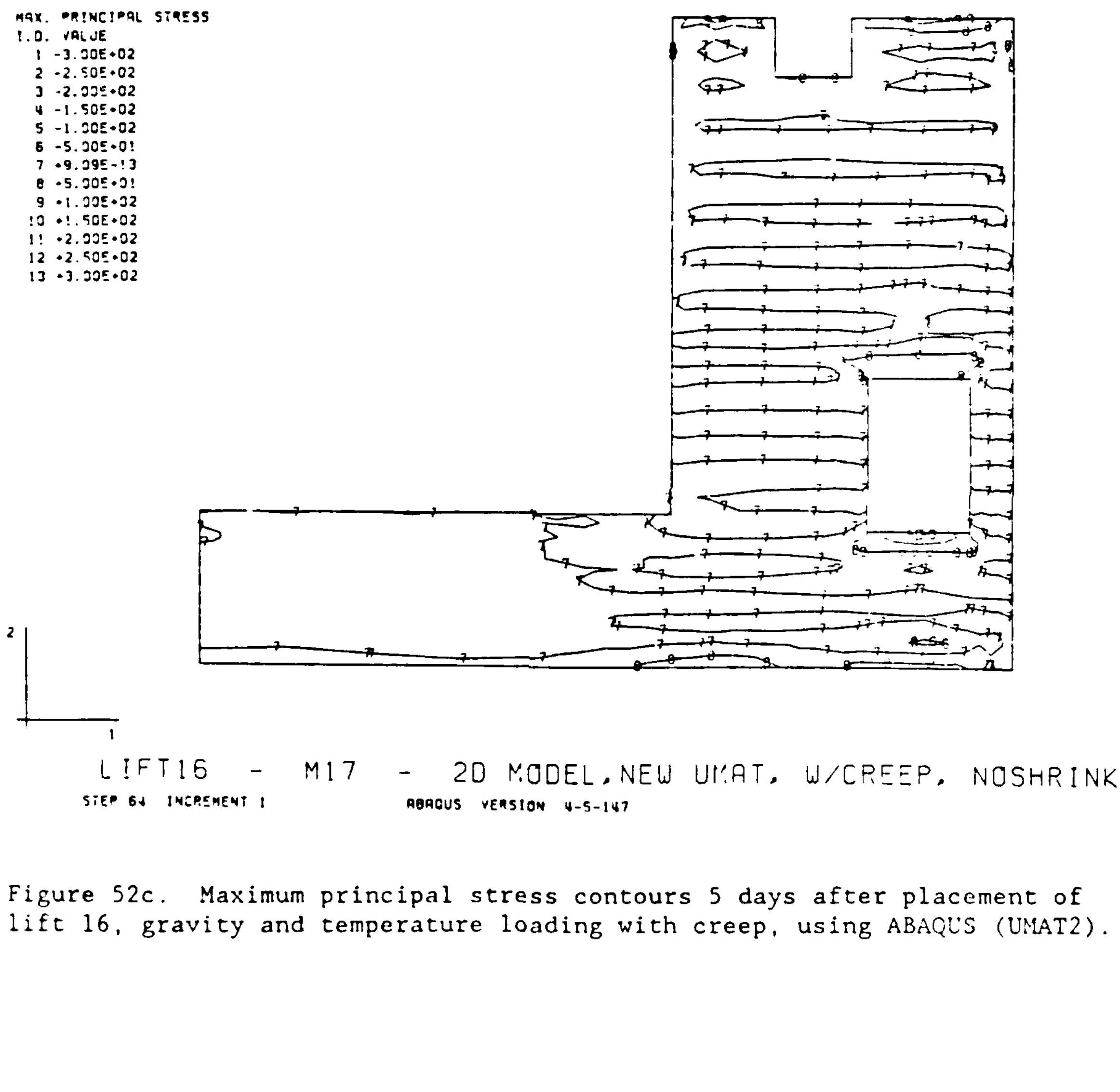


Figure 52c. Maximum principal stress contours 5 days after placement of lift 16, gravity and temperature loading with creep, using ABAQUS (UMAT2).

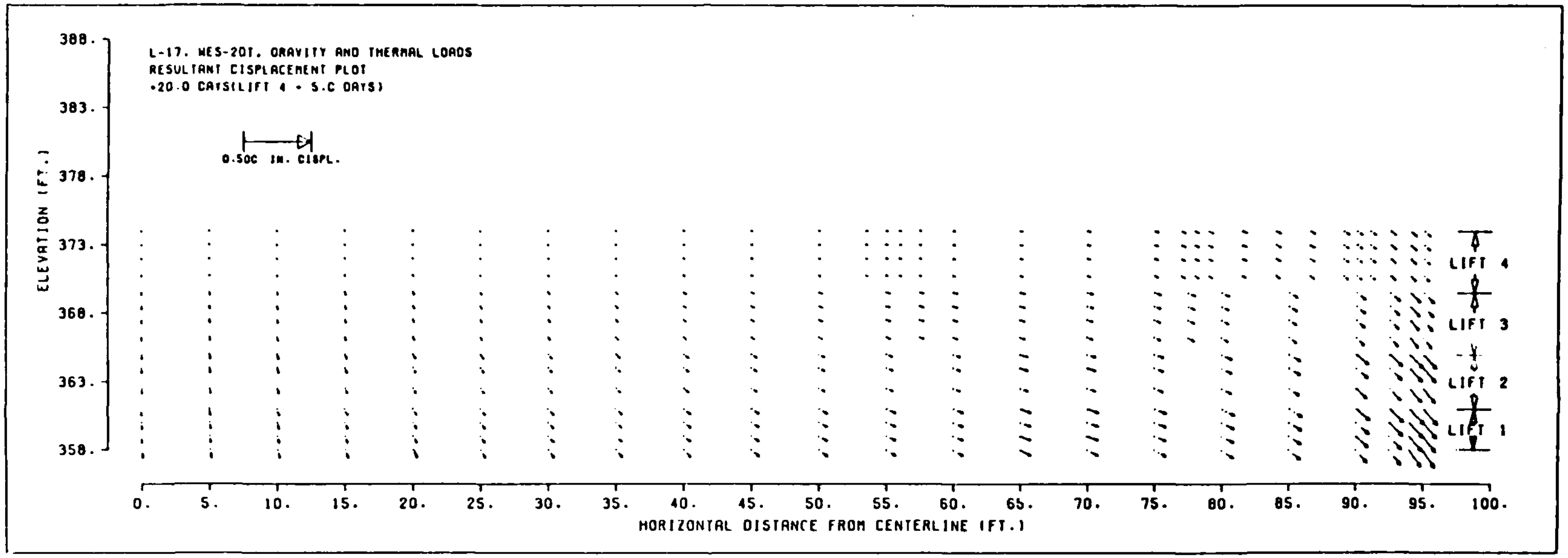


Figure 53a. Resultant displacement vector plot of structure 5 days after placement of lift 4, gravity and temperature loading including creep, using WES2DT.

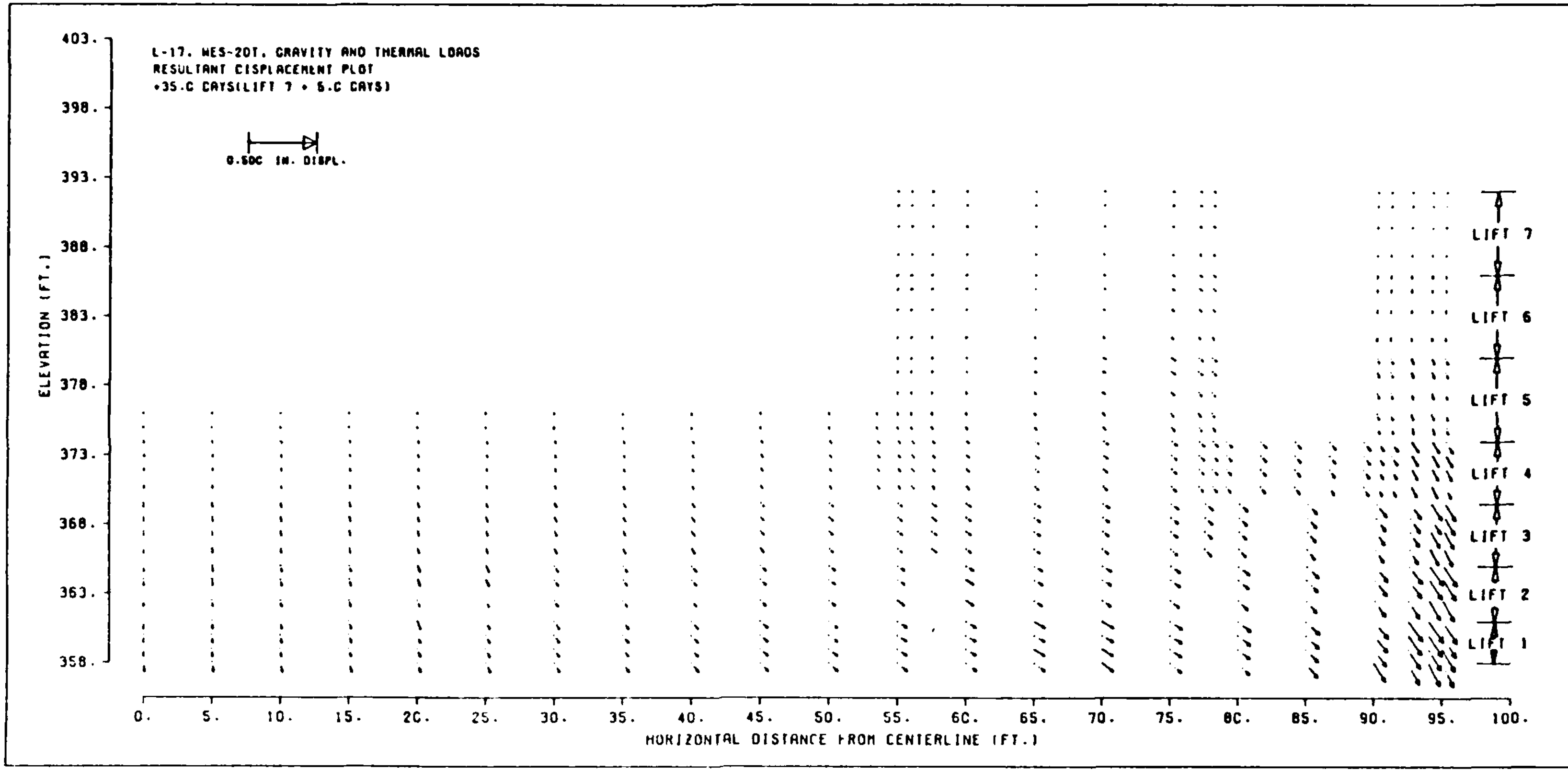


Figure 53b. Resultant displacement vector plot of structure 5 days after placement of lift 7, gravity and temperature loading including creep, using WES2DT.

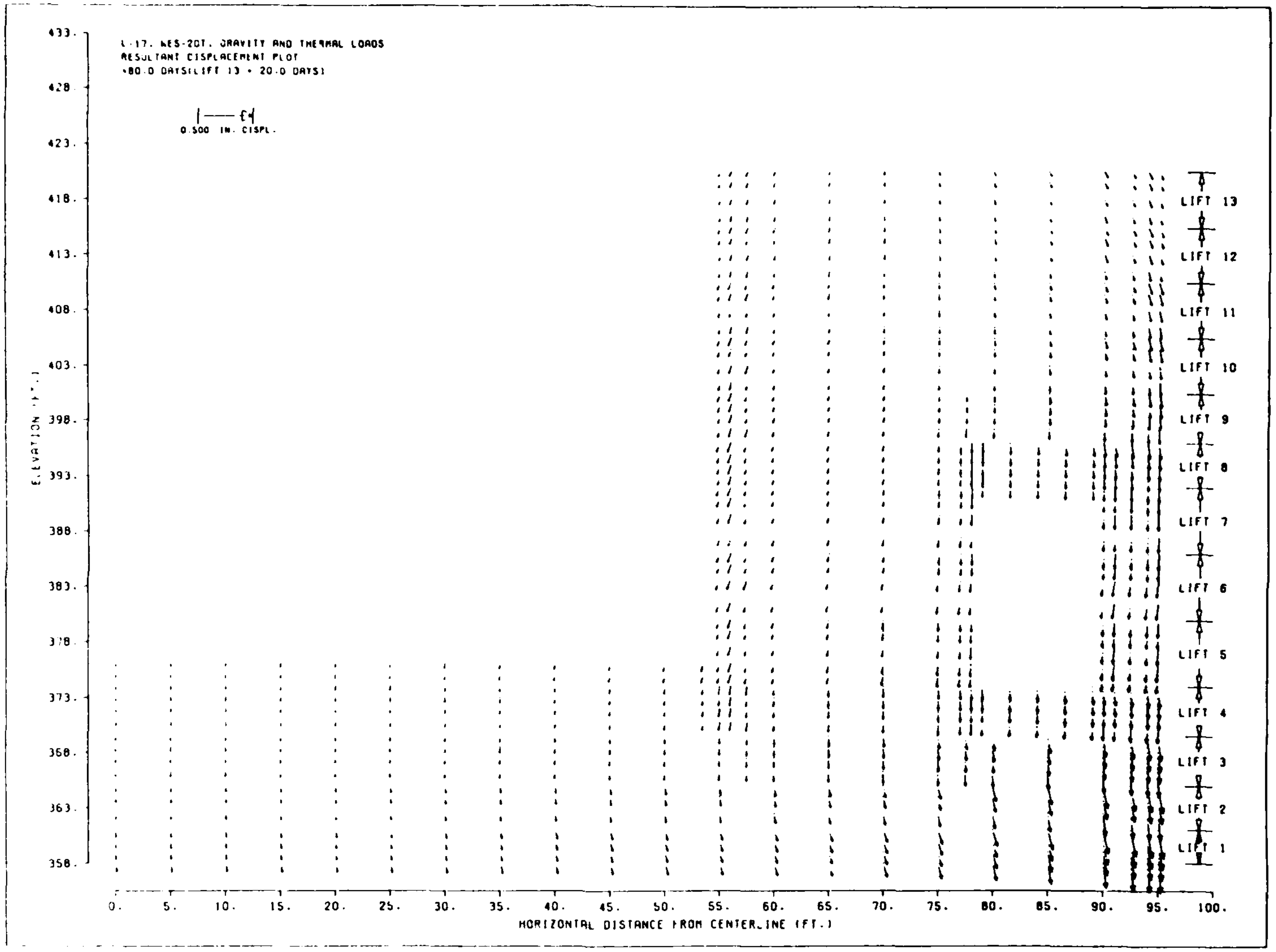


Figure 53c. Resultant displacement vector plot of structure 20 days after placement of lift 13, gravity and temperature loading including creep, using WES2DT. (This corresponds to 5 days after lift 16 is placed).

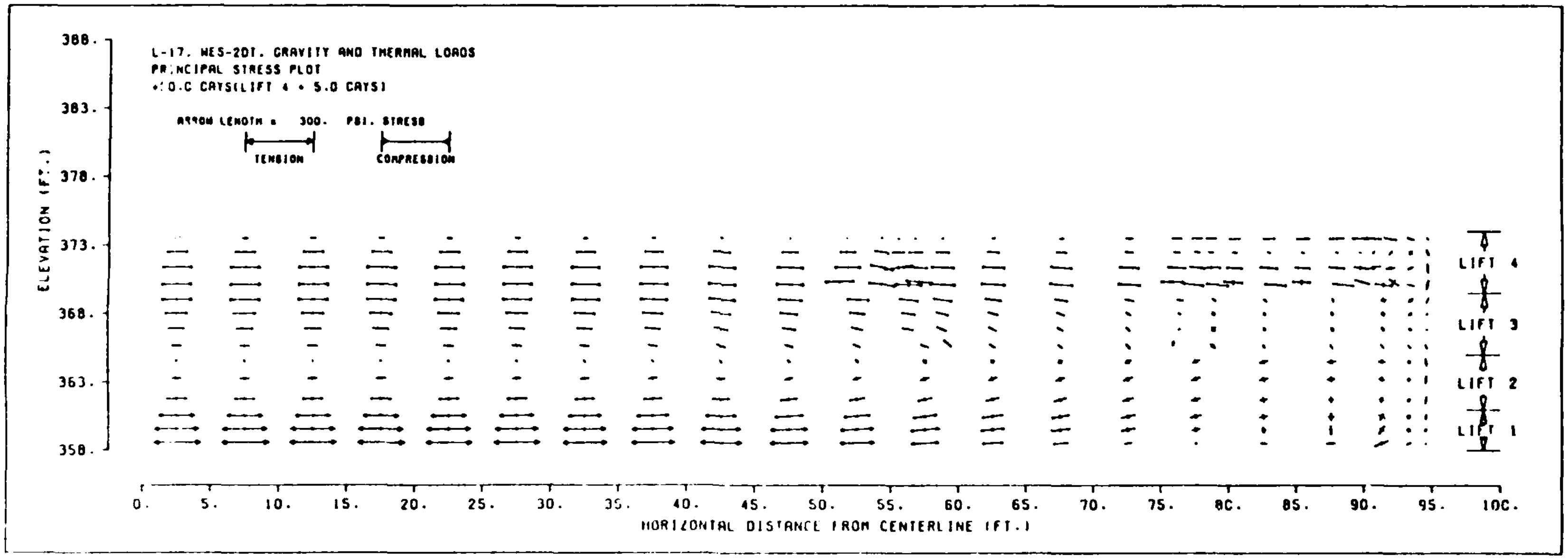


Figure 54a. Principal stress contours of structure 5 days after lift 4 is placed, gravity and temperature loading including creep, using WES2DT.

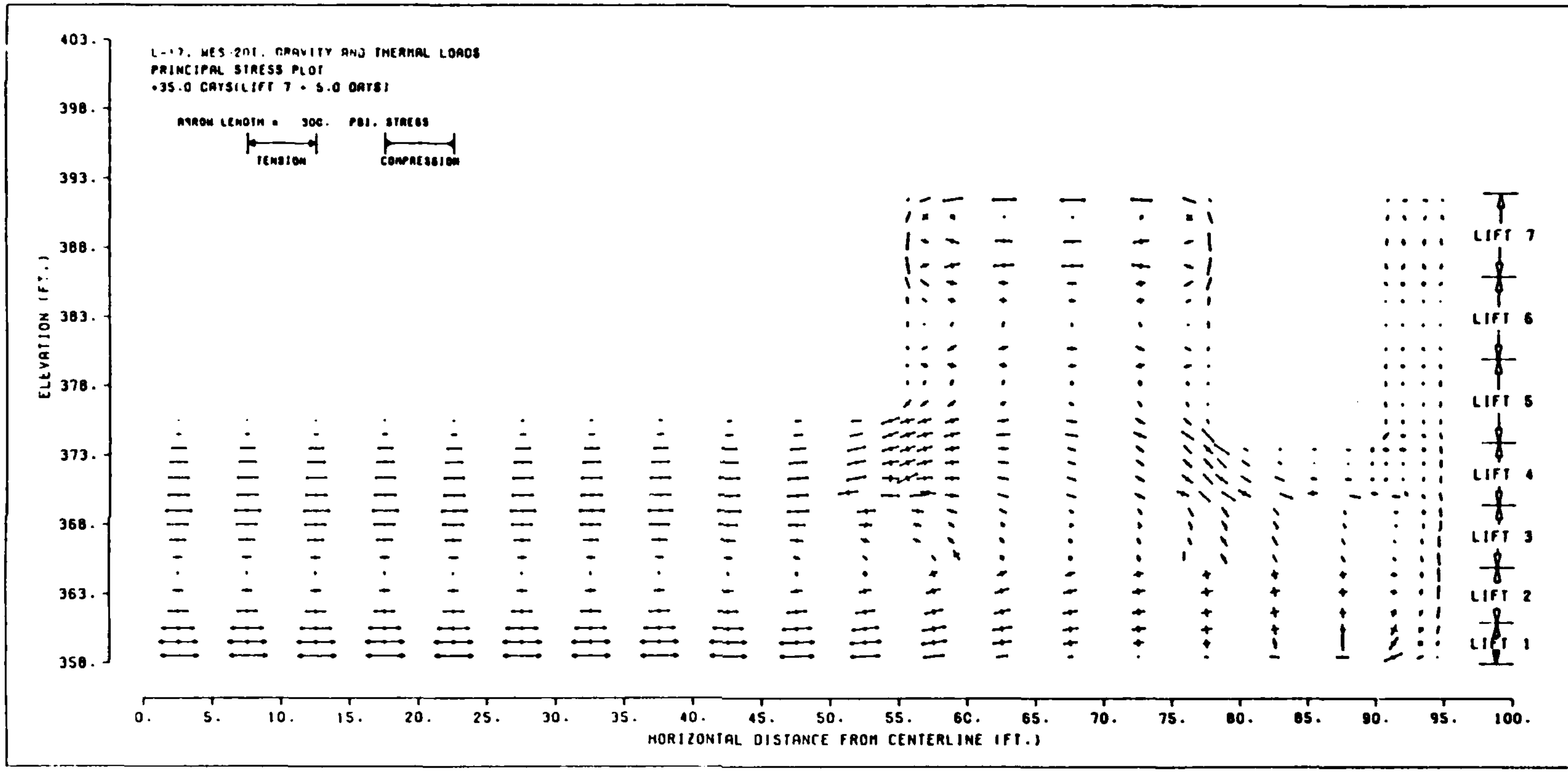


Figure 54b. Principal stress contours of structure 5 days after lift 7 is placed, gravity and temperature loading including creep, using WES2DT.

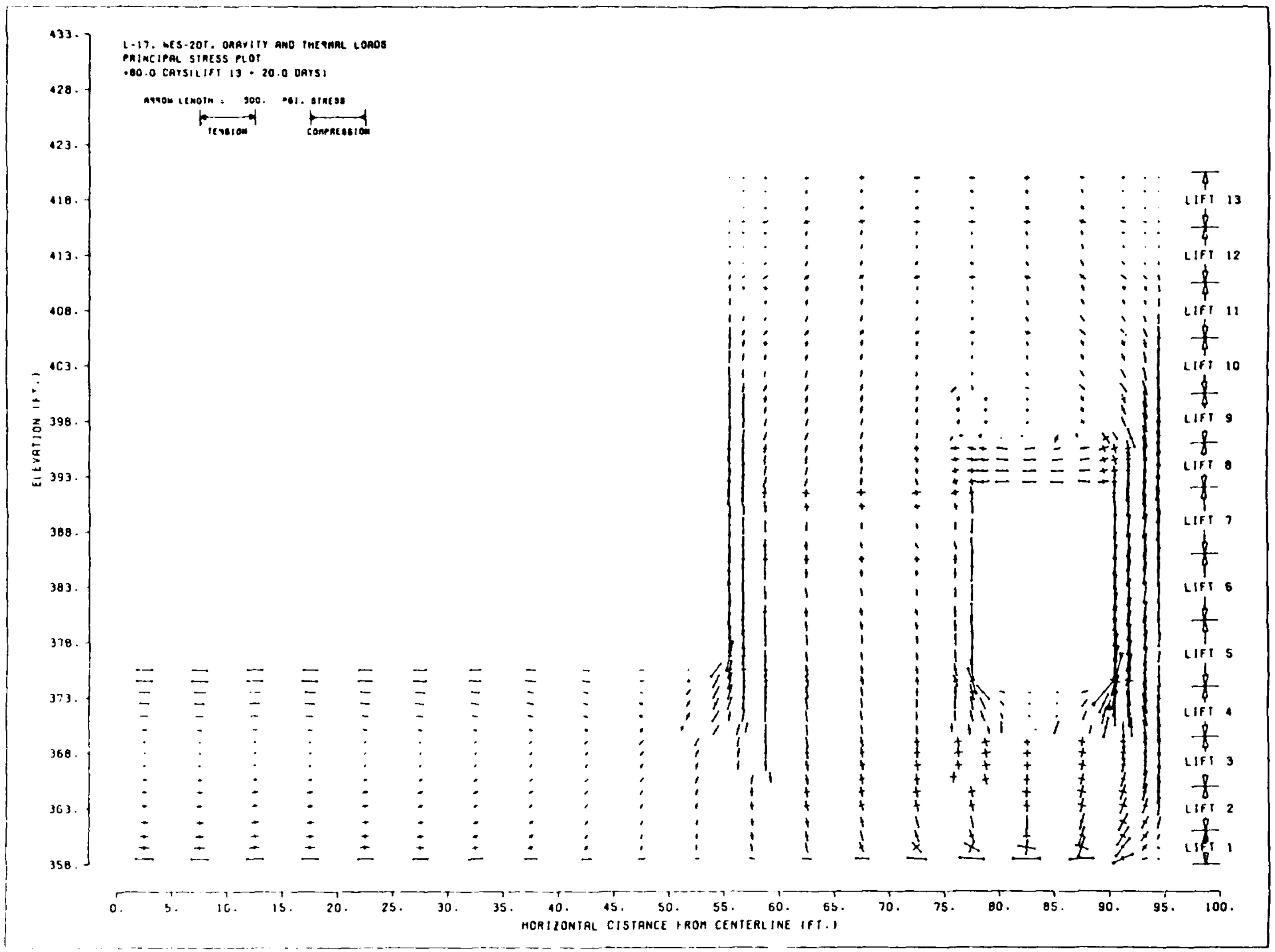


Figure 54c. Principal stress contours of structure 20 days after lift 13 is placed, gravity and temperature loading including creep, using WES2DT.

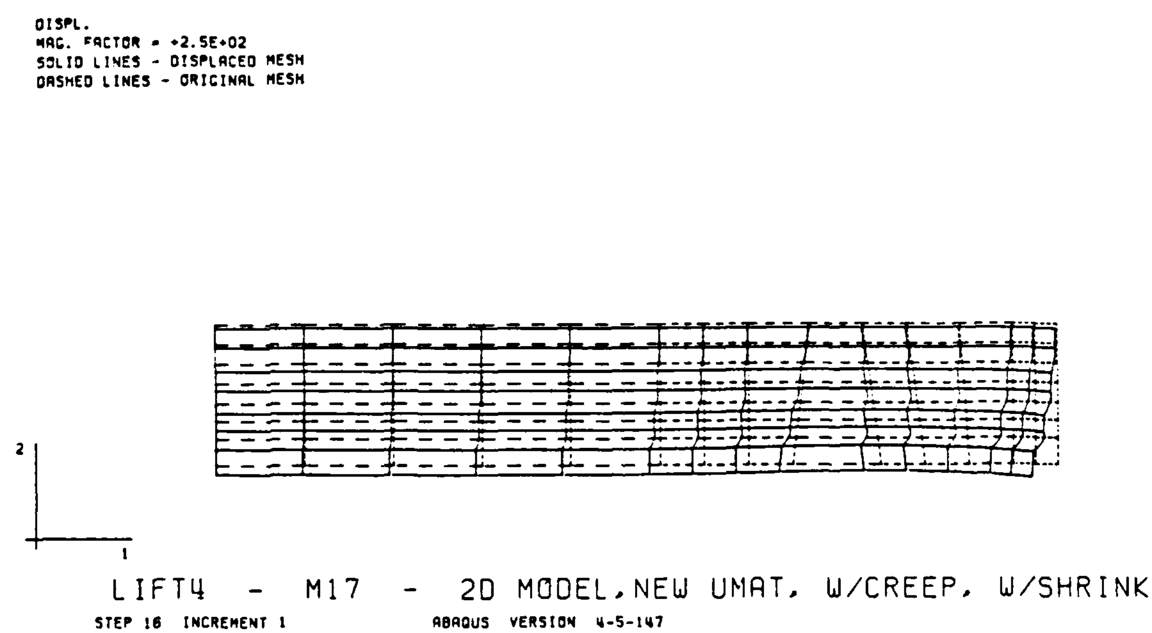


Figure 55a. Displaced structure 5 days after placement of lift 4, gravity and temperature loading with creep and shrinkage, using ABAQUS (UMAT2).

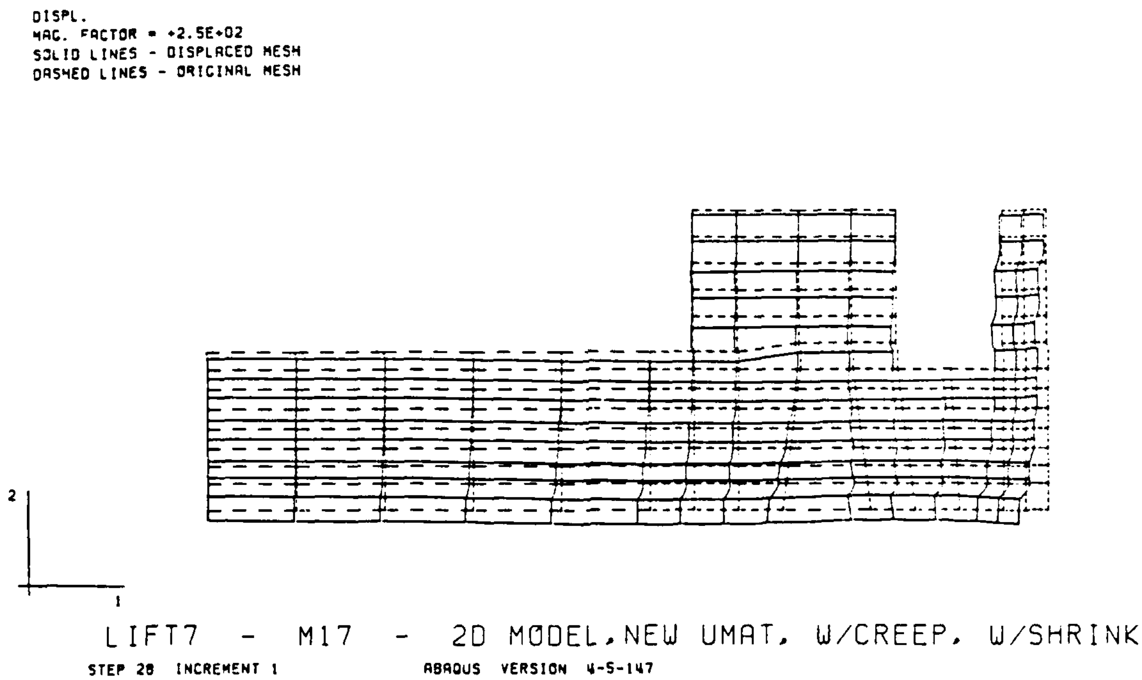


Figure 55b. Displaced structure 5 days after placement of lift 7, gravity and temperature loading with creep and shrinkage, using ABAQUS (UMAT2).

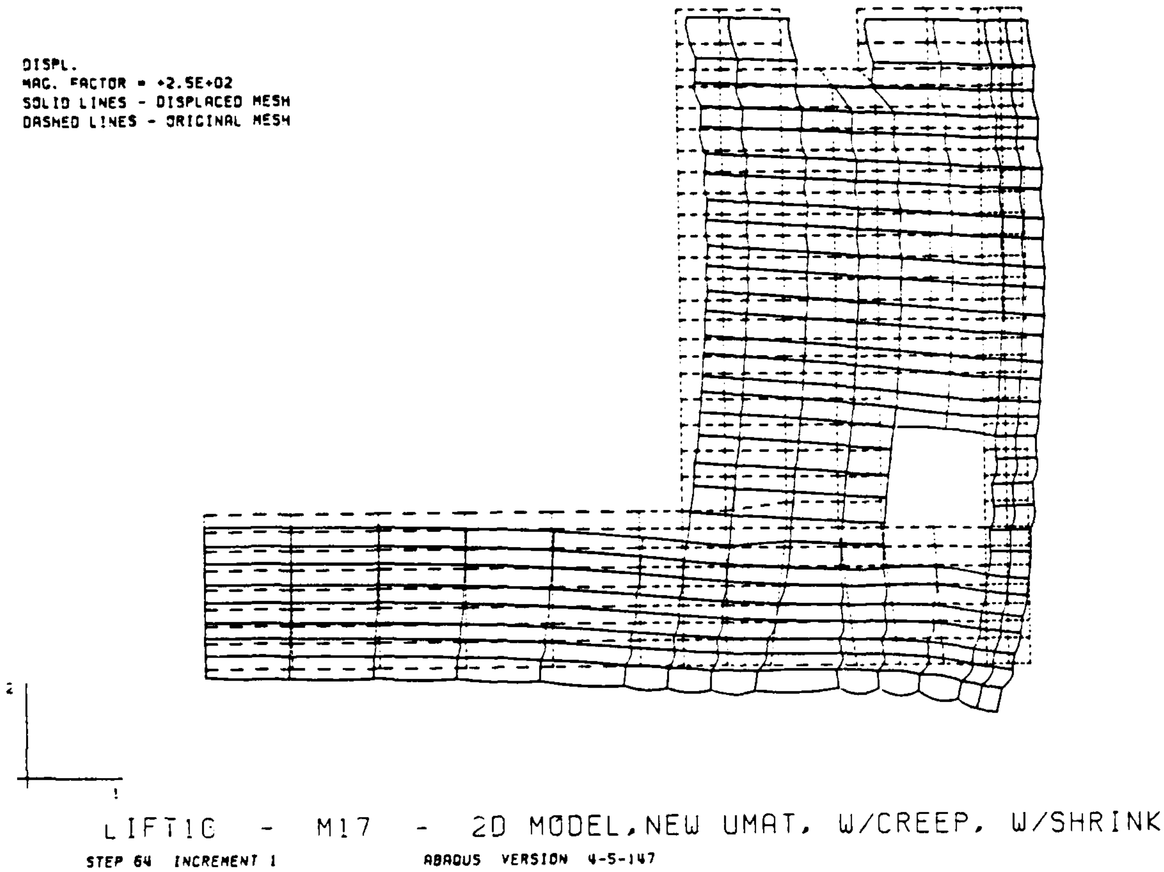


Figure 55c. Displaced structure 5 days after placement of lift 16, gravity and temperature loading with creep and shrinkage, using ABAQUS (UMAT2).

