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Analytical Verification of the ACI Approach of Estimating Tensile Strain Capacity of Mass Concrete

Cristina Diane Seay
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Cristina Diane Seay entitled "Analytical Verification of the ACI Approach of Estimating Tensile Strain Capacity of Mass Concrete." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Civil Engineering.

Edwin Burdette, Major Professor

We have read this thesis and recommend its acceptance:

Hal Deatherage, David Goodpasture

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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ANALYTICAL VERIFICATION OF THE ACI APPROACH OF ESTIMATING TENSILE STRAIN CAPACITY OF MASS CONCRETE

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Cristina Diane Seay
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ABSTRACT

Mass concrete fill is being used for the support of a facility foundation in Oak Ridge, Tennessee. The facility design requires the support foundation to be relatively crack-free in order to attain the shear wave velocity of 6000 fps, which is necessary for acceptable structural behavior during a design basis earthquake. Specifications were developed for use during construction of the support foundation to ensure that the mix design, sequential placement, and curing are performed to standards that would best ensure a relatively crack-free product. The mix design and subsequent placement strategy were developed by using an American Concrete Institute (ACI) approach. A test pad was used to aid in a better understanding of the mass concrete fill support foundation behavior.

To assess the correctness of the ACI approach, the objective of this research was to analytically verify this process by the combination of short and long-term temperature data coupled with a simple analytical finite element (FE) model of sequential vertical placements using the structural analysis program GTSTRUDL.

The result was a final shear wave velocity of 7500 fps. Therefore, the project support foundation will meet its facility requirements by means of the current design specifications. In conclusion, the appropriateness of the ACI approach was verified by the combined use of field data and finite element analyses. Analytical modeling allowed for the input of the real time lab and field data to assess the behavior of the mass concrete, and provide the unique ability to model the sequential construction to capture the time dependent interaction between successful concrete lifts.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES CONTINUED

CHAPTER 1: MASS CONCRETE

1.0 INTRODUCTION

From decades of experience and theoretical considerations, it is well known that early temperatures and temperature induced stresses may have a great influence on the quality of mass concrete structures (Breugel 1998). Mass concrete is any volume of concrete with dimensions large enough to require that measures be taken to cope with the generation of heat from hydration of the cement (ACI 207.1R-96). Since the cement-water reaction is exothermic by nature, the temperature rise within a large concrete mass, where the heat is not dissipated, can be very high. Significant tensile stresses may develop from the volume change associated with the increase and decrease of temperature within the mass (ACI 207.1R-96). These stresses introduce a great concern in the area of mass concrete placements because they generate potential crack inducing temperatures during the curing process (ACI 207.1R-96). Cracking may cause loss of structural integrity, excessive seepage, shorten the service life of the structure, or may be aesthetically objectionable (ACI 207.1R-96).

Mass concrete fill is being used for the support of a facility foundation in Oak Ridge, Tennessee. The facility design requires the support foundation to be relatively crack-free in order to attain the shear wave velocity characteristics necessary for acceptable structural behavior during a design basis earthquake. A 50 blow count subgrade as defined by the Standard Penetration Test (SPT) is specified in order to meet the above criteria. Specifications were developed for use during construction of the support foundation to ensure that the mix design, sequential placement, and curing are performed

to standards that would best ensure a relatively crack-free product. The mix design and subsequent placement strategy were developed by using an American Concrete Institute (ACI) approach, which addresses temperature profiles with time. The intent is to allow the heat of hydration to dissipate to an acceptable level prior to placement of an adjacent layer, specifically on top of a prior layer. This would minimize the chance of tensile stresses being developed that may exceed the cracking tensile capacity of the unreinforced mass concrete and induce cracks.

1.1 BACKGROUND

Temperature Control

There are four elements, according to ACI 207.1R-96, which contribute to the temperature control within a mass concrete placement. The first one is cementitious material content. The type and amount of cement can lessen the heat generating potential of the concrete. The second element is precooling. The cooling of concrete ingredients allows a lower temperature of placement. The third element is postcooling of the concrete after placement. Embedded cooling coils may be placed inside the mass concrete fill in order to limit the temperature rise of the structure while it cures. The last element which can be used to control the temperature is construction management. Efforts can be made during the construction phase to protect the structure from excessive temperature differentials by knowledgeable concrete handling, scheduling, and procedures. All of these measures were taken into consideration while writing the construction specifications for the project.

Thermal strains and stresses are developed from the dissipation of the heat of hydration and from cycles of ambient temperature change (ACI 207.1R-96). Therefore, the height of concrete placement lifts and the time intervals between lifts are essential to providing a low heat of hydration in mass concrete. The shallower the lift the higher the percentage of total heat that will escape before the next lift is placed. However, if the lift thickness is increased above ten feet, the internal temperature is not significantly influenced by the time interval between lifts because heat losses from the upper surface become a decreasing percentage of the total heat generated within the full depth of the lift. ACI estimates that a five foot thick lift would require a week to become thermally stable. Therefore, the next lift should not be placed until a week after the previous lift. However, a long exposure of lift surface to changes in ambient temperature may initiate cracking, so there should not be a huge delay between placements.

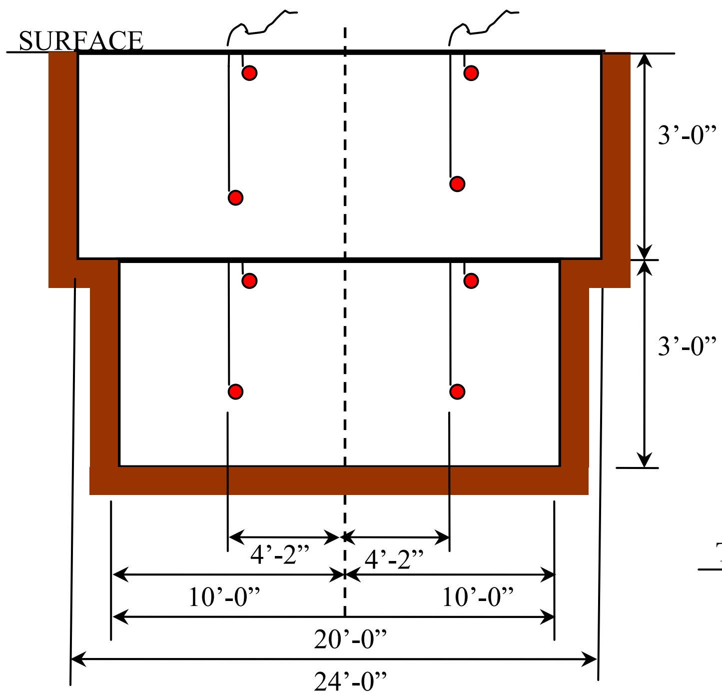
Test Pad

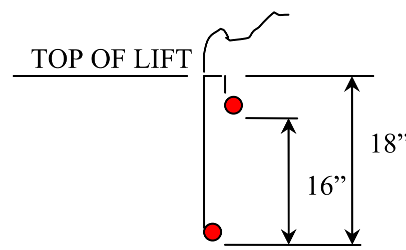
A total of 50,000 cubic yards of mass concrete are to be poured for the project support foundation. Since the volume of concrete to be poured is so large, a determination was made to construct a test pad. The purpose of the test pad is to aid in a better understanding of the mass concrete fill support foundation behavior. The data captured by the test pad will contribute to the evaluation of the thermal properties of the concrete mix as a function of time. The project specifications require a shear wave velocity of 6000 fps and a compressive strength of 2500 psi. The data gathered from the test pad will ensure that the specifications are met during the placement of the mass

concrete fill. They will also determine if any changes or alterations need to be made to the mix design and construction procedures specified.

The test pad consists of two concrete lifts, and each lift is three feet thick. The first lift is approximately 20’-0” x 20’-0”. The second lift is 24’-0” x 24’-0” (see Figure 1). The lifts are placed at one foot increments to allow for adequate vibration and consolidation to take place. Vibrators are used during the concrete pour to avoid honey combing and voids.

Thermocouples were installed in the test pad to monitor the temperature as a function of time during the curing process. The locations of thermocouples are shown in Figure 2 and Figure 3, which are discussed further in chapter three. The temperature is read from the thermocouples at intervals of one hour during daylight periods until peak temperatures are reached and then twice daily thereafter. A total of 34 standard concrete cylinders (6” diameter x 12” long) and two 24” diameter x 48” long cylinders were made for every three foot lift. Thirty of the standard concrete cylinders were standard cured in accordance with section 10.1 of ASTM C31, “Standard Practice for Making and Curing Concrete Test Specimens in the Field”. The remaining four standard concrete cylinders and the two 24” diameter x 48” long cylinders from each lift were field cured in accordance with section 10.2 of ASTM C31. Concrete compressive strength tests, Young’s Modulus tests, and Poisson’s Ratio tests were performed on the cylinders to determine the material properties of the concrete during different phases after placement. Various seismic tests were performed on the test pad cylinders to determine the shear wave velocity.





SST THERMOCOUPLE PAIR

FIGURE 1: TEST PAD SECTION

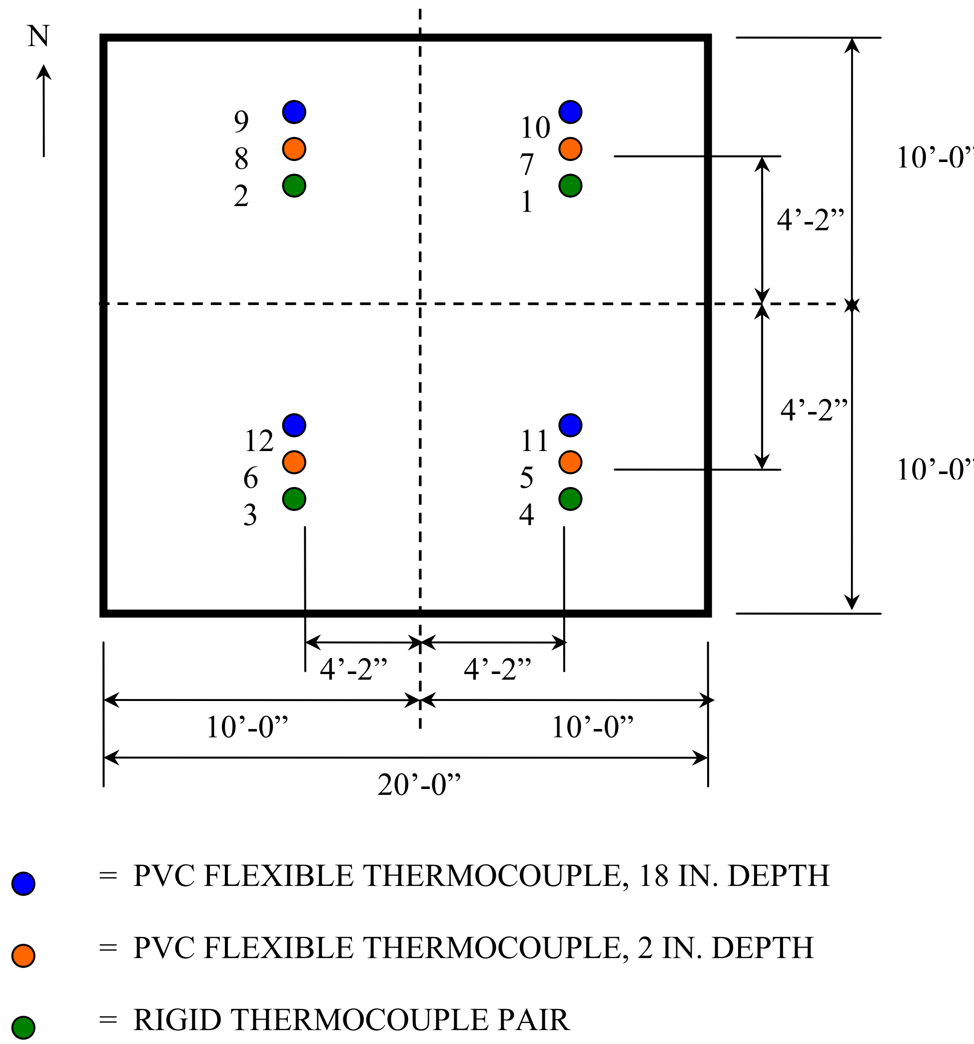
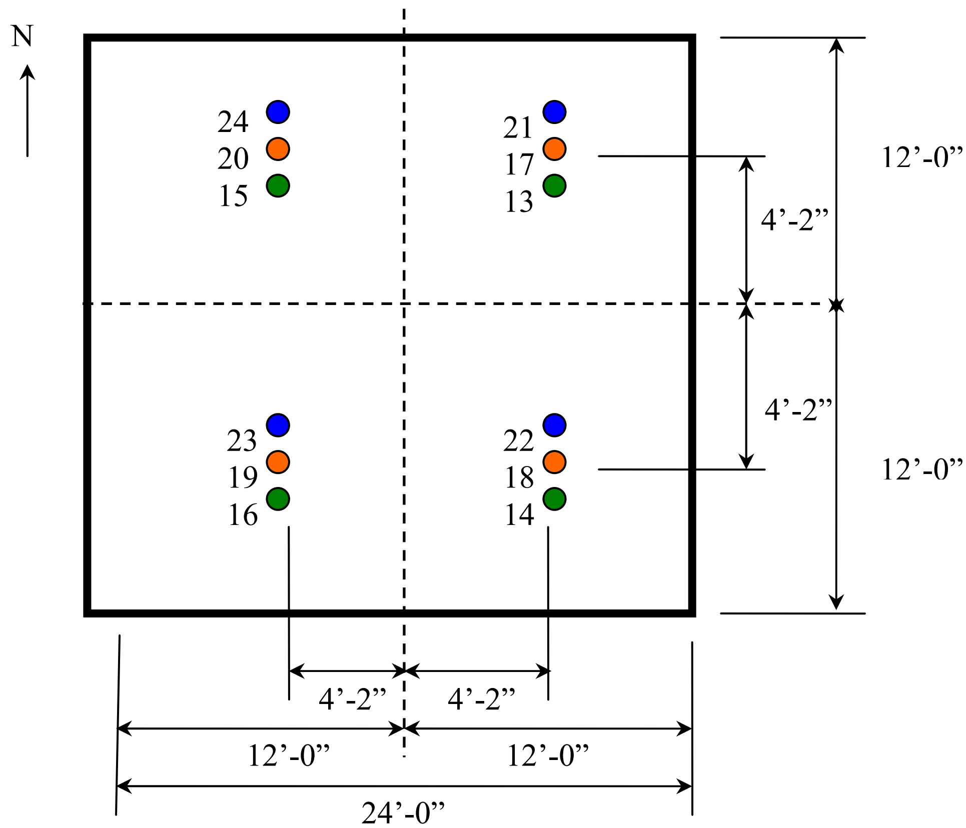


FIGURE 2: TEST PAD LIFT 1



= PVC FLEXIBLE THERMOCOUPLE, 18 IN. DEPTH

= PVC FLEXIBLE THERMOCOUPLE, 2 IN. DEPTH

= RIGID THERMOCOUPLE PAIR

FIGURE 3: TEST PAD LIFT 2

Based on the ACI approach, the project specifications state that the maximum temperature gradient between two thermocouples shall not exceed twenty degrees Fahrenheit. The maximum temperature gradient between the interior temperature and surface temperature of mass concrete shall be thirty-five degrees Fahrenheit in a seven day curing period. Maintaining a maximum gradient of thirty-five degrees Fahrenheit is crucial for the first 72 hours (Mass 2004). After 72 hours, the maximum differential can be increased without cracking due to increased strain capacity of the concrete with age (Mass 2004). Keeping the temperature gradient below these specifications limits the probability of tensile strains which result in thermal induced cracking.

1.2 OBJECTIVE

The specification for the project is based on an ACI approach. Equations were used to determine the maximum temperature differential in which cracking will occur, and the project specification was written to keep temperatures below these values. The variables used to evaluate the maximum temperature differential include restraint factor, coefficient of expansion, aggregate factor, the static modulus of elasticity, and the compressive strength of concrete.

To access the accuracy of the ACI approach used to determine the project specifications, a finite element (FE) model was generated. A finite element model is a numerical analysis technique for obtaining solutions to a wide variety of engineering problems (Huebner 1975). There is no simple solution to a finite element model (Huebner 1975). Governing equations and boundary conditions are key factors to a successful model (Huebner 1975). The model envisions the solution region as built up of

many small, interconnected elements (Huebner 1975). The software used to develop the test pad finite element model is GTSTRUDL.

Thermocouple data from the test pad gathered in the field were input into the finite element model to determine the temperature differential throughout the entire concrete mass. The change in temperature between the distributed thermocouple temperature and placement temperature was calculated. A linear distribution from the thermocouple locations to the boundary of the model was assumed. The static analysis consisted of a series of FE models, each one adding additional layers of mass concrete elements to represent the construction sequence. Temperature readings were taken for the initial lift of the test pad after the placement of the second lift. Therefore, as the temperature values were used as input data to the modeling, they were representative of the actual temperatures of the layers as the model progressed. GTSTRUDL generates the internally induced stresses due to the temperature changes input into the model. Finite element model temperature induced tensile stresses are compared to those obtained using the ACI approach, which was used to create the project specification in order to validate the ACI method for mass concrete placement with respect to crack minimization due to the dissipation of the heat of hydration.

To assess the correctness of the ACI approach, the objective of this research was to analytically verify this process by the combination of short and long-term temperature data coupled with a simple analytical finite element (FE) model of sequential vertical placements using the structural analysis program GTSTRUDL. The results of this research are reported in this thesis. The comparative results from the pre-construction

ACI approach design and the actual field results of the test pad will determine the path forward of the project. If the field results from the test pad were inconsistent in relation to the ACI approach design, then an alteration of the concrete mix design and construction process specified is needed before the placement of 50,000 cubic yards of concrete in the project mass fill.

CHAPTER 2: LITERATURE REVIEW

2.0 THURSTON, PRIESTLEY, AND COOKE

Thermal analysis of mass concrete sections subjected to heat of hydration release and surface heat transfer is discussed in an ACI journal technical paper titled "Thermal Analysis of Thick Concrete Sections" (Thurston, Priestley, and Cooke 1980). The analysis technique is developed and forms the basis of a computer program, which considers transient heat-flow analysis, thermal stress analysis, and the effects of creep and shrinkage. A comparison between the predicted and measured temperatures and stresses are reported for an 11.8 foot deep foundation pad.

The technical paper concludes that the actual temperature rise is not significant by itself because the mechanical properties of concrete are independent of temperature within the time range of interest. However, deformations are induced by the temperature rise and cooling, and non-linear temperature gradients through a section can induce thermal stresses of a magnitude to cause cracking.

Heat flow is a three-dimensional phenomenon, though in many real cases it is accurate to model behavior by two-dimensional heat flow. Figure 4 illustrates the main variables involved on the analysis path from heat of hydration and ambient heat input to thermal stresses.

The technical paper describes the background to an analytical computer program called THERMAL. The program is designed to model the instructions represented in Figure 4. The program was primarily developed for the purpose of predicting temperatures and stresses induced in bridge structures by solar radiation and ambient

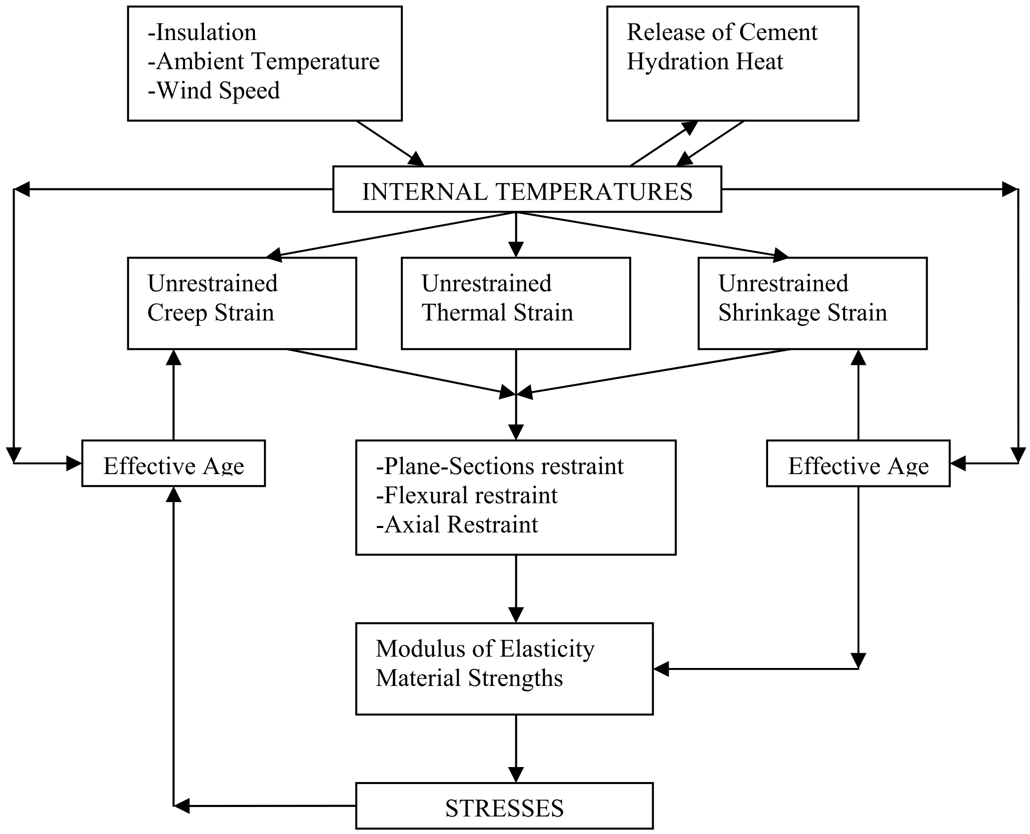


FIGURE 4: INFLUENCE OF THERMAL LOAD ON STRESSES IN CONCRETE STRUCTURES

Source: Thurston, S.J., Priestley, M.J.N., and Cooke, N. "Thermal Analysis of Thick Concrete Sections." ACI Journal 77-38 (1980)

temperature fluctuation. However, it includes consideration of heat-of-hydration effects, and creep and shrinkage, which makes the program suitable for a wide range of temperature problems.

2.1 ANALYTIC BACKGROUND TO “THERMAL” PROGRAM

The THERMAL program differentiates between the behavior of three different kinds of points, a general interior point, a point on an internal interface between two layers of different materials, and an external boundary point exposed to ambient temperatures. The body to be analyzed in a THERMAL model is assumed to consist of sequential layers of different materials. If the concrete body is supported on the ground or cast on existing concrete, those locations are input in the model as being protected from ambient. Each layer is divided into a number of equal increments with nodes located at boundaries and junctions as shown in Figure 5.

The heat of hydration loading used in THERMAL requires a knowledge of Q, the rate of heat generation per unit volume at all nodes, throughout the time domain. For a given node, Q will depend on the cement type and content per unit volume, and temperature/time history. Constant-temperature hydration curves may be used to determine Q, which are well supported by experimental data. Many forces and moment equations are used in the THERMAL program to develop a final thermal stress at a particular time.

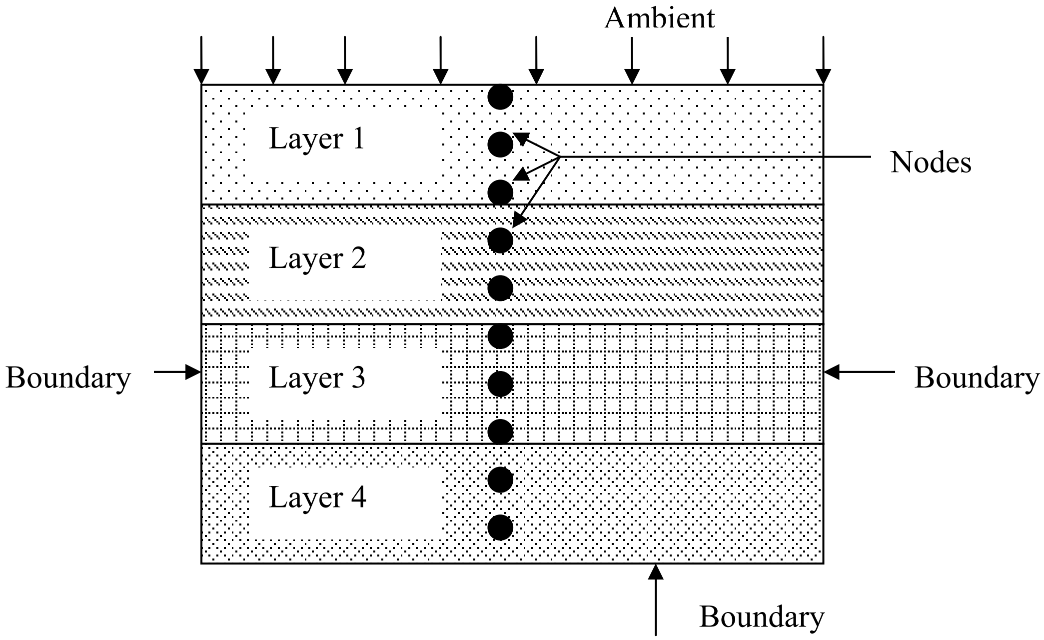


FIGURE 5: "THERMAL" MODEL EXAMPLE

Source: Thurston, S.J., Priestley, M.J.N., and Cooke, N. "Thermal Analysis of Thick Concrete Sections." ACI Journal 77-38 (1980)

The magnitude of concrete stress is heavily dependent on the modulus of elasticity, which varies rapidly with time over the first 28 days after placement. The modulus of elasticity is empirically calculated from the 28-day compressive strength and strength at age t for concrete cured at twenty degrees Celsius. THERMAL allows for creep strains to be incorporated into the analysis. Creep strains are calculated using the method of superposition. It is assumed that each incremental stress change on an element creates an independent strain/time relationship, which for a particular section depends on temperature, humidity, age, and concrete properties. Concrete shrinkage strains are also taken account within the program by ACI Committee 209 recommendations adopted for

shrinkage at twenty degrees Celsius. Similar equations for creep strains are used for shrinkage strains except different constants are used.

2.2 COMPARISON BETWEEN THEORY AND EXPERIMENT

The analytical approach explained in the previous section is developed into the computer program THERMAL for the instantaneous temperature and thermal stress analysis of sections (Thurston, Priestley, and Cook 1980). The program can analyze a two-dimensional complex section with many independent heat paths that are structurally interconnected. Comparisons between the THERMAL empirical predictions and experimental results are given for two 78.7 ft x 49.2 ft x 11.8 ft deep concrete foundation pads. The foundation pads were for the main columns of a 407 ft span prestressed concrete box-girder beam supporting the roof of a large aircraft hanger. It was desirable to place each pad in one continuous operation, so cooling coils to reduce the temperature rise of the concrete during hydration were considered. After using THERMAL the researchers found that insulation of the pad by backfilling the sides and covering the top surface with a one foot layer of gravel and sand as soon as possible resulted in much lower tensile stresses at a fraction of the cost of installing cooling coils. The concrete foundation pads were poured and nickel resistant thermometers were placed at numerous locations and depths to monitor the temperature. Ambient temperature, air speed, and solar radiation were also measured. As a result, excellent agreement between measured temperatures and THERMAL predictions were observed.

CHAPTER 3: THE ANALYSIS

3.0 GTSTRUDL VERSUS THERMAL

The technical paper described in the last chapter used empirical formulas based on a program called THERMAL to analyze a mass concrete section. It then compared field data to the empirical solutions of THERMAL. The above approach is similar to the analysis described in this thesis in many ways. However, the main difference between the two is the computer programs chosen for the evaluation. The program available for this project analysis was a structural program called GTSTRUDL. GTSTRUDL solves a concrete finite element model by taking temperature values and concrete properties input into the program and calculating the various thermal stresses and strains that will result from the data given. GTSTRUDL does not distribute a thermal load throughout a concrete finite element model using heat of hydration equations as the program THERMAL does. If a thermal load is to be evaluated in GTSTRUDL, the temperatures must be input at every joint within the finite element model.

The second difference between the two approaches is that in the technical paper, "Thermal Analysis of Thick Concrete Sections", the empirical data analyzed comes from the THERMAL program, and the field results are taken from nickel thermometers. In this paper, the empirical equations come mainly from the ACI approach, which includes ACI 207.1R-96, the Liu and McDonald article, "Prediction of Tensile Strain Capacity of Mass Concrete", and Construction Industry Research and Information Association (CIRIA), "Early Age Thermal Crack Control in Concrete". The experimental results in

this research are a combination of field data and the GTSTRUDL finite element program, which generates the temperature induced stresses.

3.1 FIELD DATA

Temperature Data

The experimental analysis, as stated above, is made-up of a combination of field data and a finite element model. Two different kinds of thermocouples were placed inside both lifts of the mass concrete test pad. The first kind was a SST rigid thermocouple pair. The thermocouple pairs were placed within each lift in the locations shown in Figure 2 and Figure 3, respectfully. Two temperature locations were read from the rigid thermocouple pairs. One reading was taken at a depth of two inches and the other at a depth of eighteen inches. The rigid pair was read for a total of seven days during the concrete curing process. Once the next sequential lift is placed, after the specified seven days, the rigid thermocouple pair may no longer be used. The second kind of thermocouple placed in each lift was long-term thermocouples called PVC flexible thermocouple singles. The long-term thermocouple singles were placed within each lift in the locations shown in Figure 2 and Figure 3, respectfully. One of these long-term single thermocouples was placed at a two inch depth and the other at an eighteen inch depth. The long-term thermocouples were read for a total of 28-days for each lift. The longer readings of temperature data allowed for an observation of the behavior of the first test pad lift, after the second lift is placed. One was able to witness the way each lift interacted with the other, and determine the effect of the second lift on the thermal behavior of the first. The results of the thermocouple readings can be seen in

Table 1 through Table 8. The highlighted rows indicate the time of day at which each finite element model represents and the time calculations were performed. If two adjacent rows are highlighted, the average temperature value between the two rows in the previous lift was used in the analysis to coincide with the exact time for which the next finite element model lift calculations were performed.

The temperature of the fresh concrete pour plays a very important role (Springenschmid and Breitenbucher 1998). High pouring temperatures in mass concrete allow for a faster internal temperature increase because of the acceleration of hydration (Springenschmid and Breitenbucher 1998). While the mass cools down with time, the thermal contraction is much higher in comparison to concrete with a lower pouring temperature (Springenschmid and Breitenbucher 1998). The project specification states that the maximum concrete pouring temperature shall be seventy degrees Fahrenheit. The temperature of the concrete mix was recorded from every concrete truck before the concrete was poured to verify that the specified temperature was not exceeded. The pouring temperatures of each truck for both lifts of the test pad were between 55 and 57 degrees Fahrenheit.

Ambient air temperatures also influence thermal stresses within mass concrete. It would be a complete error in judgment if only interior temperature difference and pouring temperatures were used as crack criterion for a mass concrete section. If a mass concrete section is exposed to low air temperature and a higher initial casting temperature, the concrete maturity near the surface will be retarded by heat losses to the cold environment while the maturity development in the core would be enhanced by the

TABLE 1: THERMOCOUPLE MONITORING REPORT FOR LIFT 1, THERMOCOUPLE 1								
CADDELL/BLAINE			THERMOCOUPLE MONITORING REPORT - LIFT 1					FORM 4
MT&E NO.:					CAL. DUE DATE: 9-28-05			
Thermocouple Number:		#1			LOCATION: Test Bed			
Monitor Day	DATE	TIME	AMBIENT TEMP.	UPPER TEMP.	LOWER TEMP.	TEMP. DIFFERENCE	STR NOTIFICATION REQUIRED*	READER INITIALS
1	2/5/2005	8:07 AM	31	67.5	77.9	10.4	NO	JB
1	2/5/2005	9:22 AM	38	65.7	78.2	12.5	NO	JB
1	2/5/2005	10:24 AM	42	66.2	79.3	13.1	NO	JB
1	2/5/2005	11:15 AM	46	68.5	79.4	10.9	NO	JB
1	2/5/2005	12:20 PM	48	71.5	80.1	8.6	NO	JB
1	2/5/2005	1:21 PM	53	73.1	80.9	7.8	NO	JB
1	2/5/2005	2:36 PM	57	74.7	80.8	6.1	NO	JB
1	2/5/2005	3:15 PM	64	78.4	81.8	3.4	NO	JB
1	2/5/2005	4:25 PM	61	75.5	81.1	5.6	NO	JB
1	2/5/2005	5:10 PM	62	74.3	80.3	6.0	NO	JB
2	2/6/2005	8:29 AM	33	79.3	84.1	4.8	NO	JB
2	2/6/2005	9:29 AM	39	75.3	83.5	8.2	NO	JB
2	2/6/2005	10:10 AM	43	74.0	83.1	9.1	NO	JB
2	2/6/2005	11:09 AM	50	74.1	82.6	8.5	NO	JB
2	2/6/2005	12:12 PM	55	75.7	83.0	7.3	NO	JB
2	2/6/2005	1:13 PM	59	76.1	82.3	6.2	NO	JB
2	2/6/2005	2:15 PM	62	78.0	82.4	4.4	NO	JB
2	2/6/2005	3:15 PM	65	78.4	81.8	3.4	NO	JB
2	2/6/2005	4:08 PM	64	77.0	82.0	5.0	NO	JB
2	2/6/2005	5:02 PM	63	76.1	81.7	5.6	NO	JB
3	2/7/2005	9:37 AM	50	73.8	81.7	7.9	NO	JB
3	2/7/2005	10:25 AM	52	72.1	80.7	8.6	NO	JB
3	2/7/2005	11:19 AM	55	72.2	80.7	8.5	NO	JB
3	2/7/2005	12:07 PM	56	72.6	80.7	8.1	NO	JB
3	2/7/2005	1:05 PM	58	72.9	78.7	5.8	NO	JB
3	2/7/2005	2:09 PM	60	73.8	79.0	5.2	NO	JB
3	2/7/2005	3:03 PM	62	73.9	79.3	5.4	NO	JB
3	2/7/2005	4:13 PM	63	73.0	78.5	5.5	NO	JB
3	2/7/2005	5:11 PM	64	73.1	79.9	6.8	NO	JB
4	2/8/2005	9:10 AM	50	71.9	78.6	6.7	NO	JB
4	2/8/2005	10:28 AM	51	70.1	76.7	6.6	NO	JB
4	2/8/2005	11:15 AM	51	69.3	76.5	7.2	NO	JB
4	2/8/2005	12:17 PM	52	69.7	77.3	7.6	NO	JB
4	2/8/2005	1:19 PM	54	69.3	77.0	7.7	NO	JB
4	2/8/2005	2:10 PM	54	69.9	77.8	7.9	NO	JB
4	2/8/2005	3:06 PM	55	69.9	76.9	7.0	NO	JB
4	2/8/2005	4:17 PM	55	70.7	76.3	5.6	NO	JB
4	2/8/2005	5:45 PM	54	70.2	76.0	5.8	NO	JB
5	2/9/2005	9:05 AM	51	66.9	72.0	5.1	NO	JB
5	2/9/2005	10:08 AM	52	67.1	72.4	5.3	NO	JB
5	2/9/2005	11:21 AM	52	66.5	72.3	5.8	NO	JB
5	2/9/2005	12:20 PM	54	66.4	72.2	5.8	NO	JB
5	2/9/2005	1:10 PM	55	66.9	72.8	5.9	NO	JB
5	2/9/2005	2:07 PM	57	66.6	72.3	5.7	NO	JB
5	2/9/2005	3:06 PM	57	66.9	71.7	4.8	NO	JB
5	2/9/2005	4:06 PM	56	66.6	71.9	5.3	NO	JB
5	2/9/2005	5:34 PM	55	66.2	71.3	5.1	NO	JB
6	2/10/2005	10:04 AM	34	59.7	68.3	8.6	NO	JB
6	2/10/2005	4:08 PM	36	55.1	69.3	14.2	NO	JB

TABLE 2: THERMOCOUPLE MONITORING REPORT FOR LIFT 1, THERMOCOUPLE 4								
CADDELL/BLAINE		THERMOCOUPLE MONITORING REPORT - LIFT 1						FORM 4
MT&E NO.:					CAL. DUE DATE: 9-28-05			
Thermocouple Number:		#4			LOCATION: Test Bed			
Monitor Day	DATE	TIME	AMBIENT TEMP.	UPPER TEMP.	LOWER TEMP.	TEMP. DIFFERENCE	STR NOTIFICATION REQUIRED*	READER INITIALS
1	2/5/2005	8:10 AM	31	63.4	76.4	13.0	NO	JB
1	2/5/2005	9:32 AM	38	64.4	77.4	13.0	NO	JB
1	2/5/2005	10:28 AM	42	66.3	79.3	13.0	NO	JB
1	2/5/2005	11:23 AM	46	67.2	78.3	11.1	NO	JB
1	2/5/2005	12:28 PM	48	70.4	80.8	10.4	NO	JB
1	2/5/2005	1:23 PM	53	74.5	80.8	6.3	NO	JB
1	2/5/2005	2:38 PM	57	70.8	75.6	4.8	NO	JB
1	2/5/2005	3:49 PM	59	76.7	81.9	5.2	NO	JB
1	2/5/2005	4:28 PM	61	76.4	81.9	5.5	NO	JB
1	2/5/2005	5:15 PM	62	76.1	81.8	5.7	NO	JB
2	2/6/2005	8:33 AM	33	77.5	85.1	7.6	NO	JB
2	2/6/2005	9:32 AM	39	74.2	85.1	10.9	NO	JB
2	2/6/2005	10:12 AM	43	73.1	84.9	11.8	NO	JB
2	2/6/2005	11:12 AM	50	74.2	84.3	10.1	NO	JB
2	2/6/2005	12:15 PM	55	75.8	84.5	8.7	NO	JB
2	2/6/2005	1:16 PM	59	77.3	84.3	7.0	NO	JB
2	2/6/2005	2:17 PM	62	76.9	83.1	6.2	NO	JB
2	2/6/2005	3:17 PM	65	78.9	84.1	5.2	NO	JB
2	2/6/2005	4:10 PM	64	77.5	83.7	6.2	NO	JB
2	2/6/2005	5:05 PM	63	77.0	83.7	6.7	NO	JB
3	2/7/2005	9:41 AM	50	74.3	83.7	9.4	NO	JB
3	2/7/2005	10:27 AM	52	73.1	83.1	10.0	NO	JB
3	2/7/2005	11:21 AM	55	72.7	82.6	9.9	NO	JB
3	2/7/2005	12:10 PM	56	72.0	80.7	8.7	NO	JB
3	2/7/2005	1:08 PM	58	73.8	80.7	6.9	NO	JB
3	2/7/2005	2:16 PM	60	75.1	81.7	6.6	NO	JB
3	2/7/2005	3:05 PM	62	75.4	81.5	6.1	NO	JB
3	2/7/2005	4:15 PM	63	74.9	80.9	6.0	NO	JB
3	2/7/2005	5:13 PM	64	75.8	81.5	5.7	NO	JB
4	2/8/2005	9:40 AM	50	71.4	79.7	8.3	NO	JB
4	2/8/2005	10:33 AM	51	70.1	79.0	8.9	NO	JB
4	2/8/2005	11:20 AM	51	69.2	79.1	9.9	NO	JB
4	2/8/2005	12:22 PM	52	69.9	79.8	9.9	NO	JB
4	2/8/2005	1:22 PM	54	69.6	79.5	9.9	NO	JB
4	2/8/2005	2:14 PM	54	70.8	81.1	10.3	NO	JB
4	2/8/2005	3:10 PM	55	70.2	78.5	8.3	NO	JB
4	2/8/2005	4:23 PM	55	70.8	77.7	6.9	NO	JB
4	2/8/2005	6:03 PM	54	70.9	77.3	6.4	NO	JB
5	2/9/2005	9:06 AM	51	66.3	74.3	8.0	NO	JB
5	2/9/2005	10:09 AM	52	67.1	76.2	9.1	NO	JB
5	2/9/2005	11:24 AM	52	65.9	74.3	8.4	NO	JB
5	2/9/2005	12:27 PM	54	66.5	74.5	8.0	NO	JB
5	2/9/2005	1:18 PM	55	66.8	74.7	7.9	NO	JB
5	2/9/2005	2:09 PM	57	67.0	76.5	9.5	NO	JB
5	2/9/2005	4:10 PM	57	66.7	73.7	7.0	NO	JB
5	2/9/2005	4:17 PM	56	67.0	76.0	9.0	NO	JB
5	2/9/2005	5:33 PM	55	66.7	73.8	7.1	NO	JB
6	2/10/2005	10:05 AM	0:00	59.8	70.5	10.7	NO	JB
6	2/10/2005	4:45 PM	36	58.5	65.4	6.9	NO	JB