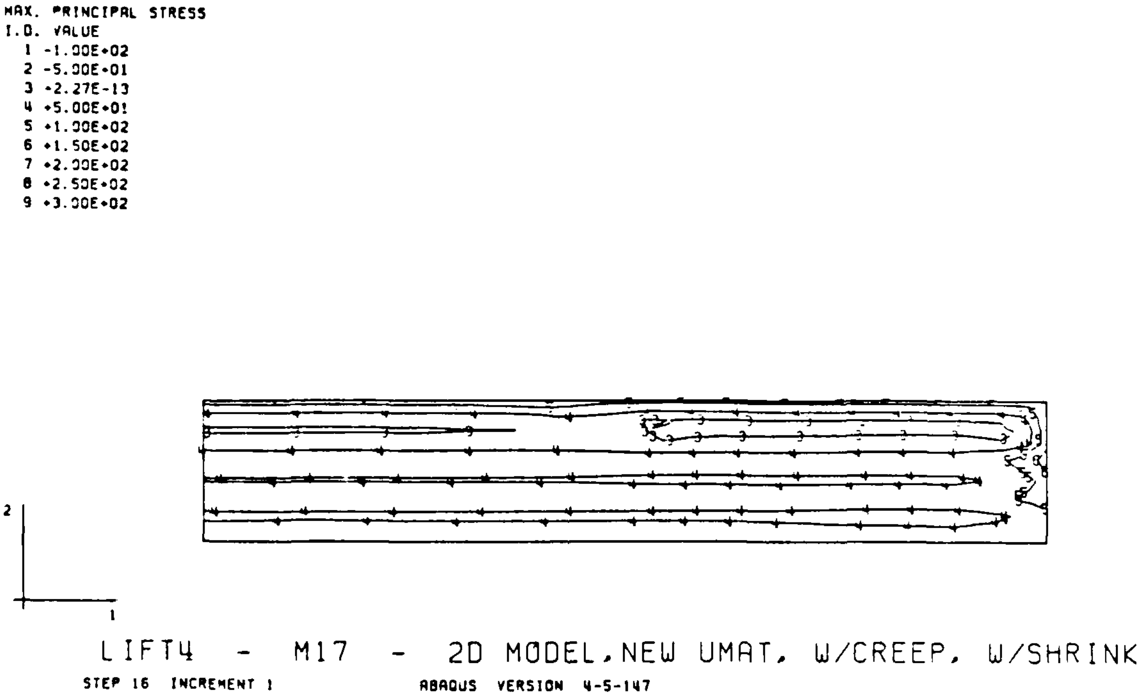


Figure 56a. Maximum principal stress contours 5 days after placement of lift 4, gravity and temperature loading with creep and shrinkage, using ABAQUS (UMAT2).

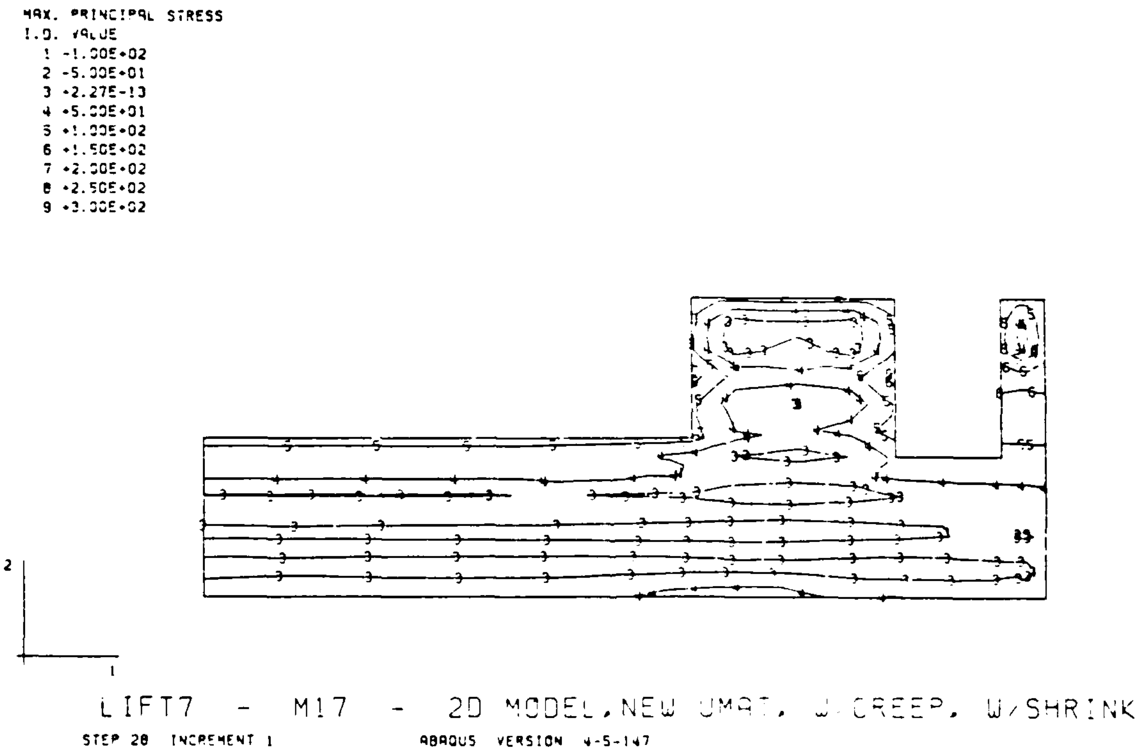


Figure 56b. Maximum principal stress contours 5 days after placement of lift 7, gravity and temperature loading with creep and shrinkage, using ABAQUS (UMAT2).

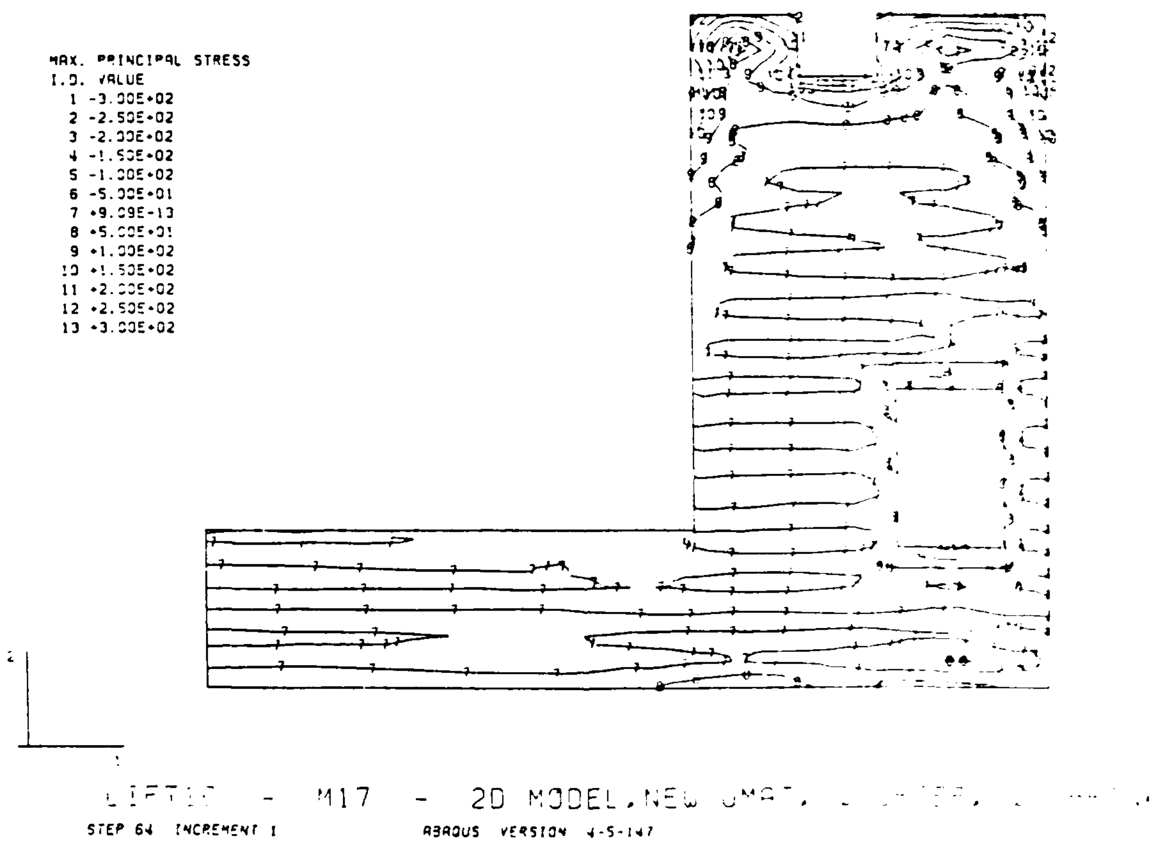


Figure 56c. Maximum principal stress contours 5 days after placement of lift 16, gravity and temperature loading with creep and shrinkage using ABAQUS (UMAT2).

PART XI: CONCLUSIONS AND RECOMMENDATIONS

125. Throughout the course of this study, the ABAQUS computer program seemed to adequately capture the behavior of the lock monoliths during construction. Options existed in the program to adequately model the phenomena that occurs during the incremental construction process. While at the present time there is a need to refine the aging creep model used during this study, it does appear that an adequate two-dimensional incremental construction thermal stress analysis can be accomplished using this computer program.

126. Accuracy and precision of results in finite element thermal stress analysis of mass concrete structures are strongly dependent on the accuracy and precision of material properties test results such as moduli, specific creep, shrinkage, etc., which are used as input to the numerical model in the computer program. For the aging creep numerical model used in ABAQUS in this study, it is clear that the early-age E versus time values are higher than those values for the Lock and Dam 26(R) concrete being modeled. This led to calculation of excessive thermal stresses and creep relaxation at early time. A better representation for the modulus should be developed and verified for concrete similar to that used in Lock and Dam 26(R).

127. Distribution of pile loads beneath the lock sections is significantly affected by the assumptions made in the analysis (i.e., gravity turn on, incremental [illegible] with [illegible] creep, shrinkage, etc.). It was [illegible]

[illegible]

necessary to perform an incremental construction analysis, preferably with an aging creep model, in some instances, if practical.

128. Incremental construction models better simulate actual field construction conditions than simple gravity turn-on analyses in producing realistic construction-related stresses. It was found that the interaction of the many mechanisms at work during construction can produce results that are not obtainable by simple analysis methods. More research is required in this area to delineate the extent to which incremental construction analyses should be required in structural design. It has become evident that the effects of the construction process should be considered in the design process, because cracking in mass concrete structures during the construction phase may alter design considerations.

129. As pointed out in paragraph 95, the costs of performing the three-dimensional incremental construction temperature and thermal stress analyses was prohibitive. The ABAQUS three-dimensional computer runs were to be made using a commercial computer service. It became apparent that using commercial computer resources to perform three-dimensional analyses was not economically feasible at the present time. Alternative computer resources at government-owned installations on which the ABAQUS computer program was installed and running were examined and also found to be too costly to use.

[illegible] ABAQUS is now available on several "super mini" computers [illegible] three-dimensional analyses of incremental construction problems. This formulation was developed in a modern, general purpose heat transfer and structural analysis code. Every effort was made to ensure that the analysis concept was effective, rational, and consistent. With this requirement in mind it soon became apparent that effective modeling of key parameters affecting final stresses in incrementally constructed mass concrete structures were pushed far beyond the current state of the art. These key parameters include: early age (1 day, 2 day, ...) properties such as shrinkage, creep, material aging, and cracking strength. Also, the concept of the incremental formulation itself presents some unusual, subtle problems.

132. Currently, research programs are underway to better define and verify these parameters through carefully planned theoretical, computational, and experimental research programs. The intent of this research is to provide effective and efficient design and analysis guidance to the field engineers in the area of mass concrete construction. The approach taken here is a cooperative research effort among research and design staffs at District and Division Offices, major universities, private engineering firms, and Corp's laboratories.

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APPENDIX A: ABAQUS TWO-DIMENSIONAL NODE FILE USED FOR MONOLITH L-17

NODE NO	X	Y	Z	NODE NO	X	Y	Z	NODE NO.	X	Y	Z
51	360.000	4236.000	0.000	101	660.000	4296.000	0.000	151	895.500	4332.000	0.000
52	420.000	4236.000	0.000	102	690.000	4296.000	0.000	152	925.500	4332.000	0.000
53	480.000	4236.000	0.000	103	720.000	4296.000	0.000	153	955.500	4332.000	0.000
54	[illegible]	4236.000	0.000	104	750.000	4296.000	0.000	154	986.625	4332.000	0.000
55	[illegible]	4236.000	0.000	105	780.000	4296.000	0.000	155	1017.750	4332.000	0.000
56	[illegible]	[illegible]	0.000	106	840.000	4296.000	0.000	156	1048.875	4332.000	0.000
57	[illegible]	[illegible]	0.000	107	900.000	4296.000	0.000	157	1080.000	4332.000	0.000
58	[illegible]	4236.000	[illegible]	108	930.000	4296.000	0.000	158	1095.000	4332.000	0.000
[illegible]	[illegible]	4236.000	0.000	109	960.000	4296.000	0.000	159	1110.000	4332.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	110	990.000	4296.000	0.000	160	1125.000	4332.000	0.000
[illegible]	[illegible]	4236.000	[illegible]	111	1020.000	4296.000	0.000	161	1140.000	4332.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	112	1050.000	4296.000	0.000	162	0.000	4344.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	113	1080.000	4296.000	0.000	163	120.000	4344.000	0.000
[illegible]	[illegible]	4236 [illegible]	[illegible]	114	1095.000	4296.000	0.000	164	240.000	4344.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	115	1110.000	4296.000	0.000	165	360.000	4344.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	116	1125.000	4296.000	0.000	166	480.000	4344.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	117	1140.000	4296.000	0.000	167	600.000	4344.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	118	0.000	4314.000	0.000	168	660.000	4344.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	119	120.000	4314.000	0.000	169	720.000	4344.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	120	240.000	4314.000	0.000	170	786.000	4344.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	121	360.000	4314.000	0.000	171	894.000	4344.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	122	480.000	4314.000	0.000	172	954.000	4344.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	123	600.000	4314.000	0.000	173	1017.000	4344.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	124	660.000	4314.000	0.000	174	1080.000	4344.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	125	720.000	4314.000	0.000	175	1110.000	4344.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	126	782.250	4314.000	0.000	176	1140.000	4344.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	127	897.750	4314.000	0.000	177	0.000	4356.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	128	[illegible]	4314.000	0.000	178	60.000	4356.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	129	1018.875	4314.000	0.000	179	120.000	4356.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	130	1080.000	4314.000	0.000	180	180.000	4356.000	0.000
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[illegible]	[illegible]	[illegible]	[illegible]	132	1140.000	4314.000	0.000	182	300.000	4356.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	133	0.000	4332.000	0.000	183	360.000	4356.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	134	60.000	4332.000	0.000	184	420.000	4356.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	135	120.000	4332.000	0.000	185	480.000	4356.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	136	180.000	4332.000	0.000	186	540.000	4356.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	137	240.000	4332.000	0.000	187	600.000	4356.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	138	[illegible]	4332.000	0.000	188	630.000	4356.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	139	[illegible]	4332.000	0.000	189	660.000	4356.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	140	420.000	4332.000	0.000	190	690.000	4356.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	141	[illegible]	4332.000	0.000	191	720.000	4356.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	142	540.000	4332.000	0.000	192	753.750	4356.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	143	[illegible]	4332.000	0.000	193	787.500	4356.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	144	[illegible]	4332.000	0.000	194	840.000	4356.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	145	[illegible]	4332.000	0.000	195	892.500	4356.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	146	690.000	4332.000	0.000	196	922.500	4356.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	147	720.000	4332.000	0.000	197	952.500	4356.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	148	752.250	4332.000	0.000	198	984.375	4356.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	149	784.500	4332.000	0.000	199	1016.250	4356.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	150	840.000	4332.000	0.000	200	1048.125	4356.000	0.000

[illegible] ELEMENTS IN STRESS ANALYSIS NOT USED

NODE NO	X	Y	Z	NODE NO	X	Y	Z	NODE NO	X	Y	Z
251	120.000	4393.500	0.000	301	720.000	4420.500	0.000	351	1110.000	4447.500	0.000
252	240.000	4393.500	0.000	302	795.563	4420.500	0.000	352	1140.000	4447.500	0.000
[illegible]	[illegible]	4393.500	0.000	303	884.438	4420.500	0.000	353	0.000	4461.000	0.000
[illegible]	[illegible]	4393.500	0.000	304	944.438	4420.500	0.000	354	60.000	4461.000	0.000
[illegible]	[illegible]	4393.500	0.000	305	1012.219	4420.500	0.000	355	120.000	4461.000	0.000
[illegible]	[illegible]	4393.500	0.000	306	1080.000	4420.500	0.000	356	180.000	4461.000	0.000
[illegible]	[illegible]	4393.500	0.000	307	1110.000	4420.500	0.000	357	240.000	4461.000	0.000
258	[illegible] 188	4393.500	0.000	308	1140.000	4420.500	0.000	358	300.000	4461.000	0.000
[illegible]	[illegible]	4393.500	0.000	309	0.000	4434.000	0.000	359	360.000	4461.000	0.000
[illegible]	[illegible]	4393.500	0.000	310	60.000	4434.000	0.000	360	420.000	4461.000	0.000
[illegible]	[illegible]	4393.500	0.000	311	120.000	4434.000	0.000	361	480.000	4461.000	0.000
[illegible]	[illegible]	4393.500	0.000	312	180.000	4434.000	0.000	362	540.000	4461.000	0.000
[illegible]	[illegible]	4393.500	0.000	313	240.000	4434.000	0.000	363	600.000	4461.000	0.000
[illegible]	[illegible]	4393.500	0.000	314	300.000	4434.000	0.000	364	630.000	4461.000	0.000
[illegible]	[illegible]	4407.000	0.000	315	360.000	4434.000	0.000	365	660.000	4461.000	0.000
[illegible]	[illegible]	4407.000	0.000	316	420.000	4434.000	0.000	366	690.000	4461.000	0.000
[illegible]	[illegible]	4407.000	0.000	317	480.000	4434.000	0.000	367	720.000	4461.000	0.000
268	[illegible]	4407.000	0.000	318	540.000	4434.000	0.000	368	760.313	4461.000	0.000
[illegible]	[illegible]	4407.000	0.000	319	600.000	4434.000	0.000	369	800.625	4461.000	0.000
[illegible]	[illegible]	4407.000	0.000	320	630.000	4434.000	0.000	370	840.000	4461.000	0.000
[illegible]	[illegible]	4407.000	0.000	321	660.000	4434.000	0.000	371	879.375	4461.000	0.000
[illegible]	[illegible]	4407.000	0.000	322	690.000	4434.000	0.000	372	909.375	4461.000	0.000
[illegible]	[illegible]	4407.000	0.000	323	720.000	4434.000	0.000	373	939.375	4461.000	0.000
[illegible]	[illegible]	4407.000	0.000	324	758.625	4434.000	0.000	374	974.532	4461.000	0.000
[illegible]	[illegible]	4407.000	0.000	325	797.250	4434.000	0.000	375	1009.688	4461.000	0.000
[illegible]	[illegible]	4407.000	0.000	326	840.000	4434.000	0.000	376	1044.844	4461.000	0.000
[illegible]	[illegible]	4407.000	0.000	327	882.750	4434.000	0.000	377	1080.000	4461.000	0.000
[illegible]	[illegible]	4407.000	0.000	328	912.750	4434.000	0.000	378	1095.000	4461.000	0.000
[illegible]	723.[illegible]	4407.000	0.000	329	942.750	4434.000	0.000	379	1110.000	4461.000	0.000
[illegible]	756.938	4407.000	0.000	330	977.063	4434.000	0.000	380	1125.000	4461.000	0.000
[illegible]	793.875	4407.000	0.000	331	1011.375	4434.000	0.000	381	1140.000	4461.000	0.000
[illegible]	[illegible]	4407.000	0.000	332	1045.688	4434.000	0.000	382	0.000	4474.500	0.000
283	886.125	4407.000	0.000	333	1080.000	4434.000	0.000	383	120.000	4474.500	0.000
284	916.125	4407.000	0.000	334	1095.000	4434.000	0.000	384	240.000	4474.500	0.000
285	946.125	4407.000	0.000	335	1110.000	4434.000	0.000	385	360.000	4474.500	0.000
286	979.594	4407.000	0.000	336	1125.000	4434.000	0.000	386	480.000	4474.500	0.000
287	[illegible] 063	4407.000	0.000	337	1140.000	4434.000	0.000	387	600.000	4474.500	0.000
288	1046.532	4407.000	0.000	338	0.000	4447.500	0.000	388	660.000	4474.500	0.000
[illegible]	[illegible]	4407.000	0.000	339	120.000	4447.500	0.000	389	720.000	4474.500	0.000
290	1095.000	4407.000	0.000	340	240.000	4447.500	0.000	390	802.313	4474.500	0.000
291	1110.000	4407.000	0.000	341	360.000	4447.500	0.000	391	877.688	4474.500	0.000
292	1125.000	4407.000	0.000	342	480.000	4447.500	0.000	392	937.688	4474.500	0.000
293	1140.000	4407.000	0.000	343	600.000	4447.500	0.000	393	1008.844	4474.500	0.000
294	0.000	4420.500	0.000	344	660.000	4447.500	0.000	394	1080.000	4474.500	0.000
295	120.000	4420.500	0.000	345	720.000	4447.500	0.000	395	1110.000	4474.500	0.000
296	240.000	4420.500	0.000	346	798.938	4447.500	0.000	396	1140.000	4474.500	0.000
297	360.000	4420.500	0.000	347	881.063	4447.500	0.000	397	0.000	4488.000	0.000
298	480.000	4420.500	0.000	348	941.063	4447.500	0.000	398	60.000	4488.000	0.000
299	600.000	4420.500	0.000	349	1010.532	4447.500	0.000	399	120.000	4488.000	0.000
300	660.000	4420.500	0.000	350	1080.000	4447.500	0.000	400	180.000	4488.000	0.000

NODE NO.	X	Y	Z	NODE NO.	X	Y	Z	NODE NO.	X	Y	Z	NODE NO.	X	Y	Z
401	240.000	4488.000	0.000	451	600.000	4512.000	0.000	501	1008.000	4578.000	0.000	551	876.000	4650.000	0.000
402	[illegible]	4488.000	0.000	452	630.000	4512.000	0.000	502	1080.000	4578.000	0.000	552	936.000	4650.000	0.000
403	360.000	4488.000	0.000	453	660.000	4512.000	0.000	503	1110.000	4578.000	0.000	553	1008.000	4650.000	0.000
404	420.000	4488.000	0.000	454	690.000	4512.000	0.000	504	1140.000	4578.000	0.000	554	1080.000	4650.000	0.000
405	480.000	4488.000	0.000	455	720.000	4512.000	0.000	505	660.000	4596.000	0.000	555	1110.000	4650.000	0.000
406	540.000	4488.000	0.000	456	762.000	4518.000	0.000	506	690.000	4596.000	0.000	556	1140.000	4650.000	0.000
407	600.000	4488.000	0.000	457	804.000	4524.000	0.000	507	720.000	4596.000	0.000	557	660.000	4668.000	0.000
408	630.000	4488.000	0.000	458	840.000	4524.000	0.000	508	762.000	4596.000	0.000	558	690.000	4668.000	0.000
409	660.000	4488.000	0.000	459	876.000	4524.000	0.000	509	804.000	4596.000	0.000	559	720.000	4668.000	0.000
410	690.000	4488.000	0.000	460	906.000	4524.000	0.000	510	840.000	4596.000	0.000	560	762.000	4668.000	0.000
411	720.000	4488.000	0.000	461	936.000	4524.000	0.000	511	876.000	4596.000	0.000	561	804.000	4668.000	0.000
412	762.000	4488.000	0.000	462	972.000	4524.000	0.000	512	906.000	4596.000	0.000	562	840.000	4668.000	0.000
413	804.000	4488.000	0.000	463	1008.000	4524.000	0.000	513	936.000	4596.000	0.000	563	876.000	4668.000	0.000
414	840.000	4488.000	0.000	464	1044.000	4524.000	0.000	514	972.000	4596.000	0.000	564	906.000	4668.000	0.000
415	876.000	4488.000	0.000	465	1080.000	4524.000	0.000	515	1008.000	4596.000	0.000	565	936.000	4668.000	0.000
416	906.000	4488.000	0.000	466	1095.000	4524.000	0.000	516	1044.000	4596.000	0.000	566	972.000	4668.000	0.000
417	936.000	4488.000	0.000	467	1110.000	4524.000	0.000	517	1080.000	4596.000	0.000	567	1008.000	4668.000	0.000
418	972.000	4488.000	0.000	468	1125.000	4524.000	0.000	518	1095.000	4596.000	0.000	568	1044.000	4668.000	0.000
419	1008.000	4488.000	0.000	469	1140.000	4524.000	0.000	519	1110.000	4596.000	0.000	569	1080.000	4668.000	0.000
420	[illegible]	4488.000	0.000	470	660.000	4536.000	0.000	520	1125.000	4596.000	0.000	570	1095.000	4668.000	0.000
421	[illegible]	4488.000	0.000	471	720.000	4536.000	0.000	521	1140.000	4596.000	0.000	571	1110.000	4668.000	0.000
422	[illegible]	4488.000	0.000	472	804.000	4542.000	0.000	522	660.000	4614.000	0.000	572	1125.000	4668.000	0.000
423	[illegible]	4488.000	0.000	473	876.000	4542.000	0.000	523	720.000	4614.000	0.000	573	1140.000	4668.000	0.000
424	1125.000	4488.000	0.000	474	936.000	4542.000	0.000	524	804.000	4614.000	0.000	574	660.000	4686.000	0.000
425	[illegible]	4488.000	0.000	475	1008.000	4542.000	0.000	525	876.000	4614.000	0.000	575	720.000	4686.000	0.000
426	[illegible]	[illegible]	0.000	476	1080.000	4542.000	0.000	526	936.000	4614.000	0.000	576	804.000	4686.000	0.000
427	[illegible]	[illegible]	0.000	477	1110.000	4542.000	0.000	527	1008.000	4614.000	0.000	577	876.000	4686.000	0.000
428	[illegible]	[illegible]	0.000	478	1140.000	4542.000	0.000	528	1080.000	4614.000	0.000	578	936.000	4686.000	0.000
429	[illegible]	[illegible]	0.000	479	660.000	4560.000	0.000	529	1110.000	4614.000	0.000	579	1008.000	4686.000	0.000
430	[illegible]	[illegible]	0.000	480	690.000	4560.000	0.000	530	1140.000	4614.000	0.000	580	1080.000	4686.000	0.000
431	[illegible]	[illegible]	0.000	481	720.000	4560.000	0.000	531	660.000	4632.000	0.000	581	1110.000	4686.000	0.000
432	[illegible]	[illegible]	0.000	482	762.000	4560.000	0.000	532	690.000	4632.000	0.000	582	1140.000	4686.000	0.000
433	[illegible]	[illegible]	0.000	483	804.000	4560.000	0.000	533	720.000	4632.000	0.000	583	660.000	4704.000	0.000
434	[illegible]	[illegible]	0.000	484	840.000	4560.000	0.000	534	762.000	4632.000	0.000	584	690.000	4704.000	0.000
435	[illegible]	4506.000	0.000	485	876.000	4560.000	0.000	535	804.000	4632.000	0.000	585	720.000	4704.000	0.000
436	[illegible]	4506.000	0.000	486	906.000	4560.000	0.000	536	840.000	4632.000	0.000	586	762.000	4704.000	0.000
437	[illegible]	[illegible]	0.000	487	936.000	4560.000	0.000	537	876.000	4632.000	0.000	587	804.000	4704.000	0.000
438	[illegible]	[illegible]	0.000	488	972.000	4560.000	0.000	538	906.000	4632.000	0.000	588	840.000	4704.000	0.000
439	[illegible]	4506.000	0.000	489	1008.000	4560.000	0.000	539	936.000	4632.000	0.000	589	876.000	4704.000	0.000
440	[illegible]	[illegible]	0.000	490	1044.000	4560.000	0.000	540	972.000	4632.000	0.000	590	906.000	4704.000	0.000
441	[illegible]	4512.000	0.000	491	1080.000	4560.000	0.000	541	1008.000	4632.000	0.000	591	936.000	4704.000	0.000
442	[illegible]	4512.000	0.000	492	1095.000	4560.000	0.000	542	1044.000	4632.000	0.000	592	972.000	4704.000	0.000
443	[illegible]	4512.000	0.000	493	1110.000	4560.000	0.000	543	1080.000	4632.000	0.000	593	1008.000	4704.000	0.000
444	[illegible]	4512.000	0.000	494	1125.000	4560.000	0.000	544	1095.000	4632.000	0.000	594	1044.000	4704.000	0.000
445	[illegible]	4512.000	0.000	495	1140.000	4560.000	0.000	545	1110.000	4632.000	0.000	595	1080.000	4704.000	0.000
446	[illegible]	4512.000	0.000	496	660.000	4578.000	0.000	546	1125.000	4632.000	0.000	596	1095.000	4704.000	0.000
447	[illegible]	4512.000	0.000	497	720.000	4578.000	0.000	547	1140.000	4632.000	0.000	597	1110.000	4704.000	0.000
448	[illegible]	4512.000	0.000	498	804.000	4578.000	0.000	548	660.000	4650.000	0.000	598	1125.000	4704.000	0.000
449	[illegible]	4512.000	0.000	499	876.000	4578.000	0.000	549	720.000	4650.000	0.000	599	1140.000	4704.000	0.000
450	[illegible]	4512.000	0.000	500	936.000	4578.000	0.000	550	804.000	4650.000	0.000	600	660.000	4716.000	0.000

NODE NO	X	Y	Z	NODE NO.	X	Y	Z	NODE NO.	X	Y	Z	NODE NO.	X	Y	Z
601	720.000	4716.000	0.000	651	1140.000	4752.000	0.000	701	1110.000	4806.000	0.000	751	1080.000	4866.000	0.000
602	804.000	4716.000	0.000	652	660.000	4765.500	0.000	702	1125.000	4806.000	0.000	752	1095.000	4866.000	0.000
603	876.000	4716.000	0.000	653	720.000	4765.500	0.000	703	1140.000	4806.000	0.000	753	1110.000	4866.000	0.000
604	936.000	4716.000	0.000	654	804.000	4765.500	0.000	704	660.000	4821.000	0.000	754	1125.000	4866.000	0.000
605	1008.000	4716.000	0.000	655	876.000	4765.500	0.000	705	720.000	4821.000	0.000	755	1140.000	4866.000	0.000
606	1080.000	4716.000	0.000	656	936.000	4765.500	0.000	706	804.000	4821.000	0.000	756	660.000	4881.000	0.000
607	1110.000	4716.000	0.000	657	1008.000	4765.500	0.000	707	876.000	4821.000	0.000	757	720.000	4881.000	0.000
608	1140.000	4716.000	0.000	658	1080.000	4765.500	0.000	708	936.000	4821.000	0.000	758	804.000	4881.000	0.000
609	660.000	4728.000	0.000	659	1110.000	4765.500	0.000	709	1008.000	4821.000	0.000	759	876.000	4881.000	0.000
610	690.000	4728.000	0.000	660	1140.000	4765.500	0.000	710	1080.000	4821.000	0.000	760	936.000	4881.000	0.000
611	720.000	4728.000	0.000	661	660.000	4779.000	0.000	711	1110.000	4821.000	0.000	761	1008.000	4881.000	0.000
612	762.000	4728.000	0.000	662	690.000	4779.000	0.000	712	1140.000	4821.000	0.000	762	1080.000	4881.000	0.000
613	804.000	4728.000	0.000	663	720.000	4779.000	0.000	713	660.000	4836.000	0.000	763	1110.000	4881.000	0.000
614	840.000	4728.000	0.000	664	762.000	4779.000	0.000	714	690.000	4836.000	0.000	764	1140.000	4881.000	0.000
615	876.000	4728.000	0.000	665	804.000	4779.000	0.000	715	720.000	4836.000	0.000	765	660.000	4896.000	0.000
616	906.000	4728.000	0.000	666	840.000	4779.000	0.000	716	762.000	4836.000	0.000	766	690.000	4896.000	0.000
617	936.000	4728.000	0.000	667	876.000	4779.000	0.000	717	804.000	4836.000	0.000	767	720.000	4896.000	0.000
618	972.000	4728.000	0.000	668	906.000	4779.000	0.000	718	840.000	4836.000	0.000	768	762.000	4896.000	0.000
619	1008.000	4728.000	0.000	669	936.000	4779.000	0.000	719	876.000	4836.000	0.000	769	804.000	4896.000	0.000
620	1044.000	4728.000	0.000	670	972.000	4779.000	0.000	720	906.000	4836.000	0.000	770	840.000	4896.000	0.000
621	1080.000	4728.000	0.000	671	1008.000	4779.000	0.000	721	936.000	4836.000	0.000	771	876.000	4896.000	0.000
622	1095.000	4728.000	0.000	672	1044.000	4779.000	0.000	722	972.000	4836.000	0.000	772	906.000	4896.000	0.000
623	1110.000	4728.000	0.000	673	1080.000	4779.000	0.000	723	1008.000	4836.000	0.000	773	936.000	4896.000	0.000
624	1125.000	4728.000	0.000	674	1095.000	4779.000	0.000	724	1044.000	4836.000	0.000	774	972.000	4896.000	0.000
625	1140.000	4728.000	0.000	675	1110.000	4779.000	0.000	725	1080.000	4836.000	0.000	775	1008.000	4896.000	0.000
626	660.000	4740.000	0.000	676	1125.000	4779.000	0.000	726	1095.000	4836.000	0.000	776	1044.000	4896.000	0.000
627	720.000	4740.000	0.000	677	1140.000	4779.000	0.000	727	1110.000	4836.000	0.000	777	1080.000	4896.000	0.000
628	804.000	4740.000	0.000	678	660.000	4792.500	0.000	728	1125.000	4836.000	0.000	778	1095.000	4896.000	0.000
629	876.000	4740.000	0.000	679	720.000	4792.500	0.000	729	1140.000	4836.000	0.000	779	1110.000	4896.000	0.000
630	936.000	4740.000	0.000	680	804.000	4792.500	0.000	730	660.000	4851.000	0.000	780	1125.000	4896.000	0.000
631	1008.000	4740.000	0.000	681	876.000	4792.500	0.000	731	720.000	4851.000	0.000	781	1140.000	4896.000	0.000
632	1080.000	4740.000	0.000	682	936.000	4792.500	0.000	732	804.000	4851.000	0.000	782	660.000	4911.000	0.000
633	1110.000	4740.000	0.000	683	1008.000	4792.500	0.000	733	876.000	4851.000	0.000	783	720.000	4911.000	0.000
634	1140.000	4740.000	0.000	684	1080.000	4792.500	0.000	734	936.000	4851.000	0.000	784	804.000	4911.000	0.000
635	660.000	4752.000	0.000	685	1110.000	4792.500	0.000	735	1008.000	4851.000	0.000	785	876.000	4911.000	0.000
636	690.000	4752.000	0.000	686	1140.000	4792.500	0.000	736	1080.000	4851.000	0.000	786	936.000	4911.000	0.000
637	720.000	4752.000	0.000	687	660.000	4806.000	0.000	737	1110.000	4851.000	0.000	787	1008.000	4911.000	0.000
638	762.000	4752.000	0.000	688	690.000	4806.000	0.000	738	1140.000	4851.000	0.000	788	1080.000	4911.000	0.000
639	804.000	4752.000	0.000	689	720.000	4806.000	0.000	739	660.000	4866.000	0.000	789	1110.000	4911.000	0.000
640	840.000	4752.000	0.000	690	762.000	4806.000	0.000	740	690.000	4866.000	0.000	790	1140.000	4911.000	0.000
641	876.000	4752.000	0.000	691	804.000	4806.000	0.000	741	720.000	4866.000	0.000	791	660.000	4926.000	0.000
642	906.000	4752.000	0.000	692	840.000	4806.000	0.000	742	762.000	4866.000	0.000	792	690.000	4926.000	0.000
643	936.000	4752.000	0.000	693	876.000	4806.000	0.000	743	804.000	4866.000	0.000	793	720.000	4926.000	0.000
644	972.000	4752.000	0.000	694	906.000	4806.000	0.000	744	840.000	4866.000	0.000	794	762.000	4926.000	0.000
645	1008.000	4752.000	0.000	695	936.000	4806.000	0.000	745	876.000	4866.000	0.000	795	804.000	4926.000	0.000
646	1044.000	4752.000	0.000	696	972.000	4806.000	0.000	746	906.000	4866.000	0.000	796	840.000	4926.000	0.000
647	1080.000	4752.000	0.000	697	1008.000	4806.000	0.000	747	936.000	4866.000	0.000	797	876.000	4926.000	0.000
648	1095.000	4752.000	0.000	698	1044.000	4806.000	0.000	748	972.000	4866.000	0.000	798	906.000	4926.000	0.000
649	1110.000	4752.000	0.000	699	1080.000	4806.000	0.000	749	1008.000	4866.000	0.000	799	936.000	4926.000	0.000
650	1125.000	4752.000	0.000	700	1095.000	4806.000	0.000	750	1044.000	4866.000	0.000	800	972.000	4926.000	0.000

NODE NO.	X	Y	Z	NODE NO.	X	Y	Z	NODE NO.	X	Y	Z	NODE NO.	X	Y	Z
801	[illegible]	4926.000	0.000	851	936.000	4986.000	0.000	901	876.000	5046.000	0.000	951	804.000	5106.000	0.000
[illegible]	[illegible]	4926.000	0.000	852	972.000	4986.000	0.000	902	906.000	5046.000	0.000	952	840.000	5106.000	0.000
[illegible]	[illegible]	4926.000	0.000	853	1008.000	4986.000	0.000	903	936.000	5046.000	0.000	953	876.000	5106.000	0.000
[illegible]	1095.000	4926.000	0.000	854	1044.000	4986.000	0.000	904	972.000	5046.000	0.000	954	906.000	5106.000	0.000
[illegible]	[illegible]	4926.000	0.000	855	1080.000	4986.000	0.000	905	1008.000	5046.000	0.000	955	936.000	5106.000	0.000
806	1125.000	4926.000	0.000	856	1095.000	4986.000	0.000	906	1044.000	5046.000	0.000	956	972.000	5106.000	0.000
807	[illegible]	4926.000	0.000	857	1110.000	4986.000	0.000	907	1080.000	5046.000	0.000	957	1008.000	5106.000	0.000
808	[illegible]	4941.000	0.000	858	1125.000	4986.000	0.000	908	1095.000	5046.000	0.000	958	1044.000	5106.000	0.000
[illegible]	720.000	4941.000	0.000	859	1140.000	4986.000	0.000	909	1110.000	5046.000	0.000	959	1080.000	5106.000	0.000
[illegible]	804.000	4941.000	0.000	860	660.000	5001.000	0.000	910	1125.000	5046.000	0.000	960	1095.000	5106.000	0.000
811	876.000	4941.000	0.000	861	720.000	5001.000	0.000	911	1140.000	5046.000	0.000	961	1110.000	5106.000	0.000
812	936.000	4941.000	0.000	862	804.000	5001.000	0.000	912	660.000	5061.000	0.000	962	1125.000	5106.000	0.000
[illegible]	[illegible]	4941.000	[illegible]	863	876.000	5001.000	0.000	913	720.000	5061.000	0.000	963	1140.000	5106.000	0.000
[illegible]	[illegible]	4941.000	[illegible]	864	936.000	5001.000	0.000	914	804.000	5061.000	0.000	964	660.000	5118.000	0.000
[illegible]	[illegible]	4941.000	[illegible]	865	1008.000	5001.000	0.000	915	876.000	5061.000	0.000	965	720.000	5118.000	0.000
[illegible]	[illegible]	4941.000	[illegible]	866	1080.000	5001.000	0.000	916	936.000	5061.000	0.000	966	804.000	5118.000	0.000
[illegible]	[illegible]	4956.000	[illegible]	867	1110.000	5001.000	0.000	917	1008.000	5061.000	0.000	967	867.000	5118.000	0.000
[illegible]	[illegible]	4956.000	[illegible]	868	1140.000	5001.000	0.000	918	1080.000	5061.000	0.000	968	924.000	5118.000	0.000
[illegible]	[illegible]	4956.000	[illegible]	869	660.000	5016.000	0.000	919	1110.000	5061.000	0.000	969	1008.000	5118.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	870	690.000	5016.000	0.000	920	1140.000	5061.000	0.000	970	1080.000	5118.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	871	720.000	5016.000	0.000	921	660.000	5076.000	0.000	971	1110.000	5118.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	872	762.000	5016.000	0.000	922	690.000	5076.000	0.000	972	1140.000	5118.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	873	804.000	5016.000	0.000	923	720.000	5076.000	0.000	973	660.000	5130.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	874	840.000	5016.000	0.000	924	762.000	5076.000	0.000	974	690.000	5130.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	875	876.000	5016.000	0.000	925	804.000	5076.000	0.000	975	720.000	5130.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	876	906.000	5016.000	0.000	926	840.000	5076.000	0.000	976	762.000	5130.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	877	936.000	5016.000	0.000	927	876.000	5076.000	0.000	977	804.000	5130.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	878	972.000	5016.000	0.000	928	906.000	5076.000	0.000	978	831.000	5130.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	879	1008.000	5016.000	0.000	929	936.000	5076.000	0.000	979	858.000	5130.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	880	1044.000	5016.000	0.000	930	972.000	5076.000	0.000	980	885.000	5130.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	881	1080.000	5016.000	0.000	931	1008.000	5076.000	0.000	981	912.000	5130.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	882	1095.000	5016.000	0.000	932	1044.000	5076.000	0.000	982	954.000	5130.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	883	1110.000	5016.000	0.000	933	1080.000	5076.000	0.000	983	1008.000	5130.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	884	1125.000	5016.000	0.000	934	1095.000	5076.000	0.000	984	1044.000	5130.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	885	1140.000	5016.000	0.000	935	1110.000	5076.000	0.000	985	1080.000	5130.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	886	660.000	5031.000	0.000	936	1125.000	5076.000	0.000	986	1095.000	5130.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	887	720.000	5031.000	0.000	937	1140.000	5076.000	0.000	987	1110.000	5130.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	888	804.000	5031.000	0.000	938	660.000	5091.000	0.000	988	1125.000	5130.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	889	876.000	5031.000	0.000	939	720.000	5091.000	0.000	989	1140.000	5130.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	890	936.000	5031.000	0.000	940	804.000	5091.000	0.000	990	660.000	5148.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	891	1008.000	5031.000	0.000	941	876.000	5091.000	0.000	991	720.000	5148.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	892	1080.000	5031.000	0.000	942	936.000	5091.000	0.000	992	804.000	5148.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	893	1110.000	5031.000	0.000	943	1008.000	5091.000	0.000	993	858.000	5148.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	894	1140.000	5031.000	0.000	944	1080.000	5091.000	0.000	994	912.000	5148.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	895	660.000	5046.000	0.000	945	1110.000	5091.000	0.000	995	1008.000	5148.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	896	690.000	5046.000	0.000	946	1140.000	5091.000	0.000	996	1080.000	5148.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	897	720.000	5046.000	0.000	947	660.000	5106.000	0.000	997	1110.000	5148.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	898	762.000	5046.000	0.000	948	690.000	5106.000	0.000	998	1140.000	5148.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	899	804.000	5046.000	0.000	949	720.000	5106.000	0.000	999	660.000	5166.000	0.000
[illegible]	[illegible]	[illegible]	[illegible]	900	840.000	5046.000	0.000	950	762.000	5106.000	0.000	1000	690.000	5166.000	0.000

NODE NO	X	Y	Z
1001	720.000	5166.000	0.000
1002	762.000	5166.000	0.000
1003	804.000	5166.000	0.000
1004	831.000	5166.000	0.000
1005	858.000	5166.000	0.000
1006	885.000	5166.000	0.000
1007	912.000	5166.000	0.000
1008	954.000	5166.000	0.000
1009	1008.000	5166.000	0.000
1010	1044.000	5166.000	0.000
1011	1080.000	5166.000	0.000
1012	1095.000	5166.000	0.000
1013	1110.000	5166.000	0.000
1014	1125.000	5166.000	0.000
1015	1140.000	5166.000	0.000
1016	660.000	5190.000	0.000
1017	720.000	5190.000	0.000
1018	804.000	5190.000	0.000
1019	858.000	5190.000	0.000
1020	912.000	5190.000	0.000
1021	1008.000	5190.000	0.000
1022	1080.000	5190.000	0.000
1023	1110.000	5190.000	0.000
1024	1140.000	5190.000	0.000
1025	660.000	5214.000	0.000
1026	690.000	5214.000	0.000
1027	720.000	5214.000	0.000
1028	762.000	5214.000	0.000
1029	804.000	5214.000	0.000
1030	831.000	5214.000	0.000
1031	858.000	5214.000	0.000
1032	885.000	5214.000	0.000
1033	912.000	5214.000	0.000
1034	954.000	5214.000	0.000
1035	1008.000	5214.000	0.000
1036	1044.000	5214.000	0.000
1037	1080.000	5214.000	0.000
1038	1095.000	5214.000	0.000
1039	1110.000	5214.000	0.000
1040	1125.000	5214.000	0.000
1041	1140.000	5214.000	0.000

APPENDIX B: ABAQUS TWO-DIMENSIONAL ELEMENT FILE USED FOR MONOLITH L-17

Element	N1	N2	N3	N4	N5	N6	N7	N8
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
46	[illegible]	[illegible]	[illegible]	183	[illegible]	166	184	165
47	[illegible]	143	[illegible]	185	142	167	186	166
48	[illegible]	145	189	187	144	168	188	167
49	[illegible]	[illegible]	191	189	146	169	190	168
50	[illegible]	149	193	191	148	170	192	169

Element	N1	N2	N3	N4	N5	N6	N7	N8
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	268	296	312	295
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	270	297	314	296
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	272	298	316	297
[illegible]	[illegible]	[illegible]	[illegible]	317	274	299	318	298
[illegible]	[illegible]	[illegible]	[illegible]	319	276	300	320	299
[illegible]	[illegible]	[illegible]	323	321	278	301	322	300
[illegible]	[illegible]	281	325	323	280	302	324	301
[illegible]	281	283	327	325	282	303	326	302
[illegible]	283	285	329	327	284	304	328	303
[illegible]	285	287	331	329	286	305	330	304
96	287	289	333	331	288	306	332	305
97	289	291	335	333	290	307	334	306
98	291	293	337	335	292	308	336	307
99	309	311	355	353	310	339	354	338
100	311	313	357	355	312	340	356	339

Element	N1	N2	N3	N4	N5	N6	N7	N8
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	314	341	358	340
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	316	342	360	341
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	318	343	362	342
[illegible]	[illegible]	[illegible]	365	363	320	344	364	343
[illegible]	[illegible]	[illegible]	367	365	322	345	366	344
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	324	346	368	345
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	326	347	370	346
[illegible]	[illegible]	[illegible]	[illegible]	371	328	348	372	347
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	330	349	374	348
[illegible]	[illegible]	[illegible]	[illegible]	375	332	350	376	349
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	334	351	378	350
[illegible]	[illegible]	[illegible]	381	[illegible]	336	352	380	351
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	354	383	398	382
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	356	384	400	383
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	358	385	402	384
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	360	386	[illegible]	385
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	362	387	[illegible]	386
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	364	388	408	387
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	366	389	[illegible]	388
[illegible]	[illegible]	[illegible]	[illegible]	411	368	390	412	389
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	370	391	[illegible]	390
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	372	392	[illegible]	391
123	[illegible]	[illegible]	[illegible]	[illegible]	374	393	418	392
124	[illegible]	[illegible]	[illegible]	[illegible]	376	394	420	393
[illegible]	[illegible]	379	[illegible]	421	378	395	422	394
126	[illegible]	381	[illegible]	423	380	396	424	395
[illegible]	[illegible]	[illegible]	443	[illegible]	398	427	442	426
128	[illegible]	[illegible]	[illegible]	[illegible]	400	428	444	427
[illegible]	[illegible]	[illegible]	447	445	402	429	446	428
[illegible]	[illegible]	[illegible]	449	447	404	430	448	429
131	[illegible]	[illegible]	451	449	406	431	450	430
132	[illegible]	[illegible]	453	451	408	432	452	431
133	[illegible]	[illegible]	455	453	410	433	454	432
134	411	413	457	455	412	434	456	433
135	413	415	459	457	414	435	458	434
136	415	417	461	459	416	436	460	435
137*	417	419	463	461	418	437	462	436
138*	419	421	465	463	420	438	464	437
139	421	423	467	465	422	439	466	438
140	423	425	469	467	424	440	468	439
141	453	455	481	479	454	471	480	470
142	455	457	483	481	456	472	482	471
143	457	459	485	483	458	473	484	472
144	459	461	487	485	460	474	486	473
145*	461	463	489	487	462	475	488	474
146*	463	465	491	489	464	476	490	475
147	465	467	493	491	466	477	492	476
148	467	469	495	493	468	478	494	477
149	479	481	507	505	480	497	506	496
150	481	483	509	507	482	498	508	497

* ELEMENTS USED ONLY IN THERMAL ANALYSES. DEACTIVATED IN STRESS ANALYSES.

ELE NO	N1	N2	N3	N4	N5	N6	N7	N8
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	534	523
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	536	524
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	526	538	525
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	514	527	540	526
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	516	528	542	527
[illegible]	[illegible]	[illegible]	[illegible]	543	518	529	544	528
[illegible]	[illegible]	[illegible]	[illegible]	545	520	530	546	529
[illegible]	[illegible]	[illegible]	559	557	532	549	558	548
[illegible]	[illegible]	535	561	559	534	550	560	549
[illegible]	[illegible]	537	563	561	536	551	562	550
168	[illegible]	539	565	563	538	552	564	551
169*	539	541	567	565	540	553	566	552
170*	541	543	569	567	542	554	568	553
171	543	545	571	569	544	555	570	554
172	545	547	573	571	546	556	572	555
173	557	559	585	583	558	575	584	574
174	559	561	587	585	560	576	586	575
175	561	563	589	587	562	577	588	576
176	563	565	591	589	564	578	590	577
177*	565	567	593	591	566	579	592	578
178*	567	569	595	593	568	580	594	579
179	569	571	597	595	570	581	596	580
180	571	573	599	597	572	582	598	581
181	583	585	611	609	584	601	610	600
182	585	587	613	611	586	602	612	601
183	587	589	615	613	588	603	614	602
184	589	591	617	615	590	604	616	603
185	591	593	619	617	592	605	618	604
186	593	595	621	619	594	606	620	605
187	595	597	623	621	596	607	622	606
188	597	599	625	623	598	608	624	607
189	609	611	637	635	610	627	636	626
190	611	613	639	637	612	628	638	627
191	613	615	641	639	614	629	640	628
192	615	617	643	641	616	630	642	629
193	617	619	645	643	618	631	644	630
194	619	621	647	645	620	632	646	631
195	621	623	649	647	622	633	648	632
196	623	625	651	649	624	634	650	633
197	635	637	663	661	636	653	662	652
198	637	639	665	663	638	654	664	653
199	639	641	667	665	640	655	666	654
200	641	643	669	667	642	656	668	655

ELE NO	N1	N2	N3	N4	N5	N6	N7	N8
[illegible]	[illegible]	[illegible]	671	669	644	657	670	656
202	[illegible]	647	673	671	646	658	672	657
203	647	649	675	673	648	659	674	658
204	649	651	677	675	650	660	676	659
205	661	663	689	687	662	679	688	678
[illegible]	[illegible]	[illegible]	691	689	664	680	690	679
207	665	667	693	691	666	681	692	680
208	667	669	695	693	668	682	694	681
209	669	671	697	695	670	683	696	682
210	671	673	699	697	672	684	698	683
211	673	675	701	699	674	685	700	684
212	675	677	703	701	676	686	702	685
213	687	689	715	713	688	705	714	704
214	689	691	717	715	690	706	716	705
215	691	693	719	717	692	707	718	706
216	693	695	721	719	694	708	720	707
217	695	697	723	721	696	709	722	708
218	697	699	725	723	698	710	724	709
219	699	701	727	725	700	711	726	710
220	701	703	729	727	702	712	728	711
221	713	715	741	739	714	731	740	730
222	715	717	743	741	716	732	742	731
223	717	719	745	743	718	733	744	732
224	719	721	747	745	720	734	746	733
225	721	723	749	747	722	735	748	734
226	723	725	751	749	724	736	750	735
227	725	727	753	751	726	737	752	736
228	727	729	755	753	728	738	754	737
229	739	741	767	765	740	757	766	756
230	741	743	769	767	742	758	768	757
231	743	745	771	769	744	759	770	758
232	745	747	773	771	746	760	772	759
233	747	749	775	773	748	761	774	760
234	749	751	777	775	750	762	776	761
235	751	753	779	777	752	763	778	762
236	753	755	781	779	754	764	780	763
237	765	767	793	791	766	783	792	782
238	767	769	795	793	768	784	794	783
239	769	771	797	795	770	785	796	784
240	771	773	799	797	772	786	798	785
241	773	775	801	799	774	787	800	786
242	775	777	803	801	776	788	802	787
243	777	779	805	803	778	789	804	788
244	779	781	807	805	780	790	806	789
245	791	793	819	817	792	809	818	808
246	793	795	821	819	794	810	820	809
247	795	797	823	821	796	811	822	810
248	797	799	825	823	798	812	824	811
249	799	801	827	825	800	813	826	812
250	801	803	829	827	802	814	828	813

ELE NO	N1	N2	N3	N4	N5	N6	N7	N8
251	803	805	831	829	804	815	830	814
252	805	807	833	831	806	816	832	815
253	817	819	845	843	818	835	844	834
254	819	821	847	845	820	836	846	835
255	821	823	849	847	822	837	848	836
256	823	825	851	849	824	838	850	837
257	825	827	853	851	826	839	852	838
258	827	829	855	853	828	840	854	839
259	829	831	857	855	830	841	856	840
260	831	833	859	857	832	842	858	841
261	843	845	871	869	844	861	870	860
262	845	847	873	871	846	862	872	861
263	847	849	875	873	848	863	874	862
264	849	851	877	875	850	864	876	863
265	851	853	879	877	852	865	878	864
266	853	855	881	879	854	866	880	865
267	855	857	883	881	856	867	882	866
268	857	859	885	883	858	868	884	867
269	869	871	897	895	870	887	896	886
270	871	873	899	897	872	888	898	887
271	873	875	901	899	874	889	900	888
272	875	877	903	901	876	890	902	889
273	877	879	905	903	878	891	904	890
274	879	881	907	905	880	892	906	891
275	881	883	909	907	882	893	908	892
276	883	885	911	909	884	894	910	893
277	895	897	923	921	896	913	922	912
278	897	899	925	923	898	914	924	913
279	899	901	927	925	900	915	926	914
280	901	903	929	927	902	916	928	915
281	903	905	931	929	904	917	930	916
282	905	907	933	931	906	918	932	917
283	907	909	935	933	908	919	934	918
284	909	911	937	935	910	920	936	919
285	921	923	949	947	922	939	948	938
286	923	925	951	949	924	940	950	939
287	925	927	953	951	926	941	952	940
288	927	929	955	953	928	942	954	941
289	929	931	957	955	930	943	956	942
290	931	933	959	957	932	944	958	943
291	933	935	961	959	934	945	960	944
292	935	937	963	961	936	946	962	945
293	947	949	975	973	948	965	974	964
294	949	951	977	975	950	966	976	965
295	951	953	979	977	952	967	978	966
296	953	955	981	979	954	968	980	967
297	955	957	983	981	956	969	982	968
298	957	959	985	983	958	970	984	969
299	959	961	987	985	960	971	986	970
300	961	963	989	987	962	972	988	971

ELE NO.	N1	N2	N3	N4	N5	N6	N7	N8
301	973	975	1001	999	974	991	1000	990
302	975	977	1003	1001	976	992	1002	991
303*	977	979	1005	1003	978	993	1004	992
304*	979	981	1007	1005	980	994	1006	993
305	981	983	1009	1007	982	995	1008	994
306	983	985	1011	1009	984	996	1010	995
307	985	987	1013	1011	986	997	1012	996
308	987	989	1015	1013	988	998	1014	997
309	999	1001	1027	1025	1000	1017	1026	1016
310	1001	1003	1029	1027	1002	1018	1028	1017
311*	1003	1005	1031	1029	1004	1019	1030	1018
312*	1005	1007	1033	1031	1006	1020	1032	1019
313	1007	1009	1035	1033	1008	1021	1034	1020
314	1009	1011	1037	1035	1010	1022	1036	1021
315	1011	1013	1039	1037	1012	1023	1038	1022
316	1013	1015	1041	1039	1014	1024	1040	1023

APPENDIX C: ABAQUS TWO-DIMENSIONAL THERMAL ANALYSIS INPUT FILE FOR MONOLITH L-1[illegible]

```
*HEADING
 L-17 2D MODEL, THERMAL ANALYSIS OF GATE MONOLITH - INCLUDES AIR ELEMENTS
*NODE,INPUT=15                                  <Inserts node file here
*ELEMENT,TYPE=DC2D8,INPUT=16                    <Inserts element file here
*ELSET,ELSET=AIR5
 137,138,145,146
*ELSET,ELSET=AIR6
 153,154,161,162                                <Define element sets for
*ELSET,ELSET=AIR7                                  air in internal voids
 169,170,177,178
*ELSET,ELSET=AIREL
 AIR5,AIR6,AIR7
*ELSET,ELSET=AIR15
303,304                                         <Define element sets for
*ELSET,ELSET=AIR                                 air in top recess
311,312
*ELSET,ELSET=AIRET
AIREL,AIR15,AIR16
*ELSET,ELSET=SOILT,GENERATE
 15,28,1
*ELSET,ELSET=SOILB,GENERATE                     <Define element sets for
 1,14,1                                          soil elements
*ELSET,ELSET=SOIL
 SOILT,SOILB
*ELSET,ELSET=LIFT1,GENERATE                     <Begin definition of element
 29,42,1                                         sets for concrete elements
*ELSET,ELSET=LIFT1R                              Where more than one row of
 42                                              elements exists in a lift,
*ELSET,ELSET=LIFT2B,GENERATE                     one element set is defined
 43,56,1                                         for each row and one for the
*ELSET,ELSET=LIFT2T,GENERATE                     entire lift  These element
 57,70,1                                         sets are used for various
*ELSET,ELSET=LIFT2                               purposes during the analysis
 LIFT2B,LIFT2T
*ELSET,ELSET=LIFT2R
 56,70
*ELSET,ELSET=LIFT3B,GENERATE
 71,84,1
*ELSET,ELSET=LIFT3T,GENERATE
 85,98,1
*ELSET,ELSET=LIFT3
 LIFT3B,LIFT3T
*ELSET,ELSET=LIFT3R
 84,98
*ELSET,ELSET=LIFT4B,GENERATE
 99,112,1
*ELSET,ELSET=LIFT4T,GENERATE
 113,126,1
*ELSET,ELSET=LIFT4IF
 123,124
```



```
*ELSET,ELSET=LIFT4                                   <Continue element set definition
         LIFT4B,LIFT4T
*ELSET,ELSET=LIFT4R
 112,126
*ELSET,ELSET=LIFT5F,GENERATE
 127,132
*ELSET,ELSET=LIFT5WB
 134,133,135,136,139,140
*ELSET,ELSET=LIFT5B
 LIFT5F,LIFT5WB
*ELSET,ELSET=LIFT5T
 141,142,143,144,147,148
*ELSET,ELSET=LIFT5
 LIFT5B,LIFT5T
*ELSET,ELSET=LIFT5IR
 136,144
*ELSET,ELSET=LIFT5IL
 139,147
*ELSET,ELSET=LIFT5R
 140,148
*ELSET,ELSET=LIFT5L
 141
*ELSET,ELSET=LIFT6B
 149,150,151,152,155,156
*ELSET,ELSET=LIFT6T
 157,158,159,160,163,164
*ELSET,ELSET=LIFT6
 LIFT6B,LIFT6T
*ELSET,ELSET=LIFT6IR
 152,160
*ELSET,ELSET=LIFT6IL
 155,163
*ELSET,ELSET=LIFT6R
 156,164
*ELSET,ELSET=LIFT6L
 149,157
*ELSET,ELSET=LIFT7B
 165,166,167,168,171,172
*ELSET,ELSET=LIFT7T
 173,174,175,176,179,180
*ELSET,ELSET=LIFT7
 LIFT7B,LIFT7T
*ELSET,ELSET=LIFT7IR
 168,176
*ELSET,ELSET=LIFT7IL
 171,179
*ELSET,ELSET=LIFT7R
 172,180
*ELSET,ELSET=LIFT7L
 165,173
```

```
*ELSET,ELSET=LIFT8B,GENERATE                    <Continue element set definition
 181,188,1
*ELSET,ELSET=LIFT8T,GENERATE
 189,196,1
*ELSET,ELSET=LIFT8
 LIFT8B,LIFT8T
*ELSET,ELSET=LIFT8R
 188,196
*ELSET,ELSET=LIFT8L
 181,189
*ELSET,ELSET=LIFT8IB
 185,186
*ELSET,ELSET=LIFT9B,GENERATE
 197,204,1
*ELSET,ELSET=LIFT9T,GENERATE
 205,212,1
*ELSET,ELSET=LIFT9
 LIFT9B,LIFT9T
*ELSET,ELSET=LIFT9R
 204,212
*ELSET,ELSET=LIFT9L
 197,205
*ELSET,ELSET=LIFT10B,GENERATE
 213,220,1
*ELSET,ELSET=LIFT10T,GENERATE
 221,228,1
*ELSET,ELSET=LIFT10
 LIFT10B,LIFT10T
*ELSET,ELSET=LIFT10R
 220,228
*ELSET,ELSET=LIFT10L
 213,221
*ELSET,ELSET=LIFT11B,GENERATE
 229,236,1
*ELSET,ELSET=LIFT11T,GENERATE
 237,244,1
*ELSET,ELSET=LIFT11
 LIFT11B,LIFT11T
*ELSET,ELSET=LIFT11R
 236,244
*ELSET,ELSET=LIFT11L
 229,237
*ELSET,ELSET=LIFT12B,GENERATE
 245,252,1
*ELSET,ELSET=LIFT12T,GENERATE
 253,260,1
*ELSET,ELSET=LIFT12
 LIFT12B,LIFT12T
*ELSET,ELSET=LIFT12R
 252,260
```