TABLE 3: THERMOCOUPLE MONITORING REPORT FOR LIFT 1, THERMOCOUPLE 5								
CADDELL/BLAINE			THERMOCOUPLE MONITORING REPORT - LIFT 1					FORM 4
MT&E NO.:					CAL. DUE DATE: 9-28-05			
Thermocouple Number:		LONG-TERM #5			LOCATION: Test Bed			
Monitor Day	DATE	TIME	AMBIENT TEMP.	UPPER TEMP.	LOWER TEMP.	TEMP. DIFFERENCE	STR NOTIFICATION REQUIRED*	READER INITIALS
1	2/5/2005	8:12 AM	31	65.0		0.0	NO	JB
1	2/5/2005	9:35 AM	38	66.9		0.0	NO	JB
1	2/5/2005	10:29 AM	42	68.5		0.0	NO	JB
1	2/5/2005	11:28 AM	46	70.2		0.0	NO	JB
1	2/5/2005	12:31 PM	48	72.7		0.0	NO	JB
1	2/5/2005	1:25 PM	53	75.1		0.0	NO	JB
1	2/5/2005	2:48 PM	54	75.7		0.0	NO	JB
1	2/5/2005	3:50 PM	59	78.1		0.0	NO	JB
1	2/5/2005	4:28 PM	61	78.1		0.0	NO	JB
1	2/5/2005	5:16 PM	62	77.7		0.0	NO	JB
2	2/6/2005	8:34 AM	33	79.8		0.0	NO	JB
2	2/6/2005	9:31 AM	39	77.1		0.0	NO	JB
2	2/6/2005	10:13 AM	43	76.1		0.0	NO	JB
2	2/6/2005	11:15 AM	50	75.9		0.0	NO	JB
2	2/6/2005	12:16 PM	55	76.6		0.0	NO	JB
2	2/6/2005	1:17 PM	59	77.7		0.0	NO	JB
2	2/6/2005	2:18 PM	62	78.1		0.0	NO	JB
2	2/6/2005	3:18 PM	65	79.1		0.0	NO	JB
2	2/6/2005	4:11 PM	64	79.1		0.0	NO	JB
2	2/6/2005	5:06 PM	63	75.0		0.0	NO	JB
3	2/7/2005	9:43 AM	50	76.8		0.0	NO	JB
3	2/7/2005	10:28 AM	52	75.7		0.0	NO	JB
3	2/7/2005	11:23 AM	55	74.9		0.0	NO	JB
3	2/7/2005	12:13 PM	56	74.2		0.0	NO	JB
3	2/7/2005	1:09 PM	58	74.9		0.0	NO	JB
3	2/7/2005	2:16 PM	60	76.5		0.0	NO	JB
3	2/7/2005	4:06 PM	62	76.7		0.0	NO	JB
3	2/7/2005	4:16 PM	63	75.9		0.0	NO	JB
3	2/7/2005	5:13 PM	64	77.6		0.0	NO	JB
4	2/8/2005	9:22 AM	50	73.0		0.0	NO	JB
4	2/8/2005	10:35 AM	51	71.6		0.0	NO	JB
4	2/8/2005	11:21 AM	51	70.7		0.0	NO	JB
4	2/8/2005	12:22 PM	52	71.4		0.0	NO	JB
4	2/8/2005	1:23 PM	54	70.9		0.0	NO	JB
4	2/8/2005	2:15 PM	54	71.2		0.0	NO	JB
4	2/8/2005	3:12 PM	55	70.1		0.0	NO	JB
4	2/8/2005	4:24 PM	55	71.3		0.0	NO	JB
4	2/8/2005	6:03 PM	54	70.9		0.0	NO	JB
5	2/9/2005	9:07 AM	51	66.4		0.0	NO	JB
5	2/9/2005	10:09 AM	52	66.7		0.0	NO	JB
5	2/9/2005	11:25 AM	52	67.2		0.0	NO	JB
5	2/9/2005	12:25 PM	54	69.5		0.0	NO	JB
5	2/9/2005	1:14 PM	55	69.8		0.0	NO	JB
5	2/9/2005	2:10 PM	57	69.3		0.0	NO	JB
5	2/9/2005	3:11 PM	57	68.3		0.0	NO	JB
5	2/9/2005	4:13 PM	56	67.9		0.0	NO	JB
5	2/9/2005	5:34 PM	55	67.6		0.0	NO	JB
6	2/10/2005	10:07 AM	34	61.9		0.0	NO	JB
6	2/10/2005	4:46 PM	36	61.1		0.0	NO	JB
7	2/11/2005	7:12 AM	28	75.9		0.0	NO	JB
8	2/12/2005	8:00 AM	30	76.2		0.0	NO	JB
8	2/12/2005	4:51 PM	61	71.1		0.0	NO	JB
9	2/13/2005	8:24 AM	41	80.5		0.0	NO	JB
9	2/13/2005	5:29 PM	52	81.6		0.0	NO	JB
10	2/14/2005	8:36 AM	47	84.1		0.0	NO	JB
10	2/14/2005	4:51 PM	51	81.9		0.0	NO	JB
11	2/15/2005	8:40 AM	53	84.0		0.0	NO	JB
11	2/15/2005	4:15 PM	61	79.5		0.0	NO	JB
12	2/16/2005	8:28 AM	42	75.7		0.0	NO	JB
12	2/16/2005	5:33 PM	56	64.6		0.0	NO	JB
13	2/17/2005	7:27 AM	28	62.9		0.0	NO	JB
13	2/17/2005	6:31 PM	45	63.6		0.0	NO	JB
14	2/18/2005	7:15 AM	26	59.6		0.0	NO	JB
14	2/18/2005	6:05 PM	48	60.4		0.0	NO	JB
15	2/19/2005	8:31 AM	36	57.1		0.0	NO	JB
15	2/19/2005	6:00 PM	52	81.9		0.0	NO	JB
16	2/20/2005	8:26 AM	48	77.8		0.0	NO	JB
16	2/20/2005	6:40 PM	53	75.1		0.0	NO	JB

TABLE 4: THERMOCOUPLE MONITORING REPORT FOR LIFT 1, THERMOCOUPLE 7								
CADDELL/BLAINE			THERMOCOUPLE MONITORING REPORT-LIFT 1					FORM 4
MT&E NO.:					CAL. DUE DATE: 9-28-05			
Thermocouple Number:		LONG-TERM #7			LOCATION: Test Bed			
Monitor Day	DATE	TIME	AMBIENT TEMP.	UPPER TEMP.	LOWER TEMP.	TEMP. DIFFERENCE	STR NOTIFICATION REQUIRED*	READER INITIALS
1	2/5/2005	8:06 AM	31	66.5		0.0	NO	JB
1	2/5/2005	9:23 AM	38	65.0		0.0	NO	JB
1	2/5/2005	10:26 AM	42	65.9		0.0	NO	JB
1	2/5/2005	11:19 AM	46	66.7		0.0	NO	JB
1	2/5/2005	12:22 PM	48	70.6		0.0	NO	JB
1	2/5/2005	1:22 PM	53	74.0		0.0	NO	JB
1	2/5/2005	2:37 PM	57	74.6		0.0	NO	JB
1	2/5/2005	3:47 PM	59	76.4		0.0	NO	JB
1	2/5/2005	4:26 PM	61	76.0		0.0	NO	JB
1	2/5/2005	5:11 PM	62	74.9		0.0	NO	JB
2	2/6/2005	8:29 AM	33	77.9		0.0	NO	JB
2	2/6/2005	9:30 AM	39	74.5		0.0	NO	JB
2	2/6/2005	10:11 AM	43	73.3		0.0	NO	JB
2	2/6/2005	11:10 AM	50	74.0		0.0	NO	JB
2	2/6/2005	12:13 PM	55	75.6		0.0	NO	JB
2	2/6/2005	1:13 PM	59	76.6		0.0	NO	JB
2	2/6/2005	2:15 PM	62	76.8		0.0	NO	JB
2	2/6/2005	3:15 PM	65	78.2		0.0	NO	JB
2	2/6/2005	4:08 PM	64	77.0		0.0	NO	JB
2	2/6/2005	5:03 PM	63	76.0		0.0	NO	JB
3	2/7/2005	9:40 AM	50	73.3		0.0	NO	JB
3	2/7/2005	10:26 AM	52	71.7		0.0	NO	JB
3	2/7/2005	11:20 AM	55	71.6		0.0	NO	JB
3	2/7/2005	12:08 PM	56	71.3		0.0	NO	JB
3	2/7/2005	1:07 PM	58	72.9		0.0	NO	JB
3	2/7/2005	2:11 PM	60	73.4		0.0	NO	JB
3	2/7/2005	3:04 PM	62	73.9		0.0	NO	JB
3	2/7/2005	4:14 PM	63	73.6		0.0	NO	JB
3	2/7/2005	5:12 PM	64	74.4		0.0	NO	JB
4	2/8/2005	9:20 AM	50	70.9		0.0	NO	JB
4	2/8/2005	10:32 AM	51	69.3		0.0	NO	JB
4	2/8/2005	11:17 AM	51	68.3		0.0	NO	JB
4	2/8/2005	12:18 PM	52	69.4		0.0	NO	JB
4	2/8/2005	1:21 PM	54	69.2		0.0	NO	JB
4	2/8/2005	2:12 PM	54	68.9		0.0	NO	JB
4	2/8/2005	3:07 PM	55	69.5		0.0	NO	JB
4	2/8/2005	4:18 PM	55	70.5		0.0	NO	JB
4	2/8/2005	6:01 PM	54	70.2		0.0	NO	JB
5	2/9/2005	9:06 AM	51	66.8		0.0	NO	JB
5	2/9/2005	10:08 AM	52	72.4		0.0	NO	JB
5	2/9/2005	11:22 AM	52	72.2		0.0	NO	JB
5	2/9/2005	12:21 PM	54	67.1		0.0	NO	JB
5	2/9/2005	1:13 PM	55	67.9		0.0	NO	JB
5	2/9/2005	2:08 PM	57	68.2		0.0	NO	JB
5	2/9/2005	3:07 PM	57	67.1		0.0	NO	JB
5	2/9/2005	4:11 PM	56	68.4		0.0	NO	JB
5	2/9/2005	5:34 PM	55	67.8		0.0	NO	JB
6	2/10/2005	10:02 AM	34	60.2		0.0	NO	JB
6	2/10/2005	4:43 PM	36	67.2		0.0	NO	JB
7	2/11/2005	7:15 AM	28	66.2		0.0	NO	JB
8	2/12/2005	8:10 AM	30	65.8		0.0	NO	JB
8	2/12/2005	5:06 PM	61	71.8		0.0	NO	JB
9	2/13/2005	8:20 AM	41	80.6		0.0	NO	JB
9	2/13/2005	5:37 PM	52	81.2		0.0	NO	JB
10	2/14/2005	8:40 AM	47	84.2		0.0	NO	JB
10	2/14/2005	4:06 PM	51	83.1		0.0	NO	JB
11	2/15/2005	8:40 AM	53	85.2		0.0	NO	JB
11	2/15/2005	4:14 PM	61	81.2		0.0	NO	JB
12	2/16/2005	8:26 AM	42	79.8		0.0	NO	JB
12	2/16/2005	5:28 PM	56	78.7		0.0	NO	JB
13	2/17/2005	7:29 AM	28	76.4		0.0	NO	JB
13	2/17/2005	6:33 PM	45	77.7		0.0	NO	JB
14	2/18/2005	7:18 AM	26	67.3		0.0	NO	JB
14	2/18/2005	6:10 PM	48	72.4		0.0	NO	JB
15	2/19/2005	8:35 AM	36	68.2		0.0	NO	JB
15	2/19/2005	6:04 PM	52	82.3		0.0	NO	JB
16	2/20/2005	8:25 AM	48	76.4		0.0	NO	JB
16	2/20/2005	6:35 PM	53	73.9		0.0	NO	JB

TABLE 5: THERMOCOUPLE MONITORING REPORT FOR LIFT 1, THERMOCOUPLE 11								
CADDELL/BLAINE			THERMOCOUPLE MONITORING REPORT - LIFT 1					FORM 4
MT&E NO.:					CAL. DUE DATE: 9-28-05			
Thermocouple Number:		LONG-TERM #11			LOCATION: Test Bed			
Monitor Day	DATE	TIME	AMBIENT TEMP.	UPPER TEMP.	LOWER TEMP.	TEMP. DIFFERENCE	STR NOTIFICATION REQUIRED*	READER INITIALS
1	2/5/2005	8:21 AM	31	76.3		0.0	NO	JB
1	2/5/2005	9:24 AM	38	77.1		0.0	NO	JB
1	2/5/2005	10:31 AM	42	78.7		0.0	NO	JB
1	2/5/2005	11:25 AM	46	78.8		0.0	NO	JB
1	2/5/2005	12:30 PM	48	79.5		0.0	NO	JB
1	2/5/2005	1:24 PM	53	80.8		0.0	NO	JB
1	2/5/2005	2:44 PM	57	80.2		0.0	NO	JB
1	2/5/2005	3:49 PM	59	81.7		0.0	NO	JB
1	2/5/2005	4:29 PM	61	81.3		0.0	NO	JB
1	2/5/2005	5:17 PM	62	81.7		0.0	NO	JB
2	2/6/2005	8:34 AM	33	84.4		0.0	NO	JB
2	2/6/2005	9:32 AM	39	84.4		0.0	NO	JB
2	2/6/2005	10:13 AM	43	84.4		0.0	NO	JB
2	2/6/2005	11:14 AM	50	84.1		0.0	NO	JB
2	2/6/2005	12:15 PM	55	84.0		0.0	NO	JB
2	2/6/2005	1:17 PM	59	77.7		0.0	NO	JB
2	2/6/2005	2:17 PM	62	83.2		0.0	NO	JB
2	2/6/2005	3:17 PM	65	84.1		0.0	NO	JB
2	2/6/2005	4:10 PM	64	83.6		0.0	NO	JB
2	2/6/2005	5:05 PM	63	83.6		0.0	NO	JB
3	2/7/2005	9:45 AM	50	83.1		0.0	NO	JB
3	2/7/2005	10:28 AM	52	82.9		0.0	NO	JB
3	2/7/2005	11:22 AM	55	82.7		0.0	NO	JB
3	2/7/2005	12:14 PM	56	81.9		0.0	NO	JB
3	2/7/2005	1:10 PM	58	82.3		0.0	NO	JB
3	2/7/2005	2:17 PM	60	82.3		0.0	NO	JB
3	2/7/2005	3:06 PM	62	82.3		0.0	NO	JB
3	2/7/2005	4:16 PM	63	81.3		0.0	NO	JB
3	2/7/2005	5:17 PM	64	82.7		0.0	NO	JB
4	2/8/2005	9:26 AM	50	79.6		0.0	NO	JB
4	2/8/2005	10:35 AM	51	79.5		0.0	NO	JB
4	2/8/2005	11:22 AM	51	79.1		0.0	NO	JB
4	2/8/2005	12:23 PM	52	78.8		0.0	NO	JB
4	2/8/2005	1:24 PM	54	78.4		0.0	NO	JB
4	2/8/2005	2:15 PM	54	78.6		0.0	NO	JB
4	2/8/2005	3:13 PM	55	77.6		0.0	NO	JB
4	2/8/2005	4:24 PM	55	78.2		0.0	NO	JB
4	2/8/2005	6:04 PM	54	77.8		0.0	NO	JB
5	2/9/2005	9:08 AM	51	74.3		0.0	NO	JB
5	2/9/2005	10:10 AM	52	74.4		0.0	NO	JB
5	2/9/2005	11:25 AM	52	74.5		0.0	NO	JB
5	2/9/2005	12:25 PM	54	75.3		0.0	NO	JB
5	2/9/2005	1:15 PM	55	75.7		0.0	NO	JB
5	2/9/2005	2:10 PM	57	75.5		0.0	NO	JB
5	2/9/2005	3:12 PM	57	75.3		0.0	NO	JB
5	2/9/2005	4:13 PM	56	74.8		0.0	NO	JB
5	2/9/2005	5:34 PM	55	74.2		0.0	NO	JB
6	2/10/2005	10:11 AM	34	71.1		0.0	NO	JB
6	2/10/2005	4:38 PM	36	73.2		0.0	NO	JB
7	2/11/2005	7:26 AM	28	72.6		0.0	NO	JB
8	2/12/2005	8:20 AM	30	70.4		0.0	NO	JB
8	2/12/2005	5:03 PM	61	66.5		0.0	NO	JB
9	2/13/2005	8:23 AM	41	72.9		0.0	NO	JB
9	2/13/2005	5:41 PM	52	73.3		0.0	NO	JB
10	2/14/2005	8:45 AM	47	76.3		0.0	NO	JB
10	2/14/2005	4:11 PM	51	74.9		0.0	NO	JB
11	2/15/2005	8:42 AM	53	78.5		0.0	NO	JB
11	2/15/2005	4:16 PM	61	68.3		0.0	NO	JB
12	2/16/2005	8:29 AM	42	65.8		0.0	NO	JB
12	2/16/2005	5:34 PM	56	62.3		0.0	NO	JB
13	2/17/2005	7:32 AM	28	61.1		0.0	NO	JB
13	2/17/2005	6:36 PM	45	62.6		0.0	NO	JB
14	2/18/2005	7:25 AM	26	71.4		0.0	NO	JB
14	2/18/2005	6:20 PM	48	70.7		0.0	NO	JB
15	2/19/2005	8:50 AM	36	69.4		0.0	NO	JB
15	2/19/2005	6:08 PM	52	82.5		0.0	NO	JB
16	2/20/2005	8:27 AM	48	77.4		0.0	NO	JB
16	2/20/2005	6:41 PM	53	75.1		0.0	NO	JB

TABLE 6: THERMOCOUPLE MONITORING REPORT FOR LIFT 1, THERMOCOUPLE 10								
CADDELL/BLAINE		THERMOCOUPLE MONITORING REPORT-LIFT 1						FORM 4
MT&E NO.:					CAL. DUE DATE: 9-28-05			
Thermocouple Number:		LONG-TERM #10			LOCATION: Test Bed			
Monitor Day	DATE	TIME	AMBIENT TEMP.	UPPER TEMP.	LOWER TEMP.	TEMP. DIFFERENCE	STR NOTIFICATION REQUIRED*	READER INITIALS
1	2/5/2005	8:20 AM	31	77.3		0.0	NO	JB
1	2/5/2005	9:23 AM	38	78.0		0.0	NO	JB
1	2/5/2005	10:25 AM	42	79.3		0.0	NO	JB
1	2/5/2005	11:21 AM	46	77.3		0.0	NO	JB
1	2/5/2005	12:25 PM	48	78.8		0.0	NO	JB
1	2/5/2005	1:22 AM	53	80.7		0.0	NO	JB
1	2/5/2005	2:38 PM	57	80.1		0.0	NO	JB
1	2/5/2005	3:48 PM	59	81.8		0.0	NO	JB
1	2/5/2005	4:27 PM	61	81.1		0.0	NO	JB
1	2/5/2005	5:12 PM	62	80.7		0.0	NO	JB
2	2/6/2005	8:30 AM	33	83.6		0.0	NO	JB
2	2/6/2005	9:30 AM	39	82.9		0.0	NO	JB
2	2/6/2005	10:11 AM	43	82.9		0.0	NO	JB
2	2/6/2005	11:11 AM	50	82.4		0.0	NO	JB
2	2/6/2005	12:13 PM	55	82.5		0.0	NO	JB
2	2/6/2005	1:20 PM	59	82.3		0.0	NO	JB
2	2/6/2005	2:16 PM	62	81.3		0.0	NO	JB
2	2/6/2005	3:16 PM	65	82.5		0.0	NO	JB
2	2/6/2005	4:09 PM	64	81.9		0.0	NO	JB
2	2/6/2005	5:04 PM	63	81.9		0.0	NO	JB
3	2/7/2005	9:38 AM	50	81.8		0.0	NO	JB
3	2/7/2005	10:26 AM	52	80.8		0.0	NO	JB
3	2/7/2005	11:10 AM	55	80.7		0.0	NO	JB
3	2/7/2005	12:08 PM	56	79.9		0.0	NO	JB
3	2/7/2005	1:06 PM	58	79.9		0.0	NO	JB
3	2/7/2005	2:10 PM	60	78.6		0.0	NO	JB
3	2/7/2005	3:04 PM	62	79.7		0.0	NO	JB
3	2/7/2005	4:14 PM	63	79.5		0.0	NO	JB
3	2/7/2005	5:12 PM	64	80.1		0.0	NO	JB
4	2/8/2005	9:15 AM	50	77.3		0.0	NO	JB
4	2/8/2005	10:30 AM	51	77.5		0.0	NO	JB
4	2/8/2005	11:16 AM	51	76.3		0.0	NO	JB
4	2/8/2005	12:17 PM	52	76.5		0.0	NO	JB
4	2/8/2005	1:20 PM	54	76.8		0.0	NO	JB
4	2/8/2005	2:12 PM	54	76.9		0.0	NO	JB
4	2/8/2005	3:07 PM	55	76.8		0.0	NO	JB
4	2/8/2005	4:18 PM	55	76.5		0.0	NO	JB
4	2/8/2005	6:00 PM	54	76.1		0.0	NO	JB
5	2/9/2005	9:05 AM	51	72.2		0.0	NO	JB
5	2/9/2005	10:08 AM	52	72.4		0.0	NO	JB
5	2/9/2005	11:22 AM	52	72.3		0.0	NO	JB
5	2/9/2005	12:21 PM	54	72.3		0.0	NO	JB
5	2/9/2005	1:12 PM	55	72.4		0.0	NO	JB
5	2/9/2005	2:08 PM	57	73.1		0.0	NO	JB
5	2/9/2005	3:07 PM	57	72.1		0.0	NO	JB
5	2/9/2005	4:11 PM	56	72.3		0.0	NO	JB
5	2/9/2005	5:31 PM	55	71.9		0.0	NO	JB
6	2/10/2005	10:03 AM	34	68.3		0.0	NO	JB
6	2/10/2005	4:42 PM	36	67.2		0.0	NO	JB
7	2/11/2005	7:25 AM	28	64.6		0.0	NO	JB
8	2/12/2005	8:18 AM	30	62.3		0.0	NO	JB
8	2/12/2005	5:11 PM	61	65.7		0.0	NO	JB
9	2/13/2005	8:26 AM	41	72.2		0.0	NO	JB
9	2/13/2005	5:45 PM	52	73.1		0.0	NO	JB
10	2/14/2005	8:41 AM	47	78.8		0.0	NO	JB
10	2/14/2005	4:10 PM	51	79.5		0.0	NO	JB
11	2/15/2005	8:45 AM	53	80.5		0.0	NO	JB
11	2/15/2005	4:19 PM	61	75.2		0.0	NO	JB
12	2/16/2005	8:30 AM	42	72.6		0.0	NO	JB
12	2/16/2005	5:40 PM	56	72.2		0.0	NO	JB
13	2/17/2005	7:31 AM	28	70.8		0.0	NO	JB
13	2/17/2005	6:35 PM	45	71.4		0.0	NO	JB
14	2/18/2005	7:23 AM	26	72.6		0.0	NO	JB
14	2/18/2005	6:15 PM	48	74.2		0.0	NO	JB
15	2/19/2005	8:45 AM	36	71.8		0.0	NO	JB
15	2/19/2005	6:08 PM	52	76.0		0.0	NO	JB
16	2/20/2005	8:30 AM	48	73.2		0.0	NO	JB
16	2/20/2005	6:50 PM	53	74.1		0.0	NO	JB

TABLE 7: THERMOCOUPLE MONITORING REPORT FOR LIFT 2, THERMOCOUPLE 13									
CADDELL/BLAINE			THERMOCOUPLE MONITORING REPORT - LIFT 2						FORM 4
MT&E NO.:					CAL. DUE DATE:		9/28/2005		
Thermocouple Number:		#13			LOCATION:		TEST BED		
Monitor Day	DATE	TIME	AMBIENT TEMP.	UPPER TEMP.	LOWER TEMP.	TEMP. DIFFERENCE	STR NOTIFICATION REQUIRED*	READER INITIALS	
1	2/12/2005	8:05 AM	30	70.3	74.7	4.4	NO	JB	
1	2/12/2005	9:11 AM	33	70.2	78.7	8.5	NO	JB	
1	2/12/2005	10:28 AM	34	70.5	79.3	8.8	NO	JB	
1	2/12/2005	11:12 AM	44	73.4	79.7	6.3	NO	JB	
1	2/12/2005	12:15 PM	51	75.6	80.9	5.3	NO	JB	
1	2/12/2005	1:13 PM	55	76.3	80.7	4.4	NO	JB	
1	2/12/2005	2:37 PM	58	77.3	81.5	4.2	NO	JB	
1	2/12/2005	3:21 PM	60	77.5	81.5	4.0	NO	JB	
1	2/12/2005	4:02 PM	61	77.6	81.9	4.3	NO	JB	
2	2/13/2005	8:28 AM	41	91.1	92.6	1.5	NO	JB	
2	2/13/2005	9:02 AM	44	91.6	93.4	1.8	NO	JB	
2	2/13/2005	10:34 AM	48	91.7	92.5	0.8	NO	JB	
2	2/13/2005	5:18 PM	52	89.6	92.2	2.6	NO	JB	
2	2/13/2005	6:10 PM	46	89.1	92.5	3.4	NO	JB	
3	2/14/2005	8:06 AM	47	87.1	91.8	4.7	NO	JB	
3	2/14/2005	9:05 AM	46	89.3	92.7	3.4	NO	JB	
3	2/14/2005	10:35 AM	47	89.4	92.3	2.9	NO	JB	
3	2/14/2005	11:37 AM	48	88.7	95.5	6.8	NO	JB	
3	2/14/2005	12:47 PM	50	89.0	95.6	6.6	NO	JB	
3	2/14/2005	1:02 PM	51	89.2	95.3	6.1	NO	JB	
3	2/14/2005	2:35 PM	50	80.9	89.1	8.2	NO	JB	
3	2/14/2005	3:26 PM	51	81.6	90.0	8.4	NO	JB	
4	2/15/2005	8:30 AM	53	86.1	89.5	3.4	NO	JB	
4	2/15/2005	4:40 PM	61	76.8	79.5	2.7	NO	JB	
5	2/16/2005	7:12 AM	42	74.7	77.9	3.2	NO	JB	
5	2/16/2005	5:46 PM	56	75.3	78.4	3.1	NO	JB	
6	2/17/2005	7:06 AM	28	73.6	76.6	3.0	NO	JB	
6	2/17/2005	5:08 PM	45	74.8	77.1	2.3	NO	JB	
7	2/18/2005	8:00 AM	28	76.7	73.6	3.1	NO	JB	
7	2/18/2005	6:05 PM	48	75.6	71.8	3.8	NO	JB	
8	2/19/2005	8:10 AM	36	73.2	69.8	3.4	NO	JB	
8	2/19/2005	6:11 PM	52	65.2	72.1	6.9	NO	JB	
9	2/20/2005	8:02 AM	48	66.4	71.8	5.4	NO	JB	
9	2/20/2005	6:06 PM	53	65.9	71.4	5.5	NO	JB	

TABLE 8: THERMOCOUPLE MONITORING REPORT FOR LIFT 2, THERMOCOUPLE 14									
CADDELL/BLAINE			THERMOCOUPLE MONITORING REPORT- LIFT 2						FORM 4
MT&E NO.:					CAL. DUE DATE:		9/28/2005		
Thermocouple Number:		#14			LOCATION:		TEST BED		
Monitor Day	DATE	TIME	AMBIENT TEMP.	UPPER TEMP.	LOWER TEMP.	TEMP. DIFFERENCE	STR NOTIFICATION REQUIRED*	READER INITIALS	
1	2/12/2005	8:29 AM	30	72.7	75.9	3.2	NO	JB	
1	2/12/2005	9:11 AM	30	71.4	76.3	4.9	NO	JB	
1	2/12/2005	10:30 AM	36	70.8	78.7	7.9	NO	JB	
1	2/12/2005	11:14 AM	44	71.4	78.9	7.5	NO	JB	
1	2/12/2005	12:20 PM	51	73.9	79.6	5.7	NO	JB	
1	2/12/2005	1:15 PM	55	74.6	81.3	6.7	NO	JB	
1	2/12/2005	2:40 PM	58	77.5	82.3	4.8	NO	JB	
1	2/12/2005	3:19 PM	60	79.7	83.0	3.3	NO	JB	
1	2/12/2005	4:03 PM	61	78.4	82.8	4.4	NO	JB	
2	2/13/2005	8:28 AM	41	90.3	91.5	1.2	NO	JB	
2	2/13/2005	9:02 AM	44	90.6	91.9	1.3	NO	JB	
2	2/13/2005	10:36 AM	48	91.7	93.3	1.6	NO	JB	
2	2/13/2005	5:16 PM	52	88.2	91.2	3.0	NO	JB	
2	2/13/2005	6:15 PM	46	87.5	91.1	3.6	NO	JB	
3	2/14/2005	8:05 AM	47	86.9	91.6	4.7	NO	JB	
3	2/14/2005	9:10 AM	46	86.5	92.0	5.5	NO	JB	
3	2/14/2005	10:48 AM	47	86.5	91.7	5.2	NO	JB	
3	2/14/2005	11:40 AM	48	89.5	94.7	5.2	NO	JB	
3	2/14/2005	12:48 PM	50	89.1	94.8	5.7	NO	JB	
3	2/14/2005	1:31 PM	51	88.2	92.6	4.4	NO	JB	
3	2/14/2005	2:48 PM	50	83.3	88.7	5.4	NO	JB	
3	2/14/2005	3:38 PM	51	78.7	88.3	9.6	NO	JB	
4	2/15/2005	8:31 AM	53	84.7	87.5	2.8	NO	JB	
4	2/15/2005	4:13 PM	61	77.8	81.4	3.6	NO	JB	
5	2/16/2005	7:08 AM	42	75.8	77.9	2.1	NO	JB	
5	2/16/2005	5:38 PM	56	76.2	81.1	4.9	NO	JB	
6	2/17/2005	7:05 AM	28	75.4	78.7	3.3	NO	JB	
6	2/17/2005	5:10 PM	45	75.0	77.3	2.3	NO	JB	
7	2/18/2005	8:05 AM	28	70.6	73.9	3.3	NO	JB	
7	2/18/2005	6:10 PM	48	69.8	73.5	3.7	NO	JB	
8	2/19/2005	8:15 AM	36	67.4	72.7	5.3	NO	JB	
8	2/19/2005	6:12 PM	52	66.2	73.3	7.1	NO	JB	
9	2/20/2005	8:05 AM	48	67.2	72.6	5.4	NO	JB	
9	2/20/2005	6:08 PM	53	66.9	72.8	5.9	NO	JB	

higher temperature there (Emborg, 1998). Hence, much of the expansion phase in the central parts of the concrete section would take place while the concrete at the surface is in a more plastic stage (Emborg 1998). This condition is favorable because it decreases the risk of early age surface cracks (Emborg 1998).

If a mass concrete section is exposed to high air temperature and a lower initial casting temperature, the surface concrete would lead the strength and maturity development across the section (Emborg 1998). Eventually, the delayed rapid volume expansion takes place in the interior, and the surface has developed stiffness due to an advanced maturity level (Emborg 1998). As a result, higher stresses develop in the stiffer surface concrete layers and the risk of surface cracking increases dramatically (Emborg 1998). Ambient air temperatures were recorded on the thermocouple data sheets shown on Table 1 through Table 8, and were taken into account in the finite element analysis. Ambient temperatures are discussed in more detail later in this chapter.

Compressive Test and Resonant Column Test Data

Thermal cracking occurs in concrete sections because of induced stresses, which exceed the strength of the material (Springenshmid and Breitenbucher 1998). Therefore, in order to accurately model a mass concrete pour, the mechanical properties of the concrete must be monitored with age. In order to do this, thirty-four standard concrete cylinders were made of each test pad lift, and cured according to section 10.1 of ASTM C31. Compressive strength tests and resonant-column tests were performed on cylinders to determine the mechanical properties of the concrete with age. The intervals in which compressive strength tests were performed for each concrete placement are shown in

Table 9. Resonant-column tests were performed on the standard cylinders before the compressive strength tests, and the intervals in which these tests were performed are shown in Table 10. The results of the field tests can be found for each lift in Table 11 and Table 12. Static Modulus of Elasticity, Shear Modulus, Unit Weight, Poisson's Ratio, and Compressive Strength values from field tests were plotted versus time for each lift to accurately show the mechanical behavior of the test pad with age. These plots are shown in Figure 6 through Figure 15. Note that the dashed lines on the figures represent interpolated values from the exact time each finite element model is taken, which is explained later in this chapter.

3.2 BUILDING THE GTSTRUDL FINITE ELEMENT MODEL

Once all the field data was collected and concrete property testing was conducted, these values were input into a GTSTRUDL finite element model to be analyzed for thermal stresses and strains. Two finite element models were developed for this thesis. One model shows the first concrete test pad lift (see Figure 16). The other model shows both the first and second lift, (see Figure 17). A two-dimensional finite element was built in GTSTRUDL to model the test pad. By nature, all structures are three-dimensional, but in practical situations they can be reduced to two dimensions or sometimes even to one dimension without any important loss of accuracy (Emborg 1998). The stresses of a cross-section and risks of surface cracking may be computed by a conventional 2D finite element model analysis (Emborg 1998).