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```
*ELSET,ELSET=LIFT12L                            <Continue element set definition
 245,253
*ELSET,ELSET=LIFT13B,GENERATE
 261,268,1
*ELSET,ELSET=LIFT13T,GENERATE
 269,276,1
*ELSET,ELSET=LIFT13
 LIFT13B,LIFT13T
*ELSET,ELSET=LIFT13R
 268,276
*ELSET,ELSET=LIFT13L
 261,269
*ELSET,ELSET=LIFT14B,GENERATE
 277,284,1
*ELSET,ELSET=LIFT14T,GENERATE
 285,292,1
*ELSET,ELSET=LIFT14
 LIFT14B,LIFT14T
*ELSET,ELSET=LIFT14R
 284,292
*ELSET,ELSET=LIFT14L
 277,285
*ELSET,ELSET=LIFT15B,GENERATE
 293,300,1
*ELSET,ELSET=LIFT15T
 301,302,305,306,307,308
*ELSET,ELSET=LIFT15
 LIFT15B,LIFT15T
*ELSET,ELSET=LIFT15IR
 302
*ELSET,ELSET=LIFT15IL
 305
*ELSET,ELSET=LIFT15R
300,308
*ELSET,ELSET=LIFT15L
 293,301
*ELSET,ELSET=LIFT15IF
 295,296
*ELSET,ELSET=LIFT16
 309,310,313,314,315,316
*ELSET,ELSET=LIFT16IR
 310
*ELSET,ELSET=LIFT16IL
 313
*ELSET,ELSET=LIFT16R
 316
*ELSET,ELSET=LIFT16L
*ELSET,ELSET=CONCE1
 LIFT2,LIFT3,LIFT4,LIFT5                        <Concrete elements sets
*ELSET,ELSET=CONCE2                              completed
```

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```
 LIFT6,LIFT7,LIFT8,LIFT9,LIFT10,LIFT11,LIFT12,LIFT13,LIFT14,LIFT15,LIFT16
*ELSET,ELSET=REMOVEL                        <Remove all lifts but lift 1
 CONCE1,CONCE2
*ELSET,ELSET=CONCE                          <Define one element set for all
 LIFT1,REMOVEL                               concrete elements
*ELSET,ELSET=LFT12R
 LIFT1R,LIFT2R                              <Begin definition of element
*ELSET,ELSET=LFT13R                          sets for thermal convection
 LFT12R,LIFT3R                               boundary element surfaces
*ELSET,ELSET=LFT14R
 LFT13R,LIFT4R
*ELSET,ELSET=LFT15R
 LFT14R,LIFT5R
*ELSET,ELSET=LFT16R
 LFT15R,LIFT6R
*ELSET,ELSET=LFT56L
 LIFT5L,LIFT6L
*ELSET,ELSET=LFT561R
 LIFT51R,LIFT61R
*ELSET,ELSET=LFT561L
 LIFT51L,LIFT61L
*ELSET,ELSET=LFT17R
 LFT16R,LIFT7R
*ELSET,ELSET=LFT57L
 LFT56L,LIFT7L
*ELSET,ELSET=LFT571R
 LFT561R,LIFT71R
*ELSET,ELSET=LFT571L
 LFT561L,LIFT71L
*ELSET,ELSET=LFT18R
 LFT17R,LIFT8R
*ELSET,ELSET=LFT58L
 LFT57L,LIFT8L
*ELSET,ELSET=LFT19R
 LFT18R,LIFT9R
*ELSET,ELSET=LFT59L
 LFT58L,LIFT9L
*ELSET,ELSET=LFT110R
 LFT19R,LIFT10R
*ELSET,ELSET=LFT510L
 LFT59L,LIFT10L
*ELSET,ELSET=LFT111R
 LFT110R,LIFT11R
*ELSET,ELSET=LFT511L
 LFT510L,LIFT11L
*ELSET,ELSET=LFT112R
 LFT111R,LIFT12R
*ELSET,ELSET=LFT512L
 LFT511L,LIFT12L
*ELSET,ELSET=LFT113R
```



```
 LFT112R,LIFT13R                            <Continue element set
*ELSET,ELSET=LFT513L                         definition
 LFT512L,LIFT13L
*ELSET,ELSET=LFT114R
 LFT113R,LIFT14R
*ELSET,ELSET=LFT514L
 LFT513L,LIFT14L
*ELSET,ELSET=LFT115R
 LFT114R,LIFT15R
*ELSET,ELSET=LFT515L
 LFT514L,LIFT15L
*ELSET,ELSET=LFT116R
 LFT115R,LIFT16R
*ELSET,ELSET=LFT516L                        <Complete element sets for
 LFT515L,LIFT16L                             thermal boundaries
*NSET,NSET=SOIL1,GENERATE                   <Define node sets for soil node
 1,29                                        layers to permit assignment of
*NSET,NSET=SOIL2,GENERATE                    soil temperatures
 30,44
*NSET,NSET=SOIL3,GENERATE
 45,73
*NSET,NSET=SOIL4,GENERATE
 74,88
*NSET,NSET=SOIL5,GENERATE
 89,117
*NSET,NSET=CONCN,GENERATE                   <Define one node set for all
 118,436                                     concrete nodes to permit
 438,461                                     assignment of initial
 465,474                                     concrete temperature
 476,487
 491,503
 502,5[illegible]
 517,526
 528,539
 54[illegible],552
 554,565
 569,578
 580,[illegible]
 [illegible]
 [illegible]
 1020,[illegible]
 [illegible]
*NSET,NSET=AIRN[illegible]                  <Define node sets for air
 [illegible]                                 nodes to permit assignment
*NSET,NSET=A[illegible],GENERATE             of initial air temperatures
 [illegible]                                 when air elements become
 [illegible]                                 activated
 [illegible]
 [illegible]
 [illegible]
```

```
*NSET,NSET=AIRN
  AIRNS,AIRNM
*MATERIAL,ELSET=SOIL                          <Thermal properties input
*CONDUCTIVITY                                  for soil
0.066
*DENSITY
0.0758
*SPECIFIC HEAT
0.45
*MATERIAL,ELSET=CONCE                         <Thermal properties input
*CONDUCTIVITY                                  for concrete
0.09789
*DENSITY
0.08714
*SPECIFIC HEAT
0.21
*MATERIAL,ELSET=AIRET                         <Thermal properties input
*CONDUCTIVITY                                  for air.  Conductivity is
  1000.0                                       a composite value to model
*DENSITY                                       convection heat flow
  0.000046
*SPECIFIC HEAT
  0.24
*INITIAL CONDITIONS,TYPE=TEMPERATURE          <Assign initial temperatures
SOIL1,55.0
SOIL2,54.6
SOIL3,60.65
SOIL4,67.09
SOIL5,70
CONCN,65.0
AIRN,74.2
*BOUNDARY                                     <Assign fixed temperature of
SOIL1,11,,55                                   lower soil boundary
*AMPLITUDE,NAME=AMB,TIME=HEAT VALUE,ABS       <Input ambient temperature data
     0.00      77.85     216.00      79.00     504.00      80.00     744.00      [illegible]
   936.00      79.60    1176.00      78.00    1416.00      75.70    1656.00      [illegible]
  2616.00      57.80    3096.00      49.00    3336.00      44.80    3576.00      [illegible]
  3816.00      37.70    4056.00      35.20    4296.00      33.20    4536.00      32.2[illegible]
  4776.00      32.10    4896.00      32.20    5136.00      32.80    5376.00      [illegible]
  5616.00      36.60    5856.00      39.50    6336.00      46.50    6816.00      54.2[illegible]
  7296.00      61.20    7776.00      68.00    8016.00      71.00    8256.00      [illegible]
  8496.00      76.20    8760.00      77.85    8976.00      79.[illegible]    9216.00      80.00
  9456.00      80.10    9648.00      79.60    9888.00      78.00   10128.00      75.70
 10368.00      73.20   11328.00      57.80   11808.00      49.00   12048.00      44.80
 12288.00      41.00   12528.00      37.70   12768.00      [illegible]   13[illegible]      [illegible]
 13248.00      32.20   13488.00      32.10   13608.00      32.20   13848.00      32.80
 14088.00      34.10   14328.00      36.60   14568.00      [illegible]   [illegible]      [illegible]
 15528.00      54.20   16008.00      61.20   16488.00      [illegible]   [illegible]      [illegible]
 16968.00      73.90   17208.00      76.20   17472.00      76.55   [illegible]      [illegible]
*RESTART,WRITE,FREQUENCY=100
```



```
*STEP                                          <Starts thermal analysis step
PLACE LIFT1   DAY [illegible]                  <Lift 1 to be placed
*HEAT TRANSFER                                 Designates thermal analysis
 6.,48                                         in 6 hr increments for 48 hr
*MODEL CHANGE,REMOVE                           Remove all elements except
 REMOVE1,AIR2,AIR3,AIR4                        those in soil and lift 1
*FILM,AMPLITUDE=AMB                            Apply convection boundary
LIFT1,F3,0.0281                                conditions on designated face
LIFT1R,F2,0.00588                              of element sets with coef. shown
*DFLUX                                         Initiates hydration heat gener-
 ONCE,BFNU                                     ation with user subroutine
*NODE FILE
[illegible]
*PLOT,FREQ=[illegible]                         <Plotting instructions
LIFT1,[illegible],2D MODEL
*DETAIL
[illegible]
*CONTOUR
[illegible]
*END STEP
*STEP                                          Step 2: Lift 1 started
LIFT1   DAY [illegible]   RE[illegible]   REMOVE [illegible]  EXT. FORMS
*HEAT TRANSFER
12.,72
*FILM,AMPLITUDE=AMB                            New value of convection coef
LIFT1R,F2,0.0281                               for surface with forms removed
*END STEP
*STEP                                          <Analysis continues with step 1
PLACE LIFT2   DAY 6   RE[illegible]             lift 2
*HEAT TRANSFER
6.,48
*MODEL CHANGE,INCLUDE                          Lift 2 elements added
LIFT2
*FILM,AMPLITUDE=AMB,OP=NEW                     Deleting convection boundary on
LIFT1R,F2,0.0281                               top of lift 1 requires that all
LIFT2T,F3,0.0281                               defined boundaries be removed by
LIFT2R,F2,0.00588                              OP=NEW.  Then input for lifts 1&2
*PLOT,FREQ=2
LIFT2,[illegible],2D MODEL
*DETAIL
[illegible]
*CONTOUR
100,11,65,115
*END STEP
*STEP
LIFT2   DAY 8 [illegible]   RE[illegible]   REMOVE L2 EXT. FORMS
*HEAT TRANSFER
12.,72
*FILM,AMPLITUDE=AMB
[illegible]
```

```
*END STEP
*STEP                                              *Start Lift 3
 PLACE LIFT3  - DAY 11,12  -(REL  1,2)
*HEAT TRANSFER
6,48
*MODEL CHANGE,INCLUDE
LIFT3
*FILM AMPLITUDE=AMB,OP=NEW
LFT12R,F2,,0.0283
LIFT3T,F3,,0.0283
LIFT3R,F2,,0.00588
*PLOT,FREQ=2
 LIFT3 - M17 - 2D MODEL
*DETAIL
 -0.001,4295.99,0,1140.01,4434.01,0
*CONTOUR
 100,11,65,115,
*END STEP
*STEP
 LIFT3  -  DAY 13,14,15 -(REL 3,4,5) REMOVE L3 EXT  FORMS
*HEAT TRANSFER
12,72
*FILM,AMPLITUDE AMB
LIFT3R,F2,,0.0283
*END STEP
*STEP                                              *Start Lift 4
 PLACE LIFT4  - DAY 16,17 (REL  1,2)
*HEAT TRANSFER
6,48
*MODEL CHANGE,INCLUDE
LIFT4
*FILM,AMPLITUDE AMB,OP NEW
LFT13R,F2,,0.0283
LIFT4T,F3,,0.0283
LIFT4R,F2,,0.00588
*PLOT,FREQ=2
 LIFT4 - M17 - 2D MODEL
*DETAIL
 -0.001,4295.99,0,1140.01,4488.01,0
*CONTOUR
 100,11,65,115,
*END STEP
*STEP
 LIFT4  - DAY 18,19,20  (REL  3,4,5) REMOVE L4 EXT  F[illegible]
*HEAT TRANSFER
12,72
*FILM,AMPLITUDE-AMB
LIFT4R,F2,,0.0283
*END STEP
*STEP                                              *Start Lift 5
```



```
[illegible]
*HEAT TRANSFER
[illegible]
*MODEL CHANGE [illegible]
[illegible]
*FILM AMPLITUDE AMB OP NEW
[illegible]
*PLOT FREQ [illegible]
[illegible]
*DETAIL
[illegible]
*CONTOUR
[illegible]
*END STEP
*STEP
[illegible] REMOVE [illegible]
*HEAT TRANSFER
[illegible]
*FILM AMPLITUDE AMB
[illegible]
*END STEP
*STEP                                              [illegible]
[illegible]
*HEAT TRANSFER
[illegible]
*MODEL CHANGE [illegible]
[illegible]
*FILM AMPLITUDE AMB OP NEW
[illegible]
```

```
 LIFT6 - M17 - 2D MODEL
*DETAIL
 -0 001,4295 99,0,1140 01,4632 01,0
*CONTOUR
 100,11,65,115,
*END STEP
*STEP
 LIFT6  - DAY 28,29,30 (REL  3,4,5)  REMOVE L6 EXT  & L3 5 INT  FORMS)
*HEAT TRANSFER
12,72
*FILM,AMPLITUDE=AMB
LIFT6R,F2,,0 0283
LIFT6L,F4,,0 0283
LIFT6IR,F2,,0 0176
LIFT6IL,F4,,0.0176
*END STEP
*STEP                                         <Start lift 7
 PLACE LIFT7  - DAYS 31,32 (REL  1,2)
*HEAT TRANSFER
6,48
*MODEL CHANGE,INCLUDE
LIFT7
*FILM,AMPLITUDE=AMB,OP=NEW
LFT16R,F2,,0 0283
LIFT5F,F3,,0.0283
LIFT4IF,F3,,0.01760
LFT56L,F4,,0 0283
LFT56IR,F2,,0 01760
LFT56IL,F4,,0 01760
LIFT7IR,F2,,0 00522
LIFT7IL,F4,,0 00522
LIFT7R,F2,,0.00588
LIFT7L,F4,,0 00588
LIFT7T,F3,,0 0283
*PLOT,FREQ-2
 LIFT7 - M17 - 2D MODEL
*DETAIL
 -0 001,4295 99,0,1140 01,4704 01,0
*CONTOUR
 100,11,65,115,
*END STEP
*STEP
 LIFT7  - DAY 33,34,35  (REL 3,4,5) REMOVE L7 EXT  FORMS
*HEAT TRANSFER
12,72
*FILM,AMPLITUDE-AMB
LIFT7R,F2,,0.0283
LIFT7L,F4,,0.0283
LIFT7IR,F2,,0 0176
LIFT7IL,F4,,0 0176
```



```
*END STEP
*STEP                                          Start lift 8 which encloses
 PLACE LIFT8    DAY 36 37  REL  1 2)           void
*HEAT TRANSFER
6 48
*MODEL CHANGE INCLUDE                          <Activate lift 8 concrete and
LIFT8 AIRE1                                    void's air elements
*FILM AMPLITUDE-AMB OP-NEW                     <Update convection boundary
LFT17R F2  0 0283                              input   No convection
LIFT5F F3  0 0283                              conditions applied to void
LFT57L F4  0 0283                              boundaries
LIFT8R F2  0 00588
LIFT8L F4  0 00588
LIFT8T F3  0 0283
*PLOT FREQ 2
 LIFT8   M17   2D MODEL
*DETAIL
 0 001 4295 99 0 1140 01 4752 01 0
*CONTOUR
 100 11 65 115
*END STEP
*STEP
 LIFT8    DAY 38 39 40   (REL 3 4 5)  REMOVE L8 EXT  FORMS
*HEAT TRANSFER
12 72
*FILM AMPLITUDE-AMB
LIFT8R F2  0 0283
LIFT8L F4  0 0283
*END STEP
*STEP                                          <Start lift 9
 PLACE LIFT9    DAY 41 42 (REL  1 2)
*HEAT TRANSFER
6 48
*MODEL CHANGE,INCLUDE
LIFT9
*FILM,AMPLITUDE-AMB,OP-NEW
LFT18R F2  0 0283
LIFT5F F3  0 0283
LFT58L F4  0 0283
LIFT9L F4  0 00588
LIFT9R F2  0 00588
LIFT9T F3  0 0283
*PLOT,FREQ-2
 LIFT9 - M17 - 2D MODEL
*DETAIL
 0 001 4295 99 0 1140 01 4806 01 0
*CONTOUR
 100 11 65 115,
*END STEP
*STEP
```

```
 LIFT9  - DAY 43-45  (REL  3-5)  REMOVE L9 EXT  FORMS
*HEAT TRANSFER
12,72
*FILM,AMPLITUDE=AMB
LIFT9L,F4,,0.0283
LIFT9R,F2,,0.0283
*END STEP
*STEP                                              <Start lift 10
 PLACE LIFT10 - DAY 46,47 (REL. 1,2)
*HEAT TRANSFER
6,48
*MODEL CHANGE,INCLUDE
LIFT10,
*FILM,AMPLITUDE=AMB,OP=NEW
LFT19R,F2,,0.0283
LIFT5F,F3,,0.0283
LFT59L,F4,,0.0283
LIFT10R,F2,,0.00588
LIFT10L,F4,,0.00588
LIFT10T,F3,,0.0283
*PLOT,FREQ=2
 LIFT10 - M17 - 2D MODEL
*DETAIL
 -0.001,4295.99,0,1140.01,4866.01,0
*CONTOUR
 100,11,65,115,
*END STEP
*STEP
 LIFT10  - DAY 48,49,50  (REL 3,4,5)  REMOVE L10 EXT  FORMS
*HEAT TRANSFER
12,72
*FILM,AMPLITUDE-AMB
LIFT10R,F2,,0.0283
LIFT10L,F4,,0.0283
*END STEP
*STEP                                              <Start lift 11
 PLACE LIFT11 - DAY 51,52 (REL  1,2)
*HEAT TRANSFER
6,48
*MODEL CHANGE,INCLUDE
LIFT11,
*FILM,AMPLITUDE=AMB,OP=NEW
LFT110R,F2,,0.0283
LIFT5F,F3,,0.0283
LFT510L,F4,,0.0283
LIFT11R,F2,,0.00588
LIFT11L,F4,,0.00588
LIFT11T,F3,,0.0283
*PLOT,FREQ=2
 LIFT11 - M17  2D MODEL
```



```
*DETAIL
 0.001,4295.99,0,1140.01,4926.01,0
*CONTOUR
 100,11,65,115
*END STEP
*STEP
 LIFT11   DAY 53,54,55   (REL 3,4,5)  REMOVE L11 EXT  FORMS
*HEAT TRANSFER
12,72
*FILM,AMPLITUDE-AMB
LIFT11R,F2,,0.0283
LIFT11L,F4,,0.0283
*END STEP
*STEP                                              <Start lift 12
 PLACE LIFT12  DAY 56,57 (REL  1,2)
*HEAT TRANSFER
6,48
*MODEL CHANGE,INCLUDE
LIFT12,
*FILM,AMPLITUDE-AMB,OP-NEW
LFT111R,F2,,0.0283
LIFT5F,F3,,0.0283
LFT511L,F4,,0.0283
LIFT12R,F2,,0.00588
LIFT12L,F4,,0.00588
LIFT12T,F3,,0.0283
*PLOT,FREQ=2
 LIFT12 - M17 - 2D MODEL
*DETAIL
 0.001,4295.99,0,1140.01,4986.01,0
*CONTOUR
 100,11,65,115,
*END STEP
*STEP
 LIFT12   DAY 58,59,60  (REL 3,4,5)  REMOVE L12 EXT  FORMS
*HEAT TRANSFER
12,72
*FILM,AMPLITUDE-AMB
LIFT12R,F2,,0.0283
LIFT12L,F4,,0.0283
*END STEP
*STEP                                              <Start lift 13
 PLACE LIFT13  DAY 61,62 (REL  1,2)
*HEAT TRANSFER
6,48
*MODEL CHANGE,INCLUDE
LIFT13,
*FILM,AMPLITUDE-AMB,OP-NEW
LFT112R,F2,,0.0283
LIFT5F,F3,,0.0283
```

```
LFT512L,F4,,0 0283
LIFT13R,F2,,0.00588
LIFT13L,F4,,0.00588
LIFT13T,F3,,0.0283
*PLOT,FREQ=2
 LIFT13 - M17 - 2D MODEL
*DETAIL
 -0 001,4295 99,0,1140 01,5046 01,0
*CONTOUR
 100,11,65,115,
*END STEP
*STEP
 LIFT13 - DAY 63,64,65  (REL 3,4,5)  REMOVE L13 EXT  FORMS
*HEAT TRANSFER
12,72
*FILM,AMPLITUDE-AMB
LIFT13R,F2,,0.0283
LIFT13L,F4,,0 0283
*END STEP
*STEP                                          <Start lift 14
 PLACE LIFT14- DAY 66,67 (REL  1,2)
*HEAT TRANSFER
6,48
*MODEL CHANGE,INCLUDE
LIFT14,
*FILM,AMPLITUDE=AMB,OP=NEW
LFT113R,F2,,0.0283
LIFT5F,F3,,0 0283
LFT513L,F4,,0.0283
LIFT14R,F2,,0.00588
LIFT14L,F4,,0 00588
LIFT14T,F3,,0 0283
*PLOT,FREQ=2
 LIFT14 - M17 - 2D MODEL
*DETAIL
 -0 001,4295 99,0,1140 01,5106 01,0
*CONTOUR
 100,11,65,115,
*END STEP
*STEP
 LIFT14  - DAY 68,69,70  (REL 3,4,5)  REMOVE L14 EXT  FORMS
*HEAT TRANSFER
12,72
*FILM,AMPLITUDE=AMB
LIFT14R,F2,,0 0283
LIFT14L,F4,,0 0283
*END STEP
*STEP                                          <Start lift 15
 PLACE LIFT15- DAY 71,72 (REL. 1,2)
*HEAT TRANSFER
```



```
6,48
*MODEL CHANGE,INCLUDE
LIFT15,
*FILM,AMPLITUDE-AMB,OP=NEW
LFT114R,F2,,0 0283
LIFT5F,F3,,0 0283
LFT514L,F4,,0 0283
LIFT15R,F2,,0 00588
LIFT15L,F4,,0 00588
LIFT15T,F3,,0 0283
LIFT15IF,F3,,0 0283
LIFT15IR,F2,,0 00588
LIFT15IL,F4,,0 00588
*PLOT,FREQ=2
 LIFT15   M17 - 2D MODEL
*DETAIL
 0 001,4295 99,0,1140 01,5166 01,0
*CONTOUR
 100,11,65,115,
*END STEP
*STEP
 LIFT15  - DAY 73,74,75 (REL 3,4,5)  REMOVE L15 EXT  FORMS
*HEAT TRANSFER
12,72
*FILM,AMPLITUDE-AMB
LIFT15R,F2,,0 0283
LIFT15L,F4,,0 0283
LIFT15IR,F2,,0 0283
LIFT15IL,F4,,0 0283
*END STEP
*STEP                                          <Start lift 16
 PLACE LIFT16- DAY 76,77 (REL  1,2)
*HEAT TRANSFER
6,48
*MODEL CHANGE,INCLUDE
LIFT16,
*FILM,AMPLITUDE-AMB,OP=NEW
LFT115R,F2,,0 0283
LIFT5F,F3,,0.0283
LIFT4IF,F3,,0 01760
LFT515L,F4,,0 0283
LIFT15IF,F3,,0 0283
LIFT15IR,F2,,0 0283
LIFT15IL,F4,,0 0283
LIFT16R,F2,,0 00588
LIFT16L,F4,,0 00588
LIFT16,F3,,0 0283
LIFT16IR,F2,,0 005220
LIFT16IL,F4,,0 005220
*PLOT,FREQ=2
```

```
 LIFT16 - M17 - 2D MODEL
*DETAIL
 -0.001,4295.99,0,1140.01,5214.01,0
*CONTOUR
 100,11,65,115,
*END STEP
*STEP
 LIFT16  - DAY 78,79,80  (REL.3,4,5)  REMOVE L16 EXT  FORMS
*HEAT TRANSFER
12,72
*FILM,AMPLITUDE=AMB
LIFT16R,F2,,0.0283
LIFT16L,F4,,0.0283
LIFT16IR,F2,,0.0283
LIFT16IL,F4,,0.0283
*END STEP
```

APPENDIX D - ABAQUS TWO DIMENSIONAL STRESS ANALYSIS
INPUT COMMAND FILE USED FOR MAIN [illegible]

```
*HEADING
[illegible] MODEL, THERMAL STRESS ANALYSIS WITH SUBROUTINE UMAT
*NODE INPUT 15                          <Inputs node file
*ELEMENT TYPE CPE8R, INPUT 16           <Inputs element file
*ELSET,ELSET=LIFT1,GENERATE             <Begin definition of element
 29,42,1                                 sets.  One element set created
*ELSET,ELSET=LIFT2B,GENERATE             for each row of elements and
 43,56,1                                 one for each lift
*ELSET,ELSET=LIFT2T,GENERATE
 57,70,1
*ELSET,ELSET=LIFT2
 LIFT2B,LIFT2T
*ELSET,ELSET=LIFT3B,GENERATE
 71,84,1
*ELSET,ELSET=LIFT3T,GENERATE
 85,98,1
*ELSET,ELSET=LIFT3
 LIFT3B,LIFT3T
*ELSET,ELSET=LIFT4B,GENERATE
 99,112,1
*ELSET,ELSET=LIFT4T,GENERATE
 113,126,1
*ELSET,ELSET=LIFT4
 LIFT4B,LIFT4T
*ELSET,ELSET=LIFT5F,GENERATE
 127,132
*ELSET,ELSET=LIFT5WB
 134,133,135,136,139,140
*ELSET,ELSET=LIFT5B
 LIFT5F,LIFT5WB
*ELSET,ELSET=LIFT5T
 141,142,143,144,147,148
*ELSET,ELSET=LIFT5
 LIFT5B,LIFT5T
*ELSET,ELSET=LIFT6B
 149,150,151,152,155,156
*ELSET,ELSET=LIFT6T
 157,158,159,160,163,164
*ELSET,ELSET=LIFT6
 LIFT6B,LIFT6T
*ELSET,ELSET=LIFT7B
 165,166,167,168,171,172
*ELSET,ELSET=LIFT7T
 173,174,175,176,179,180
*ELSET,ELSET=LIFT7
 LIFT7B,LIFT7T
*ELSET,ELSET=LIFT8B,GENERATE
 181,188,1
*ELSET,ELSET=LIFT8T,GENERATE
 [illegible]
```

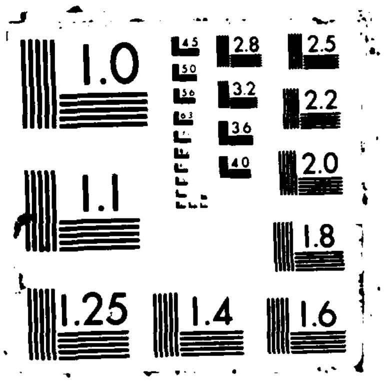


```
*ELSET,ELSET=LIFT8                                        [illegible]
 LIFT8B,LIFT8T
*ELSET,ELSET=LIFT9B,GENERATE
 [illegible]
*ELSET,ELSET=LIFT9T,GENERATE
 205,212,1
*ELSET,ELSET=LIFT9
LIFT9B,LIFT9T
*ELSET,ELSET=LIFT9F
 197,205
*ELSET,ELSET=LIFT10B,GENERATE
 213,220,1
*ELSET,ELSET=LIFT10T,GENERATE
 221,228,1
*ELSET,ELSET=LIFT10
 LIFT10B,LIFT10T
*ELSET,ELSET=LIFT11B,GENERATE
 229,236,1
*ELSET,ELSET=LIFT11T,GENERATE
 237,244,1
*ELSET,ELSET=LIFT11
 LIFT11B,LIFT11T
*ELSET,ELSET=LIFT12B,GENERATE
 245,252,1
*ELSET,ELSET=LIFT12T,GENERATE
 253,260,1
*ELSET,ELSET=LIFT12
 LIFT12B,LIFT12T
*ELSET,ELSET=LIFT13B,GENERATE
 261,268,1
*ELSET,ELSET=LIFT13T,GENERATE
 269,276,1
*ELSET,ELSET=LIFT13
 LIFT13B,LIFT13T
*ELSET,ELSET=LIFT14B,GENERATE
 277,284,1
*ELSET,ELSET=LIFT14T,GENERATE
 285,292,1
*ELSET,ELSET=LIFT14
 LIFT14B,LIFT14T
*ELSET,ELSET=LIFT15B
 293,294,297,298,299,300
*ELSET,ELSET=LIFT15F
 295,296
*ELSET,ELSET=LIFT15T
 301,302,305,306,307,308
*ELSET,ELSET=LIFT15
 LIFT15B,LIFT15F,LIFT15T
*ELSET,ELSET=LIFT16
 309,310,313,314,315,316
```

AD-A183 664 THERMAL STRESS ANALYSES OF MISSISSIPPI RIVER LOCK AND DAM 26(R)(U) ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MS STRUCTURES LAB A A BOMBICH ET AL. JUL 87 4/4

UNCLASSIFIED WES/TR/SL-87-21 F/G 13/13 NL

END
9-87
DTIC


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0

```
*ELSET,ELSET=CONCE1                          <Define element sets that
  LIFT2,LIFT3,LIFT4,LIFT5                     combine lifts to facilitate
*ELSET,ELSET=CONCE2                           deactivation of unplaced lifts
  LIFT6,LIFT7,LIFT8,LIFT9,LIFT10,LIFT11,LIFT12,LIFT13,LIFT14,LIFT15,LIFT16
*ELSET,ELSET=REMOVEL
  CONCE1,CONCE2
*ELSET,ELSET=CONCE                           <Element set for all concrete
  LIFT1,REMOVEL                               elements
*ELSET,ELSET=LFT12                           <Define element sets to include
LIFT1,LIFT2                                   all elements at each stage
*ELSET,ELSET=LFT13
LFT12,LIFT3
*ELSET,ELSET=LFT14
LFT13,LIFT4
*ELSET,ELSET=LFT15
LFT14,LIFT5
*ELSET,ELSET=LFT16
LFT15,LIFT6
*ELSET,ELSET=LFT17
LFT16,LIFT7
*ELSET,ELSET=LFT18
LFT17,LIFT8
*ELSET,ELSET=LFT19
LFT18,LIFT9
*ELSET,ELSET=LFT110
LFT19,LIFT10
*ELSET,ELSET=LFT111
LFT110,LIFT11
*ELSET,ELSET=LFT112
LFT111,LIFT12
*ELSET,ELSET=LFT113
LFT112,LIFT13
*ELSET,ELSET=LFT114
LFT113,LIFT14
*ELSET,ELSET=LFT115
LFT114,LIFT15
*ELSET,ELSET=LFT116
LFT115,LIFT16
*SPRING                                      <Enter x then y stiffnesses
89,1,285.273                                  of piles in lb/in
89,2,11679.60
*SPRING
90,1,570.55
90,2,23359.20
*SPRING
91 1,285.27
91,2,11679 60
*SPRING
91,1,352.524
92,2,18767.94
```



```
*SPRING                                      <Continue pile stiffness input
93,1,352.52
93,2,18767.94
*SPRING
94,1,352.52
94,2,18767.94
*SPRING
95,1,352.52
95,2,18767.94
*SPRING
96,1,352.52
96,2,18767.94
*SPRING
97,1,352.52
97,2,18767.94
*SPRING
98,1,352.52
98,2,18767.94
*SPRING
99,1,352.52
99,2,18767.94
*SPRING
101,1,352.52
101,2,18767.94
*SPRING
103,1,528.50
103,2,18767.94
*SPRING
105,1,528.50
105,2,18767.94
*SPRING
106,1,1057.02
106,2,37535.94
*SPRING
107,1,1057.02
107,2,37535.94
*SPRING
109,1,1057.02
109,2,37535.94
*SPRING
111,1,1057.02
111,2,37535.94
*SPRING
113,1,700.92
113,2,24891.18
*MPC,USER                                    <Enter data required by user
101,592,591,595                               subroutine MPC for formwork
101,593,591,595                               simulation to support concrete
101,594,591,595                               in lift 8 above void
*NSET,NSET=CLINE                             <Node set for centerline nodes
```

```
89,118,133,162,177,206,221,250,265,294,309,338,353,362,397,426
441
*BOUNDARY                                        <Invokes x-direction centerline
CLINE,1                                           node fixity
*MATERIAL,ELSET=LIFT1                            <Materials data for lift 1 incl:
*USER MATERIAL,CONSTANTS=67                       Age vs Poission' ratio and  E
    0.0,    0.17,     0.0,     0.0,    0.17,     6.0, 750000.,     0.17
   12.0,1550000.,    0.17,    18.0,2100000.,    0.17,    24.0,2500000.
    0.17,    30.0,2750000.,    0.17,    36.0,2900000.,    0.17,    42.0
3050000.,    0.17,    48.0,3250000.,    0.17,    60.0,3400000.,    0.17
   72.0,3600000.,    0.17,    96.0,3750000.,    0.17,   120.0,3950000.
    0.17,   144.0,4170000.,    0.17,   240.0,4400000.,    0.17,   336.0
4600000.,    0.17,   504.0,4800000.,    0.17,   672.0,5150000.,    0.17
  1344.0,5400000.,    0.17,  2160.0,5800000.,    0.17,  4800.0,6150000.
    0.17, 10800.0, 4.5E-06,
*MATERIAL,ELSET=LIFT2                            <Materials data for lift 2
*USER MATERIAL,CONSTANTS=67
    0.0,    0.17,     0.0,     0.0,    0.17,     6.0, 750000.,     0.17
   12.0,1550000.,    0.17,    18.0,2100000.,    0.17,    24.0,2500000.
    0.17,    30.0,2750000.,    0.17,    36.0,2900000.,    0.17,    42.0
                              Page 4 of 21
3050000.,    0.17,    48.0,3250000.,    0.17,    60.0,3400000.,    0.17
   72.0,3600000.,    0.17,    96.0,3750000.,    0.17,   120.0,3950000.
    0.17,   144.0,4170000.,    0.17,   240.0,4400000.,    0.17,   336.0
4600000.,    0.17,   504.0,4800000.,    0.17,   672.0,5150000.,    0.17
  1344.0,5400000.,    0.17,  2160.0,5800000.,    0.17,  4800.0,6150000.
    0.17, 10800.0, 4.5E-06,
*MATERIAL,ELSET=LIFT3
*USER MATERIAL,CONSTANTS=67
    0.0,    0.17,     0.0,     0.0,    0.17,     6.0, 750000.,     0.17
   12.0,1550000.,    0.17,    18.0,2100000.,    0.17,    24.0,2500000.
    0.17,    30.0,2750000.,    0.17,    36.0,2900000.,    0.17,    42.0
3050000.,    0.17,    48.0,3250000.,    0.17,    60.0,3400000.,    0.17
   72.0,3600000.,    0.17,    96.0,3750000.,    0.17,   120.0,3950000.
    0.17,   144.0,4170000.,    0.17,   240.0,4400000.,    0.17,   336.0
4600000.,    0.17,   504.0,4800000.,    0.17,   672.0,5150000.,    0.17
  1344.0,5400000.,    0.17,  2160.0,5800000.,    0.17,  4800.0,6150000.
    0.17, 10800.0, 4.5E-06,
*MATERIAL,ELSET=LIFT4
*USER MATERIAL,CONSTANTS=67
    0.0,    0.17,     0.0,     0.0,    0.17,     6.0, 750000.,     0.17
   12.0,1550000.,    0.17,    18.0,2100000.,    0.17,    24.0,2500000.
    0.17,    30.0,2750000.,    0.17,    36.0,2900000.,    0.17,    42.0
3050000.,    0.17,    48.0,3250000.,    0.17,    60.0,3400000.,    0.17
   72.0,3600000.,    0.17,    96.0,3750000.,    0.17,   120.0,3950000.
    0.17,   144.0,4170000.,    0.17,   240.0,4400000.,    0.17,   336.0
4600000.,    0.17,   504.0,4800000.,    0.17,   672.0,5150000.,    0.17
  1344.0,5400000.,    0.17,  2160.0,5800000.,    0.17,  4800.0,6150000.
    0.17, 10800.0, 4.5E-06,
*MATERIAL,ELSET=LIFT5
```



```
*USER MATERIAL,CONSTANTS=67
    0.0,    0.17,     0.0,     0.0,    0.17,     6.0, 750000.,     0.17
   12.0,1550000.,    0.17,    18.0,2100000.,    0.17,    24.0,2500000.
    0.17,    30.0,2750000.,    0.17,    36.0,2900000.,    0.17,    42.0
3050000.,    0.17,    48.0,3250000.,    0.17,    60.0,3400000.,    0.17
   72.0,3600000.,    0.17,    96.0,3750000.,    0.17,   120.0,3950000.
    0.17,   144.0,4170000.,    0.17,   240.0,4400000.,    0.17,   336.0
4600000.,    0.17,   504.0,4800000.,    0.17,   672.0,5150000.,    0.17
  1344.0,5400000.,    0.17,  2160.0,5800000.,    0.17,  4800.0,6150000.
    0.17, 10800.0, 4.5E-06,
*MATERIAL,ELSET=LIFT6
*USER MATERIAL,CONSTANTS=67
    0.0,    0.17,     0.0,     0.0,    0.17,     6.0, 750000.,     0.17
   12.0,1550000.,    0.17,    18.0,2100000.,    0.17,    24.0,2500000.
    0.17,    30.0,2750000.,    0.17,    36.0,2900000.,    0.17,    42.0
3050000.,    0.17,    48.0,3250000.,    0.17,    60.0,3400000.,    0.17
   72.0,3600000.,    0.17,    96.0,3750000.,    0.17,   120.0,3950000.
    0.17,   144.0,4170000.,    0.17,   240.0,4400000.,    0.17,   336.0
4600000.,    0.17,   504.0,4800000.,    0.17,   672.0,5150000.,    0.17
  1344.0,5400000.,    0.17,  2160.0,5800000.,    0.17,  4800.0,6150000.
    0.17, 10800.0, 4.5E-06,
*MATERIAL,ELSET=LIFT7
*USER MATERIAL,CONSTANTS=67
    0.0,    0.17,     0.0,     0.0,    0.17,     6.0, 750000.,     0.17
   12.0,1550000.,    0.17,    18.0,2100000.,    0.17,    24.0,2500000.
    0.17,    30.0,2750000.,    0.17,    36.0,2900000.,    0.17,    42.0
                              Page 5 of 21
3050000.,    0.17,    48.0,3250000.,    0.17,    60.0,3400000.,    0.17
   72.0,3600000.,    0.17,    96.0,3750000.,    0.17,   120.0,3950000.
    0.17,   144.0,4170000.,    0.17,   240.0,4400000.,    0.17,   336.0
4600000.,    0.17,   504.0,4800000.,    0.17,   672.0,5150000.,    0.17
  1344.0,5400000.,    0.17,  2160.0,5800000.,    0.17,  4800.0,6150000.
    0.17, 10800.0, 4.5E-06,
*MATERIAL,ELSET=LIFT8
*USER MATERIAL,CONSTANTS=67
    0.0,    0.17,     0.0,     0.0,    0.17,     6.0, 750000.,     0.17
   12.0,1550000.,    0.17,    18.0,2100000.,    0.17,    24.0,2500000.
    0.17,    30.0,2750000.,    0.17,    36.0,2900000.,    0.17,    42.0
3050000.,    0.17,    48.0,3250000.,    0.17,    60.0,3400000.,    0.17
   72.0,3600000.,    0.17,    96.0,3750000.,    0.17,   120.0,3950000.
    0.17,   144.0,4170000.,    0.17,   240.0,4400000.,    0.17,   336.0
4600000.,    0.17,   504.0,4800000.,    0.17,   672.0,5150000.,    0.17
  1344.0,5400000.,    0.17,  2160.0,5800000.,    0.17,  4800.0,6150000.
    0.17, 10800.0, 4.5E-06,
*MATERIAL,ELSET=LIFT9
*USER MATERIAL,CONSTANTS=67
    0.0,    0.17,     0.0,     0.0,    0.17,     6.0, 750000.,     0.17
   12.0,1550000.,    0.17,    18.0,2100000.,    0.17,    24.0,2500000.
    0.17,    30.0,2750000.,    0.17,    36.0,2900000.,    0.17,    42.0
3050000.,    0.17,    48.0,3250000.,    0.17,    60.0,3400000.,    0.17
```

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 72.0,3600000.,     0.17,     96.0,3750000.,     0.17,   120.0,3950000.
  0.17,   144.0,4170000.,     0.17,    240.0,4400000.,     0.17,    336.0
4600000.,     0.17,    504.0,4800000.,     0.17,    672.0,5150000.,     0.17
 1344.0,5400000.,     0.17,   2160.0,5800000.,     0.17,   4800.0,6150000.
  0.17, 10800.0, 4.5E-06,
*MATERIAL,ELSET=LIFT10
*USER MATERIAL,CONSTANTS=67
   0.0,     0.17,      0.0,      0.0,     0.17,      6.0, 750000.,     0.17
  12.0,1550000.,     0.17,     18.0,2100000.,     0.17,     24.0,2500000.
  0.17,     30.0,2750000.,     0.17,     36.0,2900000.,     0.17,     42.0
3050000.,     0.17,     48.0,3250000.,     0.17,     60.0,3400000.,     0.17
 72.0,3600000.,     0.17,     96.0,3750000.,     0.17,   120.0,3950000.
  0.17,   144.0,4170000.,     0.17,    240.0,4400000.,     0.17,    336.0
4600000.,     0.17,    504.0,4800000.,     0.17,    672.0,5150000.,     0.17
 1344.0,5400000.,     0.17,   2160.0,5800000.,     0.17,   4800.0,6150000.
  0.17, 10800.0, 4.5E-06,
*MATERIAL,ELSET=LIFT11
*USER MATERIAL,CONSTANTS=67
   0.0,     0.17,      0.0,      0.0,     0.17,      6.0, 750000.,     0.17
  12.0,1550000.,     0.17,     18.0,2100000.,     0.17,     24.0,2500000.
  0.17,     30.0,2750000.,     0.17,     36.0,2900000.,     0.17,     42.0
3050000.,     0.17,     48.0,3250000.,     0.17,     60.0,3400000.,     0.17
 72.0,3600000.,     0.17,     96.0,3750000.,     0.17,   120.0,3950000.
  0.17,   144.0,4170000.,     0.17,    240.0,4400000.,     0.17,    336.0
4600000.,     0.17,    504.0,4800000.,     0.17,    672.0,5150000.,     0.17
 1344.0,5400000.,     0.17,   2160.0,5800000.,     0.17,   4800.0,6150000.
  0.17, 10800.0, 4.5E-06,
*MATERIAL,ELSET=LIFT12
*USER MATERIAL,CONSTANTS=67
   0.0,     0.17,      0.0,      0.0,     0.17,      6.0, 750000.,     0.17
  12.0,1550000.,     0.17,     18.0,2100000.,     0.17,     24.0,2500000.
  0.17,     30.0,2750000.,     0.17,     36.0,2900000.,     0.17,     42.0
                         Page 6 of 21
3050000.,     0.17,     48.0,3250000.,     0.17,     60.0,3400000.,     0.17
 72.0,3600000.,     0.17,     96.0,3750000.,     0.17,   120.0,3950000.
  0.17,   144.0,4170000.,     0.17,    240.0,4400000.,     0.17,    336.0
4600000.,     0.17,    504.0,4800000.,     0.17,    672.0,5150000.,     0.17
 1344.0,5400000.,     0.17,   2160.0,5800000.,     0.17,   4800.0,6150000.
  0.17, 10800.0, 4.5E-06,
*MATERIAL,ELSET=LIFT13
*USER MATERIAL,CONSTANTS=67
   0.0,     0.17,      0.0,      0.0,     0.17,      6.0, 750000.,     0.17
  12.0,1550000.,     0.17,     18.0,2100000.,     0.17,     24.0,2500000.
  0.17,     30.0,2750000.,     0.17,     36.0,2900000.,     0.17,     42.0
3050000.,     0.17,     48.0,3250000.,     0.17,     60.0,3400000.,     0.17
 72.0,3600000.,     0.17,     96.0,3750000.,     0.17,   120.0,3950000.
  0.17,   144.0,4170000.,     0.17,    240.0,4400000.,     0.17,    336.0
4600000.,     0.17,    504.0,4800000.,     0.17,    672.0,5150000.,     0.17
 1344.0,5400000.,     0.17,   2160.0,5800000.,     0.17,   4800.0,6150000.
  0.17, 10800.0, 4.5E-06,
```



```
*MATERIAL,ELSET=LIFT14
*USER MATERIAL,CONSTANTS=67
   0.0,     0.17,      0.0,      0.0,     0.17,      6.0, 750000.,     0.17
  12.0,1550000.,     0.17,     18.0,2100000.,     0.17,     24.0,2500000.
  0.17,     30.0,2750000.,     0.17,     36.0,2900000.,     0.17,     42.0
3050000.,     0.17,     48.0,3250000.,     0.17,     60.0,3400000.,     0.17
 72.0,3600000.,     0.17,     96.0,3750000.,     0.17,   120.0,3950000.
  0.17,   144.0,4170000.,     0.17,    240.0,4400000.,     0.17,    336.0
4600000.,     0.17,    504.0,4800000.,     0.17,    672.0,5150000.,     0.17
 1344.0,5400000.,     0.17,   2160.0,5800000.,     0.17,   4800.0,6150000.
  0.17, 10800.0, 4.5E-06,
*MATERIAL,ELSET=LIFT15
*USER MATERIAL,CONSTANTS=67
   0.0,     0.17,      0.0,      0.0,     0.17,      6.0, 750000.,     0.17
  12.0,1550000.,     0.17,     18.0,2100000.,     0.17,     24.0,2500000.
  0.17,     30.0,2750000.,     0.17,     36.0,2900000.,     0.17,     42.0
3050000.,     0.17,     48.0,3250000.,     0.17,     60.0,3400000.,     0.17
 72.0,3600000.,     0.17,     96.0,3750000.,     0.17,   120.0,3950000.
  0.17,   144.0,4170000.,     0.17,    240.0,4400000.,     0.17,    336.0
4600000.,     0.17,    504.0,4800000.,     0.17,    672.0,5150000.,     0.17
 1344.0,5400000.,     0.17,   2160.0,5800000.,     0.17,   4800.0,6150000.
  0.17, 10800.0, 4.5E-06,
*MATERIAL,ELSET=LIFT16
*USER MATERIAL,CONSTANTS=67
   0.0,     0.17,      0.0,      0.0,     0.17,      6.0, 750000.,     0.17
  12.0,1550000.,     0.17,     18.0,2100000.,     0.17,     24.0,2500000.
  0.17,     30.0,2750000.,     0.17,     36.0,2900000.,     0.17,     42.0
3050000.,     0.17,     48.0,3250000.,     0.17,     60.0,3400000.,     0.17
 72.0,3600000.,     0.17,     96.0,3750000.,     0.17,   120.0,3950000.
  0.17,   144.0,4170000.,     0.17,    240.0,4400000.,     0.17,    336.0
4600000.,     0.17,    504.0,4800000.,     0.17,    672.0,5150000.,     0.17
 1344.0,5400000.,     0.17,   2160.0,5800000.,     0.17,   4800.0,6150000.
  0.17, 10800.0, 4.5E-06,
*NSET,NSET=SOIL5,GENERATE                    <Node set for top of soil used
89,117                                        for initial temperatures
*NSET,NSET=CONCN,GENERATE                    <Node set for all concrete nodes
118,436                                       for defining initial temperature
438,461                                       in thermal stress analysis
465,474
476,487
491,500
502,513
517,526
528,539
543,552
554,565
569,578
580,992
994,1003
1020,1029
```

```
1033,1041
*INITIAL CONDITIONS,TYPE=TEMPERATURE         <Specify initial temperatures
SOILS,70
CONCN,65
*RESTART WRITE,FREQUENCY=2
*STEP,AMP=STEP                               <Start step 1, lift 1 for day 1
LIFT1 PLACED DAY 1                           <**No gravity loading in step 1
*STATIC,PTOL=10,DIRECT
6,24                                         <Do in 6-hr time incr. for 24 hr
*MODEL CHANGE,REMOVE                         <Remove all elements except in
REMOVEL,                                      those in lift 1
*TEMPERATURE,FILE=17,BSTEP=1(INC=1),ESTEP=1(INC=4)   <Nodal temps from file 17
*NODE PRINT
2,
*EL PRINT,ELSET=LIFT1                        <Print element results
1,1,1,1,
1,1,1,
2,2,1,2,
*PLOT,FREQ=2                                 <Specify plotting parameters...
 LIFT1     M17  -  2D MODEL
*DETAIL
-0.01,4295.99,0,1140.01,4332.01,0
*CONTOUR                                     <... for maximum principal stress
1,13,-300.,300.
2,13,-300.,300.
3,13,-500.,100.
14,9,-100.,300.
*DISPLACED                                   <... and displaced structure plots
1,250.
*END STEP
*STEP,AMP=STEP                               <Start step 2, lift 1 for day 2
LIFT1,DAY 2
*STATIC,PTOL=10,DIRECT
12,24
*DLOAD,OP=NEW                                <Turn on body-force gravity
LIFT1,BY,-0.08714                              effects
*TEMPERATURE,FILE=17,BSTEP=1(INC=5),ESTEP=1(INC=8)
*END STEP
*STEP,AMP=STEP                               <Start step 3, lift 1 for day 3
LIFT1,DAY 3
*STATIC,PTOL=10,DIRECT
24,24
*TEMPERATURE,FILE=17,BSTEP=2(INC=2),ESTEP=2(INC=2)
*END STEP
*STEP,AMP=STEP                               <Start step 4, lift 1, days 4 & 5
LIFT1,DAYS 4-5
*STATIC,PTOL=10,DIRECT
48,48
*TEMPERATURE,FILE=17,BSTEP=2(INC=6),ESTEP=2(INC=6)
*END STEP
```



```
*STEP,AMP=STEP                               <Start step 1 of lift 2, day 6
LIFT2 PLACED DAY 6 (REL. DAY 1)
*STATIC,PTOL=10,DIRECT
6,24
*MODEL CHANGE,INCLUDE                        <Add elements in lift 2
LIFT2
*DLOAD                                       <Apply gravity effects by a
LIFT2B,P1,-4.1828                             pressure load on top of lift 1
*TEMPERATURE,FILE=17,BSTEP=3(INC=1),ESTEP=3(INC=4)
*EL PRINT,ELSET=LFT12
1,1,1,1,
1,1,1,
2,2,1,2,
*PLOT,FREQ=2
 LIFT2  -  M17  -  2D MODEL
*DETAIL
-0.01,4295.99,0,1140.01,4380.01,0
*CONTOUR
1,13,-300.,300.
2,13,-300.,300.
3,13,-500.,100.
14,9,-100.,300.
*DISPLACED
1,250.
*END STEP
*STEP,AMP=STEP                               <Start step 2 for lift 1, day 7
LIFT2,DAY 7 (REL. DAY 2)
*STATIC,PTOL=10,DIRECT
12,24
*DLOAD,OP=NEW                                <OP=NEW clears pressure gravity
LFT12,BY,-0.08714                             load.  Then apply body forces
*TEMPERATURE,FILE=17,BSTEP=3(INC=5),ESTEP=3(INC=8)
*END STEP
*STEP,AMP=STEP
LIFT2,DAY 8 (REL. DAY 3)
*STATIC,PTOL=10,DIRECT
24,24
*TEMPERATURE,FILE=17,BSTEP=4(INC=2),ESTEP=4(INC=2)
*END STEP
*STEP,AMP=STEP
LIFT2,DAYS 9-10 (REL. DAY 4-5)
*STATIC,PTOL=10,DIRECT
48,48
*TEMPERATURE,FILE=17,BSTEP=4(INC=6),ESTEP=4(INC=6)
*END STEP
*STEP,AMP=STEP                               <Start lift 3
LIFT3 PLACED DAY 11 (REL. DAY 1)
*STATIC,PTOL=10,DIRECT
6,24
*MODEL CHANGE,INCLUDE
```

```
LIFT3
*DLOAD
LIFT3B,P1,-4.7056
*TEMPERATURE,FILE=17,BSTEP=5(INC=1),ESTEP=5(INC=4)
*EL PRINT,ELSET=LFT13
1,1,1,1,
1,1,1,
2,2,1,2,
*PLOT,FREQ=2
 LIFT3     M17   -   2D MODEL
*DETAIL
 0.01,4295.99,0,1140.01,4434.01,0
*CONTOUR
1,13,-300.,300.
2,13,-300.,300.
3,13,-500.,100.
14,9,-100.,300.
*DISPLACED
1,250.
*END STEP
*STEP,AMP=STEP
LIFT3,DAY 12 (REL. DAY 2)
*STATIC,PTOL=10,DIRECT
12,24
*DLOAD,OP=NEW
LFT13,BY,-0.08714
*TEMPERATURE,FILE=17,BSTEP=5(INC=5),ESTEP=5(INC=8)
*END STEP
*STEP,AMP=STEP
LIFT3,DAY 13 (REL. DAY 3)
*STATIC,PTOL=10,DIRECT
24,24
*TEMPERATURE,FILE=17,BSTEP=6(INC=2),ESTEP=6(INC=2)
*END STEP
*STEP,AMP=STEP
LIFT3,DAYS 14-15 (REL. DAY 4-5)
*STATIC,PTOL=10,DIRECT
48,48
*TEMPERATURE,FILE=17,BSTEP=6(INC=6),ESTEP=6(INC=6)
*END STEP
*STEP,AMP=STEP                              <Start lift 4
LIFT4 PLACED DAY 16 (REL. DAY 1)
*STATIC,PTOL=10,DIRECT
6,24
*MODEL CHANGE,INCLUDE
LIFT4
*DLOAD
LIFT4B,P1,-4.7056
*TEMPERATURE,FILE=17,BSTEP=7(INC=1),ESTEP=7(INC=4)
*EL PRINT,ELSET=LFT14
```



```
1,1,1,1,
1,1,1,
2,2,1,2,
*PLOT,FREQ=2
 LIFT4  -  M17  -  2D MODEL
*DETAIL
-0.01,4295.99,0,1140.01,4488.01,0
*CONTOUR
1,13,-300.,300.
2,13,-300.,300.
3,13,-500.,100.
14,9,-100.,300.
*DISPLACED
1,250.
*END STEP
*STEP,AMP=STEP
LIFT4,DAY 17 (REL. DAY 2)
*STATIC,PTOL=10,DIRECT
12,24
*DLOAD,OP=NEW
LFT14,BY,-0.08714
*TEMPERATURE,FILE=17,BSTEP=7(INC=5),ESTEP=7(INC=8)
*END STEP
*STEP,AMP=STEP
LIFT4,DAY 18 (REL. DAY 4)
*STATIC,PTOL=10,DIRECT
24,24
*TEMPERATURE,FILE=17,BSTEP=8(INC=2),ESTEP=8(INC=2)
*END STEP
*STEP,AMP=STEP
LIFT4,DAYS 19-20 (REL. DAY 4-5)
*STATIC,PTOL=10,DIRECT
48,48
*TEMPERATURE,FILE=17,BSTEP=8(INC=6),ESTEP=8(INC=6)
*END STEP
*STEP,AMP=STEP                              <Start lift 5
LIFT5 PLACED DAY 21 (REL. DAY 1)
*STATIC,PTOL=10,DIRECT
6,24
*MODEL CHANGE,INCLUDE
LIFT5
*DLOAD
LIFT5F,P1,-2.0914
LIFT5WB,P1,-6.2742
*TEMPERATURE,FILE=17,BSTEP=9(INC=1),ESTEP=9(INC=4)
*EL PRINT,ELSET=LFT15
1,1,1,1,
1,1,1,
2,2,1,2,
*PLOT,FREQ=2
```

```
 LIFT5  -  M17  -  2D MODEL
*DETAIL
 0.01,4295.99,0,1140.01,4560.01,0
*CONTOUR
1,13,-300.,300.
2,13,-300.,300.
3,13,-500.,100.
14,9,-100.,300.
*DISPLACED
1,250
*END STEP
*STEP,AMP=STEP
LIFT5,DAY 22 (REL. DAY 2)
*STATIC,PTOL=10,DIRECT
12,24
*DLOAD,OP=NEW
LFT15,BY,-0.08714
*TEMPERATURE,FILE=17,BSTEP=9(INC=5),ESTEP=9(INC=8)
*END STEP
*STEP,AMP=STEP
LIFT5,DAY 23 (REL. DAY 4)
*STATIC,PTOL=10,DIRECT
24,24
*TEMPERATURE,FILE=17,BSTEP=10(INC=2),ESTEP=10(INC=2)
*END STEP
*STEP,AMP=STEP
LIFT5,DAYS 24-25 (REL. DAY 4-5)
*STATIC,PTOL=10,DIRECT
48,48
*TEMPERATURE,FILE=17,BSTEP=10(INC=6),ESTEP=10(INC=6)
*END STEP
*STEP,AMP=STEP                            <Start lift 6
LIFT6 PLACED DAY 26 (REL. DAY 1)
*STATIC,PTOL=10,DIRECT
6,24
*MODEL CHANGE,INCLUDE
LIFT6
*DLOAD
LIFT6B,P1,-6.2742
*TEMPERATURE,FILE=17,BSTEP=11(INC=1),ESTEP=11(INC=4)
*EL PRINT,ELSET=LFT16
1,1,1,1,
1,1,1,
2,2,1,2,
*PLOT,FREQ=2
 LIFT6  -  M17  -  2D MODEL
*DETAIL
 0.01,4295.99,0,1140.01,4632.01,0
*CONTOUR
1,13,-300.,300.
```



```
2,13,-300.,300.
3,13,-500.,100.
14,9,-100.,300.
*DISPLACED
1,250.
*END STEP
*STEP,AMP=STEP
LIFT6,DAY 27 (REL. DAY 2)
*STATIC,PTOL=10,DIRECT
12,24
*DLOAD,OP=NEW
LFT16,BY,-0.08714
*TEMPERATURE,FILE=17,BSTEP=11(INC=5),ESTEP=11(INC=8)
*END STEP
*STEP,AMP=STEP
LIFT6,DAY 28 (REL. DAY 6)
*STATIC,PTOL=10,DIRECT
24,24
*TEMPERATURE,FILE=17,BSTEP=12(INC=2),ESTEP=12(INC=2)
*END STEP
*STEP,AMP=STEP
LIFT6,DAYS 28-29 (REL. DAY 4-5)
*STATIC,PTOL=10,DIRECT
48,48
*TEMPERATURE,FILE=17,BSTEP=12(INC=6),ESTEP=12(INC=6)
*END STEP
*STEP,AMP=STEP                            <Start lift 7
LIFT7 PLACED DAY 31 (REL. DAY 1)
*STATIC,PTOL=10,DIRECT
6,24
*MODEL CHANGE,INCLUDE
LIFT7
*DLOAD
LIFT7B,P1,-6.2742
*TEMPERATURE,FILE=17,BSTEP=13(INC=1),ESTEP=13(INC=4)
*EL PRINT,ELSET=LFT17
1,1,1,1,
1,1,1,
2,2,1,2,
*PLOT,FREQ=2
 LIFT7  -  M17  -  2D MODEL
*DETAIL
-0.01,4295.99,0,1140.01,4704.01,0
*CONTOUR
1,13,-300.,300
2,13,-300.,300.
3,13,-500.,100
14,9,-100.,300
*DISPLACED
1,250
```

```
*END STEP
*STEP,AMP=STEP
LIFT7,DAY 32 (REL. DAY 2)
*STATIC,PTOL=10,DIRECT
12,24
*DLOAD,OP=NEW
LFT17,BY,-0.08714
*TEMPERATURE,FILE=17,BSTEP=13(INC=5),ESTEP=13(INC=8)
*END STEP
*STEP,AMP=STEP
LIFT7,DAY 33 (REL. DAY 3)
*STATIC,PTOL=10,DIRECT
24,24
*TEMPERATURE,FILE=17,BSTEP=14(INC=2),ESTEP=14(INC=2)
*END STEP
*STEP,AMP=STEP
LIFT7,DAYS 34-35 (REL. DAY 4-5)
*STATIC,PTOL=10,DIRECT
*TEMPERATURE,FILE=17,BSTEP=14(INC=6),ESTEP=14(INC=6)
*END STEP
*STEP,AMP=STEP                                  <Start lift 8
LIFT8 PLACED DAY 36 (REL. DAY 1)
*STATIC,PTOL=10,DIRECT
6,24
*MODEL CHANGE,INCLUDE
LIFT8
*DLOAD
LIFT8B,P1,-4.1828
*TEMPERATURE,FILE=17,BSTEP=15(INC=1),ESTEP=15(INC=4)
*EL PRINT,ELSET=LFT18
1,1,1,1,
1,1,1,
2,2,1,2,
*PLOT,FREQ=2
 LIFT8  -  M17  -  2D MODEL
*DETAIL
-0.01,4295.99,0,1140.01,4752.01,0
*CONTOUR
1,13,-300.,300.
2,13,-300.,300.
3,13,-500.,100.
14,9,-100.,300.
*DISPLACED
1,250
*END STEP
*STEP,AMP=STEP
LIFT8,DAY 37 (REL. DAY 2)
*STATIC,PTOL=10,DIRECT
12,24
*DLOAD,OP=NEW
```

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```
LFT18,BY,-0.08714
*TEMPERATURE,FILE=17,BSTEP=15(INC=5),ESTEP=15(INC=8)
*END STEP
*STEP,AMP=STEP
LIFT8,DAY 38 (REL. DAY 8)
*STATIC,PTOL=10,DIRECT
24,24
*TEMPERATURE,FILE=17,BSTEP=16(INC=2),ESTEP=16(INC=2)
*END STEP
*STEP,AMP=STEP
LIFT8,DAYS 39-40 (REL. DAY 4-5)
*STATIC,PTOL=10,DIRECT
48,48
*TEMPERATURE,FILE=17,BSTEP=16(INC=6),ESTEP=16(INC=6)
*END STEP
*STEP,AMP=STEP                                  <Start lift 9
LIFT9 PLACED DAY 41 (REL. DAY 1)
*STATIC,PTOL=10,DIRECT
6,24
*MODEL CHANGE,INCLUDE
LIFT9
*DLOAD
LIFT9B,P1,-4.7056
TEMPERATURE,FILE=17,BSTEP=17(INC=1),ESTEP=17(INC=4)
*EL PRINT,ELSET=LFT19
1,1,1,1,
1,1,1,
2,2,1,2,
*PLOT,FREQ=2
 LIFT9  -  M17  -  2D MODEL
*DETAIL
-0.01,4295.99,0,1140.01,4806.01,0
*CONTOUR
1,13,-300.,300.
2,13,-300.,300.
3,13,-500.,100.
14,9,-100.,300.
*DISPLACED
1,250
*END STEP
*STEP,AMP=STEP
LIFT9,DAY 42 (REL. DAY 2)
*STATIC,PTOL=10,DIRECT
12,24
*DLOAD,OP=NEW
LFT19,BY,-0.08714
*TEMPERATURE,FILE=17,BSTEP=17(INC=5),ESTEP=17(INC=8)
*END STEP
*STEP,AMP=STEP
LIFT9,DAY 43 (REL. DAY 3)
```

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```
*STATIC,PTOL=10,DIRECT
24,24
*TEMPERATURE,FILE=17,BSTEP=18(INC=2),ESTEP=18(INC=2)
*END STEP
*STEP,AMP=STEP
LIFT9,DAYS 44-45 (REL. DAY 4-5)
*STATIC,PTOL=10,DIRECT
48,48
*TEMPERATURE,FILE=17,BSTEP=18(INC=6),ESTEP=18(INC=6)
*END STEP
*STEP,AMP=STEP                                   <Start lift 10
LIFT10 PLACED DAY 46 (REL. DAY 1)
*STATIC,PTOL=10,DIRECT
6,24
*MODEL CHANGE,INCLUDE
LIFT10,
*DLOAD
LIFT10B,P1,-5.2282
*TEMPERATURE,FILE=17,BSTEP=19(INC=1),ESTEP=19(INC=4)
*EL PRINT,ELSET=LFT110
1,1,1,1,
1,1,1,
2,2,1,2,
*PLOT,FREQ=2
 LIFT10  -  M17  -  2D MODEL
*DETAIL
 0.001,4296.,0.,1140.01,4866.01,0
*CONTOUR
1,13,-300.,300.,3
2,13,-300.,300.,3
3,13,-300.,300.,3
14,13,-300.,300.,3
*DISPLACED
1,250
*END STEP
*STEP,AMP=STEP
LIFT10,DAY- 47 (REL. DAY 2)
*STATIC,PTOL=10,DIRECT
12,24
*DLOAD,OP=NEW
LFT110,BY,-0.08714
*TEMPERATURE,FILE=17,BSTEP=19(INC=5),ESTEP=19(INC=8)
*END STEP
*STEP,AMP=STEP
LIFT10,DAY 48 (REL. DAY 3)
*STATIC,PTOL=10,DIRECT
24,24
*TEMPERATURE,FILE=17,BSTEP=20(INC=2),ESTEP=20(INC=2)
*END STEP
*STEP,AMP=STEP
```

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```
LIFT10,DAYS 49-50 (REL. DAY 4-5)
*STATIC,PTOL=10,DIRECT
48,48
*TEMPERATURE,FILE=17,BSTEP=20(INC=6),ESTEP=20(INC=6)
*END STEP
*STEP,AMP=STEP                                   <Start lift 11
LIFT11 PLACED DAY 51 (REL. DAY 1)
*STATIC,PTOL=10,DIRECT
6,24
*MODEL CHANGE,INCLUDE
LIFT11,
*DLOAD
LIFT11B,P1,-5.2282
*TEMPERATURE,FILE=17,BSTEP=21(INC=1),ESTEP=21(INC=4)
*EL PRINT,ELSET=LFT111
1,1,1,1,
1,1,1,
2,2,1,2,
*PLOT,FREQ=2
 LIFT11  -  M17  -  2D MODEL
*DETAIL
-0.001,4296.,0.,1140.01,4926.01,0.
*CONTOUR
1,13,-300.,300.,3
2,13,-300.,300.,3
3,13,-300.,300.,3
14,13,-300.,300.,3
*DISPLACED
1,250.
*END STEP
*STEP,AMP=STEP
LIFT11,DAY- 52 (REL. DAY 2)
*STATIC,PTOL=10,DIRECT
12,24
*DLOAD,OP=NEW
LFT111,BY,-0.08714
*TEMPERATURE,FILE=17,BSTEP=21(INC=5),ESTEP=21(INC=8)
*END STEP
*STEP,AMP=STEP
LIFT11,DAY 53 (REL. DAY 3)
*STATIC,PTOL=10,DIRECT
24,24
*TEMPERATURE,FILE=17,BSTEP=22(INC=2),ESTEP=22(INC=2)
*END STEP
*STEP,AMP=STEP
LIFT11,DAYS 54-55 (REL. DAY 4-5)
*STATIC,PTOL=10,DIRECT
48,48
*TEMPERATURE,FILE=17,BSTEP=22(INC=6),ESTEP=22(INC=6)
*END STEP
```

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```
*STEP,AMP=STEP                                    <Start lift 12
LIFT12 PLACED DAY 56 (REL  DAY 1)
*STATIC,PTOL=10,DIRECT
6,24
*MODEL CHANGE,INCLUDE
LIFT12,
*DLOAD
LIFT12B,P1,-5.2282
*TEMPERATURE,FILE=17,BSTEP=23(INC=1),ESTEP=23(INC=4)
*EL PRINT,ELSET=LFT112
1,1,1,1,
1,1,1,
2,2,1,2,
*PLOT,FREQ=2
 LIFT12  -  M17  -  2D MODEL
*DETAIL
-0.001,4296.,0.,1140.01,4986.01,0.
*CONTOUR
1,13,-300.,300.,3
2,13,-300.,300.,3
3,13,-300.,300.,3
14,13,-300.,300.,3
*DISPLACED
1,250
*END STEP
*STEP,AMP=STEP
LIFT12,DAY- 57 (REL  DAY 2)
*STATIC,PTOL=10,DIRECT
12,24
*DLOAD,OP=NEW
LFT112,BY,-0.08714
*TEMPERATURE,FILE=17,BSTEP=23(INC=5),ESTEP=23(INC=8)
*END STEP
*STEP,AMP=STEP
LIFT12,DAY 58 (REL. DAY 3)
*STATIC,PTOL=10,DIRECT
24,24
*TEMPERATURE,FILE=17,BSTEP=24(INC=2),ESTEP=24(INC=2)
*END STEP
*STEP,AMP=STEP
LIFT12,DAYS 59 60 (REL. DAY 4-5)
*STATIC,PTOL=10,DIRECT
48,48
*TEMPERATURE,FILE=17,BSTEP=24(INC=6),ESTEP=24(INC=6)
*END STEP
*STEP,AMP=STEP                                    <Start lift 13
LIFT13 PLACED DAY 61 (REL. DAY 1)
*STATIC,PTOL=10,DIRECT
6,24
*MODEL CHANGE,INCLUDE
```



```
LIFT13,
*DLOAD
LIFT13B,P1,-5.2282
*TEMPERATURE,FILE=17,BSTEP=25(INC=1),ESTEP=25(INC=4)
*EL PRINT,ELSET=LFT113
1,1,1,1,
1,1,1,
2,2,1,2,
*PLOT,FREQ=2
 LIFT13  -  M17  -  2D MODEL
*DETAIL
-0.001,4296.,0.,1140.01,5046.01,0.
*CONTOUR
1,13,-300.,300.,3
2,13,-300.,300.,3
3,13,-300.,300.,3
14,13,-300.,300.,3
*DISPLACED
1,250.
*END STEP
*STEP,AMP=STEP
LIFT13,DAY- 62 (REL. DAY 2)
*STATIC,PTOL=10,DIRECT
12,24
*DLOAD,OP=NEW
LFT113,BY,-0.08714
*TEMPERATURE,FILE=17,BSTEP=25(INC=5),ESTEP=25(INC=8)
*END STEP
*STEP,AMP=STEP
LIFT13,DAY 63 (REL. DAY 3)
*STATIC,PTOL=10,DIRECT
24,24
*TEMPERATURE,FILE=17,BSTEP=26(INC=2),ESTEP=26(INC=2)
*END STEP
*STEP,AMP=STEP
LIFT13,DAYS 64-65 (REL. DAY 4-5)
*STATIC,PTOL=10,DIRECT
48,48
*TEMPERATURE,FILE=17,BSTEP=26(INC=6),ESTEP=26(INC=6)
*END STEP
*STEP,AMP=STEP                                    <Start lift 14
LIFT14 PLACED DAY 66 (REL. DAY 1)
*STATIC,PTOL=10,DIRECT
6,24
*MODEL CHANGE,INCLUDE
LIFT14,
*DLOAD
LIFT14B,P1,-5.2282
*TEMPERATURE,FILE=17,BSTEP=27(INC=1),ESTEP=27(INC=4)
*EL PRINT,ELSET=LFT114
```

```
1,1,1,1,
1,1,1,
2,2,1,2,
*PLOT,FREQ=2
 LIFT14  -  M17  -  2D MODEL
*DETAIL
-0.001,4296.,0.,1140.01,5106.01,0.
*CONTOUR
1,13,-300.,300.,3
2,13,-300.,300.,3
3,13,-300.,300.,3
14,13,-300.,300.,3
*DISPLACED
1,250.
*END STEP
*STEP,AMP=STEP
LIFT14,DAY- 67 (REL. DAY 2)
*STATIC,PTOL=10,DIRECT
12,24
*DLOAD,OP=NEW
LFT114,BY,-0.08714
*TEMPERATURE,FILE=17,BSTEP=27(INC=5),ESTEP=27(INC=8)
*END STEP
*STEP,AMP=STEP
LIFT14,DAY 68 (REL. DAY 3)
*STATIC,PTOL=10,DIRECT
24,24
*TEMPERATURE,FILE=17,BSTEP=28(INC=2),ESTEP=28(INC=2)
*END STEP
*STEP,AMP=STEP
LIFT14,DAYS 69-70 (REL. DAY 4-5)
*STATIC,PTOL=10,DIRECT
48,48
*TEMPERATURE,FILE=17,BSTEP=28(INC=6),ESTEP=28(INC=6)
*END STEP
*STEP,AMP=STEP                                <Start lift 15
LIFT15 PLACED DAY 71 (REL. DAY 1)
*STATIC,PTOL=10,DIRECT
6,24
*MODEL CHANGE,INCLUDE
LIFT15,
*DLOAD
LIFT15B,P1,-5.2282
LIFT15F,P1,-2.0914
*TEMPERATURE,FILE=17,BSTEP=29(INC=1),ESTEP=29(INC=4)
*EL PRINT,ELSET=LFT115
1,1,1,1,
1,1,1,
2,2,1,2,
*PLOT,FREQ=2
```



```
 LIFT15  -  M17  -  2D MODEL
*DETAIL
-0.001,4296.,0.,1140.01,5166.01,0.
*CONTOUR
1,13,-300.,300.,3
2,13,-300.,300.,3
3,13,-300.,300.,3
14,13,-300.,300.,3
*DISPLACED
1,250.
*END STEP
*STEP,AMP=STEP
LIFT15,DAY- 72 (REL. DAY 2)
*STATIC,PTOL=10,DIRECT
12,24
*DLOAD,OP=NEW
LFT115,BY,-0.08714
*TEMPERATURE,FILE=17,BSTEP=29(INC=5),ESTEP=29(INC=8)
*END STEP
*STEP,AMP=STEP
LIFT15,DAY 73 (REL. DAY 3)
*STATIC,PTOL=10,DIRECT
24,24
*TEMPERATURE,FILE=17,BSTEP=30(INC=2),ESTEP=30(INC=2)
*END STEP
*STEP,AMP=STEP
LIFT15,DAYS 74-75 (REL. DAY 4-5)
*STATIC,PTOL=10,DIRECT
48,48
*TEMPERATURE,FILE=17,BSTEP=30(INC=6),ESTEP=30(INC=6)
*END STEP
*STEP,AMP=STEP                                <Start lift 16
LIFT16 PLACED DAY 76 (REL. DAY 1)
*STATIC,PTOL=10,DIRECT
6,24
*MODEL CHANGE,INCLUDE
LIFT16,
*DLOAD
LIFT16,P1,-4.1828
*TEMPERATURE,FILE=17,BSTEP=31(INC=1),ESTEP=31(INC=4)
*EL PRINT,ELSET=LFT116
1,1,1,1,
1,1,1,
2,2,1,2,
*PLOT,FREQ=2
 LIFT16  -  M17  -  2D MODEL
*DETAIL
-0.001,4296.,0.,1140.01,5214.01,0.
*CONTOUR
1,13,-300.,300.,3
```

```
2,13,-300.,300.,3
3,13,-300.,300.,3
14,13,-300.,300.,3
*DISPLACED
1,250
*END STEP
*STEP,AMP-STEP
LIFT16,DAY- 77 (REL. DAY 2)
*STATIC,PTOL=10,DIRECT
12,24
*DLOAD,OP=NEW
LFT116,BY,-0.08714
*TEMPERATURE,FILE=17,BSTEP=31(INC=5),ESTEP=31(INC=8)
*END STEP
*STEP,AMP-STEP
LIFT16,DAY 78 (REL. DAY 3)
*STATIC,PTOL=10,DIRECT
24,24
*TEMPERATURE,FILE=17,BSTEP=32(INC=2),ESTEP=32(INC=2)
*END STEP
*STEP,AMP=STEP
LIFT16,DAYS 79-80 (REL. DAY 4-5)
*STATIC,PTOL=10,DIRECT
48,48
*TEMPERATURE,FILE=17,BSTEP=32(INC=6),ESTEP=32(INC=6)
*END STEP
```

APPENDIX E: ABAQUS JOB CONTROL LANGUAGE FILES USED WITH CYBERNET SYSTEM FOR TEMPERATURE AND STRESS ANALYSES OF MONOLITH L-17

CYBERNET JOB CONTROL LANGUAGE FILE USED IN ABAQUS THERMAL ANALYSES (L-17)