TABLE 9: COMPRESSIVE STRENGTH TEST INTERVALS												
DAYS AFTER PLACEMENT	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**10**	**14**	**21**	**28**	**TOTAL**
TESTS REQUIRED	2	2	2	2	2	2	2	2	2	2	10	34

TABLE 10: RESONANT-COLUMN TEST INTERVALS												
DAYS AFTER PLACEMENT	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**10**	**14**	**21**	**28**	**TOTAL**
TESTS REQUIRED	2	2	2	2	2	2	2	2	2	2	2	22

TABLE 11: STANDARD CYLINDER TEST AND RESONANT COLUMN TEST DATA LIFT 1																	
Cylinder ID	Date / Time	Age (Days)	Weight (lb.)	Length (in.)	Diameter (in.)	Compressive Strength (psi)	Longitudinal		Torsional		Unit Weight (pci)	Vc	Dynamic E	Static E	Vs	G	Poisson's Ratio
							Frequency	Bandwidth	Frequency	Bandwidth							
							(kHz)	(Hz)	(kHz)	(Hz)		(fps)	(psi)	(psi)	(fps)	(psi)	
127 2 2-5	2/5/2005 12:30	1	29.77	11.98	6.00	540	4.46	200.00	2.81	141.00	0.088	8899.42	2.585E+06	1.427E+06	5616.28	1.029E+06	0.31
127 5 2-5	2/5/2005 12:50	1	29.96	11.97	6.00	420	4.30	205.00	2.68	85.00	0.088	8584.49	2.419E+06	1.270E+06	5348.60	9.389E+05	0.32
127 1 2-6	2/6/2005 13:40	2	29.83	11.92	6.00	1500	5.74	179.00	3.36	102.50	0.087	11407.44	4.235E+06	2.369E+06	6679.17	1.452E+06	0.18
127 4 2-6	2/6/2005 13:55	2	29.82	11.93	6.00	1640	5.75	161.00	3.64	88.00	0.087	11434.91	4.258E+06	2.480E+06	7235.55	1.705E+06	0.27
127 6 2-7	2/7/2005 13:25	3	30.05	12.06	5.93	2360	6.15	144.00	3.88	103.00	0.091	12369.54	5.205E+06	3.176E+06	7788.75	2.064E+06	0.23
127 3 2-7	2/7/2005 13:30	3	30.01	12.00	5.98	2280	6.08	163.50	3.85		0.089	12160.93	4.911E+06	3.010E+06	7700.79	1.969E+06	0.24
127 2 2-8	2/8/2005 14:32	4	30.35	12.04	5.99	2780	6.33	174.00	3.98	119.00	0.090	12700.94	5.408E+06	3.372E+06	7986.23	2.138E+06	0.21
127 5 2-8	2/8/2005 14:48	4	30.15	12.02	5.97	2545	6.34	166.00	3.98	173.00	0.090	12687.84	5.394E+06	3.224E+06	7969.95	2.128E+06	0.24
127 6 2-10	2/10/2005 15:19	6	31.22	12.10	5.97	3230	6.38	122.50	3.96	100.50	0.094	12859.00	5.767E+06	3.857E+06	7978.67	2.220E+06	0.13
127 3 2-10	2/10/2005 15:21	6	31.02	12.03	5.98	3240	6.46	155.50	4.02	110.50	0.092	12946.92	5.761E+06	3.779E+06	8064.77	2.235E+06	0.15
127 2 2-11	2/11/2005 13:25	7	29.20	11.53	5.97	3400	6.92	149.00	4.35	95.00	0.083	13296.01	5.497E+06	3.331E+06	8349.64	2.168E+06	0.23
127 5 2-11	2/11/2005 13:27	7	28.95	11.53	5.98	3400	6.75	186.00	4.28	96.00	0.083	12977.02	5.182E+06	3.279E+06	8228.58	2.083E+06	0.21
127 3 2-18	2/18/2005 9:46	13	30.31	12.13	5.99	4230	6.89	113.00	4.37	84.50	0.091	13923.22	6.538E+06	4.197E+06	8834.68	2.632E+06	0.20
127 6 2-18	2/18/2005 9:40	13	30.27	12.06	5.98	4320	6.89	134.00	4.36	81.00	0.090	13856.94	6.466E+06	4.232E+06	8759.58	2.584E+06	0.18
127 2 2-25	2/25/2005 14:05	20	30.41	12.03	5.98	4640	7.14	121.00	4.50	80.00	0.091	14319.71	6.920E+06	4.400E+06	9024.51	2.748E+06	0.20
127 3 2-25	2/25/2005 14:00	20	29.95	11.96	5.99	4820	7.10		4.47	80.50	0.088	14150.67	6.595E+06	4.323E+06	8904.22	2.611E+06	0.17

TABLE 12: STANDARD CYLINDER TEST AND RESONANT COLUMN TEST DATA LIFT 2

Cylinder ID	Date / Time	Age (Days)	Weight (lb.)	Length (in.)	Diameter (in.)	Compressive Strength (psi)	Longitudinal		Torsional		Unit Weight (pci)	Vc	Dynamic E	Static E	Vs	G	Poisson's Ratio
							Frequency	Bandwidth	Frequency	Bandwidth							
							(kHz)	(Hz)	(kHz)	(Hz)		(fps)	(psi)	(psi)	(fps)	(psi)	
150 2-12	2/12/2005 14:50	1	30.03	12.03	5.97	960	5.09	208.00	3.20	118.00	0.090	10203.45	3.475E+06	1.969E+06	6416.00	1.374E+06	0.28
151 2-12	2/12/2005 14:55	1	29.99	11.97	6.01	660	4.86	203.00	3.00	120.00	0.088	9697.70	3.082E+06	1.588E+06	5981.01	1.172E+06	0.32
153 2-13	2/13/2005 14:01	2	29.98	12.10	5.99	1840	5.89	176.00	3.68	124.50	0.089	11865.20	4.691E+06	2.718E+06	7424.31	1.837E+06	0.26
152 2-13	2/13/2005 14:15	2	30.12	12.00	5.99	1860	5.89	174.50	3.70	104.50	0.089	11770.00	4.605E+06	2.723E+06	7390.00	1.815E+06	0.25
155 2-14	2/14/2005 11:40	3	28.22	11.31	5.98	2140	6.25	177.00	3.93	115.00	0.079	11779.37	4.078E+06	2.429E+06	7408.05	1.613E+06	0.25
150 2-15	2/15/2005 9:22	4	30.13	12.03	5.97	3140	6.32	137.00	3.98	96.50	0.090	12665.59	5.370E+06	3.576E+06	7979.90	2.132E+06	0.16
151 2-15	2/15/2005 9:26	4	30.05	12.03	5.97	2790	6.35	146.00	3.96	100.50	0.090	12725.74	5.410E+06	3.360E+06	7933.79	2.103E+06	0.20
152 2-16	2/16/2005 11:37	5	29.84	11.97	5.98	2960	6.37	159.00	4.01	97.00	0.088	12710.15	5.314E+06	3.382E+06	8003.94	2.107E+06	0.20
153 2-16	2/16/2005 11:40	5	30.08	12.00	5.98	3000	6.57	165.00	4.11	104.50	0.089	13132.00	5.733E+06	3.459E+06	8228.00	2.251E+06	0.23
155 2-17	2/17/2005 9:20	6	29.81	11.97	5.99	2760	6.35	156.50	3.98	112.00	0.088	12668.25	5.265E+06	3.253E+06	7932.12	2.064E+06	0.21
154 2-17	2/17/2005 9:23	6	29.92	12.03	5.99	2980	6.43	155.50	4.04	101.00	0.089	12900.17	5.499E+06	3.416E+06	8104.21	2.170E+06	0.21
150 2-18	2/18/2005 9:20	7	29.30	11.70	5.99	3720	6.88	142.00	4.35	94.00	0.084	13410.15	5.655E+06	3.544E+06	8480.55	2.262E+06	0.22
151 2-18	2/18/2005 9:22	7	29.17	11.60	5.98	3290	6.81	151.00	4.27	102.00	0.084	13164.07	5.409E+06	3.296E+06	8251.47	2.125E+06	0.22
156 2-18	2/18/2005 9:24	7	27.27	11.75	6.00	2750	6.50	178.00	4.01		0.079	12723.29	4.748E+06	2.744E+06	7845.08	1.805E+06	0.24
153 2-21	2/21/2005 9:27	10	29.10	11.53	5.99	3610	6.84	138.50	4.39	65.50	0.083	13146.12	5.334E+06	3.395E+06	8443.80	2.201E+06	0.23
152 2-21	2/21/2005 9:35	10	30.04	11.94	5.99	3670	6.65	131.50	4.22	92.80	0.089	13241.46	5.785E+06	3.783E+06	8399.79	2.328E+06	0.19
154 2-25	2/25/2005 13:55	14	29.70	11.94	5.98	3420	6.71	123.00	4.25	84.00	0.088	13348.92	5.829E+06	3.605E+06	8449.54	2.336E+06	0.23
155 2-25	2/25/2005 13:51	14	28.12	11.38	6.00	3460	7.11	154.00	4.38	100.00	0.079	13493.84	5.334E+06	3.073E+06	8307.40	2.022E+06	0.24

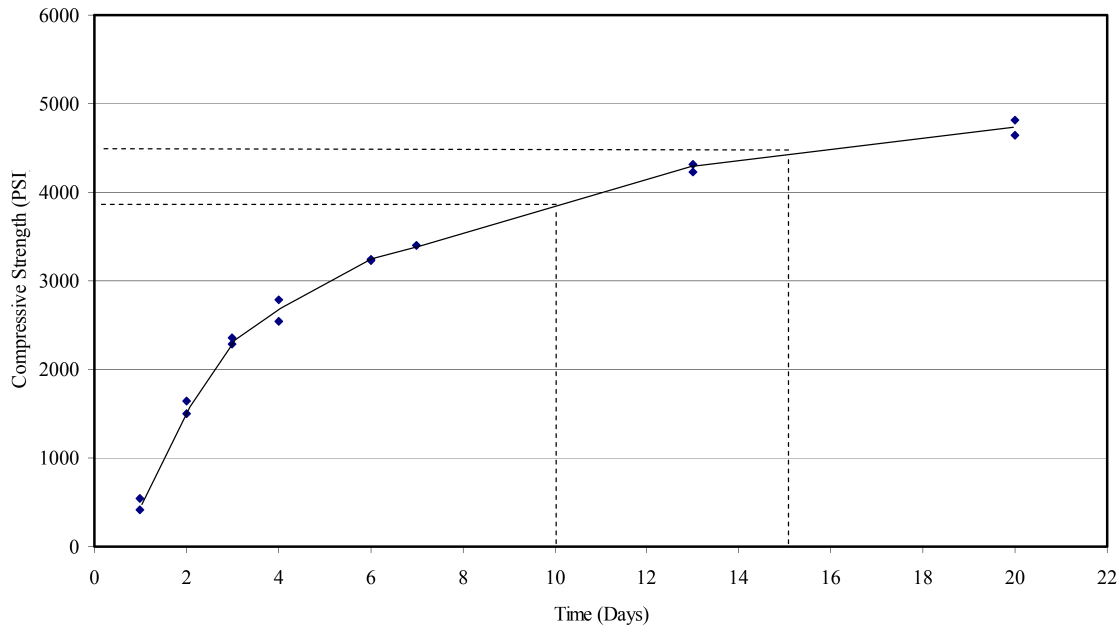


FIGURE 6: LIFT 1 CYLINDER TEST DATA
COMPRESSIVE STRENGTH VS. TIME

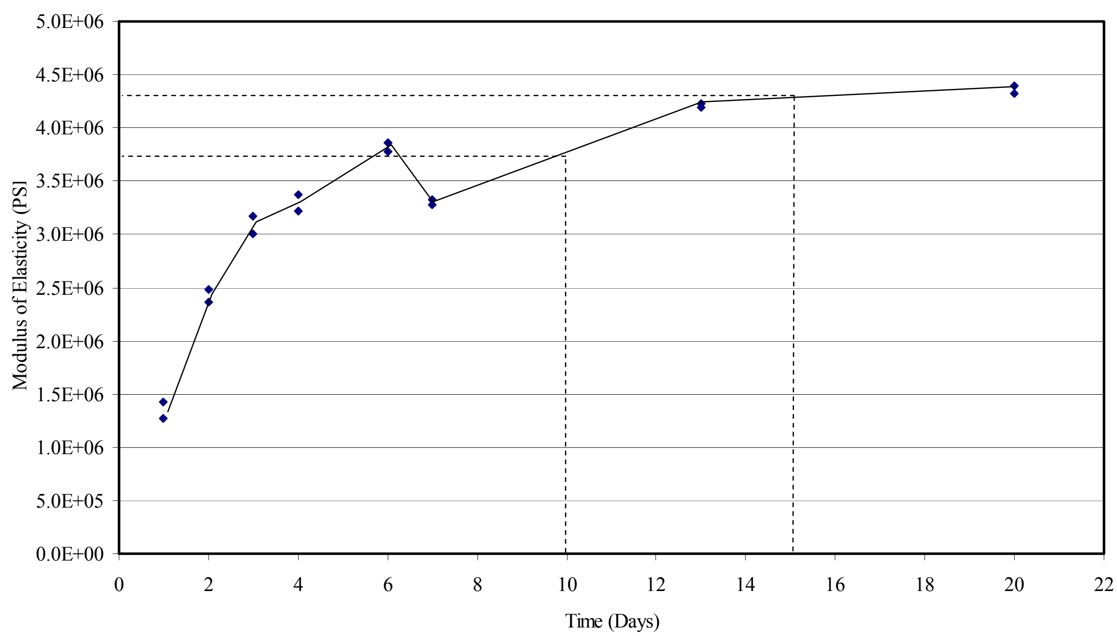


FIGURE 7: LIFT 1 CYLINDER TEST DATA
MODULUS OF ELASTICITY VS. TIME

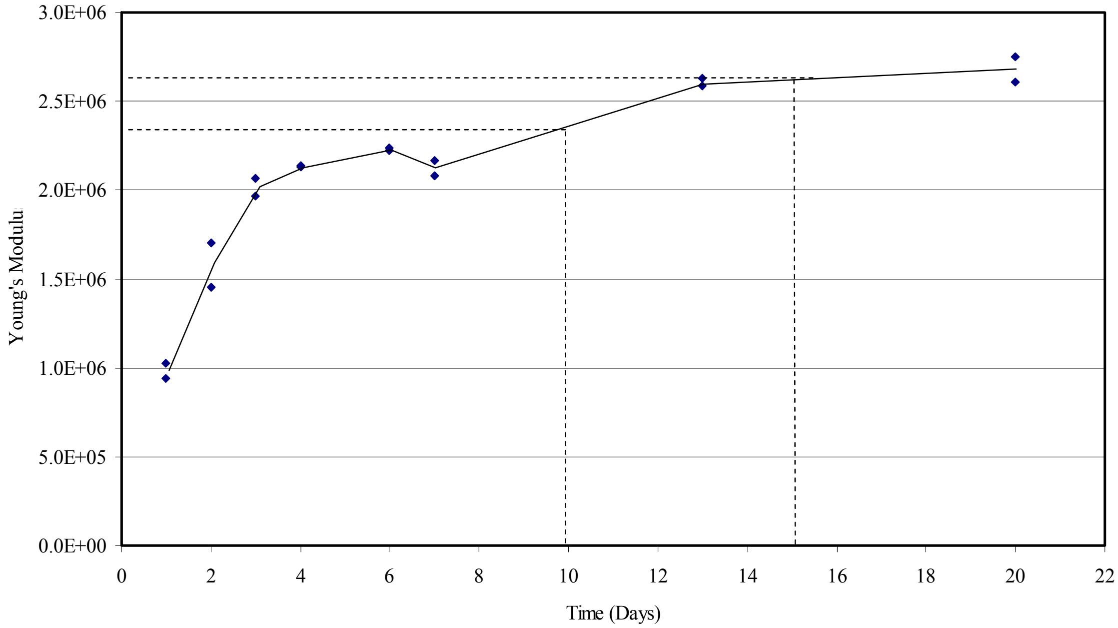


FIGURE 8: LIFT 1 CYLINDER TEST DATA
SHEAR MODULUS VS. TIME

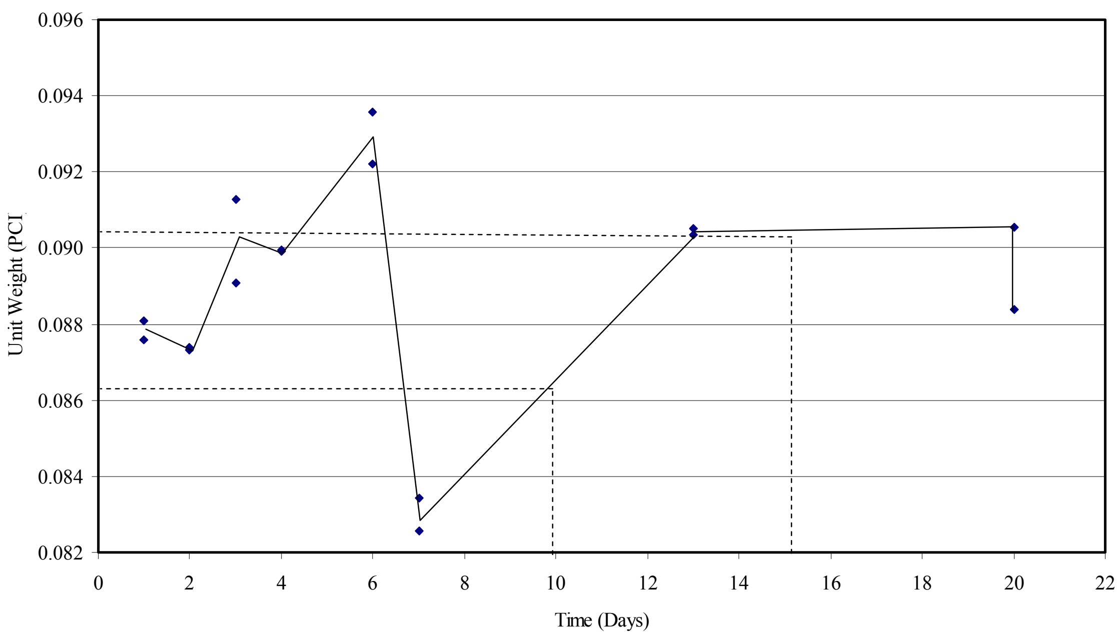


FIGURE 9: LIFT 1 CYLINDER TEST DATA
UNIT WEIGHT VS. TIME

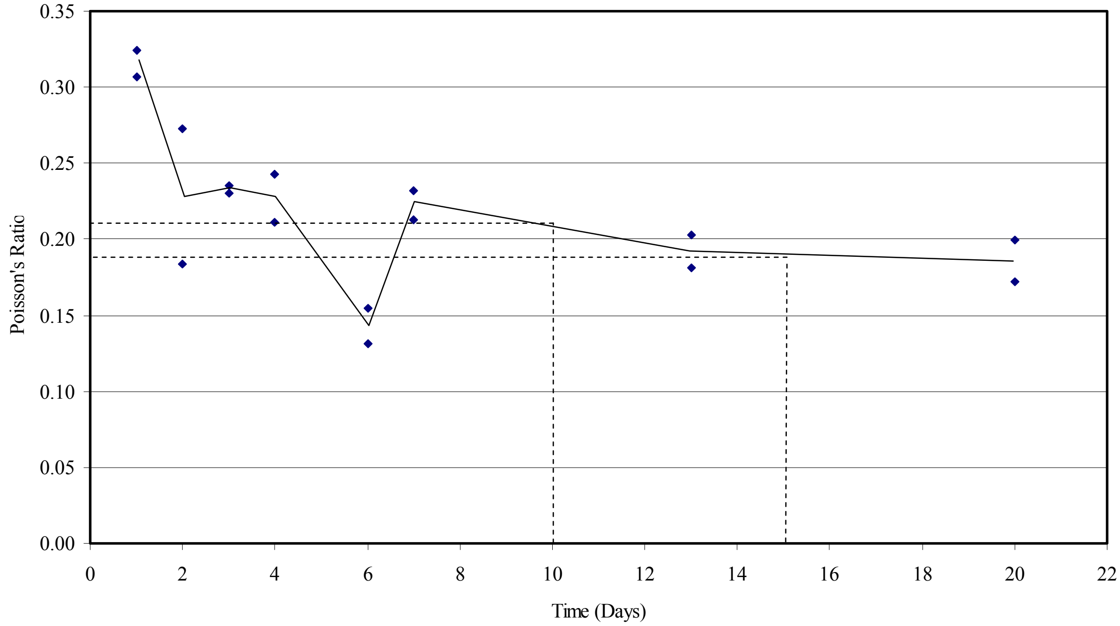


FIGURE 10: LIFT 1 CYLINDER TEST DATA
POISSON'S RATIO VS. TIME

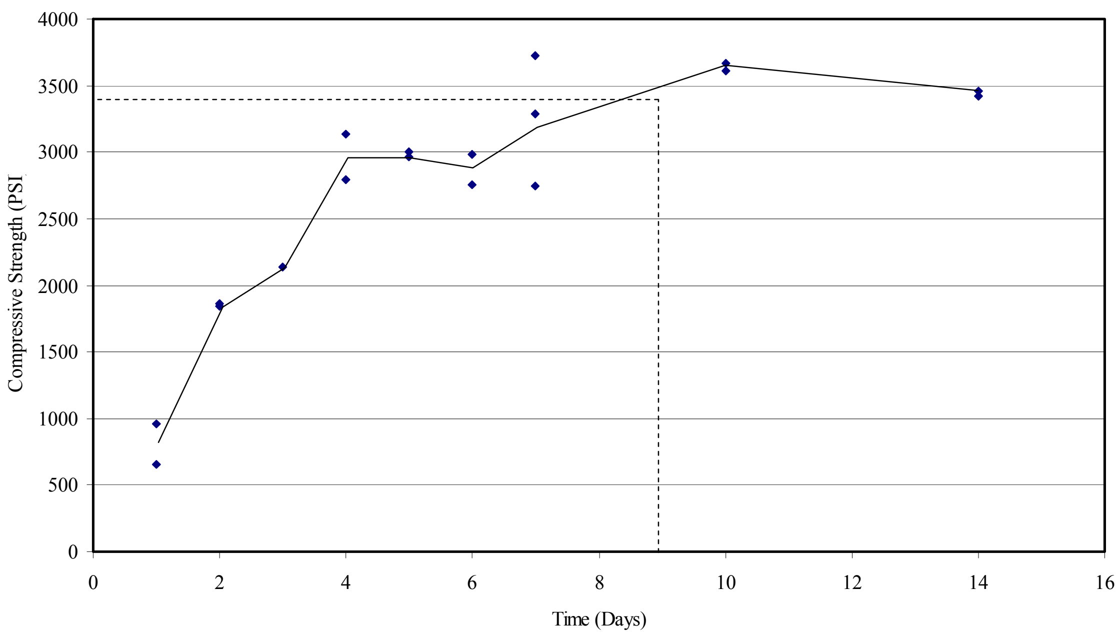


FIGURE 11: LIFT 2 CYLINDER TEST DATA
COMPRESSIVE STRENGTH VS. TIME

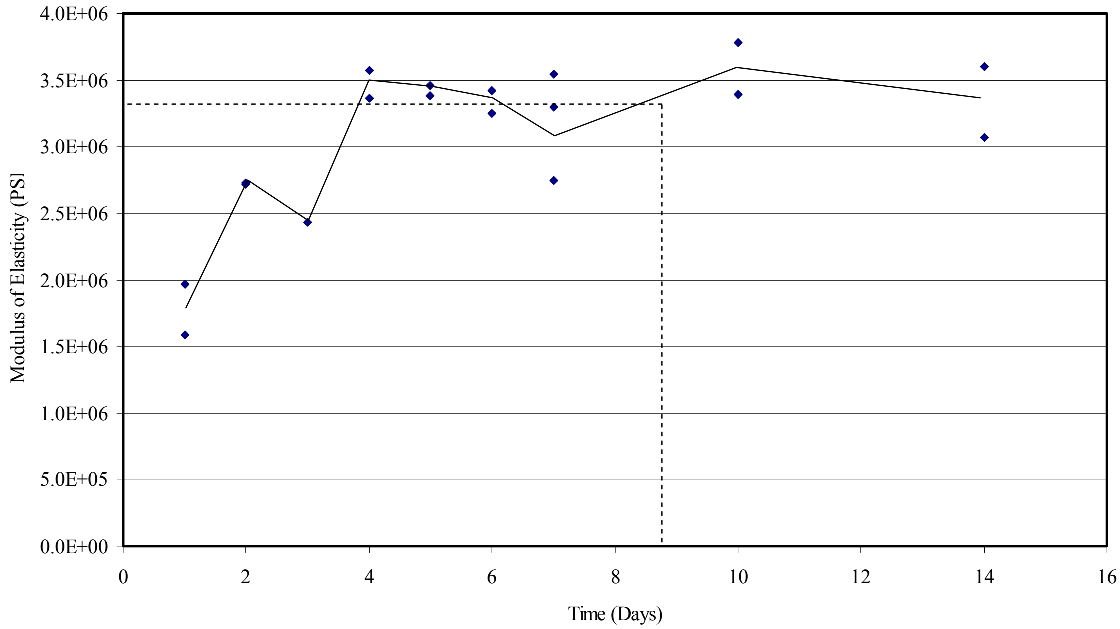


FIGURE 12: LIFT 2 CYLINDER TEST DATA
MODULUS OF ELASTICITY VS. TIME

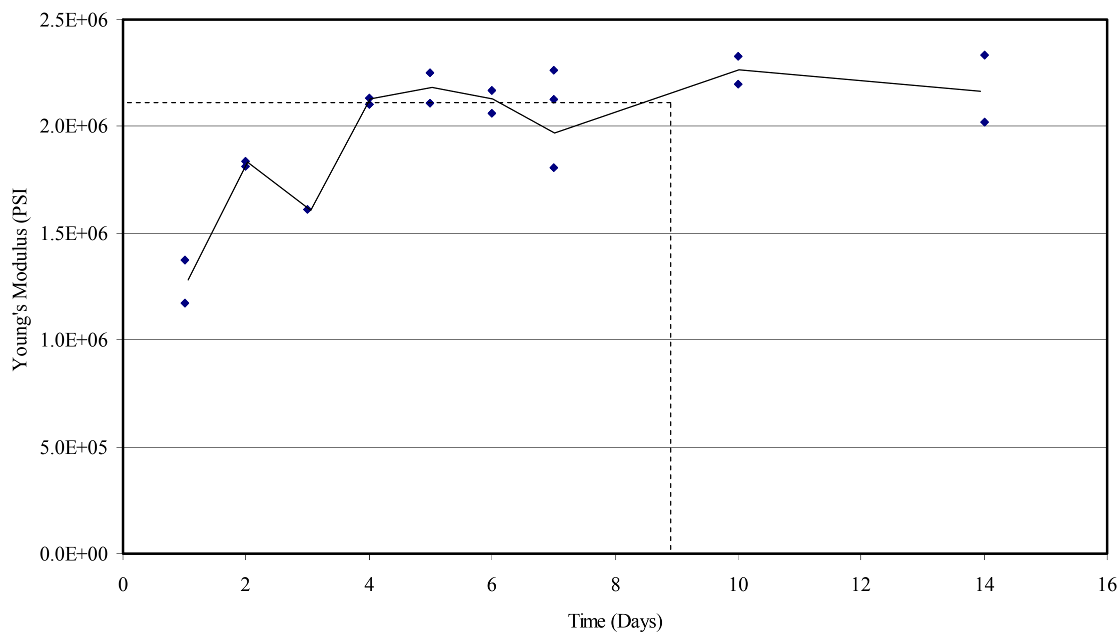


FIGURE 13: LIFT 2 CYLINDER TEST DATA
YOUNG'S MODULUS VS. TIME

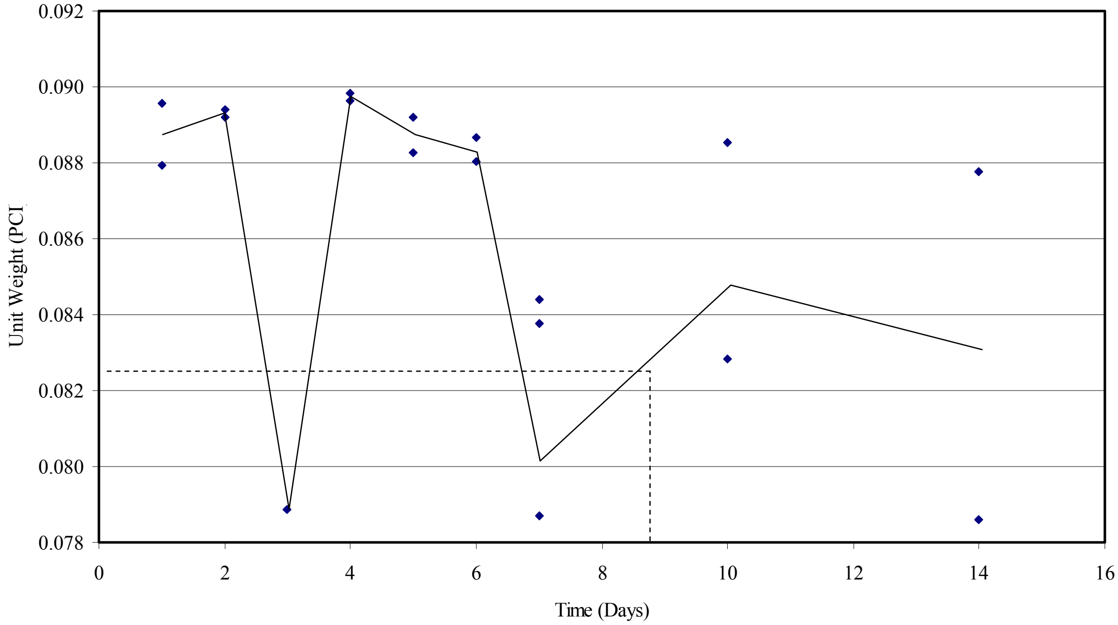


FIGURE 14: LIFT 2 CYLINDER TEST DATA
UNIT WEIGHT VS. TIME

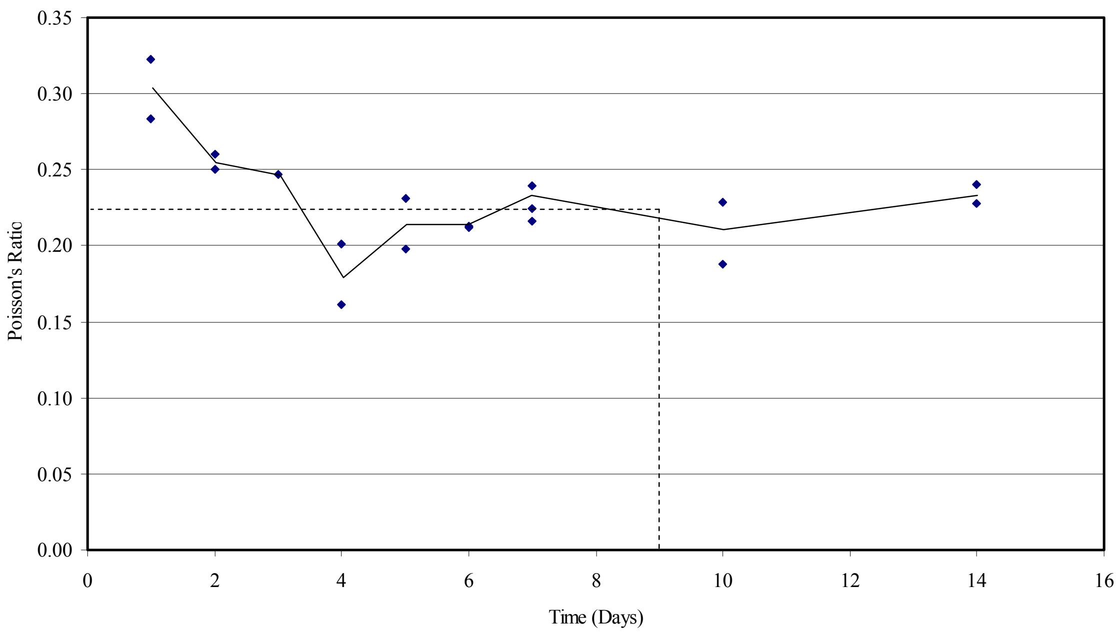


FIGURE 15: LIFT 2 CYLINDER TEST DATA
POISSON'S RATIO VS. TIME

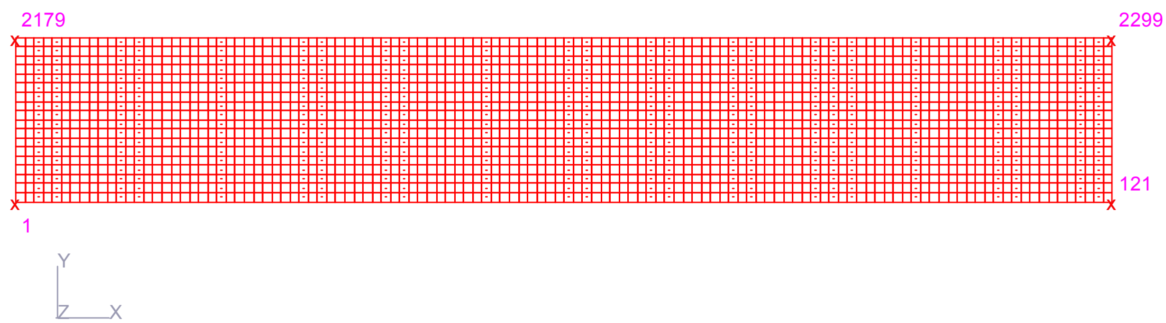


FIGURE 16: GTSTRUDL MODEL GENERATED FOR LIFT 1

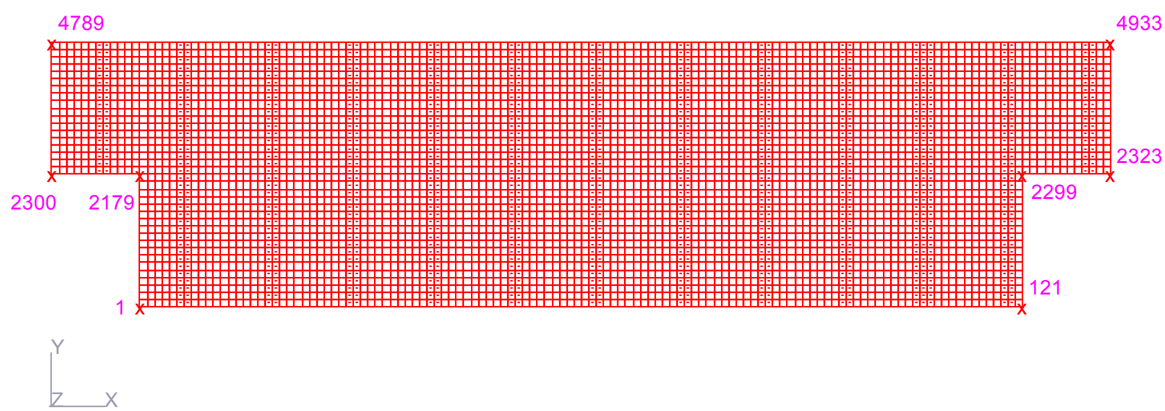


FIGURE 17: GTSTRUDL MODEL GENERATED FOR LIFT 1 AND LIFT 2

When restricting a finite element analysis to two dimensions, an important task is to define the boundary conditions of the third direction, the “out-of-plane” direction (Emborg 1998). A finite element mesh of two-inch plane stress and plane strain element squares was chosen for both concrete lifts. The stress analysis of very long solids such as concrete dams or walls whose geometry and loading are constant in the longest dimension falls into the category of plane strain problems (Huebner 1975). In these kinds of problems stresses and displacements can be determined by studying only a unit-thickness slice of the solid in the x-y plane (Huebner 1975). The GTSTRUDL plane strain element that was used in the finite element model was ‘PSHQ’, which is a hybrid quadrilateral element with four nodes and two degrees of freedom, u_1 and u_2 at each joint.

When the finite element mesh for each lift was developed, a decision needed to be made on what temperature and time period was to be analyzed. In the early period of concrete age, 24 to 36 hours, most of the hardening and most of the heating development takes place (Springenschmid and Breitenbucher 1998). The highest temperatures can be seen in the center of the concrete section, as previously discussed. It is known that the highest compression stresses are seen in the center of the mass concrete section during the time of highest temperature (Springenschmid and Breitenbucher 1998). As the expansion effect on the mass concrete takes place, tensile stresses develop (Springenschmid and Breitenbucher 1998). It was also known that the highest tensile stresses would be seen during the time of cooling (Springenschmid and Breitenbucher 1998). Two separate thermal loading conditions were modeled for each lift to account for the above behaviors. The first loading condition modeled for each lift was the time of

the highest thermocouple temperature reading. The second loading condition modeled for each lift was a time after the highest temperature, a time where the concrete had been cooling for a couple of days. For the first lift the time modeled for cooling was the day before the second lift was placed. For the second lift the time modeled for cooling was nine days after placement.

For lift one, the highest thermocouple temperature readings were on the second day after placement at 8:30 AM. The highest readings were shown at this time on the rigid thermocouple pairs numbered one and four (see Figure 2). The first finite element section was taken at this location and time. The following sections in the model were taken in concurrence with the first location for accuracy, but at different time periods. The times and locations for the four finite element input files developed are shown in Table 13.

TABLE 13: DATE AND TIME OF GTSTRUDL MODELS

LIFT	DATE	AGE (DAYS)	THERMOCOUPLE TYPE	THERMOCOUPLE NUMBER	TIME
1	02/06/05	2	SST RIGID PAIR	1,4	8:30 AM
1	02/10/05	6	SST RIGID PAIR	1,4	4:30 PM
2	02/14/05	3	SST RIGID PAIR	13,14	12:45PM
1	02/14/05	10	LONG-TERM	5,7,10, 11	12:45 PM
2	02/20/05	9	SST RIGID PAIR	13,14	6:00 PM
1	02/20/05	16	LONG-TERM	5,7,10,11	6:00 PM

Note: The long-term thermocouples were used for lift 1 temperatures 7 days after placement.

External boundary conditions for each lift of the finite element model were established in GTSTRUDL according to field conditions. For lift one only, the top of the concrete section is defined as free, and the other three sides cast against the ground are fixed. Lift two also has the same boundary conditions as stated above, after it is placed. However, after lift two is cast, the boundary conditions for lift one change. The top boundary of lift one is no longer free, it is connected to lift two. Figure 1, Figure 16, and Figure 17 may visually aid in understanding the boundary conditions.

Now that the boundary conditions have been established for the model, the type of element has been decided, the time to analyze the model has been obtained, and the temperature data/mechanical properties have been determined for each time period, only one final detail remains to be established. Since GTSTRUDL does not distribute temperature loading throughout the model using heat of hydration equations, a determination of how the temperature values, which are read from the thermocouple locations, should be distributed throughout the model, needed to be made. A linear heat distribution from thermocouple readings to boundary conditions was assumed for each concrete section. This assumption was validated by an ACI 207 Committee Member, Floyd Best, who was familiar with the test pad analysis. Floyd stated, “The thermal gradient remains essentially linear from the center of the mass to the external boundaries, providing the mass is a cube or sphere, and that all external boundaries are at the same ambient temperature”. ACI 224R-01 states that boundary temperatures in a finite element model cast against earth may be determined by using average earth temperatures from the National Weather Service. The average temperature used for earth boundary

conditions was 58 degrees Fahrenheit for the project location. The surface (external) joint temperatures were taken as an average of the linear distributed temperatures at a depth of two inches and ambient temperature. An Excel file was created to replicate every joint in the finite element model, and distribute the temperatures throughout. Another large Excel model was made to illustrate the change in temperature between the time the concrete was cast and the time the model was developed for each case. The Excel model values representing the change in temperature were then input into every joint of the GTSTRUDL finite element model. The Excel models for each of the four finite element sections are shown in Table 14 through Table 19. The Excel models are shown with breaks in them for clarity. Thermocouple locations are highlighted on Table 14 through 19 in yellow and the connection area between two lifts is highlighted in purple. Since there were no thermocouples placed directly in the center of each concrete section a temperature value had to be assumed. These values are highlighted in blue.

The center temperature values were assumed using simple algebraic expressions based on finite element model joints, boundary condition temperatures, and thermocouple locations. The analyses shown in Figure 18 illustrates the calculations performed to acquire the center of mass temperature for lift one (day 2).