```
/JOB
ABAQ,T20000,P2.
/USER
/CHARGE
PURGE,L7TT8/NA.
PURGE,L7TPLOT/NA.
PURGE,L7TREST/NA.
DEFINE,TAPE12=L7TREST.
DEFINE,TAPE8=L7TT8.
GET,TAPE15=L7TN.                                              L7TN=node file
GET,TAPE16=L7TE.                                              L7TE=element file
BEGIN,,ABAQUS,I=L7TD,TEXT=N,APLOT=Y,USUB=Y,INSUB=LDFLUX.      L7TD=command file
DEFINE,L7TPLOT.                                               LDFLUX=heat subr.
REWIND,NPFILEA.
COPYBF,NPFILEA,L7TPLOT.
EXIT.
DEFINE,L7TPLOT.
REWIND,NPFILEA.
COPYBF,NPFILEA,L7TPLOT.
/EOR
/EOF
```

CYBERNET JOB CONTROL LANGUAGE FILE USED IN ABAQUS STRESS ANALYSES (L-17)

```
/JOB
ABAQ,T30000,P2.
/USER
/CHARGE
ATTACH,TAPE17=L7TT8.
PURGE,L7SRES/NA.
PURGE,L7SPLOT/NA.
DEFINE,TAPE12=L7SRES.
GET,TAPE15=L7SN.                                              L7SN=node file
GET,TAPE16=L7SE.                                              L7SE=element file
BEGIN,,ABAQUS,I=L7SD,TEXT=N,APLOT=Y,USUB=Y,INSUB=L7SUBS.      L7SD=command file
DEFINE,L7SPLOT.                                               L7SUBS=modulus subr.
REWIND,NPFILEA.
COPYBF,NPFILEA,L7SPLOT.
REWIND,TAPE35.
COPY,TAPE35.
REPLACE,TAPE35=L7ST35.
EXIT.
DEFINE,L7SPLOT.
REWIND,NPFILEA.
COPYBF,NPFILEA,L7SPLOT.
REWIND,TAPE35.
COPY,TAPE35.
```

APPENDIX F: ABAQUS HEAT GENERATION SUBROUTINE DFLUX, FILE "LDFLUX" USED IN 2-D, L-17 ANALYSIS

```
      SUBROUTINE DFLUX(FLUX,TEMP,KSTEP,KINC,TIME,NOEL,NPT,COORDS,
     &                 JLTYP)
      DIMENSION COORDS(3),Q(23),T(23)
      COMMON /ELDEF/ STIME(316)
      DATA ENTIME/960.1/
      DATA NQ/23/
      DATA T/ 6.,  12.,  18.,  24.,  30.,  36.,  42.,  48.,
     &       60.,  72.,  84.,  96., 120., 168., 240., 288.,
     &      360., 408., 480., 528., 600., 720., 960./
      DATA Q/0.017385, 0.015158, 0.011682, 0.010309, 0.00800,
     &       0.006862, 0.005795, 0.004910, 0.003263, 0.002897,
     &       0.002211, 0.002059, 0.001357, 0.000980, 0.000628,
     &       0.000507, 0.000368, 0.000305, 0.000241, 0.000214,
     &       0.000201, 0.000175, 0.000118/
      DATA STIME/
     &     28*0.0,14*0.0,28*120.0,28*240.0,28*360.0,22*480.0,16*600.0,
     &     16*720.0,16*840.0,16*960.0,16*1080.0,16*1200.0,16*1320.0,
     &     16*1440.0,16*1560.0,16*1680.0,8*1800.0/
C *********************************************************************
C VERSION OF USER SUBROUTINE "DFLUX" USED FOR MONOLITH L-17, 2-D MODEL
C *********************************************************************
C VARIABLE DEFINITIONS-
C
C ENTIME - END OF RELATIVE HEAT GENERATION TIME + SMALL TOLERANCE (HR)
C
C NQ     - NO. OF HEAT GENERATION RATE POINTS
C
C T      - RELATIVE HEAT GENERATION TIME POINTS
C
C Q      = HEAT GENERATION POINT
C
C STIME  - VECTOR CONTAINING PLACEMENT TIME FOR EACH ELEMENT
C
C FLUX   - HEAT GENERATION RATE RETURNED TO PROGRAM
C
      TREL - TIME - STIME(NOEL)
      IF( TREL.GT.0.0.AND.TREL.LT.ENTIME ) GO TO 10
      FLUX - 0.0
      RETURN
C
   10 CONTINUE
      FLUX - 0.0
      DO 20 I-1,NQ
      J - I
      IF( TREL.LE.T(I) ) GO TO 30
   20 CONTINUE
C
      WRITE(6,35) KSTEP,KINC,TIME,NOEL
   35 FORMAT(/,"  WARNING - PASSED THROUGH DFLUX WITHOUT ASSIGNING",
     &       /,"            FLUX.  STEP -",I5,"  INC -",I5,
     &       /,"            TIME -",F12.2,"  ELEMENT -",I5)
      RETURN
   30 FLUX - Q(J)
      RETURN
      END
```

APPENDIX G: ABAQUS USER SUBROUTINE MPC,
2-D MULTIPLE POINT CONSTRAINT
VERSION USED WITH MONOLITH L-17

```
      SUBROUTINE MPC(UE,A,JDOF,N,JTYPE,X,U,NMPCE)
C
      DIMENSION A(N),JDOF(N),X(6,N),U(6,N)
      COMMON/COUNT/KINC,MINC,KITER,MITER,FATIME,ATIME,DATIME,
     1 CTIME,DCTIME,DTIME,DDTIME,HTIME,DHTIME,DDTPRE,DATPRE,HTIM1,
     2 DHTIM2,EXFAC,KSTEP,KCUTS,MCUTS,NUMBER,LSHAF1,LCUTBK,DTNEWS,
     3 KITGEN,KMDINC,TTIME,DTMIN,DTMAX,MITEIG,MITXXX,STIME,DSTIME
     4,TPREV,TNEW,TOLD,TEND
C
C   **********************************************************
C   SUBROUTINE MPC USED WITH L-17 2-D ANALYSIS.  MPC IS MERGED WITH
C   SUBROUTINE UMAT1 OR UMAT2 IN FILES "L7SUBS" AND "L7SUBN, RESPECTIVELY
C   **********************************************************
C
C       FIX NODES ACROSS TOP OF VOID DURING PLACEMENT OF LIFT 8
C       STEPS 29,30,31,32,33, AND 34
C
C
      IF(KSTEP.EQ.29.AND.JTYPE.EQ.101) GO TO 10
      IF(KSTEP.EQ.30.AND.JTYPE.EQ.101) GO TO 10
      IF(KSTEP.EQ.31.AND.JTYPE.EQ.101) GO TO 10
      IF(KSTEP.EQ.32.AND.JTYPE.EQ.101) GO TO 10
      IF(KSTEP.EQ.33.AND.JTYPE.EQ.101) GO TO 10
      IF(KSTEP.EQ.34.AND.JTYPE.EQ.101) GO TO 10
C
      NMPCE = 0
      RETURN
   10 CONTINUE
C
      B1 = X(1,3) - X(1,2)
      B2 = X(1,3) - X(1,1)
      B3 = X(1,1) - X(1,2)
C
      UE = (B2*U(2,2) - B3*U(2,3))/B1
C
      A(1) = B1
      A(2) = -B2
      A(3) = -B3
      JDOF(1) = 2
      JDOF(2) = 2
      JDOF(3) = 2
C
      RETURN
      END
```

ABAQUS USER SUBROUTINE MPC, 2-D MULTIPLE POINT CONSTRAINT USED WITH L-17

APPENDIX H: MATERIAL USER SUBROUTINE UMAT, VERSION "UMAT1", 2-D MODULUS ROUTINE WITHOUT CREEP USED WITH MONOLITH L-17

```
      SUBROUTINE UMAT(STRESS,STATEV,DDSDDE,SSE,SPD,SCD,STRAN,DSTRAN,
     1 TIME,DTIME,TEMP,DTEMP,PPREDEF,DPRED,MATERL,NDI,NSHR,NTENS,
     1 NSTATV,PROPS,NPROPS,COORDS)
      DIMENSION STRESS(NTENS),STATEV(NSTATV),DDSDDE(NTENS,NTENS),
     1 STRAN(NTENS),DSTRAN(NTENS),PREDEF(1),DPRED(1),
     1 PROPS(NPROPS),COORDS(3)
      DIMENSION EPSTH(6)
C
C  ADD COMMON BLOCK COUNT TO GET STEP AND INCREMENT NUMBERS
C
      COMMON/COUNT/KINC,XXX(17),KSTEP,XXXX(19)
C
       COMMON /EVALX/ EV(16),RT(16),YEL(17),ICONT,IX
      DATA RT/0.0,120.0,240.,360.,480.,600.,720.,840.,960.,
     &      1080.,1200.,1320.,1440.,1560.,1680.,1800./
      DATA YEL/4296.,4332.,4380.,4434.,4488.,4560.,4632.,4704.,4752.,
     &  4806.,4866.,4926.,4986.,5046.,5106.,5166.,5214./
      DATA EV/16*0.0/
      DATA IX/100/
C
C   IX IS SET TO 100 SO THE E(MATERL) WILL BE PRINTED ON 1ST PASS
C
C   ALWAYS PUT ALL USER MATERIALS BEFORE ANY OTHER MATERIAL
C     SO THEY WILL BE NUMBERED FIRST!!!!!!!
C
C***************************************************************
C THIS SUBROUTINE UMAT1 IS SET UP FOR THE L-17 2-D MODEL AND IS
C MERGED WITH SUBROUTINE MPC TO COMPRISE FILE- "L7SUBS"
C***************************************************************
C       SUBROUTINE FOR TIME DEPENDENT MODULUS OF ELASTICITY
C       DSIG=D*(DEPS-DEPSTH)
C       SIG=SIG+DSIG
C       WHERE   D=D AT TIME T+DT/2
C       PROPS(NPROPS) CONTAINS COEFFICIENT OF THERMAL EXPANSION
C       NUMBER OF POINTS ON D(TIME CURVE IS (NPROPS-U)/3
C       STORED AS E, V,  TIME
C
      IPRINT = 0
      IF(IPRINT.GT.0) WRITE(6,9999) NDI,NSHR,NTENS,NPROPS
      IF(IPRINT.GT.0) WRITE(6,8888) PROPS
      IF(IPRINT.GT.0) WRITE(6,8888) TEMP,DTEMP,TIME,DTIME
C       CALCULATE THERMAL STRAINS
C
      DEPSTH=PROPS(NPROPS)*DTEMP
      DO 5 K1=1,6
      EPSTH(K1)=0
      IF(K1.LE.NDI) EPSTH(K1)=DEPSTH
    5 CONTINUE
C
C       CALCULATE E AND V AT TIME VTIME+DTIME
```



```
C
      REL=0.0
      DO 777 III=1,9
      IIII=III+1
      IF(COORDS(2).GT.YEL(III).AND.COORDS(2).LE.YEL(IIII))REL=RT(III)
  777 CONTINUE
      NPOINT=(NPROPS-1)/3.
      I1=3
      T=TIME+DTIME*0.5-REL
      DO 10 K1=1,NPOINT
      IF(T    .LT.PROPS(I1)) GO TO 12
      I1=I1+3
   10 CONTINUE
   12 CONTINUE
      IF(K1.NE.1) GO TO 20
      E=PROPS(1)
      V=PROPS(2)
      GO TO 40
   20 CONTINUE
      IF(K1.LE.NPOINT) GO TO 30
      I1=NPOINT*3-2
      E=PROPS(I1)
      V=PROPS(I1+2)
      GO TO 40
   30 CONTINUE
      I1=K1*3
      I2=I1-3
      DENOM=PROPS(I1)-PROPS(I2)
      F1=(PROPS(I1)-T    )/DENOM
      F2=1.-F1
      E=F1*PROPS(I2-2)+F2*PROPS(I1-2)
      V=F1*PROPS(I2-1)+F2*PROPS(I1-1)
   40 CONTINUE
      DO 50 K1=1,NTENS
      DO 49 K2=1,NTENS
      DDSDDE(K1,K2)=0
   49 CONTINUE
   50 CONTINUE
C
C        FORM D BASED ON NDI AND NSHR
C
      IF(NDI.EQ.0) GO TO 150
      IF(NDI.EQ.3) GO TO 103
      IF(NDI.EQ.2) GO TO 102
      DDSDDE(1,1)=E
      GO TO 150
  102 CONTINUE
      TERM=E/(1.-V**2)
      DDSDDE(1,1)=TERM
      DDSDDE(2,1)=V*TERM
```

```
      DDSDDE(1,2)=DDSDDE(2,1)
      DDSDDE(2,2)=TERM
      GO TO 150
  103 CONTINUE
      TERM=(1.-2.*V)*(1.+V)
      TERM=E/TERM
      DDSDDE(1,1)=TERM*(1.-V)
      DDSDDE(2,1)=TERM*V
      DDSDDE(1,2)=DDSDDE(2,1)
      DDSDDE(2,2)=DDSDDE(1,1)
      DDSDDE(3,3)=DDSDDE(1,1)
      DDSDDE(1,3)=DDSDDE(2,1)
      DDSDDE(2,3)=DDSDDE(2,1)
      DDSDDE(3,1)=DDSDDE(2,1)
      DDSDDE(3,2)=DDSDDE(2,1)
  150 CONTINUE
      IF(NSHR.EQ.0) GO TO 200
      G=E/(2.*(1.+V))
      I1=NDI+1
      DO 160 K1=1,NSHR
      DDSDDE(I1,I1)=G
      I1=I1+1
  160 CONTINUE
  200 CONTINUE
      DO 300 K1=1,NTENS
      DSIG=0
      DO 290 K2=1,NTENS
      DSIG=DSIG+DDSDDE(K1,K2)*(DSTRAN(K2)-EPSTH(K2))
  290 CONTINUE
      STRESS(K1)=STRESS(K1)+DSIG
      SSE=SSE+(DSTRAN(K1)+EPSTH(K1))*(STRESS(K1)-DSIG*0.5)
  300 CONTINUE
C     IF(IPRINT.GT.0) WRITE(6,8888) E,V,SSE
C     IF(IPRINT.GT.0) WRITE(6,8888) STRESS,STRAN,DSTRAN
C     IF(IPRINT.GT.0) WRITE(6,8888) DDSDDE
C9999 FORMAT(' UMAT',20I6)
 8888 FORMAT(2X,10E12.5)
 8889 FORMAT(2X,I5,2X,I5,2X,I5,2X,3E12.5)
      DO 778 III=1,9
      IIII=III+1
      IF(COORDS(2).GT.YEL(III).AND.COORDS(2).LE.YEL(IIII)) EV(III)=E
 778  CONTINUE
      IF(MATERL.EQ.IX)GO TO 400
      WRITE(35,8889) KSTEP,KINC,MATERL,TIME,DTIME,EV(MATERL)
 400  CONTINUE
      IX = MATERL
      RETURN
      END
```

APPENDIX I: ABAQUS USER SUBROUTINE UMAT,
VERSION "UMAT2", AGING CREEP MODEL WITH SHRINKAGE
USED WITH MONOLITH L-17

```
      SUBROUTINE UMAT(STRESS,STATEV,HH,SSE,SPD,SCD,TEPS,DEP,TIME,
     $ DELTM,TEMP,DTEMP,PREDEF,DPRED,MATERL,NDI,NSHR,NTENS,
     $ NSTATV,PROPS,NPROPS,COORDS)
C
      IMPLICIT REAL (A-H,O-Z)
C
C     UMATAGE     CONCRETE MODEL WITH CREEP AND AGING
C                 WITH IMPROVED CREEP AND AGING FACTORS
C                 DATE  FEB  12, 1986
C
C                 MODEL MODIFIED TO DISTRIBUTE INITIAL
C                 SHRINKAGE LINEARLY BETWEEN 0  AND 1
C                 DAYS AGE (INITIAL SHRINKAGE ACTUALLY
C                 AN 1 DAY SHRINKAGE RATE)
C                 MODIFIED BY.  ROY L CAMPBELL, SR
C                 DATE:  FEB  24, 1986
C
C
      COMMON // SINT(1)
      COMMON /CELGI/ IDUM(7),IEDBR,JDUM(96)
C
      COMMON /BLKN/ ALFAC,ALFAS,CRUSH,TREF,DJ,ECONC,ESTEEL,
     $ ES,ITER,NT,MCOUNT,M14,NCHECK,XVC,YSTEEL,
     $ ANGLE,EFFSTR,EPSEFF,KRAC,SG(8),TF(4),V(8)
C
      COMMON /BLK1/ H(4,4),STR(4),XV,YIELD,EPFRAC
C
      DIMENSION STRESS(NTENS),AR(20,3),PH(4,4),EP(4),EPST(4),
     $ DTIM(2),PROPS(NPROPS),TEPS(NTENS),DEP(NTENS),HH(NTENS,NTENS),
     $ NPRINT(100),STATEV(1),IORDER(3)
C
      LOGICAL FIRST(100),IPRINT,FIRSTE,ONEELM
C
      DATA FIRST/100*.TRUE./, NPASS/0/, MPRINT/0/, INT1/0/,
     $ JELNO1/0/, NOUT/6/, FIRSTE/.TRUE./, JELNOL/0/, INT/0/,
     $ IORDER/1,3,2/, NINT1/0/, NSTEP/0/, ONEELM/.FALSE./
C
C     DATA IAR/'AR 11(S11 -)','AR 21(S22 -)','AR 31(S33 -)',
C    $         'AR 41(S13  )','AR 51(SS1 -)','AR 61(SS2 -)',
C    $         'AR 71(E11 -)','AR 81(E22 -)','AR 91(E33 -)',
C    $         'AR101(E13  )','AR111(SS1 +)','AR121(SS2 +)',
C    $         'AR131(TMP  )','AR141(EFS -)','AR151(PLA -)',
C    $         'AR161(CRK -)','AR171(EPS11)','AR181(EPS22)',
C    $         'AR191(EPS33)','AR201(EPS13)',
C    $         'AR 12(S11 +)','AR 22(S22 +)','AR 32(S33 +)',
C    $         'AR 42(S13 +)','AR 52(A1   )','AR 62(A2   )',
C    $         'AR 72(ANG1 )','AR 82(ANG2 )','AR 92(ANG  )',
C    $         'AR102(E MOD)','AR112(S YLD)','AR122(EFN  )',
C    $         'AR132(TMP +)','AR142(EFS +)','AR152(PLA +)',
C    $         'AR162(CRK +)','AR172(CK1 +)','AR182(CK2 +)',
```



```
C    $         'AR192(CK3 +)','AR202UMATAGE'/
C
C       AR(-,3) USED FOR INTERNAL CREEP VARIABLES
C
C     AR(17,1): EPSILON-XX(RR)--STRAIN IN X (OR R) DIRECTION
C     AR(18,1): EPSILON-ZZ(TT)-- ''     '' OUT OF PLANE (OR HOOP) DIRECTION
C     AR(19,1): EPSILON-YY(ZZ)-- ''     '' Y (OR Z) DIRECTION
C     AR(20,1): EPSILON-XY(RZ)-- SHEAR STRAIN
C
C     THESE ARE THE PHYSICAL COMPONENTS OF STRAIN.
C     THEY ARE EQUAL TO : (DU/DX) - (ALFA*DT) - (SHRINKAGE)
C     ABAQUS STRAINS ARE: (DU/DX)
C
        SAVTIM=TIME
        TIME=TIME/24.
        SAVDT=DELTM
        DELTM=DELTM/24.
      CALL ACOPDI(SINT(IEDBR+1),JELNO,1)
C
      IF (FIRSTE) THEN
        JELNO1=JELNO
        FIRSTE=.FALSE.
      ENDIF
C
      IF (NPROPS.LT.9) THEN
        WRITE(NOUT,20) NPROPS
   20   FORMAT('0THE UMAT(AGE) SUBROUTINE MUST HAVE NPROPS .GE.',
     $  ' 9.  NPROPS = ',I5)
        STOP 'TOO FEW NPROPS FOR UMAT(AGE)'
      ENDIF
      IF (NSTATV.LT.60) THEN
        WRITE(NOUT,30) NSTATV
   30   FORMAT('0THE UMAT(AGE) SUBROUTINE MUST HAVE NSTATV.GE.',
     $  '60.  NSTATV = ',I5)
        STOP 'TOO FEW NSTATV FOR UMAT(AGE)'
      ENDIF
C
      N=0
      DO 40 J=1,3
      DO 40 I=1,20
      N=N+1
   40 AR(I,J)=STATEV(N)
C
      AR(13,1)=TEMP
      AR(13,2)=TEMP+DTEMP
      AR(20,2)=0.0
C
      ECONC=PROPS(1)
      XVC=PROPS(2)
      CRUSH=PROPS(3)
```

```
C
C----ECONC=ELASTIC MODULUS AT AGE = 3 DAYS
C----CRUSH=ULTIMATE STRENGTH AT AGE = 3 DAYS
C
      EPFRAC=PROPS(4)
      ALFAC=PROPS(5)
      AGE=PROPS(6)
      IF (AGE.LE.0.0) THEN
        WRITE(NOUT,50) AGE
   50   FORMAT('0THE UMAT(AGE) SUBROUTINE MUST HAVE AGE .GT. 0')
        STOP 'UMAT(AGE) AGE NOT POSITIVE'
      ENDIF
      SHRINK=PROPS(7)
      CREEP=PROPS(8)
      TREF=PROPS(9)
      EPSHRK=PROPS(10)
      IF (SHRINK.LT.1.E-9) SHRINK=1.0
      IF (CREEP.LT.1.E-9) CREEP=1.0
C
C       SHRINK=SHRINKAGE MULTIPLIER - DEFAULT=1.0
C       CREEP=CREEP MULTIPLIER - DEFAULT=1.0
C
      TIMREF=0
      IF (NPROPS.GE.11) TIMREF=PROPS(11)
      IF (MATERL.LE.100.AND.FIRST(MATERL)) THEN
C
        WRITE(NOUT,55) MATERL,NPROPS,ECONC,XVC,CRUSH,EPFRAC,ALFAC,AGE,
     $   SHRINK,CREEP,TREF,EPSHRK,TIMREF
   55   FORMAT('0UMAT(AGE) PROPERTIES'/' MATERL = ',I5/' NPROPS = ',I5/
     $   ' ECONC = ',1PE11.3,' (PSI)'/' XVC = ',0PF7.3/' CRUSH = ',
     $   1PE11.3,' (PSI)'/' EPFRAC = ',1PE11.3,' (IN/IN)'/' ALFAC = ',
     $   1PE11.3,' (IN/IN/DEG)'/' AGE = ',1PE11.3,' (DAYS)'/,
     $   ' SHRINK = ',1PE11.3/' CREEP = ',1PE11.3/' TREF = ',1PE11.3,
     $   ' (DEG)'/' INITIAL SHRINKAGE = ',1PE11.3/' TIMREF = ',1PE11.3)
        FIRST(MATERL)=.FALSE.
        JPRINT=0
        MPROPS=12
        IF (NPROPS.GE.MPROPS+1) THEN
          IPR=NEAR(PROPS(MPROPS))
          IF (IPR.EQ.999) THEN
            MPROPS=MPROPS+1
            JPRINT=NEAR(PROPS(MPROPS))
            IF (JPRINT.LE.0.OR.NPROPS.LT.(MPROPS+JPRINT)) THEN
              WRITE(NOUT,60) NPROPS,JPRINT,MPROPS
   60         FORMAT('0BAD VALUES FOR PRINT CONTROL IN UMAT(AGE)    ',
     $         'NPROPS,JPRINT,MPROPS=',3I5)
              STOP 'BAD VALUE OF PRINT CONTROL IN UMAT(AGE)'
            ELSE
              MPRINT=MIN(JPRINT,100)
              DO 70 I=1,MPRINT
```

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```
              MPROPS=MPROPS+1
   70         NPRINT(I)=NEAR(PROPS(MPROPS))
              WRITE(NOUT,80) MPRINT,(NPRINT(I),I=1,MPRINT)
   80         FORMAT('0UMAT(AGE) INFORMATION PRINTED FOR THE FOLLOWING',
     $          ' ELEMENTS.  MPRINT = ',I5/(5X,10I8))
            ENDIF
          ENDIF
        ENDIF
        IF (MPROPS.LT.NPROPS) WRITE(NOUT,90) (PROPS(I),I=MPROPS+1,
     $   NPROPS)
   90   FORMAT('0UNRECOGNIZED USER PROPERTIES IN UMAT(AGE).'/
     $   (1P10E11.3))
      ENDIF
C
      ES=1.0
      DTIM(1)=TIME-TIMREF
      IF (DTIM(1).LT.0.0) THEN
C
        DO 120 I=1,NTENS
        STRESS(I)=0.0
        DO 110 J=1,NTENS
  110   HH(I,J)=0.0
  120   HH(I,I)=ECONC
        GO TO 900
      ENDIF
C
      DTIM(2)=DTIM(1)+DELTM
      INCRMT=NEAR(AR(8,3))+1
      NT=INCRMT
      IF (NT.GT.2) NT=2
C
      IF (INCRMT.EQ.1) THEN
        DO 125 I=17,19
  125   AR(I,2)=1.0
      ENDIF
C
      IF (NDI.EQ.3) THEN
        M14=0
        EPST(1)=TEPS(1)
        EPST(2)=TEPS(3)
        EPST(3)=TEPS(2)
        EPST(4)=TEPS(4)
        EP(1)=DEP(1)
        EP(2)=DEP(3)
        EP(3)=DEP(2)
        EP(4)=DEP(4)
      ELSE
        M14=1
        EPST(1)=TEPS(1)
        EPST(3)=TEPS(2)
```

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```
      EPST(4)=TEPS(3)
      EPST(2)= XVC*(EPST(1)+EPST(3))
      EP(1)=DEP(1)
      EP(3)=DEP(2)
      EP(4)=DEP(3)
      EP(2)= XVC*(EP(1)+EP(3))
    ENDIF
C
    ITER= 2
    MCOUNT= 1
    NCHECK=1
C
    IF (JELNO EQ JELNO1) THEN
      INT1=INT1+1
      SUM=0.0
      DO 127 I=1,NTENS
127   SUM=SUM+ABS(DEP(I))
      IF (SUM LT 1 E-12) THEN
        NPASS=0
        IF (INT1 EQ 1) NSTEP=NSTEP+1
      ELSE
        IF (NINT1 EQ 0) THEN
          IF (JELNO EQ JELNOL) ONEELM=.TRUE.
          NINT1=INT1-1
          INT1=1
        ENDIF
      IF (INT1 EQ 1) NPASS=NPASS+1
      ENDIF
    ENDIF
C
    IF (JELNO EQ JELNOL) THEN
      INT=INT+1
    ELSE
      INT=1
    ENDIF
    IF (ONEELM) INT=INT1
C
    IPRINT= FALSE
    IF (MPRINT GT 0 AND INT EQ 1) THEN
      DO 130 I=1,MPRINT
      IF (JELNO NE NPRINT(I)) GO TO 130
      IPRINT= TRUE
      GO TO 140
130   CONTINUE
    ENDIF
C
140 IF (IPRINT) WRITE(NOUT,160) JELNO,JELNO1,JELNOL,NPASS,INCRMT,
   $ NSTEP,INT,INT1,NINT1,NT,NDI,M14,ONEELM,SUM,AR
160 FORMAT('0BEFORE STRAIN CALL JELNO,JELNO1,JELNOL,NPASS,INCRMT,
   $NSTEP INT INT1 NINT1 NT NDI M14 ONEELM,SUM/AR='/1215,1X,1I1,
```



```
   $ 1PE11 3/(1P10E11.3))
C
     CALL STRAIN(TEMP,DTEMP,DTIM,EP,EPST,PH,AR,AGE,SHRINK,CREEP,
    .EPSHRK,SHRNK,TEMP1)
C    IF(NCHECK EQ.1)WRITE(6,161) DTIM(2),AR(13,1),AR(10,2),AR(9,2),
C   $AR(1,1),AR(3,1),AR(2,1),AR(17,1),AR(19,1),AR(18,1),AR(20,1),
C   $AR(16,1),AR(16,2),SHRNK,TEMP1
 161 FORMAT(1X,
    $F7.4,F6.1,F10.1,F5.0,3F8.1,4F9.6,2F4.0,2F9.6)
C
     AR(8,3)=AR(8,3)+1.0
C
     DO 170 I=1,NDI
     II=IORDER(I)
     STRESS(I)=AR(II,2)
     HH(I,NTENS)=PH(II,4)
     HH(NTENS,I)=PH(4,II)
     DO 170 J=1,NDI
     JJ=IORDER(J)
 170 HH(I,J)=PH(II,JJ)
     STRESS(NTENS)=AR(4,2)
     HH(NTENS,NTENS)=PH(4,4)
C
     IF (IPRINT) WRITE(NOUT,210) AR
 210 FORMAT('0AFTER STRAIN CALL.  AR='/(1P10E11.3))
C
     N=0
     DO 220 J=1,3
     DO 220 I=1,20
     N=N+1
 220 STATEV(N)=AR(I,J)
C
 900 JELNOL=JELNO
     STATEV(40)=7HUMATAGE
     IF (JELNO.EQ.JELNO1.AND.INT1.EQ.NINT1) INT1=0
C
        TIME=SAVTIM
        DELTM=SAVDT
     RETURN
     END

     FUNCTION NEAR(X)
     IMPLICIT REAL (A-H,O-Z)
     NEAR=NINT(X)
     RETURN
     END

     SUBROUTINE STRAIN(TEMP,DTEMP,DTIM,EP,EPST,PH,AR,AGE,SHRINK,CREEP,
    .EPSHRK,SHRNK,TEMP1)
     IMPLICIT REAL (A-H,O-Z)
```

```
C
      COMMON /BLKN/ ALFAC,ALFAS,CRUSH,DELT,DJ,ECONC,ESTEEL,ES,ITER,NT,
     $ MCOUNT,M14,NCHECK,XVC,YSTEEL,ANGLE,EFFSTR,EPSEFF,KRAC,SG(8),
     $ TF(4),V(8)
      COMMON /BLK1/ H(4,4),STR(4),XV,YIELD,EPFRAC
C
      DIMENSION SIJ(4),EPP(4),H2(4,4),DIJ(4),TAU(4),TIJ(4),TA(4),EPS(4),
     $  BF(4),B(4),FS(4),EPST(4),EP(4),PH(4,4),AR(20,3),DTIM(2)
     $,GE(4,3)
C
C**** LIST OF VARIABLES PASSED TO SUBROUTINE FROM MAIN PROGRAM
C
C     ALFAC  = COEFFICIENT OF CONCRETE THERMAL EXPANSION
C     ALFAS  = COEFFICIENT OF REBAR THERMAL EXPANSION
C     AR(I,J)= HISTORY VARIABLES
C     CRUSH  = YIELD STRESS
C     DELT   = REFERENCE (STRESS-FREE) TEMPERATURE
C     ECONC  = ELASTIC MODULUS
C     EP(I)  = 4 STRAIN INCRMENTS. RR OR XX, TT OR OUT OF PLANE,
C              ZZ OR YY, RZ OR XY
C     EPST(I)= 4 STRAIN COMPONENTS. RR OR XX, TT OR OUT OF PLANE,
C              ZZ OR YY, RZ OR XY
C     ES     = THICKNESS(DEFAULT=1.0) FOR PLANE PROBLEMS
C     ITER   = 1. INTERMIDATE ITERATION - NO UPDATING
C            = 2. FINAL ITERATION   ALL VARIABLES WILL BE UPDATED
C                ( NOTE  IF NEWTON ITERATION IS USED, OR IF NO
C                        ITERATION,  SET ITER=2 )
C     MCOUNT = ITERATION NUMBER IN A LOAD STEP
C     M14    = 0. AXISYMMETRY
C            = 1. PLANE
C     NCHECK = 0. STIFFNESS COMPUTATION
C            = 1. STRESS COMPUTATION
C     NT     = LOAD STEP NUMBER
C     XVC    = POISSON'S RATIO
C
C**** LIST OF VARIABLES PASSSED FROM SUBROUTINE TO MAIN PROGRAM
C
C     ANGLE  = ANGLE, IN DEGREE COUNTER CLOCKWISE, GIVING THE
C              DIRECTION OF THE MAXIMUM PRINCIPAL STRAIN OR
C              THE NORMAL TO THE CRACK SURFACE
C     AR(I,J)= HISTORY VARIABLES
C     EFFSTR = EFFECTIVE STRESS
C     EPSEFF = EFFECTIVE STRAIN
C     KRAC   - CRACKING IDENTIFIER
C              1 IN FIRST DIGIT INDICATES MERIDIONAL CRACK
C              2 IN TENTH DIGIT INDICATES RADIAL CRACK
C              3 IN HUNDREDTH DIGIT INDICATES ORTHOGONAL TO 1
C              0 IN ANY DIGIT INDICATES NO OR CLOSED CRACK
C     PH(I,J)= 4*4 CONSTITUTIVE MATRIX
C     SG(I)  = EIGHT STRESS COMPONENTS RR,TT,ZZ,RZ,
```