TABLE 14: EXCEL MODEL FOR LIFT 1, DAY 2

02/06/05 @ 8:30 AM

Nodes

2179	2180	2181	2182	2209	2210	2211	2212	2213	2214	2215	2216	2217	2235	2236	2237	2238	2239	2240	2241	2242	2243	2261	2262	2263	2264	2265	2266	2267	2268	2269	2296	2297	2298	2299
2058	2059	2060	2061	2088	2089	2090	2091	2092	2093	2094	2095	2096	2114	2115	2116	2117	2118	2119	2120	2121	2122	2140	2141	2142	2143	2144	2145	2146	2147	2148	2175	2176	2177	2178
1937	1938	1939	1940	1967	1968	1969	1970	1971	1972	1973	1974	1975	1993	1994	1995	1996	1997	1998	1999	2000	2001	2019	2020	2021	2022	2023	2024	2025	2026	2027	2054	2055	2056	2057
1816	1817	1818	1819	1846	1847	1848	1849	1850	1851	1852	1853	1854	1872	1873	1874	1875	1876	1877	1878	1879	1880	1898	1899	1900	1901	1902	1903	1904	1905	1906	1933	1934	1935	1936
1695	1696	1697	1698	1725	1726	1727	1728	1729	1730	1731	1732	1733	1751	1752	1753	1754	1755	1756	1757	1758	1759	1777	1778	1779	1780	1781	1782	1783	1784	1785	1812	1813	1814	1815
1574	1575	1576	1577	1604	1605	1606	1607	1608	1609	1610	1611	1612	1630	1631	1632	1633	1634	1635	1636	1637	1638	1656	1657	1658	1659	1660	1661	1662	1663	1664	1691	1692	1693	1694
1453	1454	1455	1456	1483	1484	1485	1486	1487	1488	1489	1490	1491	1509	1510	1511	1512	1513	1514	1515	1516	1517	1535	1536	1537	1538	1539	1540	1541	1542	1543	1570	1571	1572	1573
1332	1333	1334	1335	1362	1363	1364	1365	1366	1367	1368	1369	1370	1388	1389	1390	1391	1392	1393	1394	1395	1396	1414	1415	1416	1417	1418	1419	1420	1421	1422	1449	1450	1451	1452
1211	1212	1213	1214	1241	1242	1243	1244	1245	1246	1247	1248	1249	1267	1268	1269	1270	1271	1272	1273	1274	1275	1293	1294	1295	1296	1297	1298	1299	1300	1301	1328	1329	1330	1331
1090	1091	1092	1093	1120	1121	1122	1123	1124	1125	1126	1127	1128	1146	1147	1148	1149	1150	1151	1152	1153	1154	1172	1173	1174	1175	1176	1177	1178	1179	1180	1207	1208	1209	1210
969	970	971	972	999	1000	1001	1002	1003	1004	1005	1006	1007	1025	1026	1027	1028	1029	1030	1031	1032	1033	1051	1052	1053	1054	1055	1056	1057	1058	1059	1086	1087	1088	1089
848	849	850	851	878	879	880	881	882	883	884	885	886	904	905	906	907	908	909	910	911	912	930	931	932	933	934	935	936	937	938	965	966	967	968
727	728	729	730	757	758	759	760	761	762	763	764	765	783	784	785	786	787	788	789	790	791	809	810	811	812	813	814	815	816	817	844	845	846	847
606	607	608	609	636	637	638	639	640	641	642	643	644	662	663	664	665	666	667	668	669	670	688	689	690	691	692	693	694	695	696	723	724	725	726
485	486	487	488	515	516	517	518	519	520	521	522	523	541	542	543	544	545	546	547	548	549	567	568	569	570	571	572	573	574	575	602	603	604	605
364	365	366	367	394	395	396	397	398	399	400	401	402	420	421	422	423	424	425	426	427	428	446	447	448	449	450	451	452	453	454	481	482	483	484
243	244	245	246	273	274	275	276	277	278	279	280	281	299	300	301	302	303	304	305	306	307	325	326	327	328	329	330	331	332	333	360	361	362	363
122	123	124	125	152	153	154	155	156	157	158	159	160	178	179	180	181	182	183	184	185	186	204	205	206	207	208	209	210	211	212	239	240	241	242
1	2	3	4	31	32	33	34	35	36	37	38	39	57	58	59	60	61	62	63	64	65	83	84	85	86	87	88	89	90	91	118	119	120	121

Temp Ambient 33.00

58.00	45.79	46.07	46.36	54.10	54.39	54.68	54.96	55.25	55.27	55.28	55.30	55.32	55.63	55.65	55.67	55.68	55.70	55.72	55.73	55.75	55.77	56.08	56.10	56.12	56.13	56.15	55.84	55.52	55.21	54.90	46.44	46.13	45.81	58.00
58.00	58.57	59.15	59.72	75.21	75.78	76.35	76.93	77.50	77.53	77.57	77.60	77.64	78.26	78.30	78.33	78.37	78.40	78.43	78.47	78.50	78.54	79.16	79.20	79.23	79.27	79.30	78.67	78.05	77.42	76.79	59.88	59.25	58.63	58.00
58.00	58.60	59.20	59.80	75.95	76.55	77.15	77.75	78.34	78.46	78.57	78.68	78.80	80.84	80.95	81.06	81.18	81.29	81.23	81.18	81.12	81.06	80.06	80.00	79.95	79.89	79.83	79.19	78.55	77.91	77.26	59.93	59.28	58.64	58.00
58.00	58.62	59.25	59.87	76.70	77.32	77.94	78.57	79.19	79.38	79.57	79.76	79.96	83.41	83.60	83.79	83.99	84.18	84.03	83.88	83.74	83.59	80.95	80.81	80.66	80.51	80.37	79.71	79.05	78.39	77.74	59.97	59.32	58.66	58.00
58.00	58.65	59.30	59.94	77.44	78.09	78.74	79.39	80.03	80.30	80.57	80.84	81.12	85.98	86.26	86.53	86.80	87.07	86.83	86.59	86.36	86.12	81.85	81.61	81.37	81.14	80.90	80.23	79.55	78.88	78.21	60.02	59.35	58.67	58.00
58.00	58.67	59.35	60.02	78.19	78.86	79.53	80.20	80.88	81.23	81.58	81.93	82.27	88.56	88.91	89.26	89.61	89.96	89.63	89.30	88.97	88.64	82.74	82.42	82.09	81.76	81.43	80.74	80.05	79.37	78.68	60.07	59.38	58.69	58.00
58.00	58.70	59.40	60.09	78.93	79.63	80.33	81.02	81.72	82.15	82.58	83.01	83.43	91.13	91.56	91.99	92.42	92.84	92.43	92.01	91.59	91.17	83.64	83.22	82.80	82.39	81.97	81.26	80.56	79.85	79.15	60.11	59.41	58.70	58.00
58.00	58.72	59.45	60.17	79.68	80.40	81.12	81.84	82.57	83.07	83.58	84.09	84.59	93.71	94.21	94.72	95.23	95.73	95.22	94.72	94.21	93.70	84.54	84.03	83.52	83.01	82.50	81.78	81.06	80.34	79.62	60.16	59.44	58.72	58.00
58.00	58.75	59.49	60.24	80.42	81.17	81.92	82.66	83.41	84.00	84.58	85.17	85.75	96.28	96.87	97.45	98.04	98.62	98.02	97.42	96.82	96.22	85.43	84.83	84.23	83.63	83.03	82.30	81.56	80.82	80.09	60.21	59.47	58.74	58.00
58.00	58.77	59.54	60.32	81.17	81.94	82.71	83.48	84.26	84.92	85.58	86.25	86.91	98.86	99.52	100.18	100.85	101.51	100.82	100.13	99.44	98.75	86.33	85.64	84.95	84.26	83.57	82.81	82.06	81.31	80.56	60.26	59.50	58.75	58.00
58.00	58.80	59.59	60.39	81.91	82.71	83.51	84.30	85.10	85.84	86.58	87.33	88.07	101.43	102.17	102.92	103.66	104.40	103.62	102.84	102.06	101.28	87.22	86.44	85.66	84.88	84.10	83.33	82.56	81.80	81.03	60.30	59.54	58.77	58.00
58.00	58.70	59.39	60.09	78.92	79.62	80.32	81.02	81.71	82.36	83.01	83.66	84.31	96.00	96.65	97.30	97.95	98.60	97.92	97.23	96.55	95.87	83.57	82.89	82.20	81.52	80.84	80.17	79.49	78.82	78.15	60.02	59.34	58.67	58.00
58.00	58.60	59.20	59.79	75.93	76.53	77.13	77.73	78.33	78.88	79.44	80.00	80.55	90.57	91.13	91.69	92.24	92.80	92.21	91.63	91.04	90.46	79.92	79.33	78.75	78.16	77.58	77.00	76.42	75.85	75.27	59.73	59.15	58.58	58.00
58.00	58.50	59.00	59.49	72.94	73.44	73.94	74.44	74.94	75.40	75.87	76.33	76.79	85.14	85.61	86.07	86.54	87.00	86.51	86.02	85.54	85.05	76.26	75.78	75.29	74.80	74.31	73.83	73.35	72.87	72.39	59.44	58.96	58.48	58.00
58.00	58.40	58.80	59.20	69.96	70.35	70.75	71.15	71.55	71.92	72.29	72.66	73.03	79.72	80.09	80.46	80.83	81.20	80.81	80.42	80.03	79.64	72.61	72.22	71.83	71.44	71.05	70.67	70.28	69.90	69.51	59.15	58.77	58.38	58.00
58.00	58.30	58.60	58.90	66.97	67.27	67.56	67.86	68.16	68.44	68.72	69.00	69.28	74.29	74.56	74.84	75.12	75.40	75.11	74.81	74.52	74.23	68.96	68.67	68.37	68.08	67.79	67.50	67.21	66.92	66.64	58.86	58.58	58.29	58.00
58.00	58.20	58.40	58.60	63.98	64.18	64.38	64.58	64.78	64.96	65.15	65.33	65.52	68.86	69.04	69.23	69.41	69.60	69.40	69.21	69.01	68.82	65.31	65.11	64.92	64.72	64.53	64.33	64.14	63.95	63.76	58.58	58.38	58.19	58.00
58.00	58.10	58.20	58.30	60.99	61.09	61.19	61.29	61.39	61.48	61.57	61.67	61.76	63.43	63.52	63.61	63.71	63.80	63.70	63.60	63.51	63.41	61.65	61.56	61.46	61.36	61.26	61.17	61.07	60.97	60.88	58.29	58.19	58.10	58.00
58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00

Delta Pour Temp 55

3.00	-9.21	-8.93	-8.64	-0.90	-0.61	-0.32	-0.04	0.25	0.27	0.28	0.30	0.32	0.63	0.65	0.67	0.68	0.70	0.72	0.73	0.75	0.77	1.08	1.10	1.12	1.13	1.15	0.84	0.52	0.21	-0.10	-8.56	-8.87	-9.19	3.00
3.00	3.57	4.15	4.72	20.21	20.78	21.35	21.93	22.50	22.53	22.57	22.60	22.64	23.26	23.30	23.33	23.37	23.40	23.43	23.47	23.50	23.54	24.16	24.20	24.23	24.27	24.30	23.67	23.05	22.42	21.79	4.88	4.25	3.63	3.00
3.00	3.60	4.20	4.80	20.95	21.55	22.15	22.75	23.34	23.46	23.57	23.68	23.80	25.84	25.95	26.06	26.18	26.29	26.23	26.18	26.12	26.06	25.06	25.00	24.95	24.89	24.83	24.19	23.55	22.91	22.26	4.93	4.28	3.64	3.00
3.00	3.62	4.25	4.87	21.70	22.32	22.94	23.57	24.19	24.38	24.57	24.76	24.96	28.41	28.60	28.79	28.99	29.18	29.03	28.88	28.74	28.59	25.95	25.81	25.66	25.51	25.37	24.71	24.05	23.39	22.74	4.97	4.32	3.66	3.00
3.00	3.65	4.30	4.94	22.44	23.09	23.74	24.39	25.03	25.30	25.57	25.84	26.12	30.98	31.26	31.53	31.80	32.07	31.83	31.59	31.36	31.12	26.85	26.61	26.37	26.14	25.90	25.23	24.55	23.88	23.21	5.02	4.35	3.67	3.00
3.00	3.67	4.35	5.02	23.19	23.86	24.53	25.20	25.88	26.23	26.58	26.93	27.27	33.56	33.91	34.26	34.61	34.96	34.63	34.30	33.97	33.64	27.74	27.42	27.09	26.76	26.43	25.74	25.05	24.37	23.68	5.07	4.38	3.69	3.00
3.00	3.70	4.40	5.09	23.93	24.63	25.33	26.02	26.72	27.15	27.58	28.01	28.43	36.13	36.56	36.99	37.42	37.84	37.43	37.01	36.59	36.17	28.64	28.22	27.80	27.39	26.97	26.26	25.56	24.85	24.15	5.11	4.41	3.70	3.00
3.00	3.72	4.45	5.17	24.68	25.40	26.12	26.84	27.57	28.07	28.58	29.09	29.59	38.71	39.21	39.72	40.23	40.73	40.22	39.72	39.21	38.70	29.54	29.03	28.52	28.01	27.50	26.78	26.06	25.34	24.62	5.16	4.44	3.72	3.00
3.00	3.75	4.49	5.24	25.42	26.17	26.92	27.66	28.41	29.00	29.58	30.17	30.75	41.28	41.87	42.45	43.04	43.62	43.02	42.42	41.82	41.22	30.43	29.83	29.23	28.63	28.03	27.30	26.56	25.82	25.09	5.21	4.47	3.74	3.00
3.00	3.77	4.54	5.32	26.17	26.94	27.71	28.48	29.26	29.92	30.58	31.25	31.91	43.86	44.52	45.18	45.85	46.51	45.82	45.13	44.44	43.75	31.33	30.64	29.95	29.26	28.57	27.81	27.06	26.31	25.56	5.26	4.50	3.75	3.00
3.00	3.80	4.59	5.39	26.91	27.71	28.51	29.30	30.10	30.84	31.58	32.33	33.07	46.43	47.17	47.92	48.66	49.40	48.62	47.84	47.06	46.28	32.22	31.44	30.66	29.88	29.10	28.33	27.56	26.80	26.03	5.30	4.54	3.77	3.00
3.00	3.70	4.39	5.09	23.92	24.62	25.32	26.02	26.71	27.36	28.01	28.66	29.31	41.00	41.65	42.30	42.95	43.60	42.92	42.23	41.55	40.87	28.57	27.89	27.20	26.52	25.84	25.17	24.49	23.82	23.15	5.02	4.34	3.67	3.00
3.00	3.60	4.20	4.79	20.93	21.53	22.13	22.73	23.33	23.88	24.44	25.00	25.55	35.57	36.13	36.69	37.24	37.80	37.21	36.63	36.04	35.46	24.92	24.33	23.75	23.16	22.58	22.00	21.42	20.85	20.27	4.73	4.15	3.58	3.00
3.00	3.50	4.00	4.49	17.94	18.44	18.94	19.44	19.94	20.40	20.87	21.33	21.79	30.14	30.61	31.07	31.54	32.00	31.51	31.02	30.54	30.05	21.26	20.78	20.29	19.80	19.31	18.83	18.35	17.87	17.39	4.44	3.96	3.48	3.00
3.00	3.40	3.80	4.20	14.96	15.35	15.75	16.15	16.55	16.92	17.29	17.66	18.03	24.72	25.09	25.46	25.83	26.20	25.81	25.42	25.03	24.64	17.61	17.22	16.83	16.44	16.05	15.67	15.28	14.90	14.51	4.15	3.77	3.38	3.00
3.00	3.30	3.60	3.90	11.97	12.27	12.56	12.86	13.16	13.44	13.72	14.00	14.28	19.29	19.56	19.84	20.12	20.40	20.11	19.81	19.52	19.23	13.96	13.67	13.37	13.08	12.79	12.50	12.21	11.92	11.64	3.86	3.58	3.29	3.00
3.00	3.20	3.40	3.60	8.98	9.18	9.38	9.58	9.77	9.96	10.15	10.33	10.52	13.86	14.04	14.23	14.41	14.60	14.40	14.21	14.01	13.82	10.31	10.11	9.92	9.72	9.52	9.33	9.14	8.95	8.76	3.58	3.38	3.19	3.00
3.00	3.10	3.20	3.30	5.99	6.09	6.19	6.29	6.39	6.48	6.57	6.67	6.76	8.43	8.52	8.61	8.71	8.80	8.70	8.60	8.51	8.41	6.65	6.56	6.46	6.36	6.26	6.17	6.07	5.97	5.88	3.29	3.19	3.10	3.00
3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00

TABLE 15: EXCEL MODEL FOR LIFT 1, DAY 6

02/10/05 @ 4:30 PM

Nodes

2179	2180	2181	2182	2209	2210	2211	2212	2213	2214	2215	2216	2217	2235	2236	2237	2238	2239	2240	2241	2242	2243	2261	2262	2263	2264	2265	2266	2267	2268	2269	2296	2297	2298	2299
2058	2059	2060	2061	2088	2089	2090	2091	2092	2093	2094	2095	2096	2114	2115	2116	2117	2118	2119	2120	2121	2122	2140	2141	2142	2143	2144	2145	2146	2147	2148	2175	2176	2177	2178
1937	1938	1939	1940	1967	1968	1969	1970	1971	1972	1973	1974	1975	1993	1994	1995	1996	1997	1998	1999	2000	2001	2019	2020	2021	2022	2023	2024	2025	2026	2027	2054	2055	2056	2057
1816	1817	1818	1819	1846	1847	1848	1849	1850	1851	1852	1853	1854	1872	1873	1874	1875	1876	1877	1878	1879	1880	1898	1899	1900	1901	1902	1903	1904	1905	1906	1933	1934	1935	1936
1695	1696	1697	1698	1725	1726	1727	1728	1729	1730	1731	1732	1733	1751	1752	1753	1754	1755	1756	1757	1758	1759	1777	1778	1779	1780	1781	1782	1783	1784	1785	1812	1813	1814	1815
1574	1575	1576	1577	1604	1605	1606	1607	1608	1609	1610	1611	1612	1630	1631	1632	1633	1634	1635	1636	1637	1638	1656	1657	1658	1659	1660	1661	1662	1663	1664	1691	1692	1693	1694
1453	1454	1455	1456	1483	1484	1485	1486	1487	1488	1489	1490	1491	1509	1510	1511	1512	1513	1514	1515	1516	1517	1535	1536	1537	1538	1539	1540	1541	1542	1543	1570	1571	1572	1573
1332	1333	1334	1335	1362	1363	1364	1365	1366	1367	1368	1369	1370	1388	1389	1390	1391	1392	1393	1394	1395	1396	1414	1415	1416	1417	1418	1419	1420	1421	1422	1449	1450	1451	1452
1211	1212	1213	1214	1241	1242	1243	1244	1245	1246	1247	1248	1249	1267	1268	1269	1270	1271	1272	1273	1274	1275	1293	1294	1295	1296	1297	1298	1299	1300	1301	1328	1329	1330	1331
1090	1091	1092	1093	1120	1121	1122	1123	1124	1125	1126	1127	1128	1146	1147	1148	1149	1150	1151	1152	1153	1154	1172	1173	1174	1175	1176	1177	1178	1179	1180	1207	1208	1209	1210
969	970	971	972	999	1000	1001	1002	1003	1004	1005	1006	1007	1025	1026	1027	1028	1029	1030	1031	1032	1033	1051	1052	1053	1054	1055	1056	1057	1058	1059	1086	1087	1088	1089
848	849	850	851	878	879	880	881	882	883	884	885	886	904	905	906	907	908	909	910	911	912	930	931	932	933	934	935	936	937	938	965	966	967	968
727	728	729	730	757	758	759	760	761	762	763	764	765	783	784	785	786	787	788	789	790	791	809	810	811	812	813	814	815	816	817	844	845	846	847
606	607	608	609	636	637	638	639	640	641	642	643	644	662	663	664	665	666	667	668	669	670	688	689	690	691	692	693	694	695	696	723	724	725	726
485	486	487	488	515	516	517	518	519	520	521	522	523	541	542	543	544	545	546	547	548	549	567	568	569	570	571	572	573	574	575	602	603	604	605
364	365	366	367	394	395	396	397	398	399	400	401	402	420	421	422	423	424	425	426	427	428	446	447	448	449	450	451	452	453	454	481	482	483	484
243	244	245	246	273	274	275	276	277	278	279	280	281	299	300	301	302	303	304	305	306	307	325	326	327	328	329	330	331	332	333	360	361	362	363
122	123	124	125	152	153	154	155	156	157	158	159	160	178	179	180	181	182	183	184	185	186	204	205	206	207	208	209	210	211	212	239	240	241	242
1	2	3	4	31	32	33	34	35	36	37	38	39	57	58	59	60	61	62	63	64	65	83	84	85	86	87	88	89	90	91	118	119	120	121

Temp Ambient 36.00

58.00	47.01	47.01	47.02	47.22	47.23	47.24	47.24	47.25	47.22	47.18	47.15	47.12	46.53	46.50	46.47	46.43	46.40	46.37	46.33	46.30	46.27	45.68	45.65	45.62	45.58	45.55	45.59	45.64	45.68	45.72	46.87	46.91	46.96	58.00
58.00	58.01	58.03	58.04	58.44	58.46	58.47	58.49	58.50	58.43	58.37	58.30	58.24	57.06	57.00	56.93	56.87	56.80	56.73	56.67	56.60	56.54	55.36	55.30	55.23	55.17	55.10	55.19	55.27	55.36	55.44	57.74	57.83	57.91	58.00
58.00	58.04	58.07	58.11	59.12	59.15	59.19	59.23	59.27	59.25	59.23	59.21	59.19	58.83	58.81	58.79	58.78	58.76	58.68	58.60	58.52	58.44	57.00	56.92	56.84	56.76	56.68	56.72	56.76	56.79	56.83	57.88	57.92	57.96	58.00
58.00	58.06	58.12	58.18	59.79	59.85	59.91	59.97	60.03	60.06	60.09	60.11	60.14	60.61	60.63	60.66	60.69	60.71	60.62	60.52	60.43	60.33	58.63	58.54	58.44	58.35	58.26	58.25	58.24	58.23	58.23	58.02	58.02	58.01	58.00
58.00	58.08	58.16	58.25	60.47	60.55	60.64	60.72	60.80	60.87	60.94	61.02	61.09	62.38	62.45	62.52	62.59	62.67	62.56	62.45	62.34	62.23	60.27	60.16	60.05	59.94	59.83	59.78	59.73	59.67	59.62	58.16	58.11	58.05	58.00
58.00	58.10	58.21	58.31	61.15	61.25	61.36	61.46	61.57	61.68	61.80	61.92	62.04	64.15	64.27	64.39	64.50	64.62	64.50	64.38	64.25	64.13	61.91	61.78	61.66	61.53	61.41	61.31	61.21	61.11	61.01	58.30	58.20	58.10	58.00
58.00	58.13	58.25	58.38	61.82	61.95	62.08	62.21	62.33	62.50	62.66	62.82	62.99	65.92	66.09	66.25	66.41	66.58	66.44	66.30	66.16	66.03	63.54	63.40	63.26	63.13	62.99	62.84	62.70	62.55	62.40	58.44	58.29	58.15	58.00
58.00	58.15	58.30	58.45	62.50	62.65	62.80	62.95	63.10	63.31	63.52	63.73	63.94	67.70	67.91	68.12	68.32	68.53	68.38	68.23	68.08	67.92	65.18	65.02	64.87	64.72	64.57	64.37	64.18	63.99	63.79	58.58	58.39	58.19	58.00
58.00	58.17	58.35	58.52	63.18	63.35	63.52	63.69	63.87	64.12	64.38	64.63	64.89	69.47	69.72	69.98	70.23	70.49	70.32	70.15	69.99	69.82	66.81	66.65	66.48	66.31	66.14	65.90	65.67	65.43	65.19	58.72	58.48	58.24	58.00
58.00	58.20	58.39	58.59	63.85	64.05	64.24	64.44	64.63	64.93	65.23	65.53	65.84	71.24	71.54	71.84	72.14	72.44	72.26	72.08	71.90	71.72	68.45	68.27	68.09	67.90	67.72	67.44	67.15	66.86	66.58	58.86	58.57	58.29	58.00
58.00	58.22	58.44	58.65	64.53	64.75	64.96	65.18	65.40	65.75	66.09	66.44	66.78	73.02	73.36	73.71	74.05	74.40	74.20	74.01	73.81	73.62	70.08	69.89	69.69	69.50	69.30	68.97	68.64	68.30	67.97	59.00	58.66	58.33	58.00
58.00	58.19	58.38	58.57	63.71	63.90	64.09	64.28	64.48	64.78	65.08	65.38	65.69	71.14	71.44	71.74	72.05	72.35	72.18	72.01	71.84	71.66	68.57	68.40	68.23	68.06	67.89	67.60	67.31	67.02	66.72	58.87	58.58	58.29	58.00
58.00	58.16	58.33	58.49	62.90	63.06	63.22	63.39	63.55	63.81	64.07	64.33	64.59	69.26	69.52	69.78	70.04	70.30	70.15	70.01	69.86	69.71	67.06	66.92	66.77	66.62	66.48	66.23	65.98	65.73	65.48	58.75	58.50	58.25	58.00
58.00	58.14	58.27	58.41	62.08	62.22	62.35	62.49	62.63	62.84	63.06	63.27	63.49	67.38	67.60	67.82	68.03	68.25	68.13	68.00	67.88	67.76	65.55	65.43	65.31	65.19	65.06	64.85	64.65	64.44	64.23	58.62	58.42	58.21	58.00
58.00	58.11	58.22	58.33	61.26	61.37	61.48	61.59	61.70	61.87	62.05	62.22	62.39	65.51	65.68	65.85	66.03	66.20	66.10	66.00	65.91	65.81	64.04	63.94	63.85	63.75	63.65	63.48	63.32	63.15	62.99	58.50	58.33	58.17	58.00
58.00	58.08	58.16	58.24	60.45	60.53	60.61	60.69	60.78	60.90	61.03	61.16	61.29	63.63	63.76	63.89	64.02	64.15	64.08	64.00	63.93	63.86	62.53	62.46	62.38	62.31	62.24	62.11	61.99	61.86	61.74	58.37	58.25	58.12	58.00
58.00	58.05	58.11	58.16	59.63	59.69	59.74	59.80	59.85	59.94	60.02	60.11	60.20	61.75	61.84	61.93	62.01	62.10	62.05	62.00	61.95	61.90	61.02	60.97	60.92	60.87	60.83	60.74	60.66	60.58	60.49	58.25	58.17	58.08	58.00
58.00	58.03	58.05	58.08	58.82	58.84	58.87	58.90	58.93	58.97	59.01	59.05	59.10	59.88	59.92	59.96	60.01	60.05	60.03	60.00	59.98	59.95	59.51	59.49	59.46	59.44	59.41	59.37	59.33	59.29	59.25	58.12	58.08	58.04	58.00
58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00

Delta Pour Temp 55

3.00	-7.99	-7.99	-7.98	-7.78	-7.77	-7.76	-7.76	-7.75	-7.78	-7.82	-7.85	-7.88	-8.47	-8.50	-8.53	-8.57	-8.60	-8.63	-8.67	-8.70	-8.73	-9.32	-9.35	-9.38	-9.42	-9.45	-9.41	-9.36	-9.32	-9.28	-8.13	-8.09	-8.04	3.00
3.00	3.01	3.03	3.04	3.44	3.46	3.47	3.49	3.50	3.43	3.37	3.30	3.24	2.06	2.00	1.93	1.87	1.80	1.73	1.67	1.60	1.54	0.36	0.30	0.23	0.17	0.10	0.19	0.27	0.36	0.44	2.74	2.83	2.91	3.00
3.00	3.04	3.07	3.11	4.12	4.15	4.19	4.23	4.27	4.25	4.23	4.21	4.19	3.83	3.81	3.79	3.78	3.76	3.68	3.60	3.52	3.44	2.00	1.92	1.84	1.76	1.68	1.72	1.76	1.79	1.83	2.88	2.92	2.96	3.00
3.00	3.06	3.12	3.18	4.79	4.85	4.91	4.97	5.03	5.06	5.09	5.11	5.14	5.61	5.63	5.66	5.69	5.71	5.62	5.52	5.43	5.33	3.63	3.54	3.44	3.35	3.26	3.25	3.24	3.23	3.23	3.02	3.02	3.01	3.00
3.00	3.08	3.16	3.25	5.47	5.55	5.64	5.72	5.80	5.87	5.94	6.02	6.09	7.38	7.45	7.52	7.59	7.67	7.56	7.45	7.34	7.23	5.27	5.16	5.05	4.94	4.83	4.78	4.73	4.67	4.62	3.16	3.11	3.05	3.00
3.00	3.10	3.21	3.31	6.15	6.25	6.36	6.46	6.57	6.68	6.80	6.92	7.04	9.15	9.27	9.39	9.50	9.62	9.50	9.38	9.25	9.13	6.91	6.78	6.66	6.53	6.41	6.31	6.21	6.11	6.01	3.30	3.20	3.10	3.00
3.00	3.13	3.25	3.38	6.82	6.95	7.08	7.21	7.33	7.50	7.66	7.82	7.99	10.92	11.09	11.25	11.41	11.58	11.44	11.30	11.16	11.03	8.54	8.40	8.26	8.13	7.99	7.84	7.70	7.55	7.40	3.44	3.29	3.15	3.00
3.00	3.15	3.30	3.45	7.50	7.65	7.80	7.95	8.10	8.31	8.52	8.73	8.94	12.70	12.91	13.12	13.32	13.53	13.38	13.23	13.08	12.92	10.18	10.02	9.87	9.72	9.57	9.37	9.18	8.99	8.79	3.58	3.39	3.19	3.00
3.00	3.17	3.35	3.52	8.18	8.35	8.52	8.69	8.87	9.12	9.38	9.63	9.89	14.47	14.72	14.98	15.23	15.49	15.32	15.15	14.99	14.82	11.81	11.65	11.48	11.31	11.14	10.90	10.67	10.43	10.19	3.72	3.48	3.24	3.00
3.00	3.20	3.39	3.59	8.85	9.05	9.24	9.44	9.63	9.93	10.23	10.53	10.84	16.24	16.54	16.84	17.14	17.44	17.26	17.08	16.90	16.72	13.45	13.27	13.09	12.90	12.72	12.44	12.15	11.86	11.58	3.86	3.57	3.29	3.00
3.00	3.22	3.44	3.65	9.53	9.75	9.96	10.18	10.40	10.75	11.09	11.44	11.78	18.02	18.36	18.71	19.05	19.40	19.20	19.01	18.81	18.62	15.08	14.89	14.69	14.50	14.30	13.97	13.64	13.30	12.97	4.00	3.66	3.33	3.00
3.00	3.19	3.38	3.57	8.71	8.90	9.09	9.28	9.48	9.78	10.08	10.38	10.69	16.14	16.44	16.74	17.05	17.35	17.18	17.01	16.84	16.66	13.57	13.40	13.23	13.06	12.89	12.60	12.31	12.02	11.72	3.87	3.58	3.29	3.00
3.00	3.16	3.33	3.49	7.90	8.06	8.22	8.39	8.55	8.81	9.07	9.33	9.59	14.26	14.52	14.78	15.04	15.30	15.15	15.01	14.86	14.71	12.06	11.92	11.77	11.62	11.48	11.23	10.98	10.73	10.48	3.75	3.50	3.25	3.00
3.00	3.14	3.27	3.41	7.08	7.22	7.35	7.49	7.63	7.84	8.06	8.27	8.49	12.38	12.60	12.82	13.03	13.25	13.13	13.00	12.88	12.76	10.55	10.43	10.31	10.19	10.06	9.85	9.65	9.44	9.23	3.62	3.42	3.21	3.00
3.00	3.11	3.22	3.33	6.26	6.37	6.48	6.59	6.70	6.87	7.05	7.22	7.39	10.51	10.68	10.85	11.03	11.20	11.10	11.00	10.91	10.81	9.04	8.94	8.85	8.75	8.65	8.48	8.32	8.15	7.99	3.50	3.33	3.17	3.00
3.00	3.08	3.16	3.24	5.45	5.53	5.61	5.69	5.78	5.90	6.03	6.16	6.29	8.63	8.76	8.89	9.02	9.15	9.08	9.00	8.93	8.86	7.53	7.46	7.38	7.31	7.24	7.11	6.99	6.86	6.74	3.37	3.25	3.12	3.00
3.00	3.05	3.11	3.16	4.63	4.69	4.74	4.80	4.85	4.94	5.02	5.11	5.20	6.75	6.84	6.93	7.01	7.10	7.05	7.00	6.95	6.90	6.02	5.97	5.92	5.87	5.83	5.74	5.66	5.58	5.49	3.25	3.17	3.08	3.00
3.00	3.03	3.05	3.08	3.82	3.84	3.87	3.90	3.93	3.97	4.01	4.05	4.10	4.88	4.92	4.96	5.01	5.05	5.03	5.00	4.98	4.95	4.51	4.49	4.46	4.44	4.41	4.37	4.33	4.29	4.25	3.12	3.08	3.04	3.00
3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00

TABLE 16: EXCEL MODEL FOR LIFT 2, DAY 3

02/14/05 @ 12:45 PM

Nodes

4789	4790	4801	4802	4831	4832	4833	4834	4835	4836	4837	4838	4839	4857	4858	4859	4860	4861	4862	4863	4864	4865	4883	4884	4885	4886	4887	4888	4889	4890	4891	4920	4921	4932	4933
4644	4645	4656	4657	4686	4687	4688	4689	4690	4691	4692	4693	4694	4712	4713	4714	4715	4716	4717	4718	4719	4720	4738	4739	4740	4741	4742	4743	4744	4745	4746	4775	4776	4787	4788
4499	4500	4511	4512	4541	4542	4543	4544	4545	4546	4547	4548	4549	4567	4568	4569	4570	4571	4572	4573	4574	4575	4593	4594	4595	4596	4597	4598	4599	4600	4601	4630	4631	4642	4643
4354	4355	4366	4367	4396	4397	4398	4399	4400	4401	4402	4403	4404	4422	4423	4424	4425	4426	4427	4428	4429	4430	4448	4449	4450	4451	4452	4453	4454	4455	4456	4485	4486	4497	4498
4209	4210	4221	4222	4251	4252	4253	4254	4255	4256	4257	4258	4259	4277	4278	4279	4280	4281	4282	4283	4284	4285	4303	4304	4305	4306	4307	4308	4309	4310	4311	4340	4341	4352	4353
4064	4065	4076	4077	4106	4107	4108	4109	4110	4111	4112	4113	4114	4132	4133	4134	4135	4136	4137	4138	4139	4140	4158	4159	4160	4161	4162	4163	4164	4165	4166	4195	4196	4207	4208
3919	3920	3931	3932	3961	3962	3963	3964	3965	3966	3967	3968	3969	3987	3988	3989	3990	3991	3992	3993	3994	3995	4013	4014	4015	4016	4017	4018	4019	4020	4021	4050	4051	4062	4063
3774	3775	3786	3787	3816	3817	3818	3819	3820	3821	3822	3823	3824	3842	3843	3844	3845	3846	3847	3848	3849	3850	3868	3869	3870	3871	3872	3873	3874	3875	3876	3905	3906	3917	3918
3629	3630	3641	3642	3671	3672	3673	3674	3675	3676	3677	3678	3679	3697	3698	3699	3700	3701	3702	3703	3704	3705	3723	3724	3725	3726	3727	3728	3729	3730	3731	3760	3761	3772	3773
3484	3485	3496	3497	3526	3527	3528	3529	3530	3531	3532	3533	3534	3552	3553	3554	3555	3556	3557	3558	3559	3560	3578	3579	3580	3581	3582	3583	3584	3585	3586	3615	3616	3627	3628
3339	3340	3351	3352	3381	3382	3383	3384	3385	3386	3387	3388	3389	3407	3408	3409	3410	3411	3412	3413	3414	3415	3433	3434	3435	3436	3437	3438	3439	3440	3441	3470	3471	3482	3483
3194	3195	3206	3207	3236	3237	3238	3239	3240	3241	3242	3243	3244	3262	3263	3264	3265	3266	3267	3268	3269	3270	3288	3289	3290	3291	3292	3293	3294	3295	3296	3325	3326	3337	3338
3049	3050	3061	3062	3091	3092	3093	3094	3095	3096	3097	3098	3099	3117	3118	3119	3120	3121	3122	3123	3124	3125	3143	3144	3145	3146	3147	3148	3149	3150	3151	3180	3181	3192	3193
2904	2905	2916	2917	2946	2947	2948	2949	2950	2951	2952	2953	2954	2972	2973	2974	2975	2976	2977	2978	2979	2980	2998	2999	3000	3001	3002	3003	3004	3005	3006	3035	3036	3047	3048
2759	2760	2771	2772	2801	2802	2803	2804	2805	2806	2807	2808	2809	2827	2828	2829	2830	2831	2832	2833	2834	2835	2853	2854	2855	2856	2857	2858	2859	2860	2861	2890	2891	2902	2903
2614	2615	2626	2627	2656	2657	2658	2659	2660	2661	2662	2663	2664	2682	2683	2684	2685	2686	2687	2688	2689	2690	2708	2709	2710	2711	2712	2713	2714	2715	2716	2745	2746	2757	2758
2469	2470	2481	2482	2511	2512	2513	2514	2515	2516	2517	2518	2519	2537	2538	2539	2540	2541	2542	2543	2544	2545	2563	2564	2565	2566	2567	2568	2569	2570	2571	2600	2601	2612	2613
2324	2325	2336	2337	2366	2367	2368	2369	2370	2371	2372	2373	2374	2392	2393	2394	2395	2396	2397	2398	2399	2400	2418	2419	2420	2421	2422	2423	2424	2425	2426	2455	2456	2467	2468
2300	2301																																2322	2323

Temp Ambient 50.00

58.00	54.34	58.06	58.39	68.20	68.54	68.87	69.21	69.55	65.65	65.80	65.96	66.11	68.90	69.06	69.21	69.37	69.53	69.52	69.52	69.52	69.52	69.50	69.50	69.50	69.50	69.50	69.16	68.83	68.49	68.15	58.38	58.04	54.34	58.00
58.00	58.68	66.11	66.79	86.40	87.07	87.75	88.42	89.10	81.30	81.61	81.92	82.23	87.81	88.12	88.43	88.74	89.05	89.05	89.05	89.04	89.04	89.01	89.01	89.00	89.00	89.00	88.33	87.65	86.98	86.30	66.76	66.09	58.67	58.00
58.00	58.69	66.28	66.97	86.97	87.66	88.35	89.04	89.73	81.86	82.27	82.67	83.08	90.40	90.80	91.21	91.62	92.02	91.93	91.85	91.76	91.67	90.09	90.00	89.91	89.82	89.73	89.04	88.35	87.66	86.97	66.97	66.28	58.69	58.00
58.00	58.70	66.44	67.15	87.55	88.26	88.96	89.66	90.37	82.43	82.93	83.43	83.93	92.98	93.49	93.99	94.49	94.99	94.82	94.65	94.47	94.30	91.16	90.99	90.81	90.64	90.47	89.76	89.06	88.35	87.64	67.18	66.47	58.71	58.00
58.00	58.72	66.61	67.33	88.13	88.85	89.57	90.28	91.00	82.99	83.59	84.19	84.79	95.57	96.17	96.77	97.37	97.97	97.71	97.45	97.19	96.93	92.24	91.98	91.72	91.46	91.20	90.48	89.76	89.03	88.31	67.38	66.66	58.72	58.00
58.00	58.73	66.77	67.51	88.71	89.44	90.17	90.90	91.63	83.55	84.25	84.95	85.64	98.16	98.85	99.55	100.24	100.94	100.59	100.25	99.90	99.55	93.32	92.97	92.63	92.28	91.93	91.20	90.46	89.72	88.98	67.59	66.85	58.74	58.00
58.00	58.74	66.94	67.68	89.29	90.03	90.78	91.52	92.27	84.12	84.91	85.70	86.49	100.74	101.54	102.33	103.12	103.91	103.48	103.05	102.61	102.18	94.40	93.96	93.53	93.10	92.67	91.91	91.16	90.41	89.65	67.80	67.04	58.75	58.00
58.00	58.76	67.10	67.86	89.87	90.62	91.38	92.14	92.90	84.68	85.57	86.46	87.35	103.33	104.22	105.11	106.00	106.88	106.36	105.85	105.33	104.81	95.47	94.96	94.44	93.92	93.40	92.63	91.86	91.09	90.32	68.00	67.23	58.77	58.00
58.00	58.77	67.27	68.04	90.44	91.22	91.99	92.76	93.53	85.25	86.23	87.22	88.20	105.92	106.90	107.89	108.87	109.86	109.25	108.65	108.04	107.44	96.55	95.95	95.34	94.74	94.13	93.35	92.56	91.78	90.99	68.21	67.43	58.79	58.00
58.00	58.79	67.43	68.22	91.02	91.81	92.59	93.38	94.17	85.81	86.89	87.97	89.05	108.51	109.59	110.67	111.75	112.83	112.14	111.45	110.76	110.06	97.63	96.94	96.25	95.56	94.87	94.07	93.26	92.46	91.66	68.42	67.62	58.80	58.00
58.00	58.80	67.60	68.40	91.60	92.40	93.20	94.00	94.80	86.38	87.55	88.73	89.91	111.09	112.27	113.45	114.62	115.80	115.02	114.25	113.47	112.69	98.71	97.93	97.15	96.38	95.60	94.78	93.97	93.15	92.33	68.63	67.81	58.82	58.00
58.00	58.77	67.24	68.01	90.34	91.11	91.88	92.65	93.43	85.25	86.31	87.37	88.44	107.57	108.63	109.69	110.76	111.82	111.14	110.46	109.78	109.10	96.88	96.20	95.52	94.84	94.16	93.38	92.59	91.80	91.02	68.22	67.43	58.79	58.00
58.00	58.74	66.88	67.62	89.09	89.83	90.57	91.31	92.05	84.12	85.07	86.01	86.96	104.04	104.99	105.94	106.89	107.84	107.26	106.68	106.09	105.51	95.05	94.47	93.89	93.31	92.73	91.97	91.22	90.46	89.71	67.81	67.06	58.75	58.00
58.00	58.71	66.52	67.23	87.83	88.54	89.25	89.96	90.68	82.99	83.82	84.66	85.49	100.52	101.35	102.19	103.02	103.86	103.37	102.89	102.41	101.92	93.22	92.74	92.25	91.77	91.29	90.56	89.84	89.12	88.39	67.41	66.68	58.72	58.00
58.00	58.68	66.17	66.85	86.58	87.26	87.94	88.62	89.30	81.86	82.58	83.30	84.02	96.99	97.71	98.43	99.15	99.88	99.49	99.10	98.72	98.33	91.39	91.01	90.62	90.24	89.85	89.16	88.47	87.77	87.08	67.00	66.31	58.69	58.00
58.00	58.65	65.81	66.46	85.32	85.97	86.62	87.27	87.93	80.73	81.33	81.94	82.55	93.47	94.07	94.68	95.29	95.89	95.61	95.32	95.03	94.74	89.56	89.28	88.99	88.70	88.41	87.75	87.09	86.43	85.77	66.59	65.93	58.66	58.00
58.00	58.62	65.45	66.07	84.07	84.69	85.31	85.93	86.55	79.59	80.09	80.58	81.07	89.94	90.43	90.93	91.42	91.91	91.72	91.53	91.34	91.15	87.73	87.54	87.35	87.16	86.98	86.35	85.72	85.09	84.46	66.19	65.56	58.63	58.00
58.00	58.59	65.09	65.68	82.81	83.40	83.99	84.58	85.18	78.46	78.84	79.22	79.60	86.42	86.80	87.17	87.55	87.93	87.84	87.75	87.66	87.56	85.91	85.81	85.72	85.63	85.54	84.94	84.34	83.74	83.14	65.78	65.18	58.60	58.00
58.00	58.00	58.00	58.76	80.76	81.52	82.28	83.04	83.80	83.81	83.81	83.82	83.82	83.93	83.93	83.94	83.94	83.95	83.96	83.96	83.97	83.97	84.08	84.08	84.09	84.09	84.10	83.33	82.56	81.80	81.03	58.77	58.00	58.00	58.00

Delta Pour 57

1.00	-2.66	1.06	1.39	11.20	11.54	11.87	12.21	12.55	8.65	8.80	8.96	9.11	11.90	12.06	12.21	12.37	12.53	12.52	12.52	12.52	12.52	12.50	12.50	12.50	12.50	12.50	12.16	11.83	11.49	11.15	1.38	1.04	-2.66	1.00
1.00	1.68	9.11	9.79	29.40	30.07	30.75	31.42	32.10	24.30	24.61	24.92	25.23	30.81	31.12	31.43	31.74	32.05	32.05	32.05	32.04	32.04	32.01	32.01	32.00	32.00	32.00	31.33	30.65	29.98	29.30	9.76	9.09	1.67	1.00
1.00	1.69	9.28	9.97	29.97	30.66	31.35	32.04	32.73	24.86	25.27	25.67	26.08	33.40	33.80	34.21	34.62	35.02	34.93	34.85	34.76	34.67	33.09	33.00	32.91	32.82	32.73	32.04	31.35	30.66	29.97	9.97	9.28	1.69	1.00
1.00	1.70	9.44	10.15	30.55	31.26	31.96	32.66	33.37	25.43	25.93	26.43	26.93	35.98	36.49	36.99	37.49	37.99	37.82	37.65	37.47	37.30	34.16	33.99	33.81	33.64	33.47	32.76	32.06	31.35	30.64	10.18	9.47	1.71	1.00
1.00	1.72	9.61	10.33	31.13	31.85	32.57	33.28	34.00	25.99	26.59	27.19	27.79	38.57	39.17	39.77	40.37	40.97	40.71	40.45	40.19	39.93	35.24	34.98	34.72	34.46	34.20	33.48	32.76	32.03	31.31	10.38	9.66	1.72	1.00
1.00	1.73	9.77	10.51	31.71	32.44	33.17	33.90	34.63	26.55	27.25	27.95	28.64	41.16	41.85	42.55	43.24	43.94	43.59	43.25	42.90	42.55	36.32	35.97	35.63	35.28	34.93	34.20	33.46	32.72	31.98	10.59	9.85	1.74	1.00
1.00	1.74	9.94	10.68	32.29	33.03	33.78	34.52	35.27	27.12	27.91	28.70	29.49	43.74	44.54	45.33	46.12	46.91	46.48	46.05	45.61	45.18	37.40	36.96	36.53	36.10	35.67	34.91	34.16	33.41	32.65	10.80	10.04	1.75	1.00
1.00	1.76	10.10	10.86	32.87	33.62	34.38	35.14	35.90	27.68	28.57	29.46	30.35	46.33	47.22	48.11	49.00	49.88	49.36	48.85	48.33	47.81	38.47	37.96	37.44	36.92	36.40	35.63	34.86	34.09	33.32	11.00	10.23	1.77	1.00
1.00	1.77	10.27	11.04	33.44	34.22	34.99	35.76	36.53	28.25	29.23	30.22	31.20	48.92	49.90	50.89	51.87	52.86	52.25	51.65	51.04	50.44	39.55	38.95	38.34	37.74	37.13	36.35	35.56	34.78	33.99	11.21	10.43	1.79	1.00
1.00	1.79	10.43	11.22	34.02	34.81	35.59	36.38	37.17	28.81	29.89	30.97	32.05	51.51	52.59	53.67	54.75	55.83	55.14	54.45	53.76	53.06	40.63	39.94	39.25	38.56	37.87	37.07	36.26	35.46	34.66	11.42	10.62	1.80	1.00
1.00	1.80	10.60	11.40	34.60	35.40	36.20	37.00	37.80	29.38	30.55	31.73	32.91	54.09	55.27	56.45	57.62	58.80	58.02	57.25	56.47	55.69	41.71	40.93	40.15	39.38	38.60	37.78	36.97	36.15	35.33	11.63	10.81	1.82	1.00
1.00	1.77	10.24	11.01	33.34	34.11	34.88	35.65	36.43	28.25	29.31	30.37	31.44	50.57	51.63	52.69	53.76	54.82	54.14	53.46	52.78	52.10	39.88	39.20	38.52	37.84	37.16	36.38	35.59	34.80	34.02	11.22	10.43	1.79	1.00
1.00	1.74	9.88	10.62	32.09	32.83	33.57	34.31	35.05	27.12	28.07	29.01	29.96	47.04	47.99	48.94	49.89	50.84	50.26	49.68	49.09	48.51	38.05	37.47	36.89	36.31	35.73	34.97	34.22	33.46	32.71	10.81	10.06	1.75	1.00
1.00	1.71	9.52	10.23	30.83	31.54	32.25	32.96	33.68	25.99	26.82	27.66	28.49	43.52	44.35	45.19	46.02	46.86	46.37	45.89	45.41	44.92	36.22	35.74	35.25	34.77	34.29	33.56	32.84	32.12	31.39	10.41	9.68	1.72	1.00
1.00	1.68	9.17	9.85	29.58	30.26	30.94	31.62	32.30	24.86	25.58	26.30	27.02	39.99	40.71	41.43	42.15	42.88	42.49	42.10	41.72	41.33	34.39	34.01	33.62	33.24	32.85	32.16	31.47	30.77	30.08	10.00	9.31	1.69	1.00
1.00	1.65	8.81	9.46	28.32	28.97	29.62	30.27	30.93	23.73	24.33	24.94	25.55	36.47	37.07	37.68	38.29	38.89	38.61	38.32	38.03	37.74	32.56	32.28	31.99	31.70	31.41	30.75	30.09	29.43	28.77	9.59	8.93	1.66	1.00
1.00	1.62	8.45	9.07	27.07	27.69	28.31	28.93	29.55	22.59	23.09	23.58	24.07	32.94	33.43	33.93	34.42	34.91	34.72	34.53	34.34	34.15	30.73	30.54	30.35	30.16	29.98	29.35	28.72	28.09	27.46	9.19	8.56	1.63	1.00
1.00	1.59	8.09	8.68	25.81	26.40	26.99	27.58	28.18	21.46	21.84	22.22	22.60	29.42	29.80	30.17	30.55	30.93	30.84	30.75	30.66	30.56	28.91	28.81	28.72	28.63	28.54	27.94	27.34	26.74	26.14	8.78	8.18	1.60	1.00
1.00	1.00																																1.00	1.00

TABLE 17: EXCEL MODEL FOR LIFT 1, DAY 10

02/14/05 @ 12:45 PM

Nodes

2179	2180	2209	2210	2211	2212	2213	2214	2215	2216	2217	2235	2236	2237	2238	2239	2240	2241	2242	2243	2261	2262	2263	2264	2265	2266	2267	2268	2269	2298	2299
2058	2059	2088	2089	2090	2091	2092	2093	2094	2095	2096	2114	2115	2116	2117	2118	2119	2120	2121	2122	2140	2141	2142	2143	2144	2145	2146	2147	2148	2177	2178
1937	1938	1967	1968	1969	1970	1971	1972	1973	1974	1975	1993	1994	1995	1996	1997	1998	1999	2000	2001	2019	2020	2021	2022	2023	2024	2025	2026	2027	2056	2057
1816	1817	1846	1847	1848	1849	1850	1851	1852	1853	1854	1872	1873	1874	1875	1876	1877	1878	1879	1880	1898	1899	1900	1901	1902	1903	1904	1905	1906	1935	1936
1695	1696	1725	1726	1727	1728	1729	1730	1731	1732	1733	1751	1752	1753	1754	1755	1756	1757	1758	1759	1777	1778	1779	1780	1781	1782	1783	1784	1785	1814	1815
1574	1575	1604	1605	1606	1607	1608	1609	1610	1611	1612	1630	1631	1632	1633	1634	1635	1636	1637	1638	1656	1657	1658	1659	1660	1661	1662	1663	1664	1693	1694
1453	1454	1483	1484	1485	1486	1487	1488	1489	1490	1491	1509	1510	1511	1512	1513	1514	1515	1516	1517	1535	1536	1537	1538	1539	1540	1541	1542	1543	1572	1573
1332	1333	1362	1363	1364	1365	1366	1367	1368	1369	1370	1388	1389	1390	1391	1392	1393	1394	1395	1396	1414	1415	1416	1417	1418	1419	1420	1421	1422	1451	1452
1211	1212	1241	1242	1243	1244	1245	1246	1247	1248	1249	1267	1268	1269	1270	1271	1272	1273	1274	1275	1293	1294	1295	1296	1297	1298	1299	1300	1301	1330	1331
1090	1091	1120	1121	1122	1123	1124	1125	1126	1127	1128	1146	1147	1148	1149	1150	1151	1152	1153	1154	1172	1173	1174	1175	1176	1177	1178	1179	1180	1209	1210
969	970	999	1000	1001	1002	1003	1004	1005	1006	1007	1025	1026	1027	1028	1029	1030	1031	1032	1033	1051	1052	1053	1054	1055	1056	1057	1058	1059	1088	1089
848	849	878	879	880	881	882	883	884	885	886	904	905	906	907	908	909	910	911	912	930	931	932	933	934	935	936	937	938	967	968
727	728	757	758	759	760	761	762	763	764	765	783	784	785	786	787	788	789	790	791	809	810	811	812	813	814	815	816	817	846	847
606	607	636	637	638	639	640	641	642	643	644	662	663	664	665	666	667	668	669	670	688	689	690	691	692	693	694	695	696	725	726
485	486	515	516	517	518	519	520	521	522	523	541	542	543	544	545	546	547	548	549	567	568	569	570	571	572	573	574	575	604	605
364	365	394	395	396	397	398	399	400	401	402	420	421	422	423	424	425	426	427	428	446	447	448	449	450	451	452	453	454	483	484
243	244	273	274	275	276	277	278	279	280	281	299	300	301	302	303	304	305	306	307	325	326	327	328	329	330	331	332	333	362	363
122	123	152	153	154	155	156	157	158	159	160	178	179	180	181	182	183	184	185	186	204	205	206	207	208	209	210	211	212	241	242
1	2	31	32	33	34	35	36	37	38	39	57	58	59	60	61	62	63	64	65	83	84	85	86	87	88	89	90	91	120	121

Temp

58.00	58.76	80.76	81.52	82.28	83.04	83.80	83.81	83.81	83.82	83.82	83.93	83.93	83.94	83.94	83.95	83.96	83.96	83.97	83.97	84.08	84.08	84.09	84.09	84.10	83.33	82.56	81.80	81.03	58.77	58.00
58.00	58.74	80.06	80.79	81.53	82.26	83.00	83.01	83.02	83.03	83.05	83.25	83.27	83.28	83.29	83.30	83.31	83.32	83.33	83.35	83.55	83.57	83.58	83.59	83.60	82.85	82.09	81.34	80.59	58.75	58.00
58.00	58.71	79.33	80.04	80.76	81.47	82.18	82.26	82.33	82.41	82.49	83.90	83.98	84.05	84.13	84.21	84.17	84.12	84.08	84.04	83.24	83.20	83.15	83.11	83.07	82.33	81.59	80.85	80.12	58.74	58.00
58.00	58.69	78.61	79.29	79.98	80.67	81.36	81.50	81.65	81.79	81.94	84.54	84.69	84.83	84.98	85.12	85.02	84.92	84.82	84.72	82.93	82.83	82.73	82.63	82.53	81.81	81.09	80.37	79.65	58.72	58.00
58.00	58.66	77.88	78.55	79.21	79.87	80.53	80.74	80.96	81.17	81.38	85.19	85.40	85.61	85.82	86.03	85.88	85.72	85.57	85.41	82.62	82.47	82.31	82.16	82.00	81.29	80.59	79.88	79.18	58.71	58.00
58.00	58.64	77.16	77.80	78.43	79.07	79.71	79.99	80.27	80.55	80.82	85.83	86.11	86.39	86.67	86.94	86.73	86.52	86.31	86.10	82.31	82.10	81.89	81.68	81.47	80.78	80.09	79.40	78.71	58.69	58.00
58.00	58.61	76.43	77.05	77.66	78.27	78.89	79.23	79.58	79.92	80.27	86.48	86.82	87.17	87.51	87.86	87.59	87.32	87.06	86.79	82.00	81.73	81.47	81.20	80.93	80.26	79.58	78.91	78.24	58.67	58.00
58.00	58.59	75.71	76.30	76.89	77.48	78.07	78.48	78.89	79.30	79.71	87.12	87.53	87.94	88.36	88.77	88.44	88.12	87.80	87.48	81.69	81.37	81.04	80.72	80.40	79.74	79.08	78.42	77.76	58.66	58.00
58.00	58.57	74.98	75.55	76.11	76.68	77.24	77.72	78.20	78.68	79.16	87.76	88.24	88.72	89.20	89.68	89.30	88.92	88.55	88.17	81.38	81.00	80.62	80.24	79.87	79.22	78.58	77.94	77.29	58.64	58.00
58.00	58.54	74.25	74.80	75.34	75.88	76.42	76.97	77.51	78.06	78.60	88.41	88.95	89.50	90.04	90.59	90.16	89.72	89.29	88.86	81.06	80.63	80.20	79.77	79.33	78.71	78.08	77.45	76.82	58.63	58.00
58.00	58.52	73.53	74.05	74.56	75.08	75.60	76.21	76.82	77.43	78.05	89.05	89.67	90.28	90.89	91.50	91.01	90.52	90.03	89.55	80.75	80.27	79.78	79.29	78.80	78.19	77.58	76.96	76.35	58.61	58.00
58.00	58.45	71.59	72.04	72.49	72.95	73.40	73.94	74.47	75.01	75.54	85.17	85.71	86.24	86.78	87.31	86.89	86.46	86.03	85.60	77.91	77.48	77.05	76.63	76.20	75.66	75.13	74.59	74.06	58.54	58.00
58.00	58.39	69.65	70.04	70.42	70.81	71.20	71.66	72.12	72.58	73.03	81.29	81.75	82.21	82.67	83.13	82.76	82.39	82.03	81.66	75.07	74.70	74.33	73.97	73.60	73.14	72.68	72.22	71.76	58.46	58.00
58.00	58.32	67.71	68.03	68.35	68.68	69.00	69.38	69.76	70.15	70.53	77.41	77.79	78.17	78.56	78.94	78.63	78.33	78.02	77.72	72.22	71.92	71.61	71.31	71.00	70.62	70.24	69.85	69.47	58.38	58.00
58.00	58.26	65.76	66.02	66.28	66.54	66.80	67.11	67.41	67.72	68.02	73.53	73.83	74.14	74.44	74.75	74.51	74.26	74.02	73.77	69.38	69.13	68.89	68.64	68.40	68.09	67.79	67.48	67.18	58.31	58.00
58.00	58.19	63.82	64.02	64.21	64.41	64.60	64.83	65.06	65.29	65.52	69.65	69.87	70.10	70.33	70.56	70.38	70.20	70.01	69.83	66.53	66.35	66.17	65.98	65.80	65.57	65.34	65.11	64.88	58.23	58.00
58.00	58.13	61.88	62.01	62.14	62.27	62.40	62.55	62.71	62.86	63.01	65.76	65.92	66.07	66.22	66.38	66.25	66.13	66.01	65.89	63.69	63.57	63.44	63.32	63.20	63.05	62.89	62.74	62.59	58.15	58.00
58.00	58.06	59.94	60.01	60.07	60.14	60.20	60.28	60.35	60.43	60.51	61.88	61.96	62.03	62.11	62.19	62.13	62.07	62.00	61.94	60.84	60.78	60.72	60.66	60.60	60.52	60.45	60.37	60.29	58.08	58.00
58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00

Delta Pour 55

3.00	3.76	25.76	26.52	27.28	28.04	28.80	28.81	28.81	28.82	28.82	28.93	28.93	28.94	28.94	28.95	28.96	28.96	28.97	28.97	29.08	29.08	29.09	29.09	29.10	28.33	27.56	26.80	26.03	3.77	3.00
3.00	3.74	25.06	25.79	26.53	27.26	28.00	28.01	28.02	28.03	28.05	28.25	28.27	28.28	28.29	28.30	28.31	28.32	28.33	28.35	28.55	28.57	28.58	28.59	28.60	27.85	27.09	26.34	25.59	3.75	3.00
3.00	3.71	24.33	25.04	25.76	26.47	27.18	27.26	27.33	27.41	27.49	28.90	28.98	29.05	29.13	29.21	29.17	29.12	29.08	29.04	28.24	28.20	28.15	28.11	28.07	27.33	26.59	25.85	25.12	3.74	3.00
3.00	3.69	23.61	24.29	24.98	25.67	26.36	26.50	26.65	26.79	26.94	29.54	29.69	29.83	29.98	30.12	30.02	29.92	29.82	29.72	27.93	27.83	27.73	27.63	27.53	26.81	26.09	25.37	24.65	3.72	3.00
3.00	3.66	22.88	23.55	24.21	24.87	25.53	25.74	25.96	26.17	26.38	30.19	30.40	30.61	30.82	31.03	30.88	30.72	30.57	30.41	27.62	27.47	27.31	27.16	27.00	26.29	25.59	24.88	24.18	3.71	3.00
3.00	3.64	22.16	22.80	23.43	24.07	24.71	24.99	25.27	25.55	25.82	30.83	31.11	31.39	31.67	31.94	31.73	31.52	31.31	31.10	27.31	27.10	26.89	26.68	26.47	25.78	25.09	24.40	23.71	3.69	3.00
3.00	3.61	21.43	22.05	22.66	23.27	23.89	24.23	24.58	24.92	25.27	31.48	31.82	32.17	32.51	32.86	32.59	32.32	32.06	31.79	27.00	26.73	26.47	26.20	25.93	25.26	24.58	23.91	23.24	3.67	3.00
3.00	3.59	20.71	21.30	21.89	22.48	23.07	23.48	23.89	24.30	24.71	32.12	32.53	32.94	33.36	33.77	33.44	33.12	32.80	32.48	26.69	26.37	26.04	25.72	25.40	24.74	24.08	23.42	22.76	3.66	3.00
3.00	3.57	19.98	20.55	21.11	21.68	22.24	22.72	23.20	23.68	24.16	32.76	33.24	33.72	34.20	34.68	34.30	33.92	33.55	33.17	26.38	26.00	25.62	25.24	24.87	24.22	23.58	22.94	22.29	3.64	3.00
3.00	3.54	19.25	19.80	20.34	20.88	21.42	21.97	22.51	23.06	23.60	33.41	33.95	34.50	35.04	35.59	35.16	34.72	34.29	33.86	26.06	25.63	25.20	24.77	24.33	23.71	23.08	22.45	21.82	3.63	3.00
3.00	3.52	18.53	19.05	19.56	20.08	20.60	21.21	21.82	22.43	23.05	34.05	34.67	35.28	35.89	36.50	36.01	35.52	35.03	34.55	25.75	25.27	24.78	24.29	23.80	23.19	22.58	21.96	21.35	3.61	3.00
3.00	3.45	16.59	17.04	17.49	17.95	18.40	18.94	19.47	20.01	20.54	30.17	30.71	31.24	31.78	32.31	31.89	31.46	31.03	30.60	22.91	22.48	22.05	21.63	21.20	20.66	20.13	19.59	19.06	3.54	3.00
3.00	3.39	14.65	15.04	15.42	15.81	16.20	16.66	17.12	17.58	18.03	26.29	26.75	27.21	27.67	28.13	27.76	27.39	27.03	26.66	20.07	19.70	19.33	18.97	18.60	18.14	17.68	17.22	16.76	3.46	3.00
3.00	3.32	12.71	13.03	13.35	13.68	14.00	14.38	14.76	15.15	15.53	22.41	22.79	23.17	23.56	23.94	23.63	23.33	23.02	22.72	17.22	16.92	16.61	16.31	16.00	15.62	15.24	14.85	14.47	3.38	3.00
3.00	3.26	10.76	11.02	11.28	11.54	11.80	12.11	12.41	12.72	13.02	18.53	18.83	19.14	19.44	19.75	19.51	19.26	19.02	18.77	14.38	14.13	13.89	13.64	13.40	13.09	12.79	12.48	12.18	3.31	3.00
3.00	3.19	8.82	9.02	9.21	9.41	9.60	9.83	10.06	10.29	10.52	14.65	14.87	15.10	15.33	15.56	15.38	15.20	15.01	14.83	11.53	11.35	11.17	10.98	10.80	10.57	10.34	10.11	9.88	3.23	3.00
3.00	3.13	6.88	7.01	7.14	7.27	7.40	7.55	7.71	7.86	8.01	10.76	10.92	11.07	11.22	11.38	11.25	11.13	11.01	10.89	8.69	8.57	8.44	8.32	8.20	8.05	7.89	7.74	7.59	3.15	3.00
3.00	3.06	4.94	5.01	5.07	5.14	5.20	5.28	5.35	5.43	5.51	6.88	6.96	7.03	7.11	7.19	7.13	7.07	7.00	6.94	5.84	5.78	5.72	5.66	5.60	5.52	5.45	5.37	5.29	3.08	3.00
3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00

TABLE 18: EXCEL MODEL FOR LIFT 2, DAY 9

02/20/05 @ 6:00 PM

Nodes

4789	4790	4801	4802	4831	4832	4833	4834	4835	4836	4837	4838	4839	4857	4858	4859	4860	4861	4862	4863	4864	4865	4883	4884	4885	4886	4887	4888	4889	4890	4891	4920	4921	4932	4933
4644	4645	4656	4657	4686	4687	4688	4689	4690	4691	4692	4693	4694	4712	4713	4714	4715	4716	4717	4718	4719	4720	4738	4739	4740	4741	4742	4743	4744	4745	4746	4775	4776	4787	4788
4499	4500	4511	4512	4541	4542	4543	4544	4545	4546	4547	4548	4549	4567	4568	4569	4570	4571	4572	4573	4574	4575	4593	4594	4595	4596	4597	4598	4599	4600	4601	4630	4631	4642	4643
4354	4355	4366	4367	4396	4397	4398	4399	4400	4401	4402	4403	4404	4422	4423	4424	4425	4426	4427	4428	4429	4430	4448	4449	4450	4451	4452	4453	4454	4455	4456	4485	4486	4497	4498
4209	4210	4221	4222	4251	4252	4253	4254	4255	4256	4257	4258	4259	4277	4278	4279	4280	4281	4282	4283	4284	4285	4303	4304	4305	4306	4307	4308	4309	4310	4311	4340	4341	4352	4353
4064	4065	4076	4077	4106	4107	4108	4109	4110	4111	4112	4113	4114	4132	4133	4134	4135	4136	4137	4138	4139	4140	4158	4159	4160	4161	4162	4163	4164	4165	4166	4195	4196	4207	4208
3919	3920	3931	3932	3961	3962	3963	3964	3965	3966	3967	3968	3969	3987	3988	3989	3990	3991	3992	3993	3994	3995	4013	4014	4015	4016	4017	4018	4019	4020	4021	4050	4051	4062	4063
3774	3775	3786	3787	3816	3817	3818	3819	3820	3821	3822	3823	3824	3842	3843	3844	3845	3846	3847	3848	3849	3850	3868	3869	3870	3871	3872	3873	3874	3875	3876	3905	3906	3917	3918
3629	3630	3641	3642	3671	3672	3673	3674	3675	3676	3677	3678	3679	3697	3698	3699	3700	3701	3702	3703	3704	3705	3723	3724	3725	3726	3727	3728	3729	3730	3731	3760	3761	3772	3773
3484	3485	3496	3497	3526	3527	3528	3529	3530	3531	3532	3533	3534	3552	3553	3554	3555	3556	3557	3558	3559	3560	3578	3579	3580	3581	3582	3583	3584	3585	3586	3615	3616	3627	3628
3339	3340	3351	3352	3381	3382	3383	3384	3385	3386	3387	3388	3389	3407	3408	3409	3410	3411	3412	3413	3414	3415	3433	3434	3435	3436	3437	3438	3439	3440	3441	3470	3471	3482	3483
3194	3195	3206	3207	3236	3237	3238	3239	3240	3241	3242	3243	3244	3262	3263	3264	3265	3266	3267	3268	3269	3270	3288	3289	3290	3291	3292	3293	3294	3295	3296	3325	3326	3337	3338
3049	3050	3061	3062	3091	3092	3093	3094	3095	3096	3097	3098	3099	3117	3118	3119	3120	3121	3122	3123	3124	3125	3143	3144	3145	3146	3147	3148	3149	3150	3151	3180	3181	3192	3193
2904	2905	2916	2917	2946	2947	2948	2949	2950	2951	2952	2953	2954	2972	2973	2974	2975	2976	2977	2978	2979	2980	2998	2999	3000	3001	3002	3003	3004	3005	3006	3035	3036	3047	3048
2759	2760	2771	2772	2801	2802	2803	2804	2805	2806	2807	2808	2809	2827	2828	2829	2830	2831	2832	2833	2834	2835	2853	2854	2855	2856	2857	2858	2859	2860	2861	2890	2891	2902	2903
2614	2615	2626	2627	2656	2657	2658	2659	2660	2661	2662	2663	2664	2682	2683	2684	2685	2686	2687	2688	2689	2690	2708	2709	2710	2711	2712	2713	2714	2715	2716	2745	2746	2757	2758
2469	2470	2481	2482	2511	2512	2513	2514	2515	2516	2517	2518	2519	2537	2538	2539	2540	2541	2542	2543	2544	2545	2563	2564	2565	2566	2567	2568	2569	2570	2571	2600	2601	2612	2613
2324	2325	2336	2337	2366	2367	2368	2369	2370	2371	2372	2373	2374	2392	2393	2394	2395	2396	2397	2398	2399	2400	2418	2419	2420	2421	2422	2423	2424	2425	2426	2455	2456	2467	2468
2300	2301																																2322	2323

Temp Ambient 53.00

58.00	55.60	56.66	56.76	59.56	59.66	59.76	59.85	59.95	58.82	58.86	58.89	58.93	59.56	59.59	59.63	59.66	59.70	59.69	59.68	59.67	59.66	59.49	59.48	59.47	59.46	59.45	59.36	59.28	59.19	59.11	56.62	56.53	55.59	58.00
58.00	58.19	60.32	60.52	66.13	66.32	66.51	66.71	66.90	64.65	64.72	64.79	64.86	66.12	66.19	66.26	66.33	66.40	66.38	66.36	66.34	66.32	65.98	65.96	65.94	65.92	65.90	65.73	65.56	65.38	65.21	60.23	60.06	58.17	58.00
58.00	58.21	60.49	60.70	66.72	66.93	67.14	67.35	67.56	65.17	65.28	65.39	65.50	67.46	67.57	67.68	67.79	67.90	67.85	67.79	67.74	67.69	66.72	66.67	66.62	66.56	66.51	66.33	66.14	65.96	65.77	60.41	60.22	58.19	58.00
58.00	58.22	60.66	60.89	67.32	67.55	67.77	67.99	68.21	65.70	65.84	65.99	66.14	68.81	68.96	69.10	69.25	69.40	69.31	69.22	69.14	69.05	67.47	67.39	67.30	67.21	67.12	66.92	66.73	66.53	66.33	60.58	60.38	58.20	58.00
58.00	58.24	60.83	61.07	67.92	68.16	68.39	68.63	68.87	66.22	66.41	66.59	66.78	70.15	70.34	70.53	70.71	70.90	70.78	70.66	70.53	70.41	68.22	68.10	67.98	67.86	67.73	67.52	67.31	67.10	66.89	60.75	60.54	58.21	58.00
58.00	58.25	61.01	61.26	68.52	68.77	69.02	69.27	69.52	66.74	66.97	67.20	67.42	71.49	71.72	71.95	72.17	72.40	72.24	72.09	71.93	71.78	68.97	68.81	68.66	68.50	68.34	68.12	67.89	67.67	67.44	60.92	60.70	58.22	58.00
58.00	58.26	61.18	61.44	69.12	69.38	69.65	69.91	70.18	67.27	67.53	67.80	68.06	72.84	73.10	73.37	73.63	73.90	73.71	73.52	73.33	73.14	69.72	69.53	69.34	69.15	68.96	68.72	68.48	68.24	68.00	61.10	60.86	58.24	58.00
58.00	58.28	61.35	61.63	69.72	70.00	70.28	70.55	70.83	67.79	68.09	68.40	68.70	74.18	74.49	74.79	75.10	75.40	75.18	74.95	74.73	74.50	70.46	70.24	70.02	69.79	69.57	69.32	69.06	68.81	68.56	61.27	61.02	58.25	58.00
58.00	58.29	61.52	61.81	70.32	70.61	70.90	71.20	71.49	68.31	68.66	69.00	69.34	75.53	75.87	76.21	76.56	76.90	76.64	76.38	76.12	75.87	71.21	70.95	70.69	70.44	70.18	69.91	69.65	69.38	69.12	61.44	61.18	58.26	58.00
58.00	58.31	61.69	62.00	70.91	71.22	71.53	71.84	72.14	68.84	69.22	69.60	69.98	76.87	77.25	77.63	78.02	78.40	78.11	77.81	77.52	77.23	71.96	71.67	71.37	71.08	70.79	70.51	70.23	69.95	69.68	61.61	61.34	58.28	58.00
58.00	58.32	61.86	62.18	71.51	71.83	72.16	72.48	72.80	69.36	69.78	70.20	70.63	78.21	78.64	79.06	79.48	79.90	79.57	79.25	78.92	78.59	72.71	72.38	72.05	71.73	71.40	71.11	70.82	70.53	70.23	61.79	61.50	58.29	58.00
58.00	58.33	61.94	62.26	71.78	72.10	72.43	72.76	73.09	69.54	69.93	70.31	70.70	77.67	78.06	78.45	78.84	79.22	78.93	78.65	78.36	78.07	72.87	72.58	72.29	72.00	71.71	71.41	71.11	70.82	70.52	61.87	61.58	58.30	58.00
58.00	58.33	62.01	62.35	72.04	72.37	72.71	73.04	73.38	69.72	70.07	70.42	70.78	77.13	77.49	77.84	78.19	78.55	78.30	78.05	77.79	77.54	73.02	72.77	72.52	72.27	72.02	71.72	71.41	71.11	70.80	61.96	61.66	58.30	58.00
58.00	58.34	62.09	62.43	72.30	72.64	72.98	73.32	73.66	69.90	70.21	70.53	70.85	76.60	76.91	77.23	77.55	77.87	77.66	77.45	77.23	77.02	73.18	72.97	72.76	72.54	72.33	72.02	71.71	71.40	71.08	62.05	61.74	58.31	58.00
58.00	58.35	62.16	62.51	72.56	72.91	73.26	73.60	73.95	70.07	70.36	70.64	70.93	76.06	76.34	76.63	76.91	77.20	77.02	76.84	76.67	76.49	73.34	73.17	72.99	72.82	72.64	72.32	72.00	71.69	71.37	62.14	61.82	58.32	58.00
58.00	58.35	62.24	62.59	72.83	73.18	73.53	73.88	74.24	70.25	70.50	70.75	71.00	75.52	75.77	76.02	76.27	76.52	76.38	76.24	76.11	75.97	73.50	73.36	73.22	73.09	72.95	72.63	72.30	71.98	71.65	62.23	61.90	58.33	58.00
58.00	58.36	62.31	62.67	73.09	73.45	73.81	74.17	74.53	70.43	70.65	70.86	71.08	74.98	75.19	75.41	75.63	75.84	75.74	75.64	75.54	75.45	73.66	73.56	73.46	73.36	73.26	72.93	72.60	72.26	71.93	62.31	61.98	58.33	58.00
58.00	58.37	62.39	62.75	73.35	73.72	74.08	74.45	74.81	70.61	70.79	70.97	71.16	74.44	74.62	74.80	74.98	75.17	75.10	75.04	74.98	74.92	73.82	73.75	73.69	73.63	73.57	73.23	72.89	72.55	72.22	62.40	62.06	58.34	58.00
58.00	58.00	58.00	58.50	73.09	73.59	74.09	74.60	75.10	75.08	75.05	75.03	75.01	74.58	74.56	74.54	74.51	74.49	74.47	74.44	74.42	74.40	73.97	73.95	73.93	73.90	73.88	73.41	72.95	72.48	72.01	58.47	58.00	58.00	58.00