```
C              MAX PRINCIPAL STRESS, MIN.PRINCIPAL STRESS
C              FIRST REBAR STRESS, SECOND REBAR STRESS
C     TF(I)  = INTERNAL STRESSES INCLUDING THERMAL STRESSES,
C              RR OR XX, TT, ZZ OR YY, RX OR XY. THESE ARE
C              TO CONVERTED TO LOADS
C      V(I)  = EIGHT STRESS COMPONENTS RR,TT,ZZ,RZ,
C              MAX.PRINCIPAL STRAIN, MIN.PRINCIPAL STRAIN
C              FIRST REBAR STRAIN, SECOND REBAR STRAIN
C
C****
      KT = 2
      INCRMT=NT
      IF (INCRMT .EQ. 1) KT = 1
C      AR(13,KT)=TEMP+DTEMP
C      IF (KT .EQ. 1) AR(13,2)=AR(13,1)
      DTEM=DTEMP
      IF(KT.EQ.1) DTEM=AR(13,2)-DELT
      MT = KT - 1
      IF(MT.EQ.0) MT = 1
      ALFAA=ALFAC
      E0=1.0
      IF(NCHECK.EQ.0.AND.M14.NE.0) E0=ES
      XV= XVC
      T= AR(13,KT)
      XX=1.0/(DTIM(KT)+AGE)
      CALL COEF(XX,T,AGEFAC,TEMFAC)
      AGEFAC=AGEFAC*TEMFAC
C----------------------
      DAGE=1.0
      IF(INCRMT.EQ.1) GO TO 18
      XXM1=1.0/(DTIM(INCRMT-1)+AGE)
      TM1=AR(13,1)
      CALL COEF(XXM1,TM1,AGEM1,TEMFAC)
      AGEM1=AGEM1*TEMFAC
      DELAGE=AGEFAC-AGEM1
      DAGE=1.0+DELAGE/AGEM1
   18 CONTINUE
C----------------------
      EPSEFF=AR(12,2)
      FACTR=-0.02
      IF(INCRMT.EQ.1) YIELD=CRUSH*AGEFAC
      IF(INCRMT.EQ.1) AR(11,2)=YIELD*SQRT(1.0+3.0*FACTR)
      IF(INCRMT.EQ.1) AR(10,2)=ECONC*AGEFAC
C     8/31/1985
C     EI=AR(10,2)
C     YIELD=AR(11,2)
      EI= AR(10,2)*DAGE
      YIELD= AR(11,2)*DAGE
C     8/31/1985
      ALFA=0.0
```

```
C     DO 30 I=1,4
C  30 EPS(I)= EPST(I)
C
C     CALCULATIONS OF ELEMENT STRAINS
C
      DELTM=DTIM(INCRMT)-DTIM(INCRMT-1)
      IF(INCRMT.EQ.1) DELTM=DTIM(1)
      SHRNK=0.0
      DSHRNK=0.0
C
C     MODIFIED BY CAMPBELL, FEB 24, 1986
      IF(DTIM(INCRMT).LE.1.0) THEN
        SHRATE = EPSHRK
        DSHRNK = SHRATE * DELTM
        SHRNK = EPSHRK * DTIM(INCRMT)
        GO TO 154
      ENDIF
      DTM=DTIM(INCRMT) - 1.0
C
      SHRATE=-SHRINK*(204.91*0.15*EXP(-0.15*DTM)+145.09*0.0226348*
     EXP(-0.0226348*DTM))*1.E-6
      IF(DTIM(INCRMT).GT.120.0) SHRATE=0.0
      DSHRNK=SHRATE*DELTM
      IF(INCRMT.EQ.1) DSHRNK=DSHRNK+EPSHRK
      SHRNK=EPSHRK-SHRINK*(204.91*(1.0-EXP(-0.15*DTM))+145.09*
     (1.0-EXP(-0.0226348*DTM)))*1.E-6
C
C     MODIFIED BY CAMPBELL, FEB 24, 1986
  154 CONTINUE
      DTM = DTIM(INCRMT)
C
      TEMP1=ALFAA*DTEM+DSHRNK
      AGEF=DAGE*AGEM1
      INCRM=AR(8,3)
      B(4) = 0.0
      ESUM=ABS(EP(4))
      DO 155 I = 1,3
      ESUM=ESUM+ABS(EP(I))
  155 B(I)=TEMP1
      DO 165 I = 1,4
      EP(I) = EP(I) - B(I)
      EPP(I)=AR(I+16,1)
      IF(ESUM.GT.0.0) EPP(I)=AR(I+16,1)+EP(I)
      AR(I+16,1)=EPP(I)
      EPS(I)=EPP(I)
  165 CONTINUE
      X=EPS(1)
      Y=EPS(3)
      XY = EPS(4)
      RS=SQRT((Y-X)/2.0)**2+(XY/2.0)**2)
```



```
      C=(X+Y)/2.0
      SMAX=C+RS
      SMIN=C-RS
      D=10.0**6
      V(1)=X*D
      V(2)=EPS(2)*D
      V(3)=Y*D
      V(4) = XY * D
      V(5)=SMAX*D
      V(6)=SMIN*D
      EPSEFF= AR(12,2)
      DO 200 J=1,3
      DO 200 I=1,4
  200 GE(I,J)=0.0
      IF(INCRMT.EQ.1) GO TO 203
      IN=2
      DO 202 J=1,IN
      CALL MEMORY(GE,DTIM,AR,INCRMT,ITER,ECONC,J,AGE,CREEP)
  202 CONTINUE
C.... 8/31/1985
C      CALL MATCON(T,EI,YIELD,AGEFAC,INCRMT,EPSEFF,CON,ETAN)
C.....8/31/1985
  203 CONTINUE
      NPL1= (AR(15,KT)+0.001)/100.0
      NPL= (AR(15,MT)+0.001)/100.0
C.... 8/31/1985
C      IF(INCRMT.GT.1) YIELD=YIELD*SQRT(1.0+3.0*FACTR)*AGEFAC
C      IF(NPL1.EQ.0.AND.INCRMT.GT.1) YIELD=AR(11,2)*DAGE
C.....8/31/1985
      DELTAK= -(YIELD-AR(11,2))/1.732
      DELTAK= DELTAK*NPL
      EK= YIELD/1.732
      EK2= EK*EK
      EKK= EK2
      DELTAE= EI-AR(10,2)
      EI= EI*EO
      DELTAE= DELTAE*EO
      DO 310 I=1,3
      H2(I,4) = 0.0
      H2(4,I) = 0.0
      DO 300 J=1,3
  300 H2(I,J)=-1.0/6.0
      H2(I,I)=2.0/6.0
  310 CONTINUE
      H2(4,4)=1.0
      DO 410 I = 1, 4
      TA(I)= 0.0
      SG(I) = AR(I,KT)
  410 CONTINUE
      DO 450 I = 1, 3
```

```
      TAU(I)=AR(I,1)
      SIJ(I) = 0.0
      DO 450 J = 1, 3
  450 SIJ(I) = SIJ(I) + 2.0*H2(I,J)*SG(J)
      SIJ(4) = TAU(4)
      TAU(4)=AR(4,1)
      PLA = (SIJ(1)**2+SIJ(2)**2+SIJ(3)**2+2.0*SIJ(4)**2)
      EFFSTR=SQRT(1.5*PLA)
      SUM=SG(1) + SG(2) + SG(3)
      COMP = SUM * SUM * FACTR
      PLAST = (0.5 * PLA + COMP) / EK2
      EPN= 0.0
      IF(NPL1.GT.0.AND.PLAST.GT.0.0) EPN=1.0-SQRT(1.0/PLAST)
      COMP1= SUM*(1.0-EPN)
      CALL CONCRT(EPP,GE,DELTAE,DELTAK,TAU,SIJ,EI,CON,EPN,
     $ ALFA,FACTR,EP,PH,AR)
      DO 460 I=1,4
      BF(I)= SG(I)
  460 CONTINUE
      IF(NCHECK.EQ.0) GO TO 2150
C
C     ELEMENT COORDINATE STRESSES
C
      S1= 1.5/(1.0+XV)-1.0
      DO 610 I=1,4
      DO 610 J=1,4
  610 H(I,J)=0.0
      DO 620 I=1,3
      DO 615 J=1,3
  615 H(I,J)=-XV/EI
      H(I,I)=1.0/EI
  620 CONTINUE
      H(4,4)=2.0*(1.0+XV)/EI
      IF(ITER.NE.2) GO TO 606
      DO 605 I=1,4
      AR(I+6,1)= AR(I+6,1)+EPP(I)
  605 EPS(I)=AR(I+6,1)
      GO TO 607
  606 CONTINUE
      DO 20 I=1,4
   20 EPS(I)=AR(I+6,1)+EPP(I)
  607 CONTINUE
      IF(M14.EQ.1) V(2)=AR(8,1)*1.E6
      SUM=(EPS(1)+EPS(2)+EPS(3))/3.0
      DO 21 I=1,3
   21 EPS(I)=EPS(I)-SUM
      DO 630 I=1,4
      EPP(I)=0.0
      DO 630 J=1,4
  630 EPP(I)=EPP(I)+H(I,J)*AR(J,KT)
```



```
      SUM= (EPP(1)+EPP(2)+EPP(3))/3.0
      DO 601 I=1,3
  601 EPS(I)= EPS(I)+S1*(EPP(I)-SUM)
      EPS(4)=0.5*(EPS(4)+S1*EPP(4))
      EPSEFF=SQRT(2./3.*((EPS(1)**2+EPS(2)**2+EPS(3)**2+2.*EPS(4)**2)))
      AR(12,2)= EPSEFF
      NPL1= (AR(15,KT)+0.001)/100.0
      IF(ITER.EQ.2.AND.NPL1.GT.0) AR(11,2)=YIELD
      IF(ITER.NE.2) GO TO 475
C.....8/31/1985
C      CALL MATCON(T,EI,YIELD,AGEFAC,INCRMT,EPSEFF,CON,ETAN)
C      YIELD= YIELD*SQRT(1.0+3*FACTR)
C.....8/31/1985
      EK= YIELD/1.732
      EK2= EK*EK
      DELTAK= -(YIELD-AR(11,2))/1.732
      DELTAK= DELTAK*NPL
      SIGNT = SIJ(4) * SG(4) + 2.0 * (DELTAK * EK + FACTR*COMP1 * (SG(1)
     1   + SG(2) + SG(3)))
      DO 470 I=1,4
      SIGNT = SIGNT + SG(I) * SIJ(I)
  470 CONTINUE
  475 CONTINUE
      DO 2136 I = 1, 4
      IF (KT .EQ. 1) AR(I,2) = AR(I,KT)
      SG(I) = AR(I,KT)
 2136 CONTINUE
      SUM = (SG(1) + SG(2) + SG(3)) / 3.0
      TA(1) = SG(1) - SUM
      TA(2) = SG(2) - SUM
      TA(3) = SG(3) - SUM
      TA(4) = SG(4)
      EFFSTR = SQRT((TA(1)**2+TA(2)**2+TA(3)**2+2.0*TA(4)**2)*1.5)
      SUM1=0.0
      DO 571 I1=1,3
  571 SUM1 = SUM1 +  SG(I1)
      COMP = SUM1
      EFFS= EFFSTR**2+3.0*FACTR*COMP*COMP
      IF(EFFS.GT.0.0) EFFSTR=SQRT(EFFS)
      SUM1=SUM1/3.0
      DO 572 J1=1,3
  572 TA(J1) = SG(J1) - SUM1
      TA(4) = SG(4)
      PLA=0.5*(TA(1)**2 + TA(2)**2 + TA(3)**2 + 2.0*TA(4)**2)
      PLAST = (PLA + COMP * COMP * FACTR) / EK2
      IF(KT .EQ. 1) SIGNT = 0.01
      PLAST=PLAST*1.001
C
C     PLASTICITY CHECK
C
```

```
      NFACT= NPL1
C      IF(ITER.NE.2) GO TO 577
      IF(ITER.EQ.2) AR(15,MT)= NFACT*100+NPL2*10+NPL3
      MFACT= NPL
      NPL1 = 0.0
      IF(PLAST.GT.1.0) NPL1= 1
      IF(MFACT.GT.0.AND.SIGNT.GT.0.0) NPL1=1
      IF(NFACT.GT.0.AND.SIGNT.GT.0.0) NPL1=1
  577 CONTINUE
      IF(KT.EQ.1) NPL1= 0
C
C     ELEMENT PRINCIPAL STRESSES
C
      IF (KT .GT. 1) GO TO 380
      X = SG(1)
      Y = SG(3)
      XY = SG(4)
      RS = SQRT(((X-Y)/2.0)**2+XY**2)
      SG(5) = (X+Y)/2.0+RS
      SG(6) = (X+Y)/2.0-RS
  348 CONTINUE
      PA=0.0
      IF(XY.NE.0.0.OR.(X-Y).NE.0.0)
      PA=0.5*ATAN2(2.0*XY,X-Y)*45.0/ATAN(1.0)
  380 CONTINUE
      EPN = 0.0
      PLAST = (PLA+COMP*COMP*FACTR)/EKK
      IF(NFACT.GT.0.AND.PLAST.LT.0.0) EPN = 1.0 - SQRT (1.0/PLAST)
      IF(KT.EQ.1) AR(14,2) = EFFSTR
      AR(14,KT) = EFFSTR
 2150 CONTINUE
      DO 2151 I = 1,4
      DO 2151 J = 1,4
 2151 TF(I) = TF(I) PH (I,J) * B(J)
 2152 CONTINUE
       IF (NCHECK .EQ. 0) RETURN
C
C     FINAL BOOKKEEPING
C
      KRAC= AR(16,KT)
      NPLAST= AR(15,KT)+0.001
      NPP= NPLAST/100
      NPL2= (NPLAST-NPP*100)/10
      NPL3= NPLAST-NPP*100-NPL2*10
      IF(ITER.EQ.2) AR(15,MT)=NFACT*100+NPL2*10+NPL3
      AR(15,KT)= NPL1*100+NPL2*10+NPL3
      IF(ITER.EQ.1) RETURN
C-----------------
      XMULT=1.0
      IF(INCRMT.EQ.1) XMULT=0.0
```



```
      DO 2155 I=1,4
 2155 TA(I)=AR(I,2)*(1.0-EPN)-AR(I,1)*XMULT
      DO 2156 I=1,4
      AR(I+8,3)=AR(I+8,3)+GE(3,1)*TA(I)*GE(4,1)
      AR(I+12,3)=AR(I+12,3)+GE(3,2)*TA(I)*GE(4,2)
 2156 AR(I+16,3)=AR(I+16,3)+GE(3,3)*TA(I)*GE(4,3)
C      USTOR=0.0
C      UGEN=AR(20,2)
      DJ=1.0
C      DO 635 I=1,4
C      UGEN=UGEN+0.5*(AR(I,1)+AR(I,2))*EP(I)*DJ
C      USTOR=USTOR+(SG(I)*EPP(I))*0.5*DJ
C  635 CONTINUE
C      IF(KT.EQ.1) UGEN-USTOR
C      AR(20,2)=UGEN
C      AR(20,1)=USTOR
      IF(KT.EQ.1) RETURN
      DO 2170 I = 1, 4
      AR(I,2) = AR(I,2)*(1.0-EPN)
      AR(I,1) = AR(I,2)
 2170 CONTINUE
      AR(10,2)= EI
C   ..8/31/1985
      AR(11,2)=AR(11,2)*DAGE
C.. ..8/31/1985
      IF(NPL1.GT.0) AR(11,2)=YIELD*DAGE
      AR(13,1) = AR(13,2)
      AR(14,1) = AR(14,2)
      RETURN
      END

      SUBROUTINE CONCRT (EPS,GE,DELTAE, DELTAK, TAU, TIJ, EI,
     $ CON, EPN,ALFA,FACTR,EP,PH,AR)
C
      IMPLICIT REAL (A-H,O-Z)
C
      COMMON/BLKN/ ALFAC,ALFAS,CRUSH,DELT,DJ,ECONC,ESTEEL,
     $ES,ITER,NT,MCOUNT,M14,NCHECK,XVC,YSTEEL,
     $    ANGLE,EFFSTR,EPSEFF,KRAC,SG(8),TF(4),V(8)
      COMMON/BLK1/ H(4,4),STR(4),XV,YIELD,EPFRAC
C
      DIMENSION ECC(4),EPS(4),BF(4),HH(4,4),Q(4,4),DF(4),FS(4),SR(4),
     $ STN(4),HX(4,4),AS(6,6),AX(4),BX(4),TAU(4),TIJ(4),H2(4,4),
     $ HB(4,4),DIJ(4),GE(4,3),EP(4),PH(4,4),AR(20,3)
C
      DATA ZERO/0.0/
C
      KT = 2
      INCRMT=NT
      IF (INCRMT .EQ. 1) KT = 1
```

```
      MT = KT - 1
      IF(MT.EQ.0) MT = 1
      JT= 2
      COD= FACTR
      KRAC = AR(16,MT) + 0.01
      KRAK = AR(16,KT) + 0.01
      TH= AR(9,2)
      CA = COS(TH/57.29578)
      SA = SIN(TH/57.29578)
      CTC = CA * CA
      STS = SA * SA
      STC = SA * CA
      NE3 = KRAC/100
      NE2 = (KRAC-NE3*100)/10
      NE1 = KRAC-NE3*100-NE2*10
      DEE = -DELTAE/(EI*EI+1.0)
      L1 = NE1
      L2 = NE2
      C1 = XV*EI/((1.0+XV)*(1.0-2.0*XV))
      C2 = (1.0-XV)*EI/((1.0+XV)*(1.0-2.0*XV))
      C3 = 0.5*EI/(1.0+XV)
      XU= XV
      DO 280 I = 1, 4
      TF(I) = 0.0
      DF(I) = 0.0
      BF(I)=0.0
      STN(I)= 0.0
      STR(I)= 0.0
      DO 280 J=1,4
      H2(I,J) = 0.0
      Q(I,J) = 0.0
      HK(I,J) = 0.0
  280 CONTINUE
      DO 285 L = 1, 3
      DO 282 M = 1, 3
      H2(L,M) = -XU / 3.0
  282 HK(L,M) = -XV
      H2(L,L) = 1.0 / 3.0
      HK(L,L) = 1.0
  285 CONTINUE
      H2(4,4)=2.0*(1.0+XU)/3.0
      HK(4,4) = 2.0 * (1.0 + XV)
C
C     CALCULATIONS OF STRESSES FROM STRAIN HISTORIES
C
      DO 290 I=1,4
      SG(I)= AR(I,KT)*(1.0-EPN)
      TIJ(I) = TIJ(I) * (1.0 - EPN)
      ECC(I) = 1.0
      DO 290 J=1,4
```



```
      HH(I,J)=0.0
      HB(I,J)=0.0
  290 H(I,J)=0.0
      SUM=0.0
      DO 435 I = 1, 3
      K= 16+I
      ARI4 = AR(K,JT)
      FS(I) = ARI4
      IF(FS(I).LT.0.1) ECC(I)=1.E-3
      IF(FS(I).LT.0.1) FS(I)=1.E-3
      SUM=SUM+AR(I,KT)
  435 CONTINUE
      SUM = SUM * (1.0 - EPN)
      GEN=0.0
      GEN1=0.0
      DO 288 I=1,3
      GEN1=GEN1+GE(1,I)
  288 GEN=GEN+GE(1,I)-GE(2,I)*GE(3,I)
      E1 = FS(1)
      E2 = FS(2)
      E3 = FS(3)
      ALFA= 0.0
      IF(ALFA.LE.0.0) GO TO 745
      IF (E1 + E2 + E3 .LT. 0.1) GO TO 745
      DO 738 K = 1, 4
      DIJ(K) = EPS(K)
      IF (MCOUNT .GT. 1) DIJ(K) = EPS(K) - EP(K)
  738 CONTINUE
      EPP1 = CTC * DIJ(1) + STS * DIJ(3) + STC * DIJ(4)
      EPP2 = DIJ(2)
      EPP3 = STS * DIJ(1) + CTC * DIJ(3) - STC * DIJ(4)
      IF (NE1 .EQ. 0 .OR. EPP1 .LE. EPFRAC .OR. E1 .LT. 0.1) GO TO 742
      ECC(1) = (1.0 - ALFA) * AR(17,2)
      E1 = 0.0
  742 IF (NE2 .EQ. 0 .OR. EPP2 .LE. EPFRAC .OR. E2 .LT. 0.1) GO TO 743
      ECC(2) = (1.0 - ALFA) * AR(18,2)
      E2 = 0.0
  743 IF (NE3 .EQ. 0 .OR. EPP3 .LE. EPFRAC .OR. E3 .LT. 0.1) GO TO 745
      ECC(3) = (1.0 - ALFA) * AR(19,2)
      E3 = 0.0
  745 CONTINUE
      H(1,1)=C2
      H(1,2)=C1
      H(1,3)=C1
      H(2,2)=C2
      H(2,3)=C1
      H(3,3)=C2
      H(4,4)=C3
      H(2,1) = H(1,2)
      H(3,1) = H(1,3)
```

```
      H(3,2) = H(2,3)
      DO 109 K=1,4
      DO 109 L=1,4
      PH(K,L)=H(K,L)
  109 AS(K,L)=DEE*HK(K,L)+GEN*H2(K,L)
      FS(4) = MIN(FS(1),FS(3))
      ECC(4) = MIN(ECC(1),ECC(3))
      GRATIO=EPP1/EPFRAC
      IF(GRATIO.LT.1.0) GRATIO=1.0
      IF(FS(4).LT.0.1) FS(4)=0.4/GRATIO
      IF(ECC(4).LT.0.1) ECC(4)=0.4/GRATIO
      IF (E1+E2+E3.GT.2.9) GO TO 117
      DO 110 K = 1, 3
      DO 110 L = 1,3
  110 HH(K,L) = HK(K,L) * FS(K) * FS(L)
      HH(4,4) = 2.0 * (1.0 + XV  * FS(4) )/ECC(4)
      DO 115 K = 1, 3
  115 HH(K,K) = 1.0/ECC(K)
      DO 114 I = 1, 4
      DO 114 J = 1, 4
  114 HK(I,J) = HH(I,J)
      CALL SYMINV(HH)
      DO 116 I = 1, 4
      DO 116 J = 1, 4
      AS(I,J)= DEE*HK(I,J)+GEN*H2(I,J)
  116 H(I,J)= HH(I,J)*EI
  117 CONTINUE
      Q(1,1) = CTC
      Q(1,3) = STS
      Q(1,4) = STC
      Q(2,2) = 1.0
      Q(3,1) = STS
      Q(3,3) = CTC
      Q(3,4) = -STC
      Q(4,1) = -STC*2.0
      Q(4,3) = STC*2.0
      Q(4,4) = CTC-STS
      DO 780 I = 1,3
      HB(I,4) = 2.0 * Q(I,4)
      HB(4,I) = 0.5 * Q(4,I)
      DO 780 J = 1,3
  780 HB(I,J) = Q(I,J)
      HB(4,4) = Q(4,4)
      IF (E1 .GT. 0.9 .AND. E3 .GT. 0.9) GO TO 140
      DO 120 K = 1, 4
      DO 120 L = 1, 4
      AS(K,L) = 0.0
      HH(K,L) = 0.0
      DO 120 M = 1, 4
      HH(K,L) = HH(K,L) + HK(K,M) * HB(M,L)
```



```
  120 AS(K,L) = AS(K,L) + H(K,M) * Q(M,L)
      DO 130 K = 1, 4
      DO 130 L = 1, 4
      HK(K,L) = 0.0
      H(K,L) = 0.0
      DO 130 M = 1, 4
      HK(K,L) = HK(K,L) + HB(M,K) * HH(M,L)
  130 H(K,L) = H(K,L) + Q(M,K) * AS(M,L)
      DO 132 K = 1, 4
      DO 132 L = 1, 4
  132 AS(K,L) = DEE*HK(K,L)+GEN*H2(K,L)
  140 CONTINUE
      DO 707 I=1,4
      TF(I)=GEN1*AR(I,MT)-GE(2,1)*AR(I+8,3)
     .-GE(2,2)*AR(I+12,3)-GE(2,3)*AR(I+16,3)
  707 CONTINUE
      IF(ABS(DEE).LT.1.E-9.AND.GEN.LT.1.E-9) GO TO 740
      DO 720 I = 1, 4
      DO 720 J = 1, 4
      HH(I,J) = 0.0
      DO 720 K = 1, 4
  720 HH(I,J) = HH(I,J) + H(I,K)*AS(K,J)
      DO 725 I = 1,4
  725 HH (I,I) = HH(I,I) + 1.0
      CALL INVERT (HH,4,AX,BX)
      DO 730 I = 1,4
      DO 730 J = 1,4
      PH(I,J) = 0.0
      DO 730 K = 1,4
  730 PH(I,J) = PH(I,J) + HH(I,K) * H(K,J)
      DO 731 I = 1,4
      DO 731 J = 1,4
  731 H(I,J) = PH(I,J)
  740 CONTINUE
      DO 705 I = 1,4
      BF(I) =0.0
      DO 705 J = 1,4
      BF(I) = BF(I) - HK(I,J)*AR(J,MT)*DEE - H2(I,J) * TF(J)
  705 PH(I,J) = H(I,J)
      IF(M14.EQ.1) EP(2)=-(PH(2,1)*EP(1)+PH(2,3)*EP(3)+PH(2,4)*EP(4))
     .                      /PH(2,2)
      EK = YIELD/1.732
      EK2 = EK * EK
      PP= 0.0
      NPLAST= (AR(15,KT)+0.001)/100.0
      NPL1= AR(15,KT)+0.001
      NPL2= (NPL1-NPLAST*100)/10
      NPL3= NPL1-NPLAST*100-NPL2*10
      IF(NCHECK.NE.1) GO TO 650
      IF(M14.NE.1) GO TO 615
```

```
      DO 601 I=1,4
      IF(I.EQ.2) GO TO 601
      DO 600 J=1,4
      IF(J.EQ.2) GO TO 600
      H(I,J) = H(I,J) - H(I,2)*H(2,J)/H(2,2)
  600 CONTINUE
  601 CONTINUE
      DO 605 I=1,4
      DO 605 J=1,I
  605 H(I,J) = H(J,I)
      DO 610 I=1,4
      H(I,2)=0.0
  610 H(2,I)=0.0
      H(2,2)=1.0
  615 CONTINUE
      DO 620 I=1,4
      SR(I)=AR(I,1)
      DO 620 J=1,4
  620 SR(I) = SR(I) + H(I,J)*(EP(J)+BF(J)+TF(J))
      SUM = (SR(1)+SR(2)+SR(3))/3.0
      DO 625 I=1,3
      DF(I) = SR(I) - AR(I,1)
  625 SR(I) = SR(I) - SUM
      DF(4) = SR(4) - AR(4,1)
      EJ2 = 9.0*SUM*SUM*COD
      F = 0.5*(SR(1)**2+SR(2)**2+SR(3)**2+2.0*SR(4)**2) + EJ2 - EK2
      NPLAST=1
      IF(F.GT.0.0) GO TO 635
      NPLAST=0
      GO TO 650
  635 CONTINUE
      SUM1 = TAU(1)+TAU(2)+TAU(3)
      SUM2 = DF(1)+DF(2)+DF(3)
      DO 640 I=1,3
      SR(I)=DF(I)
      TAU(I) = TAU(I)- SUM1/3.0
  640 DF(I) = DF(I) - SUM2/3.0
      SR(4)=DF(4)
      T1 = 2.0*DF(4)*TAU(4)
      T2 = 2.0*DF(4)*DF(4)
      T3 = 2.0*TAU(4)*TAU(4)
      DO 645 I=1,3
      T1 = T1+DF(I)*TAU(I)
      T2 = T2+DF(I)*DF(I)
  645 T3= T3+TAU(I)*TAU(I)
      T22 = 0.5*T2+SUM2*SUM2*COD
      T11 = T1+SUM2*SUM1*COD*2.0
      T33 = 0.5*T3+SUM1*SUM1*COD
      BB = T11/T22
      RADCAL = (EK2-T33)/T22 + BB**2/4.0
```



```
      IF(RADCAL.LE.0.0) RADCAL=BB**2/4.0
      PP = -BB*0.5 + SQRT(RADCAL)
      IF(PP.LT.0.0) PP=0.0
      IF(PP.GT.1.0) PP=1.0
      DO 646 I=1,4
  646 SG(I) = AR(I,1) + PP*SR(I)
      SUM = (SG(1)+SG(2)+SG(3))/3.0
      DO 647 I=1,3
  647 TIJ(I) = SG(I)-SUM
      TIJ(4)= SG(4)
      PLA= 0.5*(TIJ(1)**2+TIJ(2)**2+TIJ(3)**2+2.0*TIJ(4)**2)
      COMP= SG(1)+SG(2)+SG(3)
      PLAST= (PLA+COMP*COMP*FACTR)/EK2
      IF(PLAST.LT.1.E-9) GO TO 650
      EPN= 1.0-SQRT(1.0/PLAST)
      DO 648 I=1,4
      SG(I)= SG(I)*(1.0-EPN)
  648 TIJ(I)= TIJ(I)*(1.0-EPN)
  650 CONTINUE
      AR(15,KT)= NPLAST*100+NPL2*10+NPL3
      IF(NPLAST.EQ.0) GO TO 2100
      FA = COD
      CI1=2.0/3.0 * CON
      SUM = SG(1)+SG(2)+SG(3)
      FA = 2.0*FA*SUM
      RT = 1.0-PP
      DO 750 I = 1,3
  750 STR(I) = TIJ(I) + FA
      STR(4) = TIJ(4)
      IF (FS(1) + FS(2) + FS(3) .GT. 2.9) GO TO 171
      DO 151 K = 1, 4
      DIJ(K) = 0.0
      DO 151 L = 1, 4
  151 DIJ(K) = DIJ(K) + HB(K,L)*SG(L)
      DO 155 M = 1, 4
  155 DIJ(M) = DIJ(M) * FS(M)
      DO 156 I = 1, 4
  156 DIJ(I) = DIJ(I) * (1.0 - EPN)
      DO 161 K = 1, 4
      STR(K) = 0.0
      DO 161 L = 1, 4
  161 STR(K) = STR(K) + Q(L,K) * DIJ(L)
      SUM = STR(1) + STR(2) + STR(3)
      DO 165 K = 1, 3
  165 STR(K) = STR(K) - SUM * (1.0 / 3.0 - 2.0 * COD)
  171 CONTINUE
      DO 755 I = 1,4
      STN(I) = 0.0
      DO 755 J = 1,4
  755 STN(I) = STN(I) + PH(I,J)*STR(J)
```

```
      RS=STR(4)*STN(4) + C11*STR(4)*STR(4)
      DO 760 I = 1,4
      RS=RS+STR(I)*STN(I)+C11*STR(I)*STR(I)
      DO 760 J = 1,4
  760 HH (I,J) = STN(I)*STN(J)
      DO 765 I = 1,4
      DO 765 J = 1,4
  765 PH(I,J) = PH(I,J) - HH(I,J)*RT/RS
      DO 294 I = 1, 4
  294 STN(I) = -2.0 * EK * DELTAK * STN(I) * RT / RS
  295 CONTINUE
  300 CONTINUE
      IF (E2.GT.0.9) GO TO 298
      DO 675 I=1,4
      IF(I.EQ.2) GO TO 675
      DO 670 J=I,4
      IF(J.EQ.2) GO TO 670
      PH(I,J) = PH(I,J) - PH(I,2)*PH(2,J)/PH(2,2)
  670 CONTINUE
  675 CONTINUE
      DO 680 I=1,4
      DO 680 J=1,I
  680 PH(I,J) = PH(J,I)
      DO 297 I=1,4
      PH(I,2)=0.0
  297 PH(2,I) = PH(I,2)
      PH(2,2)=1.0
  298 CONTINUE
      IF(E1.GT.0.9.AND.E3.GT.0.9) GO TO 2100
      DO 785 I = 1,4
      DO 785 J = 1,4
      H (I,J) = 0.0
      DO 785 K = 1,4
  785 H(I,J) = H(I,J) + HB(I,K) * PH(K,J)
      DO 790 I = 1,4
      DO 790 J = 1,4
      HK (I,J) = 0.0
      DO 790 K=1,4
  790 HK(I,J) = HK(I,J) + H(I,K) * HB(J,K)
      IF(E1.GT.0.9) GO TO 685
      DO 682 I=2,4
      DO 681 J=2,4
  681 HK(I,J) = HK(I,J) - HK(I,1)*HK(1,J)/HK(1,1)
  682 CONTINUE
  685 IF(E3.GT.0.9) GO TO 690
      DO 687 I=1,4
      IF(I.EQ.3) GO TO 687
      DO 686 J=I,4
      IF(J.EQ.3) GO TO 686
      HK(I,J) = HK(I,J) - HK(I,3)*HK(3,J)/HK(3,3)
```



```
  686 CONTINUE
  687 CONTINUE
      DO 688 I=1,4
      DO 688 J=1,I
  688 HK(I,J) = HK(J,I)
  690 CONTINUE
      DO 296 I = 1,4
      DO 296 J = I, 4
  296 H(I,J) = HK(I,J) * FS(I) * FS(J)
      DO 174 K = 1, 4
      H(K,K)= HK(K,K)*FS(K)
      DO 173 L = K, 4
      IF (H(K,K) .LE. 0.0) H(K,L) = 0.0
  173 CONTINUE
  174 CONTINUE
      DO 304 I = 1, 4
      DO 304 J = I, 4
  304 H(J,I) = H(I,J)
      DO 2000 I = 1,4
      DO 2000 J=1,4
      HH(I,J) = 0.0
      DO 2000 K = 1,4
 2000 HH(I,J) = HH(I,J)+H(I,K)*Q(K,J)
      DO 2010 I=1,4
      DO 2010 J=1,4
      PH(I,J) = 0.0
      DO 2010 K = 1,4
 2010 PH (I,J) = PH(I,J) + Q(K,I) * HH(K,J)
 2020 CONTINUE
 2100 CONTINUE
      IF(M14.NE.1) GO TO 330
      STN2 = STN(2)
      DO 324 I = 1, 4
  324 STN(I) = STN(I) - STN2 * PH(I,2) / PH(2,2)
      EP(2) = -(PH(2,1)*EP(1)+PH(2,3)*EP(3) + PH(2,4) * EP(4)) / PH(2,2)
      PH(1,1) = PH(1,1) - PH(1,2) * PH(1,2) / PH(2,2)
      PH(1,3) = PH(1,3) - PH(1,2) * PH(2,3) / PH(2,2)
      PH(3,3) = PH(3,3) - PH(2,3) * PH(2,3) / PH(2,2)
      PH(3,1) = PH(1,3)
      PH(1,4) = PH(1,4) - PH(1,2) * PH(2,4) / PH(2,2)
      PH(4,1) = PH(1,4)
      PH(3,4) = PH(3,4) - PH(2,3) * PH(2,4) / PH(2,2)
      PH(4,3) = PH(3,4)
      PH(4,4) = PH(4,4) - PH(2,4) * PH(2,4) / PH(2,2)
      DO 325 I = 1,4
      PH(2,I) = 0.0
      PH(I,2) = 0.0
  325 CONTINUE
  330 CONTINUE
      DO 2050 JJ = 1,4
```