Delta Pour 57

1.00	-1.40	-0.34	-0.24	2.56	2.66	2.76	2.85	2.95	1.82	1.86	1.89	1.93	2.56	2.59	2.63	2.66	2.70	2.69	2.68	2.67	2.66	2.49	2.48	2.47	2.46	2.45	2.36	2.28	2.19	2.11	-0.38	-0.47	-1.41	1.00
1.00	1.19	3.32	3.52	9.13	9.32	9.51	9.71	9.90	7.65	7.72	7.79	7.86	9.12	9.19	9.26	9.33	9.40	9.38	9.36	9.34	9.32	8.98	8.96	8.94	8.92	8.90	8.73	8.56	8.38	8.21	3.23	3.06	1.17	1.00
1.00	1.21	3.49	3.70	9.72	9.93	10.14	10.35	10.56	8.17	8.28	8.39	8.50	10.46	10.57	10.68	10.79	10.90	10.85	10.79	10.74	10.69	9.72	9.67	9.62	9.56	9.51	9.33	9.14	8.96	8.77	3.41	3.22	1.19	1.00
1.00	1.22	3.66	3.89	10.32	10.55	10.77	10.99	11.21	8.70	8.84	8.99	9.14	11.81	11.96	12.10	12.25	12.40	12.31	12.22	12.14	12.05	10.47	10.39	10.30	10.21	10.12	9.92	9.73	9.53	9.33	3.58	3.38	1.20	1.00
1.00	1.24	3.83	4.07	10.92	11.16	11.39	11.63	11.87	9.22	9.41	9.59	9.78	13.15	13.34	13.53	13.71	13.90	13.78	13.66	13.53	13.41	11.22	11.10	10.98	10.86	10.73	10.52	10.31	10.10	9.89	3.75	3.54	1.21	1.00
1.00	1.25	4.01	4.26	11.52	11.77	12.02	12.27	12.52	9.74	9.97	10.20	10.42	14.49	14.72	14.95	15.17	15.40	15.24	15.09	14.93	14.78	11.97	11.81	11.66	11.50	11.34	11.12	10.89	10.67	10.44	3.92	3.70	1.22	1.00
1.00	1.26	4.18	4.44	12.12	12.38	12.65	12.91	13.18	10.27	10.53	10.80	11.06	15.84	16.10	16.37	16.63	16.90	16.71	16.52	16.33	16.14	12.72	12.53	12.34	12.15	11.96	11.72	11.48	11.24	11.00	4.10	3.86	1.24	1.00
1.00	1.28	4.35	4.63	12.72	13.00	13.28	13.55	13.83	10.79	11.09	11.40	11.70	17.18	17.49	17.79	18.10	18.40	18.18	17.95	17.73	17.50	13.46	13.24	13.02	12.79	12.57	12.32	12.06	11.81	11.56	4.27	4.02	1.25	1.00
1.00	1.29	4.52	4.81	13.32	13.61	13.90	14.20	14.49	11.31	11.66	12.00	12.34	18.53	18.87	19.21	19.56	19.90	19.64	19.38	19.12	18.87	14.21	13.95	13.69	13.44	13.18	12.91	12.65	12.38	12.12	4.44	4.18	1.26	1.00
1.00	1.31	4.69	5.00	13.91	14.22	14.53	14.84	15.14	11.84	12.22	12.60	12.98	19.87	20.25	20.63	21.02	21.40	21.11	20.81	20.52	20.23	14.96	14.67	14.37	14.08	13.79	13.51	13.23	12.95	12.68	4.61	4.34	1.28	1.00
1.00	1.32	4.86	5.18	14.51	14.83	15.16	15.48	15.80	12.36	12.78	13.20	13.63	21.21	21.64	22.06	22.48	22.90	22.57	22.25	21.92	21.59	15.71	15.38	15.05	14.73	14.40	14.11	13.82	13.53	13.23	4.79	4.50	1.29	1.00
1.00	1.33	4.94	5.26	14.78	15.10	15.43	15.76	16.09	12.54	12.93	13.31	13.70	20.67	21.06	21.45	21.84	22.22	21.93	21.65	21.36	21.07	15.87	15.58	15.29	15.00	14.71	14.41	14.11	13.82	13.52	4.87	4.58	1.30	1.00
1.00	1.33	5.01	5.35	15.04	15.37	15.71	16.04	16.38	12.72	13.07	13.42	13.78	20.13	20.49	20.84	21.19	21.55	21.30	21.05	20.79	20.54	16.02	15.77	15.52	15.27	15.02	14.72	14.41	14.11	13.80	4.96	4.66	1.30	1.00
1.00	1.34	5.09	5.43	15.30	15.64	15.98	16.32	16.66	12.90	13.21	13.53	13.85	19.60	19.91	20.23	20.55	20.87	20.66	20.45	20.23	20.02	16.18	15.97	15.76	15.54	15.33	15.02	14.71	14.40	14.08	5.05	4.74	1.31	1.00
1.00	1.35	5.16	5.51	15.56	15.91	16.26	16.60	16.95	13.07	13.36	13.64	13.93	19.06	19.34	19.63	19.91	20.20	20.02	19.84	19.67	19.49	16.34	16.17	15.99	15.82	15.64	15.32	15.00	14.69	14.37	5.14	4.82	1.32	1.00
1.00	1.35	5.24	5.59	15.83	16.18	16.53	16.88	17.24	13.25	13.50	13.75	14.00	18.52	18.77	19.02	19.27	19.52	19.38	19.24	19.11	18.97	16.50	16.36	16.22	16.09	15.95	15.63	15.30	14.98	14.65	5.22	4.90	1.33	1.00
1.00	1.36	5.31	5.67	16.09	16.45	16.81	17.17	17.53	13.43	13.65	13.86	14.08	17.98	18.19	18.41	18.63	18.84	18.74	18.64	18.54	18.45	16.66	16.56	16.46	16.36	16.26	15.93	15.60	15.26	14.93	5.31	4.98	1.33	1.00
1.00	1.37	5.39	5.75	16.35	16.72	17.08	17.45	17.81	13.61	13.79	13.97	14.16	17.44	17.62	17.80	17.98	18.17	18.10	18.04	17.98	17.92	16.82	16.75	16.69	16.63	16.57	16.23	15.89	15.55	15.22	5.40	5.06	1.34	1.00
1.00	1.00																																1.00	1.00

TABLE 19: EXCEL MODEL FOR LIFT 1, DAY 16

02/20/05 @ 6:00 PM

Nodes

2179	2180	2209	2210	2211	2212	2213	2214	2215	2216	2217	2235	2236	2237	2238	2239	2240	2241	2242	2243	2261	2262	2263	2264	2265	2266	2267	2268	2269	2298	2299
2058	2059	2088	2089	2090	2091	2092	2093	2094	2095	2096	2114	2115	2116	2117	2118	2119	2120	2121	2122	2140	2141	2142	2143	2144	2145	2146	2147	2148	2177	2178
1937	1938	1967	1968	1969	1970	1971	1972	1973	1974	1975	1993	1994	1995	1996	1997	1998	1999	2000	2001	2019	2020	2021	2022	2023	2024	2025	2026	2027	2056	2057
1816	1817	1846	1847	1848	1849	1850	1851	1852	1853	1854	1872	1873	1874	1875	1876	1877	1878	1879	1880	1898	1899	1900	1901	1902	1903	1904	1905	1906	1935	1936
1695	1696	1725	1726	1727	1728	1729	1730	1731	1732	1733	1751	1752	1753	1754	1755	1756	1757	1758	1759	1777	1778	1779	1780	1781	1782	1783	1784	1785	1814	1815
1574	1575	1604	1605	1606	1607	1608	1609	1610	1611	1612	1630	1631	1632	1633	1634	1635	1636	1637	1638	1656	1657	1658	1659	1660	1661	1662	1663	1664	1693	1694
1453	1454	1483	1484	1485	1486	1487	1488	1489	1490	1491	1509	1510	1511	1512	1513	1514	1515	1516	1517	1535	1536	1537	1538	1539	1540	1541	1542	1543	1572	1573
1332	1333	1362	1363	1364	1365	1366	1367	1368	1369	1370	1388	1389	1390	1391	1392	1393	1394	1395	1396	1414	1415	1416	1417	1418	1419	1420	1421	1422	1451	1452
1211	1212	1241	1242	1243	1244	1245	1246	1247	1248	1249	1267	1268	1269	1270	1271	1272	1273	1274	1275	1293	1294	1295	1296	1297	1298	1299	1300	1301	1330	1331
1090	1091	1120	1121	1122	1123	1124	1125	1126	1127	1128	1146	1147	1148	1149	1150	1151	1152	1153	1154	1172	1173	1174	1175	1176	1177	1178	1179	1180	1209	1210
969	970	999	1000	1001	1002	1003	1004	1005	1006	1007	1025	1026	1027	1028	1029	1030	1031	1032	1033	1051	1052	1053	1054	1055	1056	1057	1058	1059	1088	1089
848	849	878	879	880	881	882	883	884	885	886	904	905	906	907	908	909	910	911	912	930	931	932	933	934	935	936	937	938	967	968
727	728	757	758	759	760	761	762	763	764	765	783	784	785	786	787	788	789	790	791	809	810	811	812	813	814	815	816	817	846	847
606	607	636	637	638	639	640	641	642	643	644	662	663	664	665	666	667	668	669	670	688	689	690	691	692	693	694	695	696	725	726
485	486	515	516	517	518	519	520	521	522	523	541	542	543	544	545	546	547	548	549	567	568	569	570	571	572	573	574	575	604	605
364	365	394	395	396	397	398	399	400	401	402	420	421	422	423	424	425	426	427	428	446	447	448	449	450	451	452	453	454	483	484
243	244	273	274	275	276	277	278	279	280	281	299	300	301	302	303	304	305	306	307	325	326	327	328	329	330	331	332	333	362	363
122	123	152	153	154	155	156	157	158	159	160	178	179	180	181	182	183	184	185	186	204	205	206	207	208	209	210	211	212	241	242
1	2	31	32	33	34	35	36	37	38	39	57	58	59	60	61	62	63	64	65	83	84	85	86	87	88	89	90	91	120	121

Temp

58.00	58.50	73.09	73.59	74.09	74.60	75.10	75.08	75.05	75.03	75.01	74.58	74.56	74.54	74.51	74.49	74.47	74.44	74.42	74.40	73.97	73.95	73.93	73.90	73.88	73.41	72.95	72.48	72.01	58.47	58.00
58.00	58.50	73.09	73.59	74.09	74.60	75.10	75.08	75.05	75.03	75.01	74.59	74.57	74.55	74.52	74.50	74.48	74.45	74.43	74.41	73.99	73.97	73.95	73.92	73.90	73.43	72.96	72.50	72.03	58.47	58.00
58.00	58.50	73.09	73.59	74.09	74.60	75.10	75.13	75.16	75.19	75.22	75.76	75.79	75.82	75.85	75.88	75.80	75.73	75.65	75.58	74.22	74.15	74.07	74.00	73.92	73.45	72.99	72.52	72.05	58.47	58.00
58.00	58.50	73.09	73.59	74.09	74.60	75.10	75.18	75.27	75.35	75.43	76.92	77.01	77.09	77.17	77.26	77.13	77.00	76.87	76.75	74.45	74.33	74.20	74.07	73.94	73.48	73.01	72.54	72.07	58.47	58.00
58.00	58.50	73.09	73.59	74.09	74.60	75.10	75.24	75.37	75.51	75.64	78.09	78.23	78.36	78.50	78.63	78.45	78.27	78.09	77.92	74.68	74.51	74.33	74.15	73.97	73.50	73.03	72.56	72.09	58.47	58.00
58.00	58.50	73.09	73.59	74.09	74.60	75.10	75.29	75.48	75.67	75.86	79.26	79.44	79.63	79.82	80.01	79.78	79.55	79.32	79.08	74.92	74.68	74.45	74.22	73.99	73.52	73.05	72.58	72.11	58.47	58.00
58.00	58.50	73.09	73.59	74.09	74.60	75.10	75.34	75.58	75.83	76.07	80.42	80.66	80.91	81.15	81.39	81.11	80.82	80.54	80.25	75.15	74.86	74.58	74.29	74.01	73.54	73.07	72.60	72.13	58.47	58.00
58.00	58.50	73.09	73.59	74.09	74.60	75.10	75.39	75.69	75.98	76.28	81.59	81.88	82.18	82.47	82.77	82.43	82.09	81.76	81.42	75.38	75.04	74.71	74.37	74.03	73.56	73.09	72.62	72.15	58.47	58.00
58.00	58.50	73.09	73.59	74.09	74.60	75.10	75.45	75.80	76.14	76.49	82.75	83.10	83.45	83.80	84.14	83.76	83.37	82.98	82.59	75.61	75.22	74.83	74.44	74.06	73.58	73.11	72.64	72.17	58.47	58.00
58.00	58.50	73.09	73.59	74.09	74.60	75.10	75.50	75.90	76.30	76.70	83.92	84.32	84.72	85.12	85.52	85.08	84.64	84.20	83.76	75.84	75.40	74.96	74.52	74.08	73.60	73.13	72.66	72.19	58.47	58.00
58.00	58.50	73.09	73.59	74.09	74.60	75.10	75.55	76.01	76.46	76.92	85.08	85.54	85.99	86.45	86.90	86.41	85.92	85.42	84.93	76.07	75.58	75.08	74.59	74.10	73.63	73.15	72.68	72.21	58.47	58.00
58.00	58.44	71.20	71.64	72.08	72.52	72.96	73.36	73.76	74.15	74.55	81.70	82.10	82.49	82.89	83.29	82.86	82.43	82.00	81.56	73.81	73.38	72.95	72.52	72.09	71.67	71.26	70.84	70.43	58.41	58.00
58.00	58.38	69.32	69.69	70.07	70.45	70.83	71.17	71.51	71.85	72.19	78.31	78.65	78.99	79.33	79.68	79.31	78.94	78.57	78.20	71.55	71.18	70.81	70.44	70.08	69.72	69.36	69.01	68.65	58.36	58.00
58.00	58.31	67.43	67.74	68.06	68.37	68.69	68.97	69.25	69.54	69.82	74.93	75.21	75.50	75.78	76.06	75.75	75.45	75.14	74.83	69.29	68.99	68.68	68.37	68.06	67.77	67.47	67.17	66.88	58.30	58.00
58.00	58.25	65.54	65.80	66.05	66.30	66.55	66.78	67.00	67.23	67.46	71.54	71.77	72.00	72.22	72.45	72.20	71.96	71.71	71.47	67.03	66.79	66.54	66.30	66.05	65.81	65.58	65.34	65.10	58.24	58.00
58.00	58.19	63.66	63.85	64.04	64.22	64.41	64.58	64.75	64.92	65.09	68.16	68.33	68.50	68.67	68.84	68.65	68.47	68.28	68.10	64.78	64.59	64.41	64.22	64.04	63.86	63.68	63.50	63.33	58.18	58.00
58.00	58.13	61.77	61.90	62.02	62.15	62.28	62.39	62.50	62.62	62.73	64.77	64.88	65.00	65.11	65.23	65.10	64.98	64.86	64.73	62.52	62.39	62.27	62.15	62.03	61.91	61.79	61.67	61.55	58.12	58.00
58.00	58.06	59.89	59.95	60.01	60.07	60.14	60.19	60.25	60.31	60.36	61.39	61.44	61.50	61.56	61.61	61.55	61.49	61.43	61.37	60.26	60.20	60.14	60.07	60.01	59.95	59.89	59.83	59.78	58.06	58.00
58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00

Delta

Pour 55

3.00	3.50	18.09	18.59	19.09	19.60	20.10	20.08	20.05	20.03	20.01	19.58	19.56	19.54	19.51	19.49	19.47	19.44	19.42	19.40	18.97	18.95	18.93	18.90	18.88	18.41	17.95	17.48	17.01	3.47	3.00
3.00	3.50	18.09	18.59	19.09	19.60	20.10	20.08	20.05	20.03	20.01	19.59	19.57	19.55	19.52	19.50	19.48	19.45	19.43	19.41	18.99	18.97	18.95	18.92	18.90	18.43	17.96	17.50	17.03	3.47	3.00
3.00	3.50	18.09	18.59	19.09	19.60	20.10	20.13	20.16	20.19	20.22	20.76	20.79	20.82	20.85	20.88	20.80	20.73	20.65	20.58	19.22	19.15	19.07	19.00	18.92	18.45	17.99	17.52	17.05	3.47	3.00
3.00	3.50	18.09	18.59	19.09	19.60	20.10	20.18	20.27	20.35	20.43	21.92	22.01	22.09	22.17	22.26	22.13	22.00	21.87	21.75	19.45	19.33	19.20	19.07	18.94	18.48	18.01	17.54	17.07	3.47	3.00
3.00	3.50	18.09	18.59	19.09	19.60	20.10	20.24	20.37	20.51	20.64	23.09	23.23	23.36	23.50	23.63	23.45	23.27	23.09	22.92	19.68	19.51	19.33	19.15	18.97	18.50	18.03	17.56	17.09	3.47	3.00
3.00	3.50	18.09	18.59	19.09	19.60	20.10	20.29	20.48	20.67	20.86	24.26	24.44	24.63	24.82	25.01	24.78	24.55	24.32	24.08	19.92	19.68	19.45	19.22	18.99	18.52	18.05	17.58	17.11	3.47	3.00
3.00	3.50	18.09	18.59	19.09	19.60	20.10	20.34	20.58	20.83	21.07	25.42	25.66	25.91	26.15	26.39	26.11	25.82	25.54	25.25	20.15	19.86	19.58	19.29	19.01	18.54	18.07	17.60	17.13	3.47	3.00
3.00	3.50	18.09	18.59	19.09	19.60	20.10	20.39	20.69	20.98	21.28	26.59	26.88	27.18	27.47	27.77	27.43	27.09	26.76	26.42	20.38	20.04	19.71	19.37	19.03	18.56	18.09	17.62	17.15	3.47	3.00
3.00	3.50	18.09	18.59	19.09	19.60	20.10	20.45	20.80	21.14	21.49	27.75	28.10	28.45	28.80	29.14	28.76	28.37	27.98	27.59	20.61	20.22	19.83	19.44	19.06	18.58	18.11	17.64	17.17	3.47	3.00
3.00	3.50	18.09	18.59	19.09	19.60	20.10	20.50	20.90	21.30	21.70	28.92	29.32	29.72	30.12	30.52	30.08	29.64	29.20	28.76	20.84	20.40	19.96	19.52	19.08	18.60	18.13	17.66	17.19	3.47	3.00
3.00	3.50	18.09	18.59	19.09	19.60	20.10	20.55	21.01	21.46	21.92	30.08	30.54	30.99	31.45	31.90	31.41	30.92	30.42	29.93	21.07	20.58	20.08	19.59	19.10	18.63	18.15	17.68	17.21	3.47	3.00
3.00	3.44	16.20	16.64	17.08	17.52	17.96	18.36	18.76	19.15	19.55	26.70	27.10	27.49	27.89	28.29	27.86	27.43	27.00	26.56	18.81	18.38	17.95	17.52	17.09	16.67	16.26	15.84	15.43	3.41	3.00
3.00	3.38	14.32	14.69	15.07	15.45	15.83	16.17	16.51	16.85	17.19	23.31	23.65	23.99	24.33	24.68	24.31	23.94	23.57	23.20	16.55	16.18	15.81	15.44	15.08	14.72	14.36	14.01	13.65	3.36	3.00
3.00	3.31	12.43	12.74	13.06	13.37	13.69	13.97	14.25	14.54	14.82	19.93	20.21	20.50	20.78	21.06	20.75	20.45	20.14	19.83	14.29	13.99	13.68	13.37	13.06	12.77	12.47	12.17	11.88	3.30	3.00
3.00	3.25	10.54	10.80	11.05	11.30	11.55	11.78	12.00	12.23	12.46	16.54	16.77	17.00	17.22	17.45	17.20	16.96	16.71	16.47	12.03	11.79	11.54	11.30	11.05	10.81	10.58	10.34	10.10	3.24	3.00
3.00	3.19	8.66	8.85	9.04	9.22	9.41	9.58	9.75	9.92	10.09	13.16	13.33	13.50	13.67	13.84	13.65	13.47	13.28	13.10	9.78	9.59	9.41	9.22	9.04	8.86	8.68	8.50	8.33	3.18	3.00
3.00	3.13	6.77	6.90	7.02	7.15	7.28	7.39	7.50	7.62	7.73	9.77	9.88	10.00	10.11	10.23	10.10	9.98	9.86	9.73	7.52	7.39	7.27	7.15	7.03	6.91	6.79	6.67	6.55	3.12	3.00
3.00	3.06	4.89	4.95	5.01	5.07	5.14	5.19	5.25	5.31	5.36	6.39	6.44	6.50	6.56	6.61	6.55	6.49	6.43	6.37	5.26	5.20	5.14	5.07	5.01	4.95	4.89	4.83	4.78	3.06	3.00
3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00

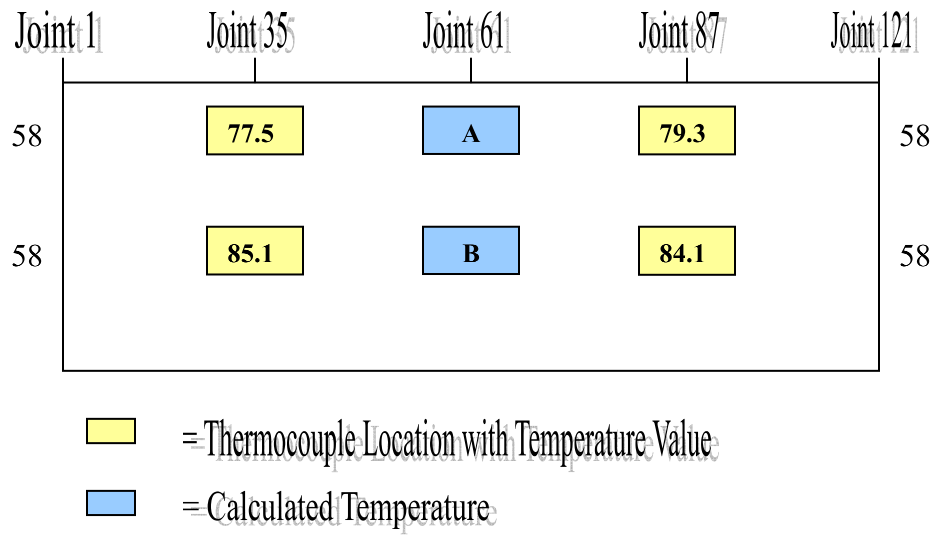


FIGURE 18: LIFT 1 SECTION ON 02/06/05 TEMPERATURE DISTRIBUTIONS
(SEE TABLE 11)

Since location A is two inches from the surface, it was assumed that the temperature rise between the thermocouple locations and the center of section would not be as significant as location B due to the dissipation of heat to the surface. Therefore, location A values were calculated by taking an average between the two inch deep thermocouple readings.

$$T_A = \frac{77.5 + 79.3}{2} = 78.4°F$$

T_A = *Temperature at location A*

Location B temperatures were calculated using algebraic equations based on finite element model joints, boundary condition temperatures, and thermocouple equations, as stated above. First, the average of the temperature readings was taken.

$$Average = \frac{85.1 + 84.1}{2} = 84.6°F$$

Then a linear algebraic expression was used, assuming a linear rise in temperature to the center of the section. $T_B = ax + b$

T_B = *Temperature at Location B*

$$a = \frac{\text{Average Temperature – Boundary Temperature}}{\text{Number of Joints}}$$

$$a = \frac{84.6 - 58}{35} = 0.76$$

b = *Boundary Constant Temperature* = 58°*F*

Substituting: $T_B = 0.76x + 58$

Therefore, when x = Joint 61

$$T_B = 0.76(61) + 58 = 104.4°F$$

Figure 19 illustrates the center of mass temperature calculations for lift one (day 6).

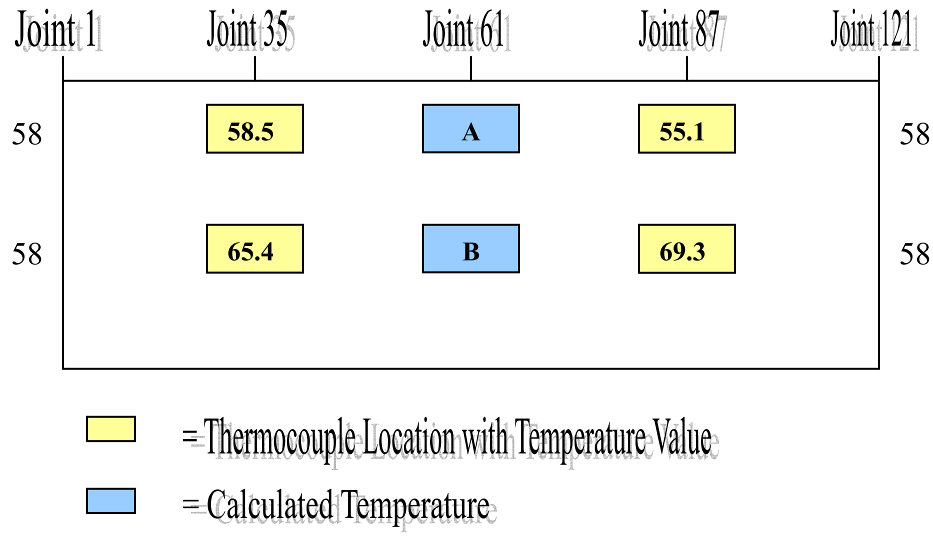


FIGURE 19: LIFT 1 SECTION ON 02/10/05 TEMPERATURE DISTRIBUTIONS
(SEE TABLE 12)

Location A

$$T_A = \frac{58.5 + 55.1}{2} = 56.8°F$$

T_A = *Temperature at location A*

Location B

$$Average = \frac{65.4 + 69.3}{2} = 67.4°F$$

$$T_B = ax + b$$

T_B = *Temperature at location B*

$$a = \frac{\text{Average Temperature} - \text{Boundary Temperature}}{\text{Number of Joints}}$$

$$a = \frac{67.4 - 58}{35} = 0.2686$$

b = Boundary Constant Temperature = 58°*F*

Substituting: $T_B = 0.2686x + 58$

Therefore, when x = Joint 61

$$T_B = 0.2686(61) + 58 = 74.4°F$$

Figure 20 illustrates the center of mass temperature calculations for lift one (day 10) and lift two (day 3).

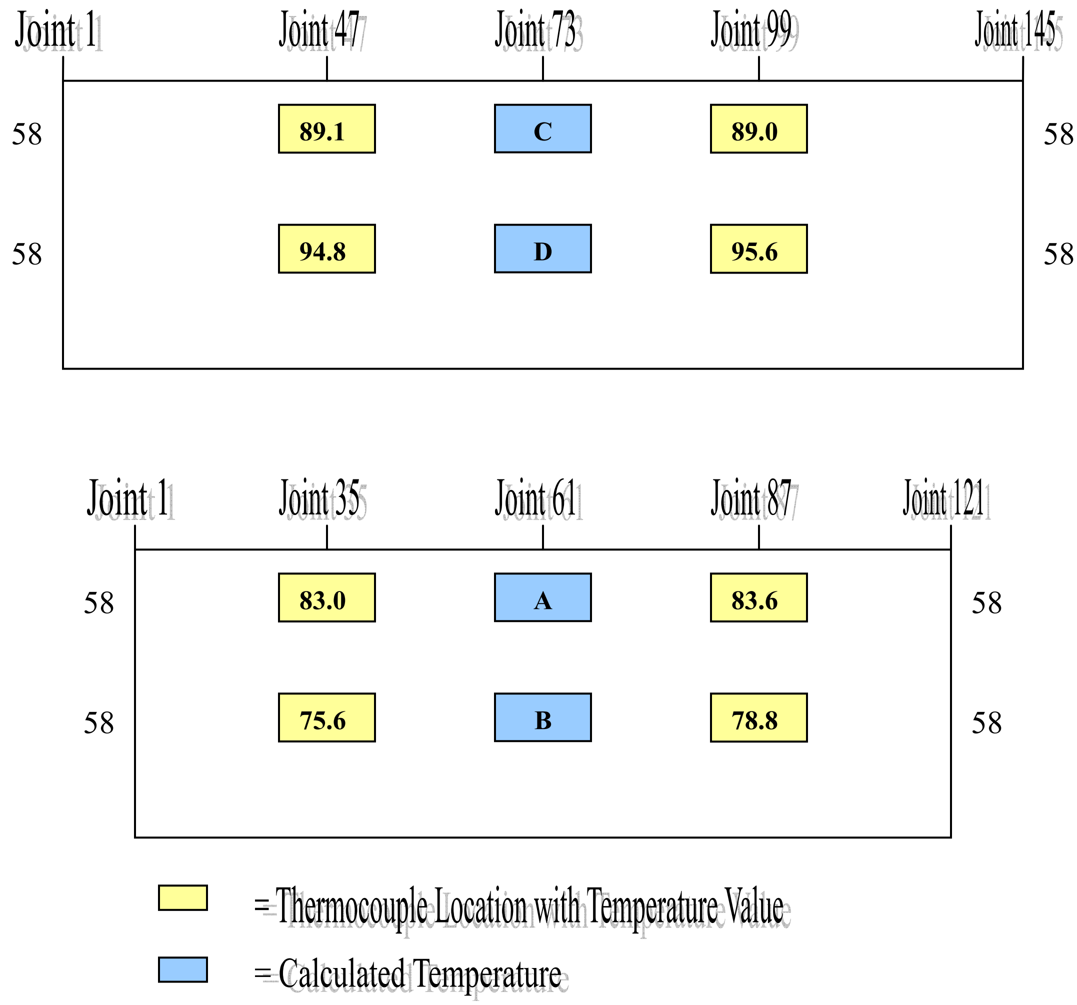


FIGURE 20: LIFT 1 AND LIFT 2 SECTIONS ON 02/14/05
TEMPERATURE DISTRIBUTIONS
(SEE TABLE 13, 14)

Location A

$$T_A = \frac{83.0 + 83.6}{2} = 83.3°F$$

T_A = Temperature at location A

Location B

$$Average = \frac{75.6 + 78.8}{2} = 77.2°F$$

$$T_B = ax + b$$

T_B = Temperature at location B

$$a = \frac{\text{Average Temperature} - \text{Boundary Temperature}}{\text{Number of Joints}}$$

$$a = \frac{77.2 - 58}{35} = 0.5486$$

b = *Boundary Constant Temperature* = 58°*F*

Substituting: $T_B = 0.5486x + 58$

Therefore, when x = Joint 61

$$T_B = 0.5486(61) + 58 = 91.5°F$$

Location C

$$T_C = \frac{89.1 + 89.0}{2} = 89.05°F$$

T_C = Temperature at location C

Location D

$$Average = \frac{94.8 + 95.6}{2} = 95.2°F$$

$$T_D = ax + b$$

T_D = Temperature at location D

$$a = \frac{\text{Average Temperature – Boundary Temperature}}{\text{Number of Joints}}$$

$$a = \frac{95.2 - 58}{47} = 0.7915$$

b = *Boundary Constant Temperature* = 58°*F*

Substituting: $T_D = 0.7915x + 58$

Therefore, when x = Joint 73

$$T_D = 0.7915(73) + 58 = 115.8°F$$

Figure 21 illustrates the center of mass temperature calculations for lift one (day 16) and lift two (day 9).

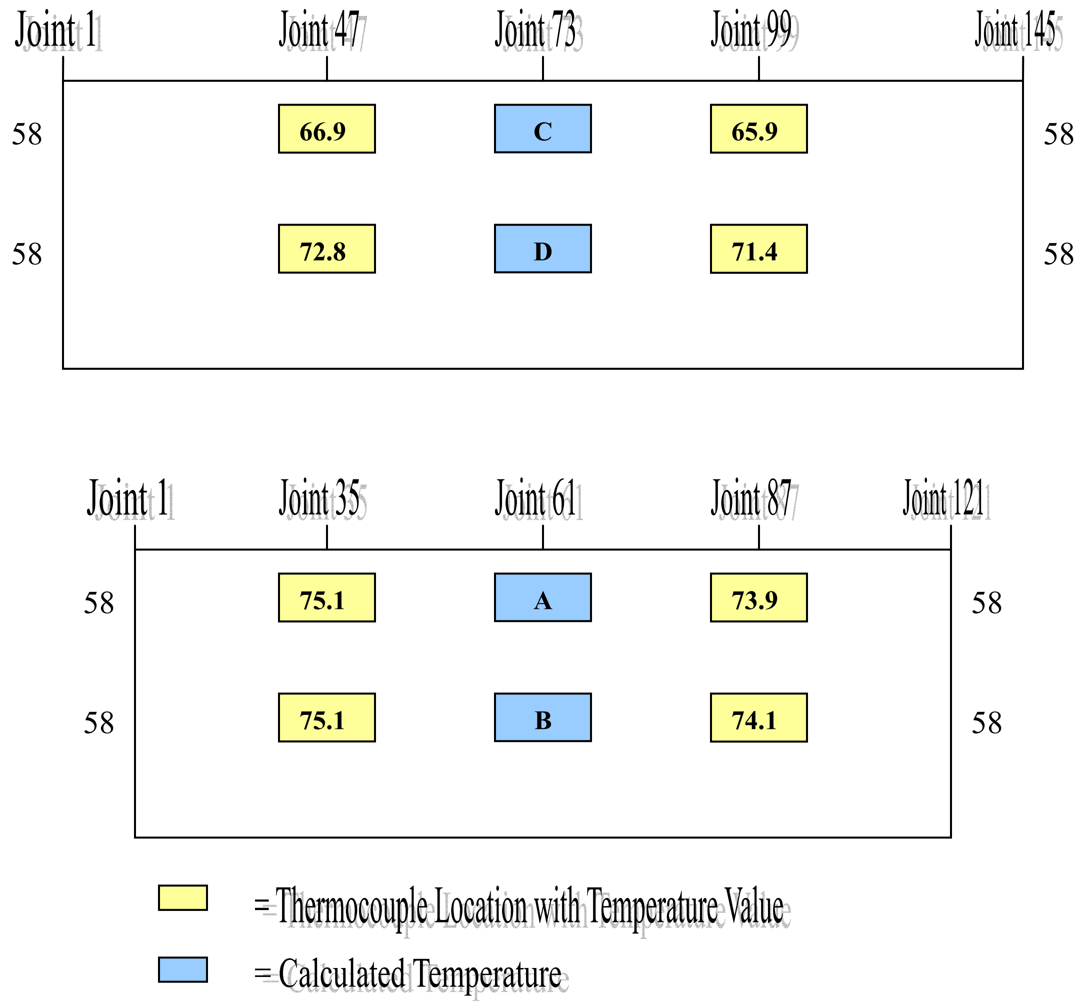


FIGURE 21: LIFT 1 AND LIFT 2 SECTIONS ON 02/20/05
TEMPERATURE DISTRIBUTIONS
(SEE TABLE 15, 16)

Location A

$$A = \frac{75.1 + 73.9}{2} = 74.5°F$$

T_A = *Temperature at location A*

Location B

$$Average = \frac{75.1 + 74.1}{2} = 74.6°F$$

$$T_B = ax + b$$

T_B = *Temperature at location B*

$$a = \frac{\text{Average Temperature} - \text{Boundary Temperature}}{\text{Number of Joints}}$$

$$a = \frac{74.6 - 58}{35} = 0.4743$$

b = *Boundary Constant Temperature* = 58°*F*

Substituting: $T_B = 0.4743x + 58$

Therefore, when x = Joint 61

$$T_B = 0.4743(61) + 58 = 86.9°F$$

Location C

$$T_C = \frac{66.9 + 65.9}{2} = 66.4°F$$

T_C = Temperature at location C

Location D

$$Average = \frac{72.8 + 71.4}{2} = 72.1°F$$

$$T_D = ax + b$$

T_D = Temperature at location D

$$a = \frac{\textit{Average Temperature – Boundary Temperature}}{\textit{Number of Joints}}$$

$$a = \frac{72.1 - 58}{47} = 0.300$$

b = *Boundary Constant Temperature* = 58°*F*

Substituting: $T_D = 0.300x + 58$

Therefore, when x = Joint 73

$$T_D = 0.300(73) + 58 = 79.9°F$$

3.3 EMPIRICAL EQUATIONS

As stated above, the empirical equations come mainly from the ACI approach, which includes ACI 207.1R-96, the ACI journal article, "Prediction of Tensile Strain Capacity of Mass Concrete" by Liu and McDonald, and "Early Age Thermal Crack Control in Concrete" by T. Harrison. These references were used during the development of the project specification in order to limit the thermal strains of the mass concrete pour. Liu and McDonald present a method for estimating tensile strain capacity of mass concrete from the compressive strength and modulus of elasticity determined by standard methods. The article verifies that the strain capacity determined by the method may be used as a guide in the preliminary studies of temperature and construction control plans for mass concrete projects. Laboratory data was analyzed to derive the following equation for tensile strain:

$$\varepsilon_t = 410K\frac{(f'c)^{1.85}}{E^2}$$

K = Aggregate Factor (1.0 for angular, 0.74 for rounded)
f'c = Compressive strength, psi
E = Modulus of Elasticity, psi
ε_t = Tensile strain capacity under slow loading conditions

By using the Liu and McDonald equation shown on page 41 with estimated compressive strength and modulus of elasticity values attained from ACI 207.1R-96, a strain capacity of the concrete may be estimated. The next step during the pre-construction design process was to determine what temperature differentials would create a thermal strain greater than the strain capacity estimated, and create a specification which keeps the temperature differentials below these values.

Thermal cracking within the concrete mass will occur when the tensile strain induced by thermal volume change exceeds the strain capacity of concrete (Harrison 1981). The relationship is expressed by the following equation (Harrison 1981):

$$RC\Delta T_t \geq \varepsilon_t$$

R = Restraint Factor (0.35 typical for internal temperature distribution)
C = Coefficient of Expansion, $5.5x10^{-6}$ in/in/°F
ΔT_t = Temperature change between the center of the mass and the surface, °F
ε_t = Tensile strain capacity under slow loading conditions

Harrison's equation is based on the awareness of "small" compressive stresses present during the heating phase of mass concrete, which means that large tensile stresses do not develop until some time after the peak temperature (Harrison 1981). Thus, the above equation represents the assumption of no stresses during the time of heating, which leads to an overestimation of the tensile stresses (Harrison 1981). Harrison states that the above equation is a safe basis for design.

Figure 5.3.1 from ACI 207.1R was used to preliminarily estimate the temperature rise of the mass concrete fill in relation to time and type of cement. Table 5.4.3(a) from ACI 207.1R was used to preliminarily estimate the adiabatic temperature rise in relation to time.

The above equations and ACI 207 figures were used to determine the concrete mix design and create a specification for the mass concrete fill, which specifies that a seven-day period between the sequential placements of lifts should be sufficient to control the temperatures within the concrete in order to reduce thermal strains below the strain capacity estimated.

CHAPTER 4: INTERPRETATION OF RESULTS

4.0 FINITE ELEMENT MODEL RESULTS

The results of the finite element models for each lift section are found in this chapter. In order to analyze and compare the experimental results to the empirical results, each section is overviewed separately. Two cases are analyzed for each test pad section taken. First, the actual compressive strength and modulus of elasticity results from the test pad are placed into the empirical equations used to create the mass concrete fill project specification in order to update the strain capacity. The empirical strain capacity value which results from these equations is then compared to the highest measured tensile strain value from GTSTRUDL. If the measured strain value is less than the empirical strain value, Liu and McDonald state that the strain capacity has not been reached. The next case analyzed is the single most important aspect required to maintain a minimum shear wave velocity of 6000 fps defined per the project specification, the cracking potential of the section. By placing the updated empirical strain capacity value into Harrison's equation, the temperature differential which would theoretically cause cracking is found. The theoretical cracking temperature differential is compared to the change in temperature between the center of the mass concrete test pad section and its corresponding surface temperature to evaluate if there is a potential for cracking. If the measured temperature differential is less than the theoretical cracking temperature differential, then Harrison states there is no potential for thermal cracking. The finite element and material property result values from the experiment for lift one (day 2) can be found in Table 20.

TABLE 20: LIFT 1 SECTION ON 02/06/05 (DAY 2) RESULTS		
Material Property Results	**Value**	**Joint**
Compressive Strength	1570 PSI	All
Modulus of Elasticity	2.4245e6 PSI	All
Temperature Results	**Value**	**Joint**
High Temperature @ Center of Mass (T_H)	104.4 °F	1029
Surface Temperature @ Center of Mass (T_S)	55.7 °F	2239
Computational Results	**Value**	**Joint**
Highest Compressive Stress	608.5 PSI	1029
Highest Tensile Stress	228.3 PSI	2262
Highest Compressive Strain	2.292e-4 IN/IN	1029
Highest Tensile Strain (ε_m)	7.537e-5 IN/IN	2262

Strain Analysis

Is $\varepsilon_t > \varepsilon_m$?

$$\varepsilon_t = 410K \frac{(f'c)^{1.85}}{E^2}$$

$$\varepsilon_t = 410(1.0)\frac{(1570)^{1.85}}{(2.4245x10^6)^2}$$ = 5.701x10^{-5} IN/IN (Theoretical Empirical Strain)

$\varepsilon_m = 7.537x10^{-5}$ IN/IN (GTSTRUDL Measured Strain)

$5.701x10^{-5} > 7.537x10^{-5}$ NO Therefore, the strain capacity has been reached.

Temperature Analysis

Is $\Delta T_t > \Delta T_m$?

$$\Delta T_t = \frac{\varepsilon_t}{RC}$$

$$\Delta T_t = \frac{5.701x10^{-5}}{(0.35)(5.5x10^{-6})} = 29.6°F$$ (Theoretical Empirical Temperature Differential)

$$\Delta T_m = T_H - T_S$$

$\Delta T_m = 104.4° - 55.7° = 48.7°F$ (Measured Temperature Differential)

$29.6°F > 48.7°F$ NO Therefore, there is a potential for cracking.

The finite element and material property result values from the experiment for lift one (day 6) can be found in Table 21.

TABLE 21: LIFT 1 SECTION ON 02/10/05 (DAY 6) RESULTS		
Material Property Results	**Value**	**Joint**
Compressive Strength	3235 PSI	All
Modulus of Elasticity	3.818e6 PSI	All
Temperature Results	**Value**	**Joint**
High Temperature @ Center of Mass (T_H)	74.4 °F	1029
Surface Temperature @ Center of Mass (T_S)	46.4 °F	2239
Computational Results	**Value**	**Joint**
Highest Compressive Stress	374.0 PSI	1029
Highest Tensile Stress	280.1 PSI	2240
Highest Compressive Strain	9.405e-5 IN/IN	1029
Highest Tensile Strain (ε_m)	6.644e-5 IN/IN	2240

Strain Analysis

Is $\varepsilon_t > \varepsilon_m$?

$$\varepsilon_t = 410K \frac{(f'c)^{1.85}}{E^2}$$

$$\varepsilon_t = 410(1.0)\frac{(3235)^{1.85}}{(3.818x10^6)^2} = 8.757\text{x}10^{-5} \text{ IN/IN}$$

$$\varepsilon_m = 6.644x10^{-5} \text{ IN/IN}$$

$8.757x10^{-5} > 6.644x10^{-5}$ OK Therefore, the strain capacity has not been reached.

Temperature Analysis

Is $\Delta T_t > \Delta T_m$?

$$\Delta T_t = \frac{\varepsilon_t}{RC}$$

$$\Delta T_t = \frac{8.757x10^{-5}}{(0.35)(5.5x10^{-6})} = 45.5°F$$

$$\Delta T_m = T_H - T_S$$

$$\Delta T_m = 74.4° - 46.4° = 28.0°F$$

$45.5°F > 28.0°F$ OK Therefore, there is no potential for cracking.

The finite element and material property result values from the experiment for lift two (day 3) can be found in Table 22.

TABLE 22: LIFT 2 SECTION ON 02/14/05 (DAY 3) RESULTS		
Material Property Results	**Value**	**Joint**
Compressive Strength	2140 PSI	All
Modulus of Elasticity	2.429e6 PSI	All
Temperature Results	**Value**	**Joint**
High Temperature @ Center of Mass (T_H)	115.8 °F	3411
Surface Temperature @ Center of Mass (T_S)	69.5 °F	4861
Computational Results	**Value**	**Joint**
Highest Compressive Stress	830.4 PSI	4933
Highest Tensile Stress	239.7 PSI	4862
Highest Compressive Strain	2.925e-4 IN/IN	4933
Highest Tensile Strain (ε_m)	6.604e-5 IN/IN	4862

Note: Table 22 results are at the same time as Table 23 results.

Strain Analysis

Is $\varepsilon_t > \varepsilon_m$?

$$\varepsilon_t = 410K \frac{(f'c)^{1.85}}{E^2}$$

$$\varepsilon_t = 410(1.0)\frac{(2140)^{1.85}}{(2.429x10^6)^2} = 1.007\text{x}10^{-4} \text{ IN/IN}$$

$$\varepsilon_m = 6.604x10^{-5} \text{ IN/IN}$$

$1.007x10^{-4} > 6.604x10^{-5}$ OK Therefore, the strain capacity has not been reached.

Temperature Analysis

Is $\Delta T_t > \Delta T_m$?

$$\Delta T_t = \frac{\varepsilon_t}{RC}$$

$$\Delta T_t = \frac{1.007x10^{-4}}{(0.35)(5.5x10^{-6})} = 52.3°F$$

$$\Delta T_m = T_H - T_S$$

$$\Delta T_m = 115.8° - 69.5° = 46.3°F$$

$52.3°F > 46.3°F$ OK Therefore, there is no potential for cracking.

The finite element and material property result values from the experiment for lift one (day 10) can be found in Table 23.

TABLE 23: LIFT 1 SECTION ON 02/14/05 (DAY 10) RESULTS		
Material Property Results	**Value**	**Joint**
Compressive Strength	3800 PSI	All
Modulus of Elasticity	3.700e6 PSI	All
Temperature Results	**Value**	**Joint**
High Temperature @ Center of Mass (T_H)	91.5 °F	1029
Surface Temperature @ Center of Mass (T_S)	69.5°F	4861
Computational Results	**Value**	**Joint**
Highest Compressive Stress	661.9 PSI	1029
Highest Tensile Stress	28.3 PSI	2298
Highest Compressive Strain	1.656e-4 IN/IN	1029
Highest Tensile Strain (ε_m)	5.456e-5 IN/IN	2298

Note: Table 22 results are at the same time as Table 23 results.

Strain Analysis

Is $\varepsilon_t > \varepsilon_m$?

$$\varepsilon_t = 410K \frac{(f'c)^{1.85}}{E^2}$$

$$\varepsilon_t = 410(1.0)\frac{(3800)^{1.85}}{(3.700x10^6)^2} = 1.256\text{x}10^{-4} \text{ IN/IN}$$

$$\varepsilon_m = 5.456x10^{-5} \text{ IN/IN}$$

$1.256x10^{-4} > 5.456x10^{-5}$ OK Therefore, the strain capacity has not been reached.

Temperature Analysis

Is $\Delta T_t > \Delta T_m$?

$$\Delta T_t = \frac{\varepsilon_t}{RC}$$

$$\Delta T_t = \frac{1.256x10^{-4}}{(0.35)(5.5x10^{-6})} = 65.2°F$$

$$\Delta T_m = T_H - T_S$$

$$\Delta T_m = 91.5° - 69.5° = 22.0°F$$

$65.2°F > 22.0°F$ OK Therefore, there is no potential for cracking.

The finite element and material property result values from the experiment for lift two (day 9) can be found in Table 24.

TABLE 24: LIFT 2 SECTION ON 02/20/05 (DAY 9) RESULTS		
Material Property Results	**Value**	**Joint**
Compressive Strength	3300 PSI	All
Modulus of Elasticity	3.200e6 PSI	All
Temperature Results	**Value**	**Joint**
High Temperature @ Center of Mass (T_H)	79.9 °F	3411
Surface Temperature @ Center of Mass (T_S)	59.7 °F	4861
Computational Results	**Value**	**Joint**
Highest Compressive Stress	553.6 PSI	4789
Highest Tensile Stress	200.5 PSI	4861
Highest Compressive Strain	1.506e-4 IN/IN	4789
Highest Tensile Strain (ε_m)	5.121e-5 IN/IN	4861

Note: Table 24 results are at the same time as Table 25 results.

Strain Analysis

Is $\varepsilon_t > \varepsilon_m$?

$$\varepsilon_t = 410K \frac{(f'c)^{1.85}}{E^2}$$

$$\varepsilon_t = 410(1.0)\frac{(3300)^{1.85}}{(3.200x10^6)^2} = 1.293\text{x}10^{-4} \text{ IN/IN}$$

$$\varepsilon_m = 5.121x10^{-5} \text{ IN/IN}$$

$1.293x10^{-4} > 5.121x10^{-5}$ OK Therefore, the strain capacity has not been reached.

Temperature Analysis

Is $\Delta T_t > \Delta T_m$?

$$\Delta T_t = \frac{\varepsilon_t}{RC}$$

$$\Delta T_t = \frac{1..293x10^{-4}}{(0.35)(5.5x10^{-6})} = 67.2°F$$

$$\Delta T_m = T_H - T_S$$

$$\Delta T_m = 79.9° - 59.7° = 20.2°F$$

$67.2°F > 20.2°F$ OK Therefore, there is no potential for cracking.

The finite element and material property result values from the experiment for lift one (day 16) can be found in Table 25.

TABLE 25: LIFT 1 SECTION ON 02/20/05 (DAY 16) RESULTS		
Material Property Results	**Value**	**Joint**
Compressive Strength	4400 PSI	All
Modulus of Elasticity	4.250e6 PSI	All
Temperature Results	**Value**	**Joint**
High Temperature @ Center of Mass (T_H)	86.9 °F	1029
Surface Temperature @ Center of Mass (T_S)	59.7 °F	4861
Computational Results	**Value**	**Joint**
Highest Compressive Stress	683.4 PSI	1029
Highest Tensile Stress	37.6 PSI	2180
Highest Compressive Strain	1.505e-4 IN/IN	1029
Highest Tensile Strain (ε_m)	3.335e-5 IN/IN	2180

Note: Table 24 results are at the same time at Table 25 results.

Strain Analysis

Is $\varepsilon_t > \varepsilon_m$?

$$\varepsilon_t = 410K \frac{(f'c)^{1.85}}{E^2}$$

$$\varepsilon_t = 410(1.0)\frac{(4400)^{1.85}}{(4.250x10^6)^2} = 1.249\text{x}10^{-4} \text{ IN/IN}$$

$$\varepsilon_m = 3.335x10^{-5} \text{ IN/IN}$$

$1.249x10^{-4} > 3.335x10^{-5}$ OK Therefore, the strain capacity has not been reached.

Temperature Analysis

Is $\Delta T_t > \Delta T_m$?

$$\Delta T_t = \frac{\varepsilon_t}{RC}$$

$$\Delta T_t = \frac{1.249x10^{-4}}{(0.35)(5.5x10^{-6})} = 64.9°F$$

$$\Delta T_m = T_H - T_S$$

$$\Delta T_m = 86.9° - 59.7° = 27.2°F$$

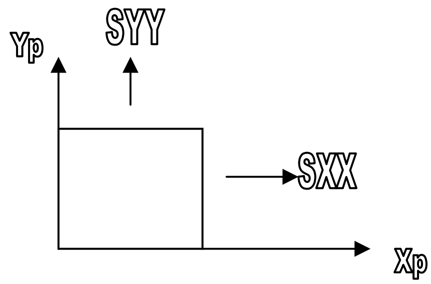
$64.9°F > 27.2°F$ OK Therefore, there is no potential for cracking.

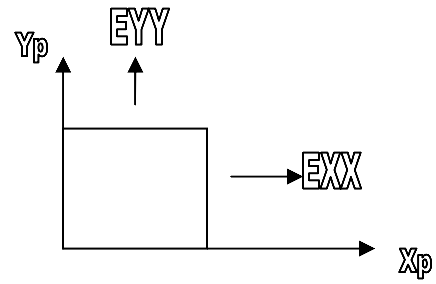
All of the above results will be discussed in Chapter 5.

Cracking due to compressive strain is negligible, and is not analyzed. The typical strain value in which concrete crushes due to compression is between 0.001 and 0.003, depending on the compressive strength of the concrete. The experimental compressive strain values shown in the resultant tables for each section are well below these values. Therefore, if any cracking potential is present within the mass concrete sections analyzed, it will be due to tensile strain.

4.1 FINITE ELEMENT CONTOURS

The empirical equations used to estimate temperature differentials and mass concrete strain capacity for this project strictly take in account strain values. However, since engineers typically relate to loads in PSI, and stress is directly related to strain, the stress contours are also displayed in this thesis. Figure 22 through Figure 37 display the GTSTRUDL finite element contours for stresses and strains. Positive sign convention for interpreting results of plane strain element contours are shown in each figure. The values in Table 20 through Table 25, shown above, tabulate the maximum parametric results for each GTSTRUDL model.





SXX = Stresses in X direction on X-face
SYY = Stresses in Y direction on Y-face

EXX = Strains in X direction on X-face
EYY = Strains in Y direction on Y-face

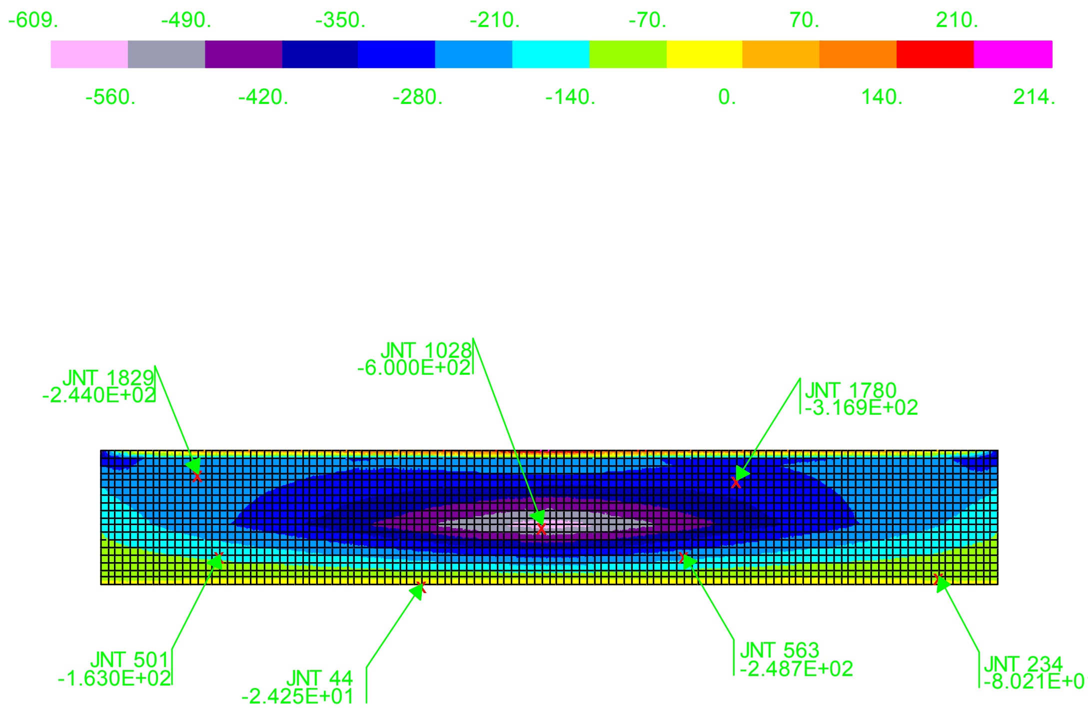
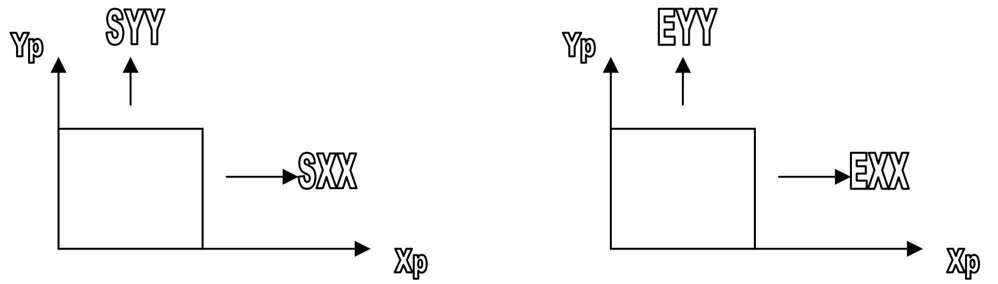


FIGURE 22: SXX STRESSES
LIFT 1 SECTION ON DAY 2



SXX = Stresses in X direction on X-face
SYY = Stresses in Y direction on Y-face

EXX = Strains in X direction on X-face
EYY = Strains in Y direction on Y-face

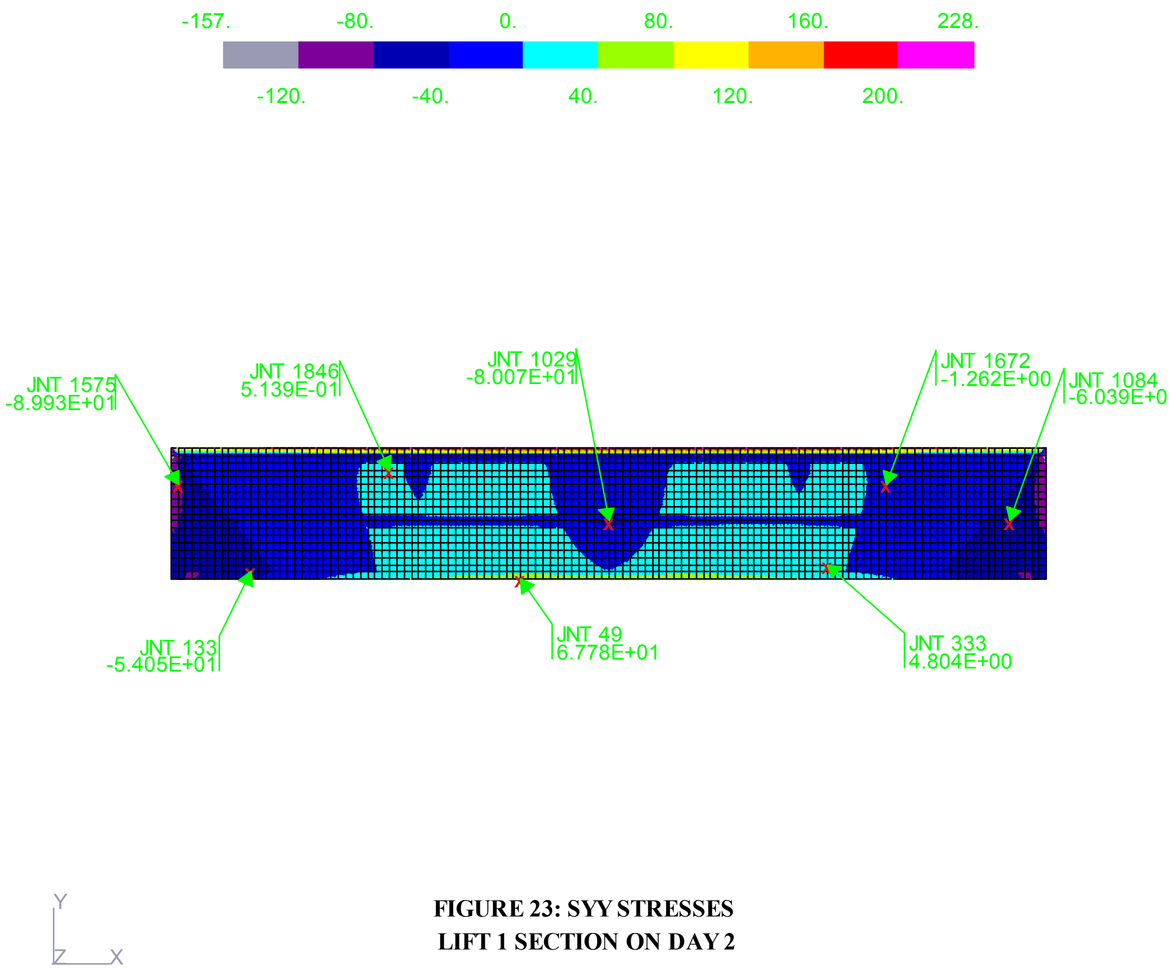
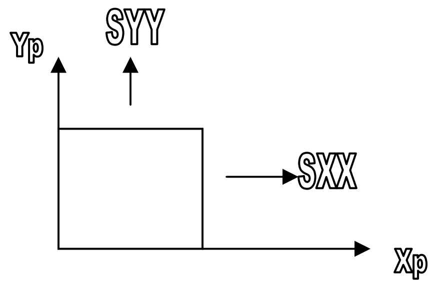
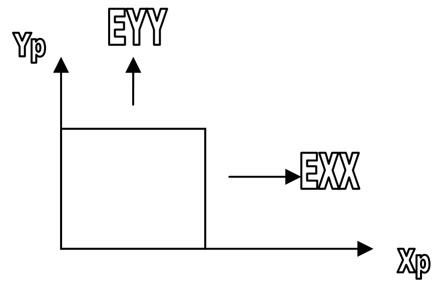


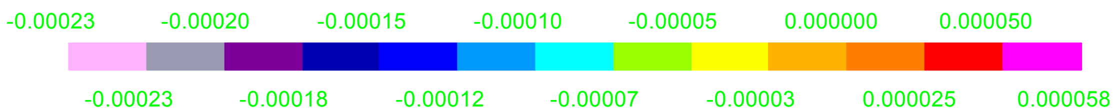
FIGURE 23: SYY STRESSES
LIFT 1 SECTION ON DAY 2

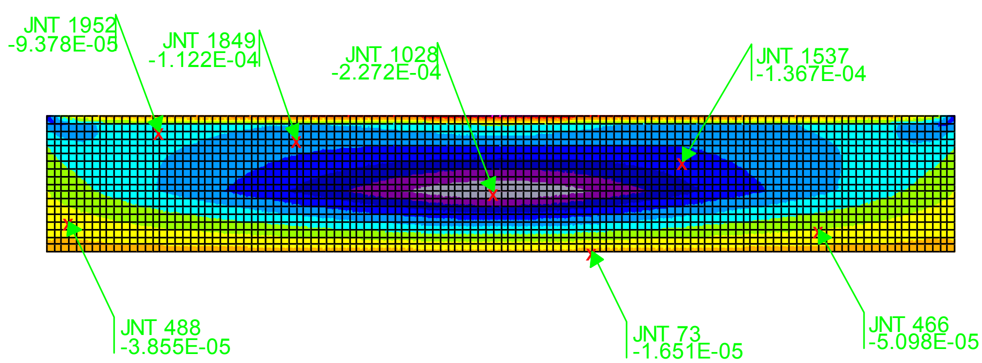




SXX = Stresses in X direction on X-face
SYY = Stresses in Y direction on Y-face

EXX = Strains in X direction on X-face
EYY = Strains in Y direction on Y-face





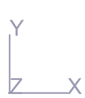
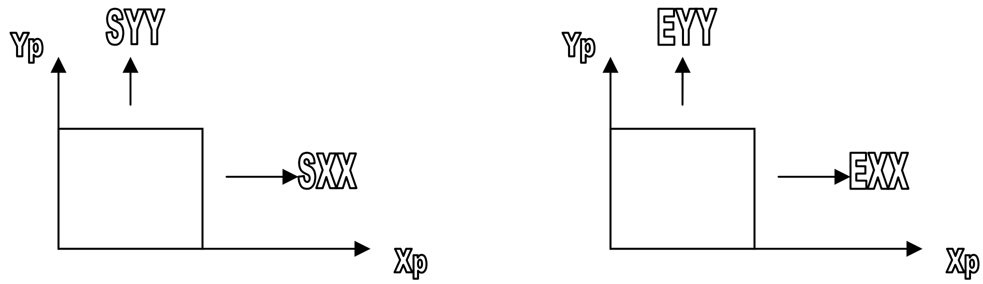
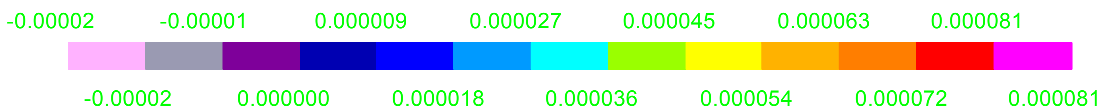


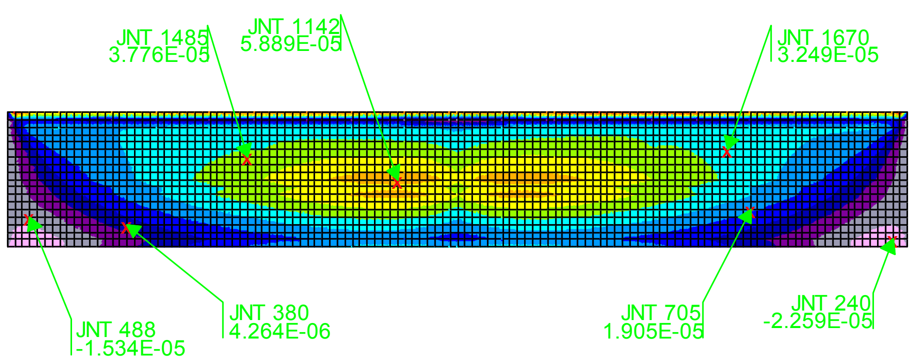
FIGURE 24: EXX STRAINS
LIFT 1 SECTION ON DAY 2



SXX = Stresses in X direction on X-face
SYY = Stresses in Y direction on Y-face

EXX = Strains in X direction on X-face
EYY = Strains in Y direction on Y-face





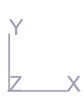
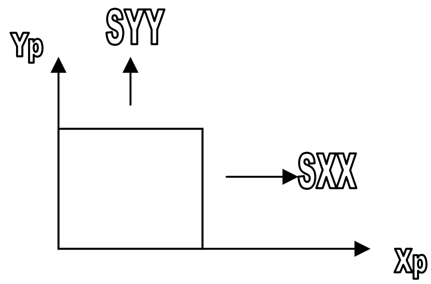
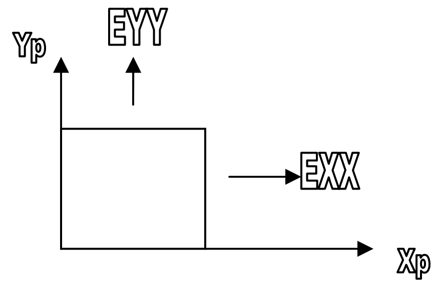


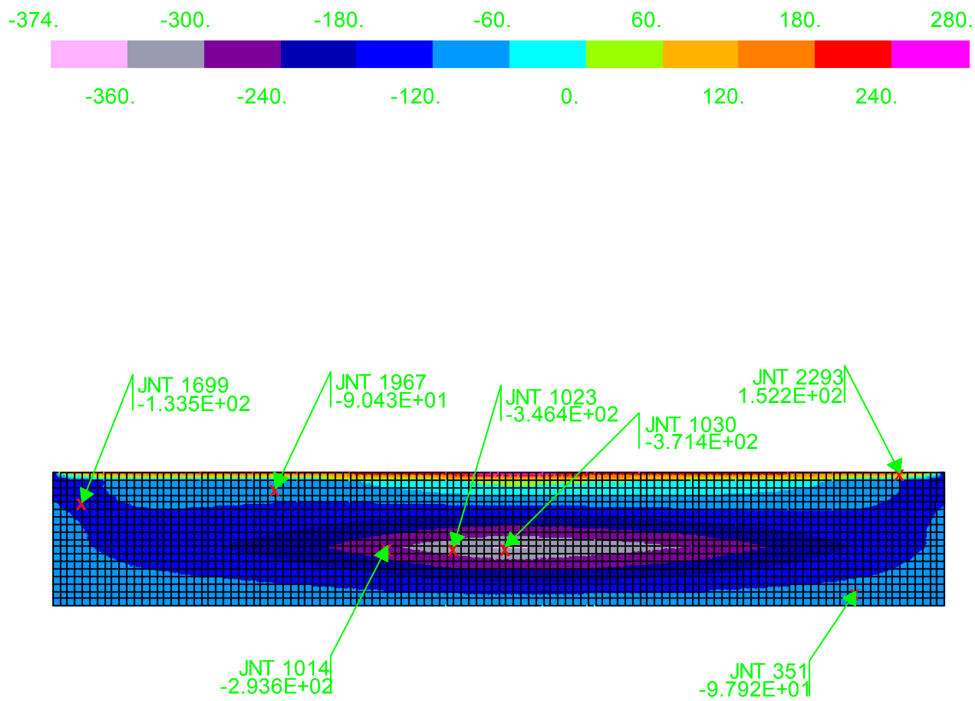
FIGURE 25: EYY STRAINS
LIFT 1 SECTION ON DAY 2





SXX = Stresses in X direction on X-face
SYY = Stresses in Y direction on Y-face

EXX = Strains in X direction on X-face
EYY = Strains in Y direction on Y-face



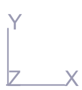
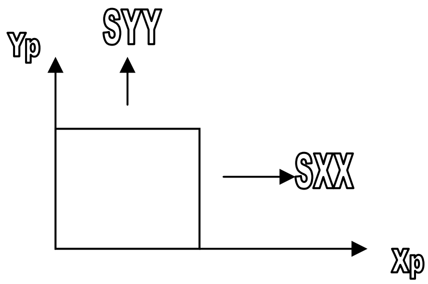
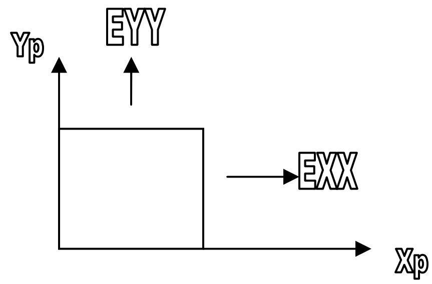


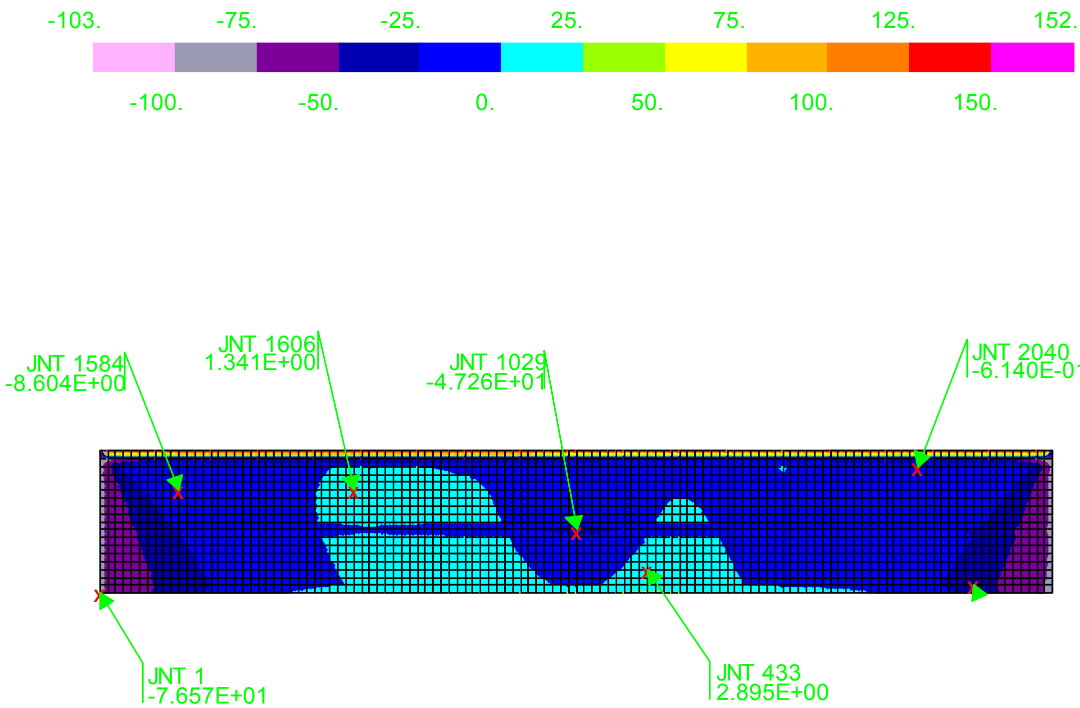
FIGURE 26: SXX STRESSES
LIFT 1 SECTION ON DAY 6





SXX = Stresses in X direction on X-face
SYY = Stresses in Y direction on Y-face

EXX = Strains in X direction on X-face
EYY = Strains in Y direction on Y-face



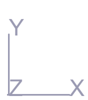
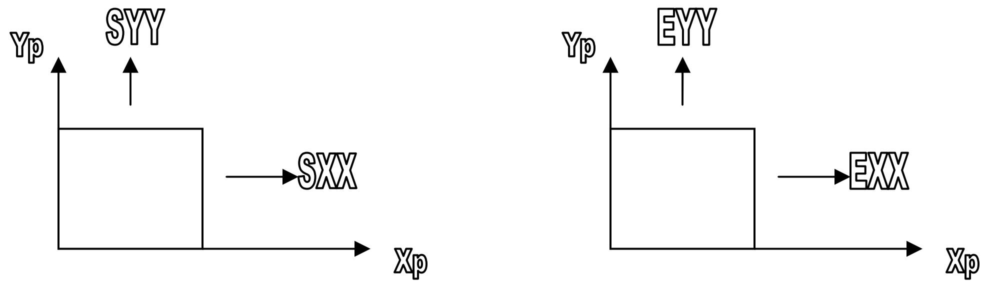


FIGURE 27: SYY STRESSES
LIFT 1 SECTION ON DAY 6



SXX = Stresses in X direction on X-face
SYY = Stresses in Y direction on Y-face

EXX = Strains in X direction on X-face
EYY = Strains in Y direction on Y-face

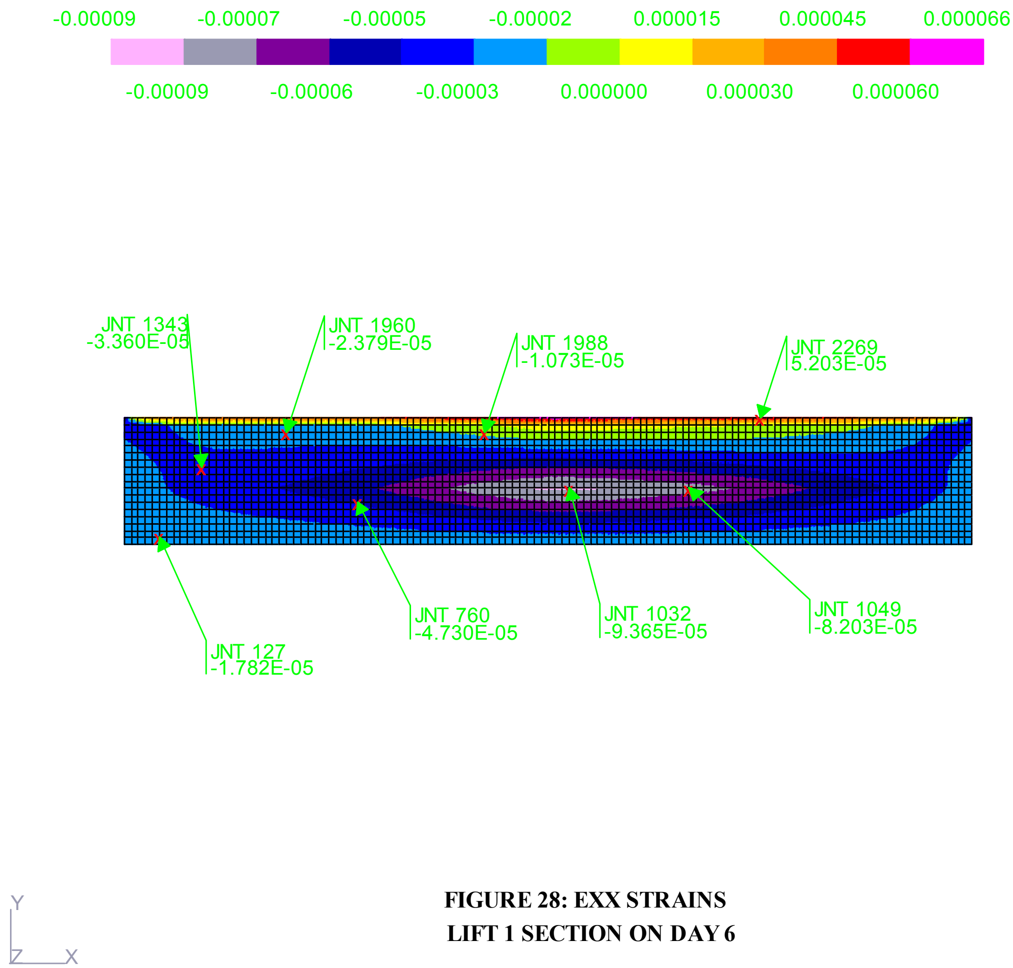
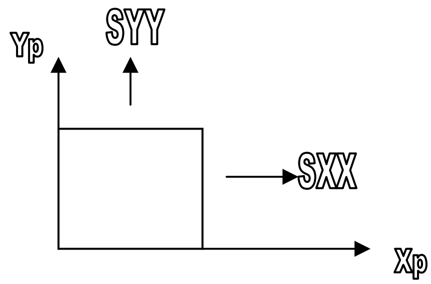
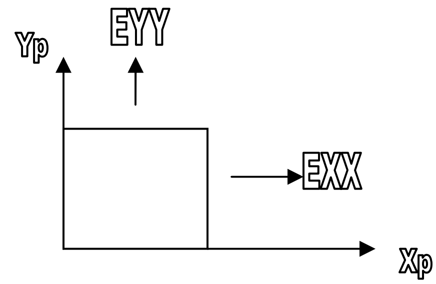