```
      TF(JJ) = STN(JJ)
      DO 2050 KK = 1,4
      TF(JJ) = TF(JJ) + PH(JJ,KK) * BF(KK)
 2050 CONTINUE
      IF(NCHECK.NE.0) GO TO 375
      DO 355 I=1,4
      IF(FS(I).LT.1.0) FS(I)=0.0
  355 TF(I)= TF(I)+AR(I,1)
      TF(2)= TF(2)*FS(2)
      IF(FS(1)+FS(3).GT.1.9) GO TO 375
      DO 365 I=1,4
      TFI= 0.0
      DO 360 J=1,4
  360 TFI=TFI+HB(I,J)*TF(J)
  365 STN(I)= TFI*FS(I)
      IF(STN(1).GT.0.0.AND.NE1.EQ.1) STN(1)=0.0
      IF(STN(2).GT.0.0.AND.NE2.EQ.2) STN(2)=0.0
      IF(STN(3).GT.0.0.AND.NE3.EQ.3) STN(3)=0.0
      IF((STN(1).GE.0.0.OR.STN(3).GE.0.0) .AND. (NE1.EQ.1.OR.NE3.EQ.3))
     $  STN(4)=0.0
      DO 370 I=1,4
      TF(I)= 0.0
      DO 370 J=1,4
  370 TF(I)= TF(I)+Q(J,I)*STN(J)
  375 CONTINUE
      IF(ABS(AR(5,2)).LT.1.E-9.AND.ABS(AR(6,2)).LT.1.E-9) GO TO 380
      CALL REBAR(AR,NCHECK,ITER,DJ,ALFAS,DELT,ESTEEL,YSTEEL,
     $             HK,BF,SG,V,EP)
      IF(NCHECK.EQ.1) GO TO 380
      DO 377 I=1,4
      TF(I)= TF(I)+BF(I)
      DO 377 J=1,4
  377 PH(I,J)= PH(I,J)+HK(I,J)
  380 CONTINUE
      IF (NCHECK.EQ.0) RETURN
      DO 2130 I=1,4
      SG(I) = TF(I)
      DO 2130 J=1,4
 2130 SG(I) = SG(I) + PH(I,J) * EP(J)
      DO 510 I = 1,4
      AR(I,KT) = AR(I,MT)+SG(I)
      BF(I)= AR(I,KT)
  510 CONTINUE
      IF(KT.EQ.1) GO TO 550
      E1 = AR(17,JT)
      E2 = AR(18,JT)
      E3 = AR(19,JT)
  511 CONTINUE
      AR(2,KT) = AR(2,KT) * E2
      SG(2) = AR(2,KT)-AR(2,MT)
```



```
      SR1 = AR(1,KT)
      SR3 = AR(3,KT)
      SR4 = AR(4,KT)
      X = SR1
      Y = SR3
      XY = SR4
      XX = SR2
      IF (E1 + E3.GT.1.99) GO TO 515
      SG1 = (CTC * SR1 + STS * SR3 + 2.0 * STC * SR4) * E1
      SG3 = (STS * SR1 + CTC * SR3 - 2.0 * STC * SR4) * E3
      SG4 = ((CTC-STS) * SR4 - STC * (SR1-SR3)) * E1 * E3
      IF (SG1 .GT. 0.0 .AND. NE1 .EQ. 1) SG1 = 0.0
      IF (SG3 .GT. 0.0 .AND. NE3 .EQ. 3) SG3 = 0.0
      IF  ((SG1 .GE. 0.0 .OR. SG3 .GE. 0.0) .AND. (NE1 .EQ. 1 .OR. NE3
     1  .EQ. 3)) SG4 = 0.0
      X = CTC * SG1 + STS * SG3 - 2.0 * STC * SG4
      Y = STS * SG1 + CTC * SG3 + 2.0 * STC * SG4
      XY = STC * (SG1-SG3) + (CTC-STS) * SG4
  515 AR(1,KT) = X
      AR(3,KT) = Y
      AR(4,KT) = XY
      SG(1) = AR(1,KT)-AR(1,MT)
      SG(3) = AR(3,KT)-AR(3,MT)
      SG(4) = AR(4,KT)-AR(4,MT)
  550 CONTINUE
      X = AR(1,KT) + 0.001
      Y = AR(3,KT) + 0.001
      XY = AR(4,KT) + 0.001
      RS = SQRT(((Y-X) / 2.0) ** 2 + XY ** 2)
      CEN = (X+Y) / 2.0
      SMAX = CEN + RS
      SMIN = CEN - RS
      SG(5) = SMAX
      SG(6) = SMIN
      PA1 = 2.0 * XY
      PA2=X-Y
      PA=0.0
      IF(PA1.NE.0.0.OR.PA2.NE.0.0)
     .PA=0.5*ATAN2(PA1,PA2)*45.0/ATAN(1.0)
      TH=PA
  560 CONTINUE
      IF (ABS(AR(9,JT)) .GT. 1.E-6.OR.NE1.NE.0.OR.NE3.NE.0) TH=AR(9,JT)
      CA = COS(TH/57.29578)
      SA = SIN(TH/57.29578)
      STS = SA * SA
      CTC = CA * CA
      STC = SA * CA
      D1 = CTC * EPS(1) + STS * EPS(3) + STC * EPS(4)
      D2 = EPS(2)
      D3 = STS * EPS(1) + CTC * EPS(3) - STC * EPS(4)
```

```
      EPP1 = CTC*EP(1)+STS*EP(3)+STC*EP(4)
      EPP2 = EP(2)
      EPP3 = STS*EP(1)+CTC*EP(3)-STC*EP(4)
      X = AR(1,KT)
      Y = AR(3,KT)
      XY = AR(4,KT)
      SG(5)=CTC * X + STS * Y + 2.0 * STC * XY
      SG(6)=STS * X + CTC * Y - 2.0 * STC * XY
      V(5) = D1 * 1.E6
      V(6) = D3 * 1.E6
      EPS(1)= EP(1)
      EPS(2)= EP(2)*FS(2)
      EPS(3)= EP(3)
      EPS(4)= EP(4)
      IF(NE1+NE3.EQ.0) GO TO 570
      EPS(4)= ((CTC-STS)*EP(4)+2.0*STC*(EP(3)-EP(1)))*FS(4)
      EPS(1)= EPP1*FS(1)
      EPS(2)= EPP2*FS(2)
      EPS(3)= EPP3*FS(3)
      DO 566 I=1,4
      FS(I)= 0.0
      DO 566 J=1,4
  566 FS(I)= FS(I)+HB(J,I)*EPS(J)
      DO 567 I=1,4
  567 EPS(I)= FS(I)
  570 CONTINUE
      ANGLE=TH
      ME3=KRAK/100
      ME2=(KRAK-ME3*100)/10
      ME1=KRAK-ME3*100-ME2*10
      IF(NE3.EQ.0) NE3=ME3
      IF(NE2.EQ.0) NE2=ME2
      IF(NE1.EQ.0) NE1=ME1
      E1 = 1-NE1
      E2 = 1-NE2/2
      E3 = 1-NE3/3
      SIGF= EPFRAC*EI
      CF=0.1
      EX1=2.0*SIGF
      S1=D1/EPFRAC
      S2=D2/EPFRAC
      S3=D3/EPFRAC
C
C     CRACKING CRITERION
C
      P1=2.0*EPFRAC*(1.0-SG(5)/EX1)
      P2=2.0*EPFRAC*(1.0-AR(2,KT)/EX1)
      P3=2.0*EPFRAC*(1.0-SG(6)/EX1)
      EPS2=P2*E2
      EPS1=P1*E1
```



```
      EPS3=P3*E3
      EPS1=MAX(EPS1,ZERO)
      EPS2=MAX(EPS2,ZERO)
      EPS3=MAX(EPS3,ZERO)
      Q1=2.0*SIGF*(1.0-0.5*S1)
      Q2=2.0*SIGF*(1.0-0.5*S2)
      Q3=2.0*SIGF*(1.0-0.5*S3)
      SIG1=Q1*E1
      SIG2=Q2*E2
      SIG3=Q3*E3
      IF (SG(5) .GE. 0.0 .AND. SG(6) .GE. 0.0) SIG1 = SIGF * E1
      IF (SG(5) .GE. 0.0 .AND. SG(6) .GE. 0.0) SIG3 = SIGF * E3
      SIG1=MAX(SIG1,ZERO)
      SIG2=MAX(SIG2,ZERO)
      SIG3=MAX(SIG3,ZERO)
      S1 = D1
      S2 = D2
      S3 = D3
      D1=MIN(D1,EPP1)*(1.0-E1)
      D2=MIN(D2,EPP2)*(1.0-E2)
      D3=MIN(D3,EPP3)*(1.0-E3)
  575 CONTINUE
      N = 16
      DO 190 I = 1,3
      K = I + N
      AR(K,2) = 1.0
  190 CONTINUE
      IF (NE1 .EQ. 0) AR(9,2) = 0.0
C
C     MATERIAL MODULI MODIFIED BY CRACKING
C
      LT = 2
      IF (EPFRAC .GT. 1.E3) GO TO 220
      SIG1 = SIG1 - 0.1
      SIG2 = SIG2 - 0.1
      SIG3 = SIG3 - 0.1
      D1= D1+1.E-5
      D2= D2+1.E-5
      D3= D3+1.E-5
      IF (S1 .GE. 0.0 .AND. S3 .GE. 0.0) EPS1 = P1 * E1
      IF (S1 .GE. 0.0 .AND. S3 .GE. 0.0) EPS3 = P3 * E3
C      IF(M14.NE.0) GO TO 200
      KRACK=2
      IF (L1.GT.0.OR.L2.GT.0) GO TO 192
      IF(S1.GT.S2) KRACK=1
  192 CONTINUE
      GO TO (200,195),KRACK
  195 IF (S2 .LT. EPS2 .AND. AR(2,KT) .LT. SIG2) GO TO 200
      IF (D2 .LT. 0.0) GO TO 200
      AR(N+2,2) = 0.0
```

```
C      IF(L2.EQ.0 AND L1.EQ.0) GO TO 220
  200 CONTINUE
      IF (S1 .LT. EPS1 .AND. SG(5) .LT. SIG1) GO TO 210
      IF (D1 .LT. 0.0) GO TO 210
      AR(N+1,2) = 0.0
      AR(9,2) = TH
C      IF(L1.EQ.0) GO TO 220
  210 CONTINUE
      IF (S3 .LT. EPS3 .AND. SG(6) .LT. SIG3) GO TO 220
      IF (D3 .LT. 0.0) GO TO 220
C      IF(L1.EQ.0.OR.L2.EQ.0) GO TO 220
      AR(N+3,2) = 0.0
  220 CONTINUE
      ME1 = 1.001 - AR(N+1,JT)
      ME2 = (1.001 - AR(N+2,JT)) * 2.0
      ME3 = (1.001 - AR(N+3,JT)) * 3.0
      AR(16,LT) = 100*ME3 + 10*ME2 + ME1
      IF (ITER .NE. 2) RETURN
C      IF(ME1.NE.0) NE1=ME1
C      IF(ME2.NE.0) NE2=ME2
C      IF(ME3.NE.0) NE3=ME3
      AR(16,MT) = 100 * NE3 + 10 * NE2 + NE1
      KRAC= AR(16,MT)
      ANGLE= AR(9,2)
      RETURN
      END

      SUBROUTINE INVERT(A,NN,M,C)
C****
C         GENERAL MATRIX INVERSION SUBROUTINE
C****
      IMPLICIT REAL (A-H,O-Z)
C
      DIMENSION A(1),M(1),C(1)
C
      DO 90 I=1,NN
   90 M(I)=-I
      DO 140 I=1,NN
C     LOCATE LARGEST ELEMENT
      D=0.0
      DO 112 L=1,NN
      IF (M(L)) 100,100,112
  100 J=L
      DO 110 K=1,NN
      IF (M(K)) 103,103,108
  103 IF (ABS(D) - ABS(A(J))) 105,105,108
  105 LD=L
      KD=K
      D=A(J)
  108 J=J+NN
```



```
  110 CONTINUE
  112 CONTINUE
C     INTERCHANGE ROWS
      TEMP=-M(LD)
      M(LD)=M(KD)
      M(KD)=TEMP
      L=LD
      K=KD
      DO 114 J=1,NN
      C(J)=A(L)
      A(L)=A(K)
      A(K)=C(J)
      L=L+NN
  114 K=K+NN
C     DIVIDE COLUMN BY LARGEST ELEMENT
      NR=(KD-1)*NN+1
      NH=NR+NN-1
      DO 115 K=NR,NH
  115 A(K)=A(K)/D
C     REDUCE REMAINING ROWS AND COLUMNS
      L=1
      DO 135 J=1,NN
      IF (J-KD) 130,125,130
  125 L=L+NN
      GO TO 135
  130 DO 134 K=NR,NH
      A(L)=A(L)-C(J)*A(K)
  134 L=L+1
  135 CONTINUE
C     REDUCE ROW
      C(KD)=-1.0
      J=KD
      DO 140 K=1,NN
      A(J)=-C(K)/D
  140 J=J+NN
C     INTERCHANGE COLUMNS
      DO 200 I=1,NN
      L=0
  150 L=L+1
      IF(M(L)-I) 150,160,150
  160 K=(L-1)*NN+1
      J=(I-1)*NN+1
      M(L)=M(I)
      M(I)=I
      DO 200 L=1,NN
      TEMP=A(K)
      A(K)=A(J)
      A(J)=TEMP
      J=J+1
  200 K=K+1
```

```
      RETURN
      END

      SUBROUTINE MATCON(T,EI,YIELD,AGEFAC,INCRMT,EPSEFF,CON,ETAN)
C
      IMPLICIT REAL (A-H,O-Z)
C
      E0 = 2.076E6*AGEFAC
      EE = 3.350E6*AGEFAC
      EPO = 2240.E-6
      SS0 = 4650 *AGEFAC
      FACTR= -0.02
      EPY0= SS0*0.5/EE
      EPFRAC=465.0/EE
      EPMIN=1.E-9
      IF(INCRMT.GT.1) GO TO 100
      EI=EE
      YIELD= SS0/2
      RETURN
  100 EPEFF=MAX(EPSEFF,EPSMIN)
      EPNORM = EPEFF/EPO
      SPLUS = EE/ ( 1.+(EE/E0-2.)*EPNORM+EPNORM**2 )
      EPS= (SPLUS)**2
      SPLUS=SPLUS*EPEFF
      EPN= (SPLUS/EPO)**2
      ETAN= (EPS-EPN)/EE
      YIELD= SPLUS
      IF (EPEFF.LE.EPY0) YIELD=SS0*0.5
      CON = ETAN*EE/(EE-ETAN)
      IF (ABS(CON).LT.0.001*EE) CON=SIGN(CON,CON)*0.001*EE
      IF (CON.LT.0.001*EE) CON=0.001*EE
      EI=EE
      IF (EPEFF.LE.EPO) RETURN
      EI= EE*(SPLUS/SS0)**2
      RETURN
      END

      SUBROUTINE SYMINV(H)
C
      IMPLICIT REAL (A-H,O-Z)
C
      DIMENSION H(4,4)
C
      DET = H(1,1)*(H(2,2)*H(3,3)-H(2,3)*H(2,3))+ H(1,2)*(H(2,3)*
         H(1,3)-H(1,2)*H(3,3))+H(1,3)*(H(1,2)*H(2,3)-H(2,2)*H(1,3))
      H(2,1)= (H(1,2)*H(3,3)-H(2,3)*H(1,3))/DET
      H(3,1)=(H(1,2)*H(2,3)-H(2,2)*H(1,3))/DET
      H(3,2)=-(H(1,1)*H(2,3)-H(1,2)*H(1,3))/DET
      H11=(H(2,2)*H(3,3)-H(2,3)*H(2,3))/DET
      H22=(H(1,1)*H(3,3)-H(1,3)*H(1,3))/DET
```



```
      H33=(H(1,1)*H(2,2)-H(1,2)*H(1,2))/DET
      H(1,1)=H11
      H(2,2)=H22
      H(3,3)=H33
      H(4,4)=1.0/H(4,4)
      H(1,2)=H(2,1)
      H(1,3)=H(3,1)
      H(2,3)=H(3,2)
      RETURN
      END

      SUBROUTINE TRANSF (A,Q,B)
      IMPLICIT REAL (A-H,O-Z)
C
C     THIS ROUTINE CREATES Q AND B (BOTH 4X4) OUT OF THE TRANSFORMATON
C     MATRIX A. Q AND B MAY THEN BE USED TO TRANSFORM A 4X4 TENSOR.
C
      DIMENSION A(3,3),Q(4,4),B(4,4),VCTR(3)
      DATA VCTR/ 1.0, 0.0, 1.0 /
C
      C= A(1,1)
      S= A(3,1)
      DO 200 I=1,3
      DO 100 K=1,3
      B(I,K)= A(I,K)*A(I,K)
  100 Q(I,K)= B(I,K)
      B(4,I)= -VCTR(I)*C*S
      B(I,4)= -2.0*B(4,I)
      Q(4,I)= -B(I,4)
      Q(I,4)= -B(4,I)
  200 CONTINUE
      B(4,4)= C*C-S*S
      Q(4,4)= B(4,4)
      RETURN
      END

      SUBROUTINE REBAR(AR,NCHECK,ITER,DJ,ALFAS,DELT,ESTEEL,YSTEEL,
     1                 HS,TS,SG,V,EP)
      IMPLICIT REAL (A-H,O-Z)
      DIMENSION AR(20,2),A(3,3),B(4,4),Q(4,4),PH(4,4),HS(4,4)
     1          ,EP(4),TS(4),TF(4),SG(8),V(8)
C
C*****
C     THIS SUBROUTINE APPLIED FOR 2D CASE
C*****
C
      DO 10 I=1,4
      TS(I)= 0.0
      DO 10 J=1,6
   10 HS(I,J)= 0.0
```

```
      NP1= 0
      NP2= 0
      IF(ABS(AR(5,2)).GT.0.0) NP1=1
      IF(ABS(AR(6,2)).GT.0.0) NP2=2
      NPLAST= AR(15,2)
      NPL1= NPLAST/100
      NPL2= (NPLAST-NPL1*100)/10
      NPL3= NPLAST-NPL1*100-NPL2*10
      IF(NP1.EQ.0) GO TO 100
      CALL ROTAT(AR(7,2),A)
      CALL TRANSF(A,Q,B)
      CALL HHH(AR,ALFAS,DELT,NP1,AR(5,1),AR(11,1),NPL2,ESTEEL,
     1         YSTEEL,NCHECK,EP,Q,B,PH,SG,V,TF)
      IF(NCHECK.EQ.1) GO TO 25
      AREA= AR(5,2)/DJ
      DO 20 I=1,4
      TS(I)= TF(I)*AREA
      DO 20 J=1,4
   20 HS(I,J)= PH(I,J)*AREA
      GO TO 100
   25 AR(11,1)= SG(7)
      IF(ITER.EQ.2) AR(5,1)=AR(11,1)
  100 CONTINUE
      IF(NP2.EQ.0) GO TO 200
      IF(AR(6,2).LT.0.0) GO TO 105
      CALL ROTAT(AR(8,2),A)
      CALL TRANSF(A,Q,B)
  105 CONTINUE
      CALL HHH(AR,ALFAS,DELT,NP2,AR(6,1),AR(12,1),NPL3,ESTEEL,
     1         YSTEEL,NCHECK,EP,Q,B,PH,SG,V,TF)
      IF(NCHECK.EQ.1) GO TO 125
      AREA= ABS(AR(6,2))/DJ
      DO 120 I=1,4
      TS(I)= TS(I)+TF(I)*AREA
      DO 120 J=1,4
  120 HS(I,J)= HS(I,J)+PH(I,J)*AREA
      GO TO 200
  125 AR(12,1)= SG(8)
      IF(ITER.EQ.2) AR(6,1)=AR(12,1)
  200 CONTINUE
      AR(15,2)= NPL1*100+NPL2*10+NPL3
      RETURN
      END

      SUBROUTINE ROTAT(TH,A)
      IMPLICIT REAL (A-H,O-Z)
      DIMENSION A(3,3)
C
      C=1.0
      S=0.0
```



```
      IF(ABS(TH).LT.1.E-6) GO TO 10
      C= 0.0
      S= 1.0
      IF(ABS(TH).GT.89.999) GO TO 10
      AA= TH/57.29578
      C= COS(AA)
      S= SIN(AA)
   10 CONTINUE
      DO 20 I=1,3
      DO 20 J=1,3
   20 A(I,J)= 0.0
      A(1,1)= C
      A(1,3)= -S
      A(3,1)= S
      A(3,3)= C
      A(2,2)= 1.0
      RETURN
      END

      SUBROUTINE HHH(AR,ALFAS,DELT,N,SIG1,SIG,NP,ES,
     1               Y,NCHECK,EP,Q,B,PH,SG,V,TF)
C****
C     SUBROUTINE TO CALCULATE STEEL ELEMENT STRESSES
C****
      IMPLICIT REAL (A-H,O-Z)
      DIMENSION EP(4),Q(4,4),B(4,4),PH(4,4),SG(8),V(8),TF(4),
     1          EPS(3),SIJ(3),H(4),AR(20,2)
C
      DO 20 I=1,4
      TF(I)= 0.0
      DO 10 J=1,4
   10 PH(I,J)= 0.0
   20 PH(I,I)= ES
      SG(6+N)= 0.0
      PH11= ES
      EK2= Y*Y/3.0
      IF(NP.EQ.0) GO TO 780
      CON=0.001
      SIJ(1)= 2.0*SIG/3.0
      SIJ(2)= -SIG/3.0
      SIJ(3)= -SIG/3.0
      PLA=0.5*(SIJ(1)**2+SIJ(2)**2+SIJ(3)**2)/EK2
      CON=CON/(1.0-CON)*2.0/3.0
      CI=ES*CON
      EPN=1.0-SQRT(1.0/PLA)
      DO 460 I=1,3
  460 SIJ(I)=SIJ(I)*(1.0-EPN)
      DO 750 K=1,3
      EPS(K)=0.0
      DO 750 L=1,3
```

```
750 EPS(K)=EPS(K)+PH(K,L)*SIJ(L)
    RS=0.0
    DO 760 K=1,3
760 RS=RS+SIJ(K)*(CI*SIJ(K)+EPS(K))
    RT=1.0/RS
    DO 770 I=1,3
    DO 770 J=1,3
770 PH(I,J)=PH(I,J)-EPS(I)*EPS(J)*RT
    PH(1,1)=PH(1,1)-PH(1,3)*PH(3,1)/PH(3,3)
    PH(1,2)=PH(1,2)-PH(1,3)*PH(3,2)/PH(3,3)
    PH(2,2)=PH(2,2)-PH(2,3)*PH(3,2)/PH(3,3)
    PH(2,1)=PH(1,2)
    PH11=PH(1,1)-PH(1,2)*PH(1,2)/PH(2,2)
780 CONTINUE
    DO 30 I=1,4
    DO 30 J=1,4
 30 PH(I,J)= 0.0
    IF(N.EQ.1.OR.AR(6,2).GE.0.0) GO TO 90
    PH(2,2)= PH11
    IF(NCHECK.EQ.1) GO TO 35
    BF= SIG1-PH11*ALFAS*DELT
    TF(2)= BF
    RETURN
 35 CONTINUE
    V(6+N)= V(2)
    SG(6+N)= SIG1+PH11*EP(2)
    GO TO 50
 90 CONTINUE
    PH(1,1)= PH11
    IF(NCHECK.EQ.1) GO TO 120
    BF= SIG1-PH11*ALFAS*DELT
    DO 100 I=1,4
100 H(I)= PH11*Q(1,I)
    DO 110 I=1,4
    TF(I)= Q(1,I)*BF
    DO 110 J=1,4
110 PH(I,J)= Q(1,I)*H(J)
    RETURN
120 CONTINUE
    DEPS= 0.0
    VV= 0.0
    DO 40 I=1,4
    VV= VV+Q(1,I)*V(I)
 40 DEPS= DEPS+Q(1,I)*EP(I)
    V(6+N)= VV
    SG(6+N)= SIG1+PH11*DEPS
 50 CONTINUE
    SIJ(1)= 2.0*SG(6+N)/3.0
    SIJ(2)= -SG(6+N)/3.0
    SIJ(3)= -SG(6+N)/3.0
```



```
      CRIT=SQRT(1.5*(SIJ(1)**2+SIJ(2)**2+SIJ(3)**2))
      NFACT= NP
      DS1= SG(6+N)-SIG1
      SIGNT=DS1*SIJ(1)
      NP= 0.0
      PLA=CRIT*CRIT/(3.0*EK2)
      IF(PLA*1.02.GT.1.0) NP=1
      IF(SIGNT.GE.0.0.AND.NFACT.EQ.1) NP=1
      IF(SIGNT.LT.0.0.AND.NFACT.EQ.1) NP=0
      RETURN
      END

      SUBROUTINE MEMORY(GE,DTIM,AR,INCRMT,ITER,EIO,IN,AGE,CREEP)
C
      IMPLICIT REAL (A-H,O-Z)
C
      DIMENSION DTIM(2),GE(4,3),TSE(6,2),AR(20,3)
      DIMENSION CE(3),SE(6),FEE(3,2),FI(3,2),PJ(2)
C
      TIMFAC=1.0
      TSE(1,1)=AR(IN,3)
      TSE(1,2)=AR(4,3)
      IF(IN.NE.1) TSE(1,2)=0.0
      SE(1)=AR(4+IN,3)
      I=2
      J=2*I-2
      J1=J+1
      T1=AR(13,1)
      T3=0.5*(AR(13,1)+AR(13,2))
      T2 = (T1 + T3) / 2.0
      DTM=DTIM(INCRMT-1)*TIMFAC+AGE
      IF(INCRMT.EQ.1) DTM=AGE
      DTP=DTIM(INCRMT)*TIMFAC+AGE
      DELTM=DTP-DTM
      DT=(DTP-DTM)/12.0
      XK=DTM
      DO 190 JJ=1,2
      DO 50 M= 1, 3
      GO TO (10, 20, 30), M
   10 T=T1
      GO TO 40
   20 T=T2
      XK=XK+DELTM*0.25
      GO TO 40
   30 T=T3
      XK=XK+DELTM*0.25
   40 CONTINUE
      XKN=1.0/XK
      CALL COEF(XKN,T,AFACT,TEMFAC)
      CON=CREEP/AFACT
```

```
      CALL SHIFT1(T,R,A,D,CON,XK,IN)
      RO=R
      FI(M,1)=R/RO
      FI(M,2) = D
      FEE(M,JJ)=A*R
   50 CONTINUE
      TIM=MIN(DELTM,1.0/R)
      DT1=TIM/12.0
      TS2 =DT*(FI(1,2) + 4.0 * FI(2,2) + FI(3,2))
      TS1 =DT1*(FI(1,1)+4.0*FI(2,1)+FI(3,1))
      IF(JJ.EQ.1) TSE(J,1)=TSE(J-1,1)+TS1
      IF(JJ.EQ.2) TSE(J1,1)=TSE(J,1)+TS1
      IF(IN.NE.1) GO TO 51
      IF(JJ.EQ.1) TSE(J,2)=TSE(J-1,2)+TS2
      IF(JJ.EQ.2) TSE(J1,2)=TSE(J,2)+TS2
   51 CONTINUE
      T1=T3
      T3=AR(13,2)
      T2=0.5*(T1+T3)
  190 CONTINUE
      TSE1=TSE(3,1)-TSE(1,1)
      TSE3=TSE(3,1)-TSE(2,1)
      TSE2=(TSE1+TSE3)/2.0
      TM=DT1
      DO 150 JJ=1,2
      DO 100 M=1,3
      GO TO (60,70,80),M
   60 TS=TSE1
      GO TO 90
   70 TS=TSE2
      GO TO 90
   80 TS=TSE3
   90 CONTINUE
      CONST=-RO*TS
      CE(M) = FEE(M,JJ) * EXP(CONST)
  100 CONTINUE
      SUM=TM*(CE(1)+4.0*CE(2)+CE(3))
      PJ(JJ)=SUM
      TSE1=TSE3
      TSE3=TSE(3,1)-TSE(3,1)
      TSE2=0.5*(TSE1+TSE3)
  150 CONTINUE
      CONST=RO*(TSE(3,1)-TSE(1,1))
      ERX1=EXP(-CONST)
      ERX2=1.0/ERX1
      SE(2)=SE(1)*ERX1+PJ(1)
      SE(3)=SE(2)+PJ(2)
      EJ1=SE(3)+TSE(3,2)
      EJ2=SE(1)+TSE(1,2)
      GE(1,IN)=3.0*(EJ1-EJ2)
```

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```
      GE(2,IN)=ERX1-1.0
      SE(1)=SE(1)*ERX1
      SUM1=(SE(1)+4.0*SE(2)+SE(3))/6.0
      GE(3,IN)=3.0*SUM1*ERX2
      GE(4,IN)=ERX1
      IF(ITER.NE.2) RETURN
      AR(4+IN,3)=SE(3)
      AR(IN,3)=TSE(3,1)
      IF(IN.EQ.1)AR(4,3)=TSE(3,2)
      RETURN
      END

      SUBROUTINE  SHIFT1(TEMP,R,A,D,CON,XK,IN)
C
      IMPLICIT REAL (A-H,O-Z)
C
      INDEX=1
      T=TEMP
      IF(TEMP.LT.60.0) TEMP=60.0
      IF(INDEX.GT.0) GO TO 50
      AP0 = 0.10425
      AP1 = -0.02775
      AP2 = 0.0062667
      CON=1.0
      FF =(AP0+AP1*LOG10(XK))*0.625
      F = FF*EXP(AP2*T)
      F=F*CON*1.E-6
      R = 0.07
      DT=T-200.0
      IF(DT.LT.0.0) DT=0.0
      D1=0.00075+DT*1.0E-5
      D2=0.0015
      D=MIN(D1,D2) * F
      GO TO (5,10,20) ,IN
    5 A=0.5*F
      R=0.6
      D=0.0
      GO TO 30
   10 A=1.5*F
      R=0.07
      D=0.0
      GO TO 30
   20 A=(0.056*DT-DT*DT*1.511E-4)*F
      R=0.0046
   30 CONTINUE
      RETURN
   50 CONTINUE
C---------------------
      IF(INDEX.GT.1) GO TO 500
C      D= CON*0.0002
```

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```
      TK=(T-32.0)*5.0/9.0+273.0
      RTK=(70.0-32.0)*5.0/9.0+273.0
      EQRT=EXP(-4345.0/(1.98*TK))/EXP(-4345.0/(1.98*RTK))
      CONN=EQRT*1.E-6
      D=3.779E-4*CON*CONN
      GO TO (100,200,300), IN
  100 CONTINUE
C      A= CON*0.04014
      A=CONN*CON*0.0579386
      R= 6.908
      RETURN
  200 CONTINUE
C      A= CON*1.233
C      R= 0.2303
      A=CONN*CON*0.132428
      R=0.2
      D= 0.0
      RETURN
  300 CONTINUE
C      A= CON*1.6
C      R= 0.007
C      D=0.0
      RETURN
  500 CONTINUE
C2501 ----------------
C**** NEW MATERIAL DATA FOR HANFORD CONCRETE - OCTOBER, 1979
      TK=(T-32.0)*5.0/9.0 + 273.0
      EQRT=EXP(-4345.0/(1.98*TK))
      A=1.11E-4*EQRT
      D=3.8265E-7*EQRT
      R=0.25
      ET = A*SIG
      EM = D*SIG
      RETURN
      END

      SUBROUTINE COEF(XKN,TEMPT,AGEFAC,TEMFAC)
C****
C     CALCULATION OF AGE AND TEMPERATURE DEPENDENT COEFFICIENTS OF THE
C     CREEP FORMULA
C****
      IMPLICIT REAL (A-H,O-Z)
C
      COMMON/CAT/ A0,A1,A2,A3,A4,A5,AP0,AP1,AP2,AP3,AP4,AP5
C
C2501 ----------------
      NWES=1
      TEMP=TEMPT
      IF(TEMP.LT.60.0) TEMP=60.0
      T=(TEMP-32.)*5.0/9.0
```



```
      XK=1.0/28.0
      FF1=0.0
      DO 10 I=1,2
      F1=FF1
       A0=.201881+T*(-1.98117E-4+T*(5.31521E-5-T*4.23376E-7))
       A1=-5.41464+T*(.40337+T*(-5.36256E-3+T*2.33622E-5))
       A2=69.245+T*(-3.38663+T*(-6.42465E-3+2.34411E-4*T))
       A3=-583.108+T*(19.8205+T*(.683703-.67766E-2*T))
       A4=3356.7+T*(-83.0216+T*(-5.91922+5.39942E-2*T))
       A5=-7664.4+T*(.132439E3+T*(17.0764-.150322*T))
      FF1= A0+XX*(A1+XX*(A2+XX*(A3+XX*(A4+XX*A5))))
      T= (70.0-32.0)*5.0/9.0
   10 CONTINUE
      F1=F1*1.E-6
      FF1=FF1*1.E-6
      ET28=1.0/F1
      ERT28=1.0/FF1
      TSHAPE=ET28/ERT28
      TM=1.0/XKN-1.0
      ETATAU=1.E6*(0.606117*(1.0-EXP(-0.2*TM))+0.978921*
     .(1.0-EXP(-0.789875*TM))+8.06452E-3*TM+4.1)*TSHAPE
      TM=3.0-1.0
      ETA3=1.E6*(0.606117*(1.0-EXP(-0.2*TM))+0.978921*
     .(1.0-EXP(-0.789875*TM))+8.06452E-3*TM+4.1)*TSHAPE
      AGEFAC=ETATAU/ETA3
      TEMFAC=TSHAPE
      IF(NWES.EQ.1) RETURN
      ALFA=0.926+4.444*XKN
      ESTAR=ET28/ALFA
      AGEFAC=ESTAR/ERT28
      F1=F1*ALFA
C**----------------
      T=(TEMP-32.)*5.0/9.0
      BETA=0.56+12.245*XKN
      XK= 1.0/28.0
      TIME=1.0/XK
   15 CONTINUE
       AP0=-.076945+T*(7.70542E-3+T*(-8.38733E-5+T*3.82484E-7))
       AP1= 14.0236+T*(-.713801+T*( 1.12008E-2-5.71309E-5*T))
       AP2=-422.681+T*( 21.8111+T*(-.347742+1.78503E-3*T))
       AP3= 6016.54+T*(-304.577+T*( 4.84830-2.48844E-2*T))
       AP4=-39844.4+T*( 1986.93+T*(-31.4952+.161156*T))
       AP5= 98581.7+T*(-4865.40+T*( 76.8028-.391529*T))
      F2= 1.E-6*(AP0+XK*(AP1+XK*(AP2+XK*(AP3+XK*(AP4+XK*AP5)))))
      IF(F2.GT.0.0) GO TO 20
      TIME=TIME+0.5
      XK=1.0/TIME
      GO TO 15
   20 CONTINUE
      F2=F2*BETA
      RETURN
      END
```

END

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DTIC