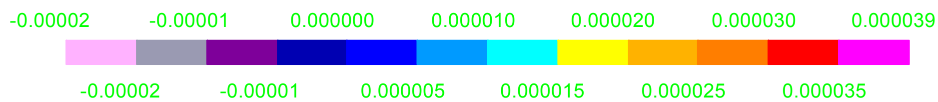
FIGURE 28: EXX STRAINS
LIFT 1 SECTION ON DAY 6

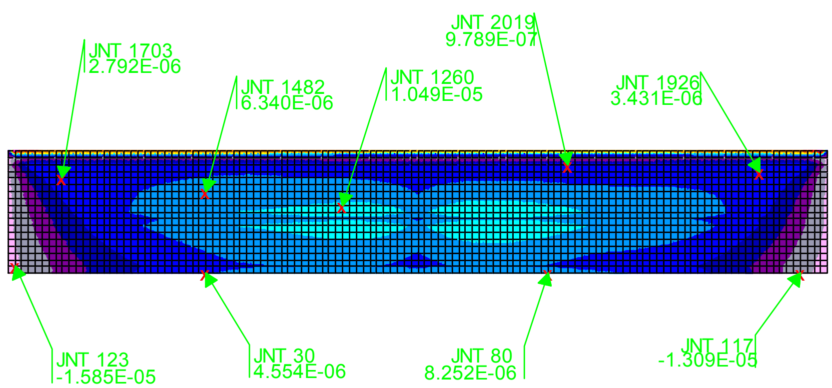




SXX = Stresses in X direction on X-face
SYY = Stresses in Y direction on Y-face

EXX = Strains in X direction on X-face
EYY = Strains in Y direction on Y-face





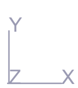
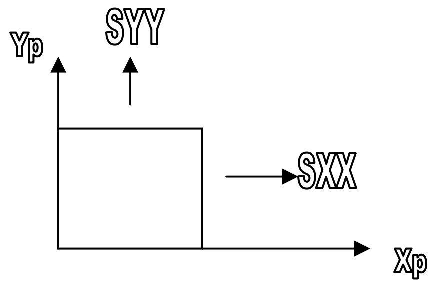
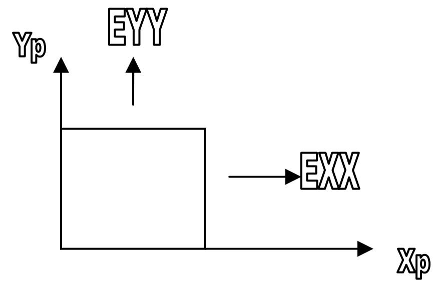


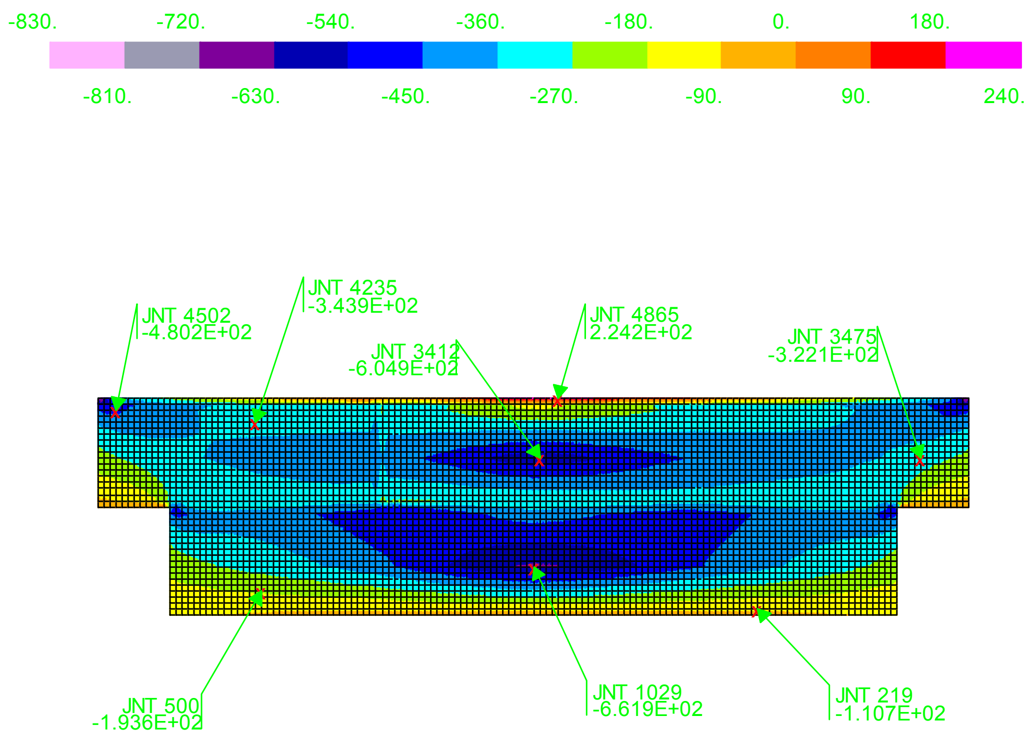
FIGURE 29: EYY STRAINS
LIFT 1 SECTION ON DAY 6





SXX = Stresses in X direction on X-face
SYY = Stresses in Y direction on Y-face

EXX = Strains in X direction on X-face
EYY = Strains in Y direction on Y-face



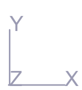
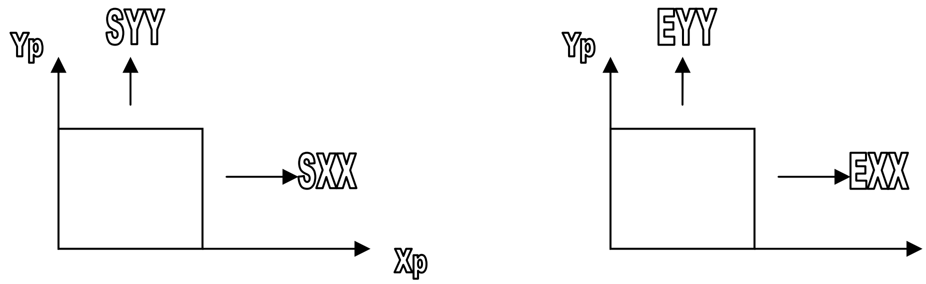


FIGURE 30: SXX STRESSES
LIFT 1 SECTION ON DAY 10 AND LIFT 2 SECTION ON DAY 3



SXX = Stresses in X direction on X-face
SYY = Stresses in Y direction on Y-face

EXX = Strains in X direction on X-face
EYY = Strains in Y direction on Y-face

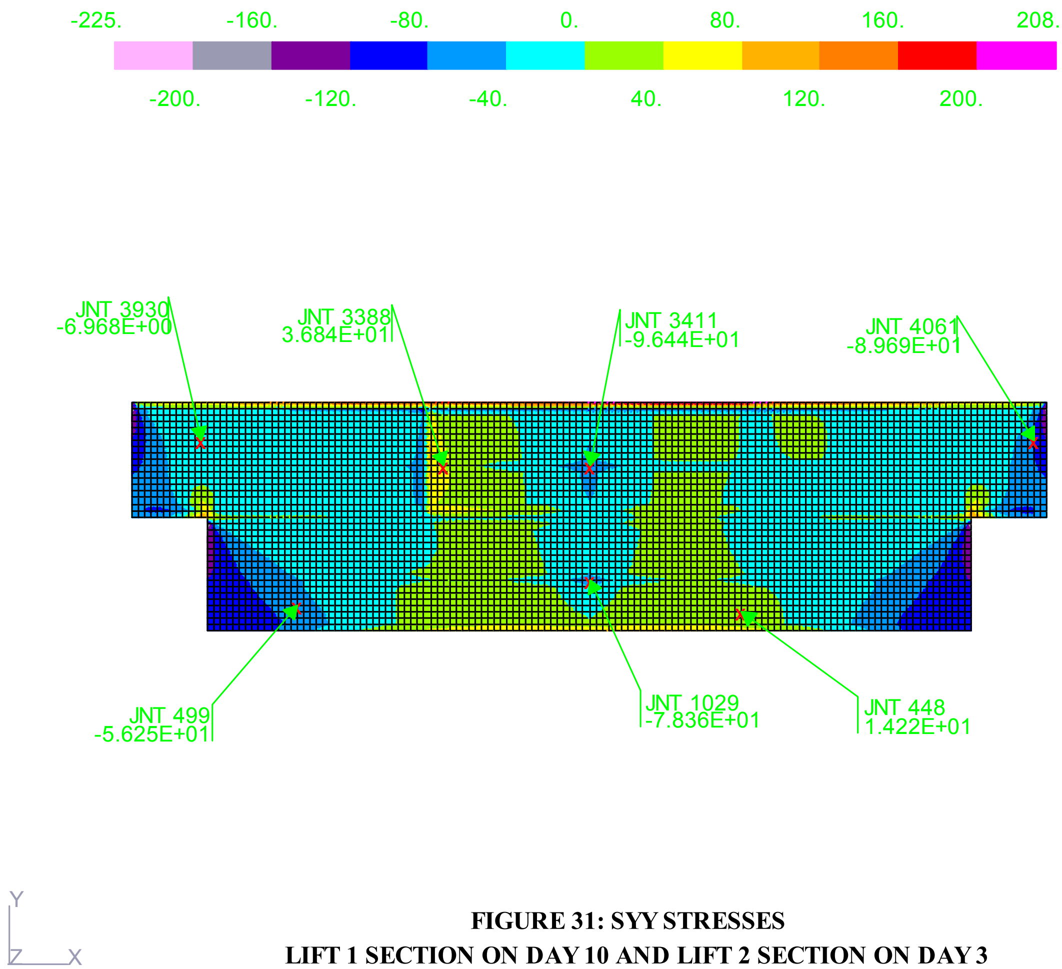
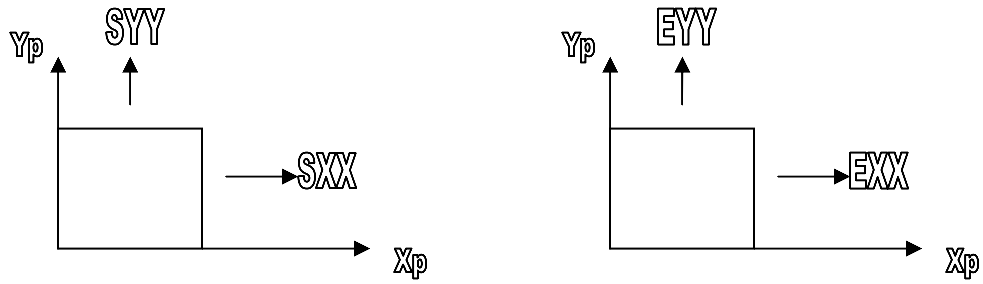


FIGURE 31: SYY STRESSES
LIFT 1 SECTION ON DAY 10 AND LIFT 2 SECTION ON DAY 3



SXX = Stresses in X direction on X-face
SYY = Stresses in Y direction on Y-face

EXX = Strains in X direction on X-face
EYY = Strains in Y direction on Y-face

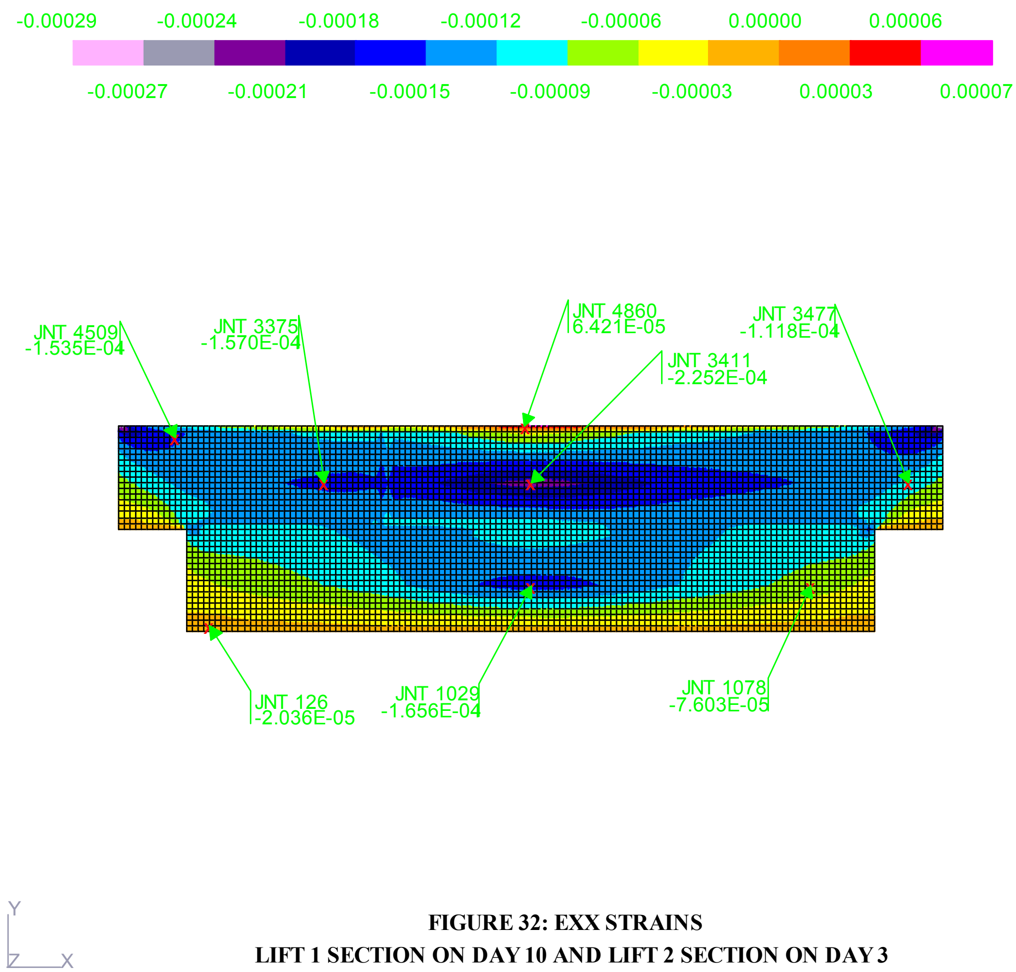
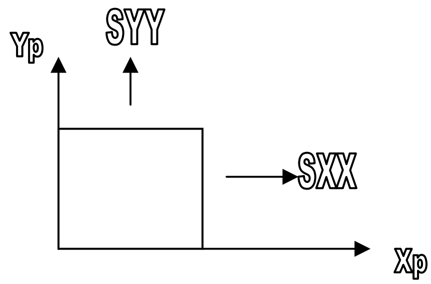
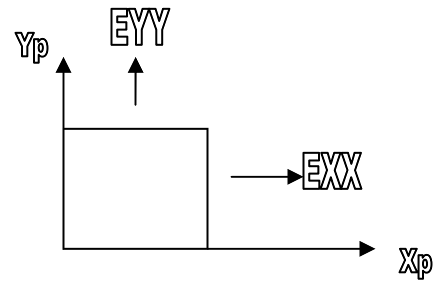


FIGURE 32: EXX STRAINS
LIFT 1 SECTION ON DAY 10 AND LIFT 2 SECTION ON DAY 3



SXX = Stresses in X direction on X-face
SYY = Stresses in Y direction on Y-face



EXX = Strains in X direction on X-face
EYY = Strains in Y direction on Y-face

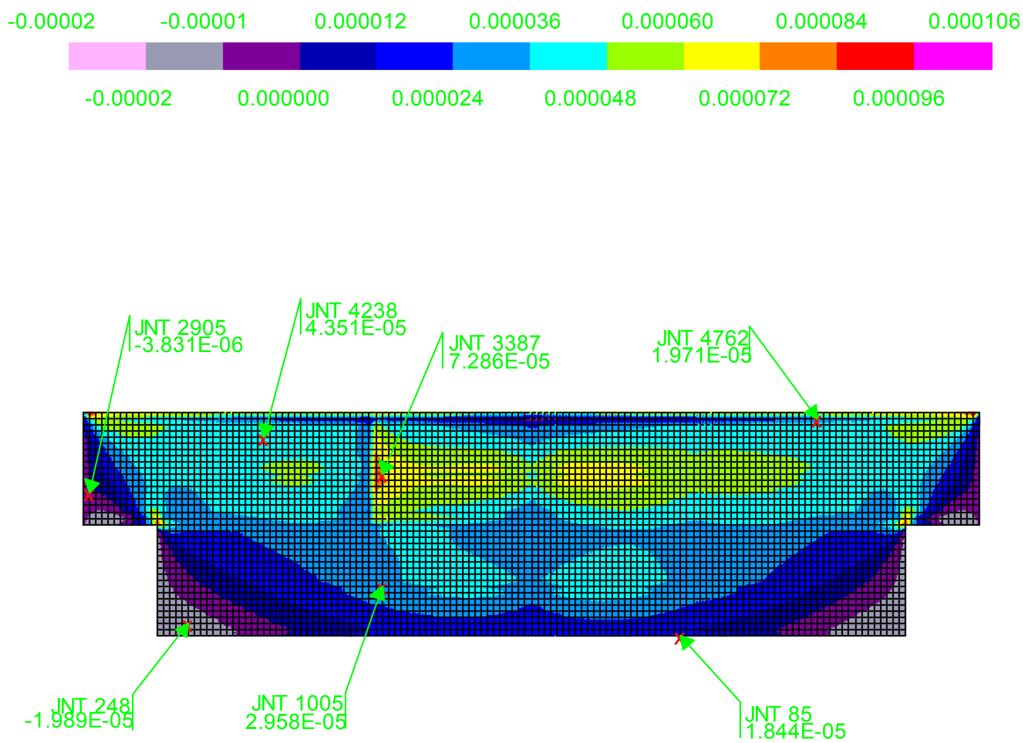
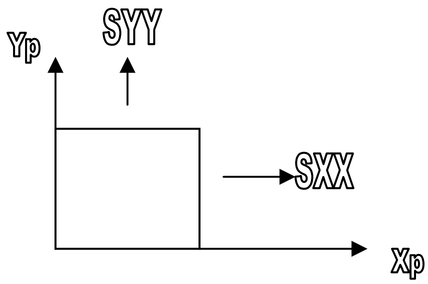
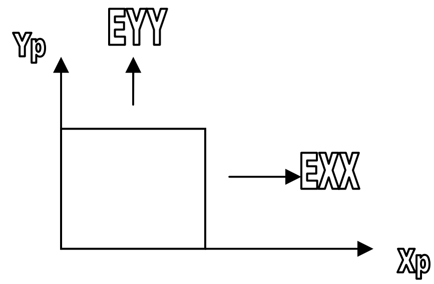


FIGURE 33: EYY STRAINS
LIFT 1 SECTION ON DAY 10 AND LIFT 2 SECTION ON DAY 3



SXX = Stresses in X direction on X-face
SYY = Stresses in Y direction on Y-face



EXX = Strains in X direction on X-face
EYY = Strains in Y direction on Y-face

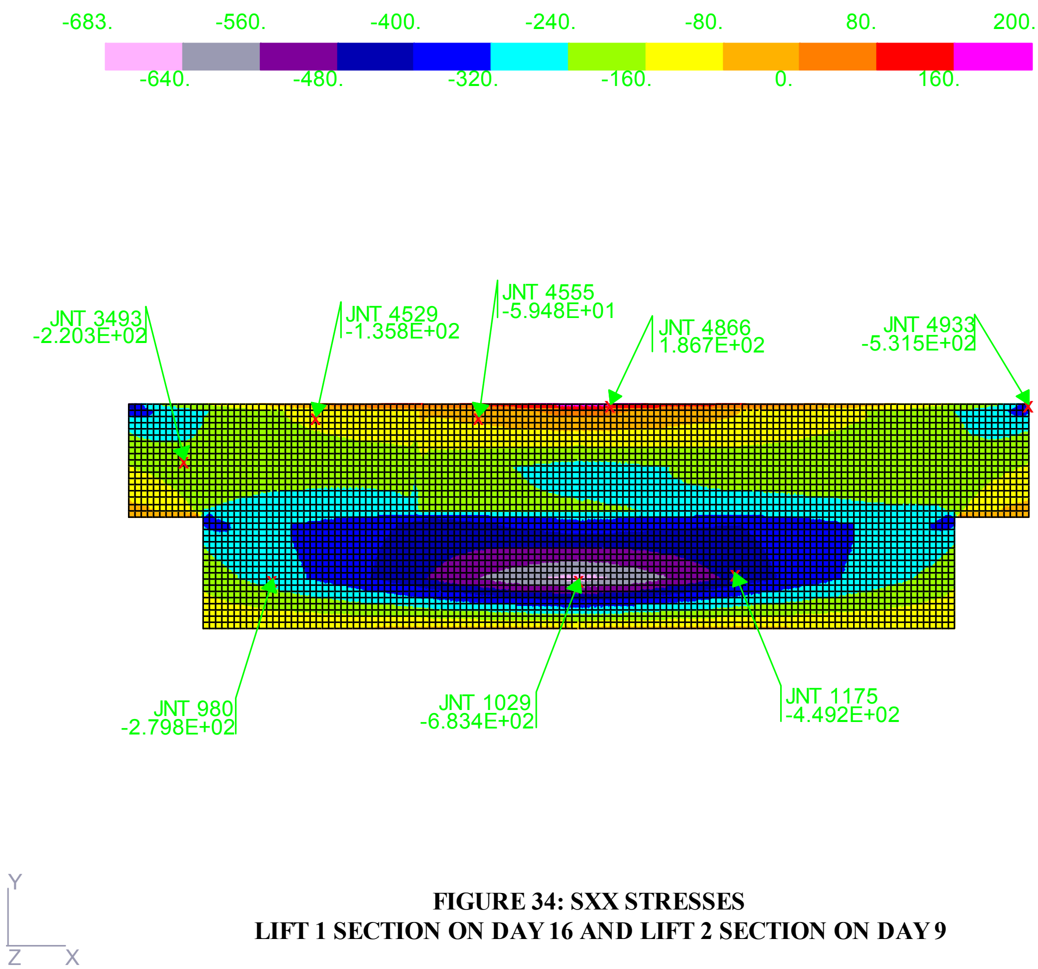
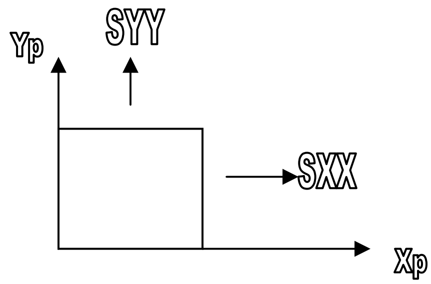
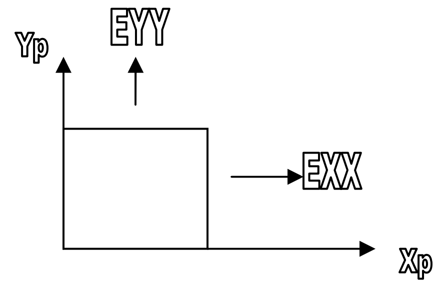


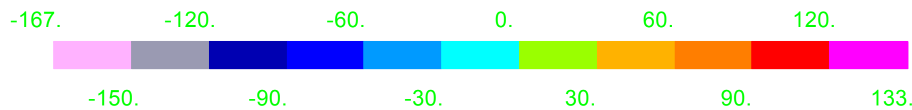
FIGURE 34: SXX STRESSES
LIFT 1 SECTION ON DAY 16 AND LIFT 2 SECTION ON DAY 9

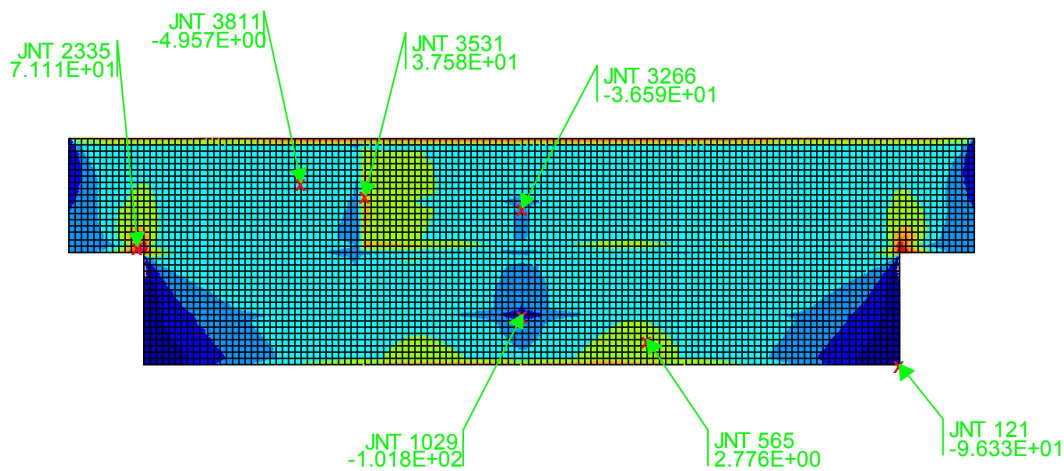


SXX = Stresses in X direction on X-face
SYY = Stresses in Y direction on Y-face



EXX = Strains in X direction on X-face
EYY = Strains in Y direction on Y-face





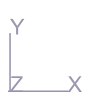
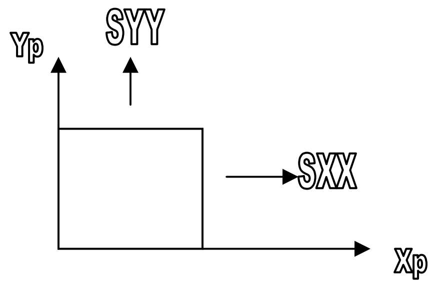
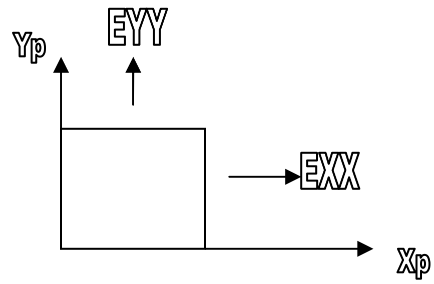


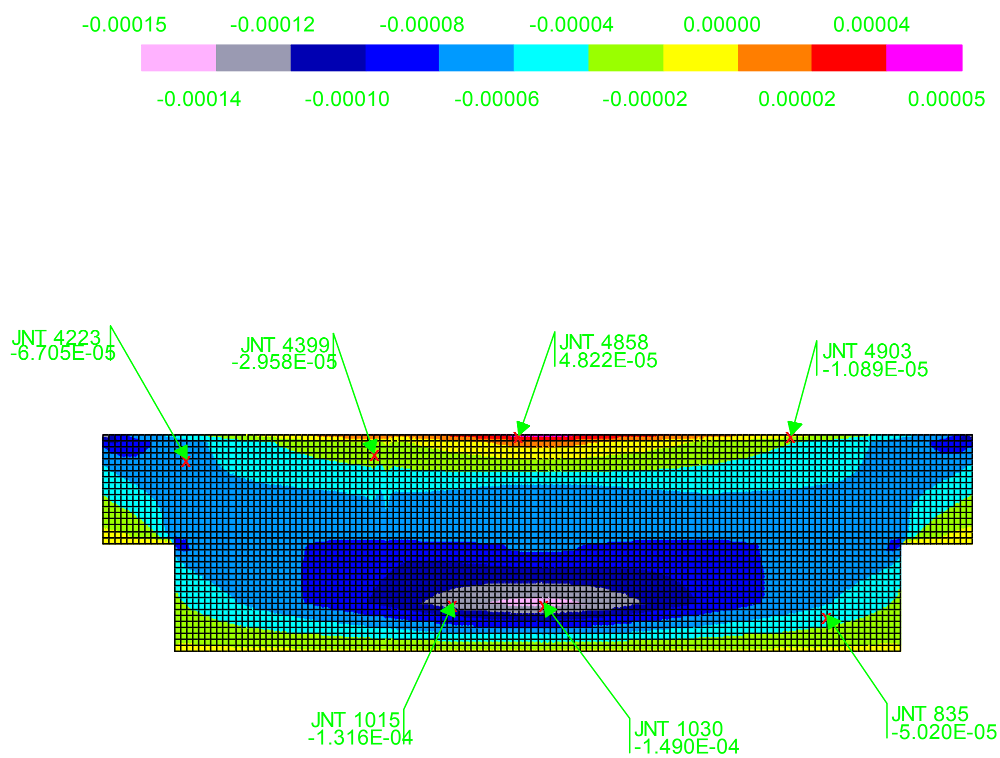
FIGURE 35: SYY STRESSES
LIFT 1 SECTION ON DAY 16 AND LIFT 2 SECTION ON DAY 9





SXX = Stresses in X direction on X-face
SYY = Stresses in Y direction on Y-face

EXX = Strains in X direction on X-face
EYY = Strains in Y direction on Y-face



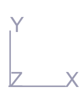
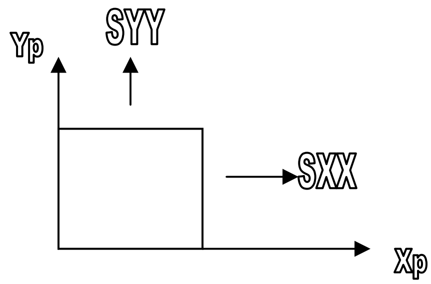
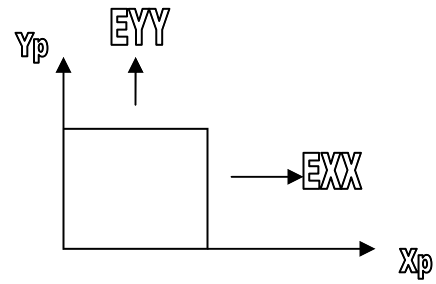


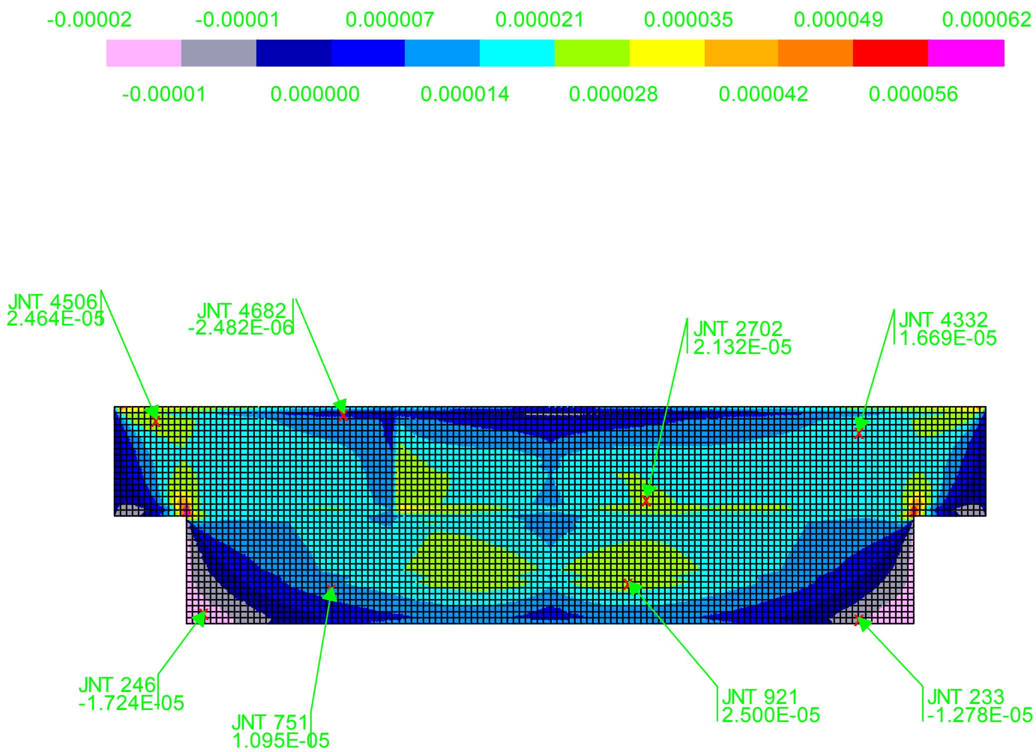
FIGURE 36: EXX STRAINS
LIFT 1 SECTION ON DAY 16 AND LIFT 2 SECTION ON DAY 9





SXX = Stresses in X direction on X-face
SYY = Stresses in Y direction on Y-face

EXX = Strains in X direction on X-face
EYY = Strains in Y direction on Y-face



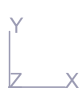


FIGURE 37: EYY STRAINS
LIFT 1 SECTION ON DAY 16 AND LIFT 2 SECTION ON DAY 9

4.2 TEMPERATURE AND CONSTRUCTION SCHEDULE

Another very important criterion to evaluate in this experimental analysis is the seven-day waiting period between sequential mass concrete lift placements to prevent potential cracking, which was defined in the project specification. During a large construction project many obstacles may present themselves, especially for a project requiring 50,000 cubic yards of concrete to be placed. One of the most important obstacles is schedule.

The utilization of a test pad was chosen because it aids in a better understanding of the mass concrete curing behavior and contributes to the evaluation of the thermal properties of the concrete mix as a function of time. The results and analyses shown above help engineers to determine if any alterations need to be made to the mix design. It also provides a chance for changes to be made to the construction schedule. By knowing the heat of hydration characteristics of the mix and the time-dependent behavior of the temperature distribution by the use of thermocouples, one can estimate whether a seven-day waiting period is accurate. If the waiting period between lifts needs to be varied from seven days due to the results observed from the test pad, it will alter the construction schedule considerably.

Figure 38 through Figure 41 illustrate the thermocouple results from each lift with time. From these figures, the temperature rise and fall with respect to time may be found. It also may be determined how much the temperature rises in a previous lift after a sequential lift is placed directly on top of it. These figures are discussed further in Chapter 5.

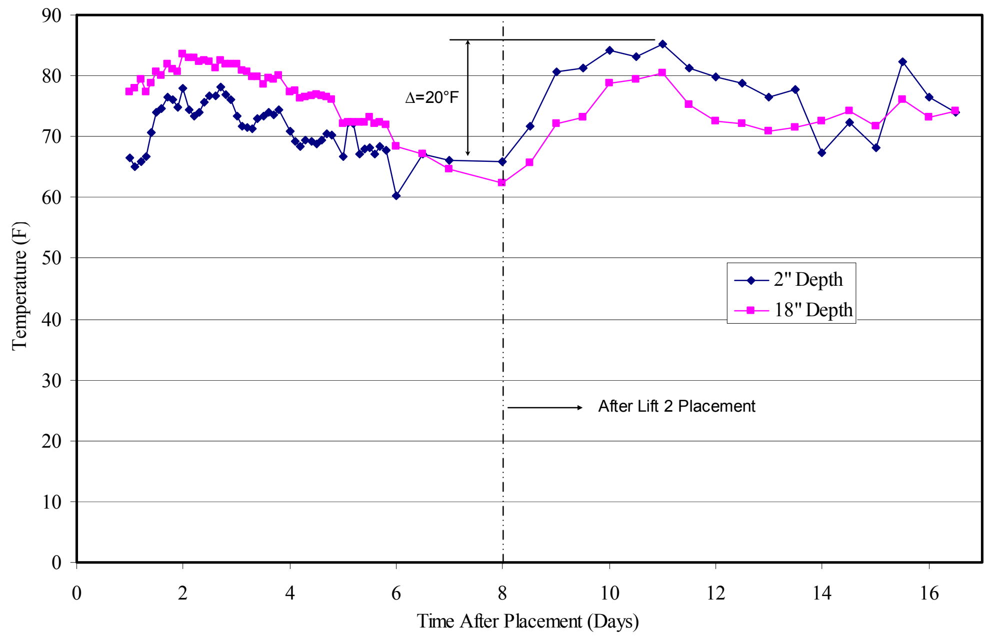


FIGURE 38: LIFT 1 THERMOCOUPLE LOCATION #1 TEMPERATURE VS. TIME

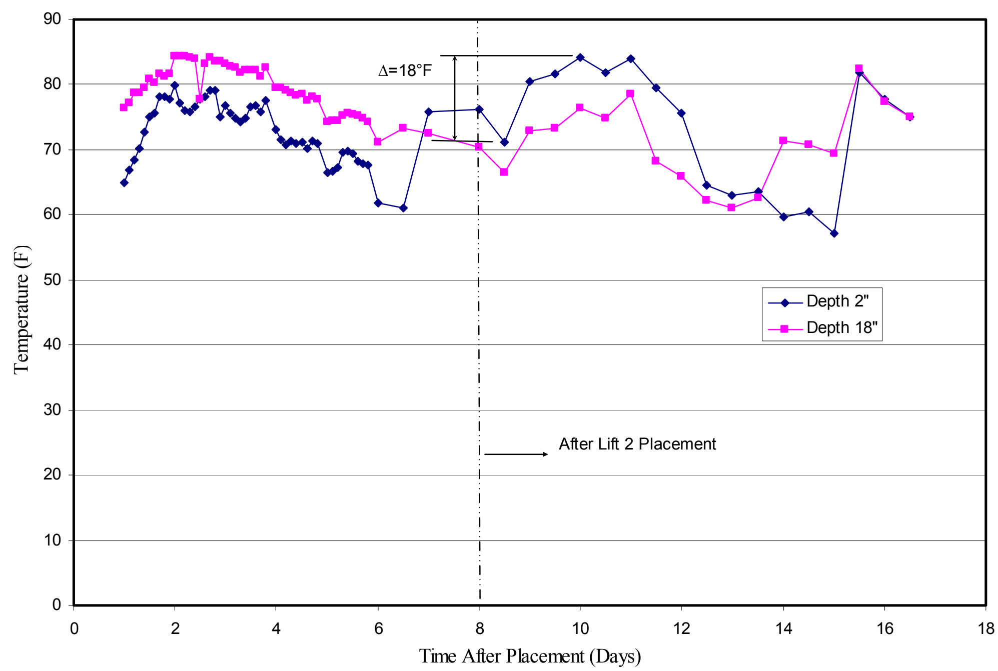


FIGURE 39: LIFT 1 THERMOCOUPLE LOCATION #4 TEMPERATURE VS. TIME

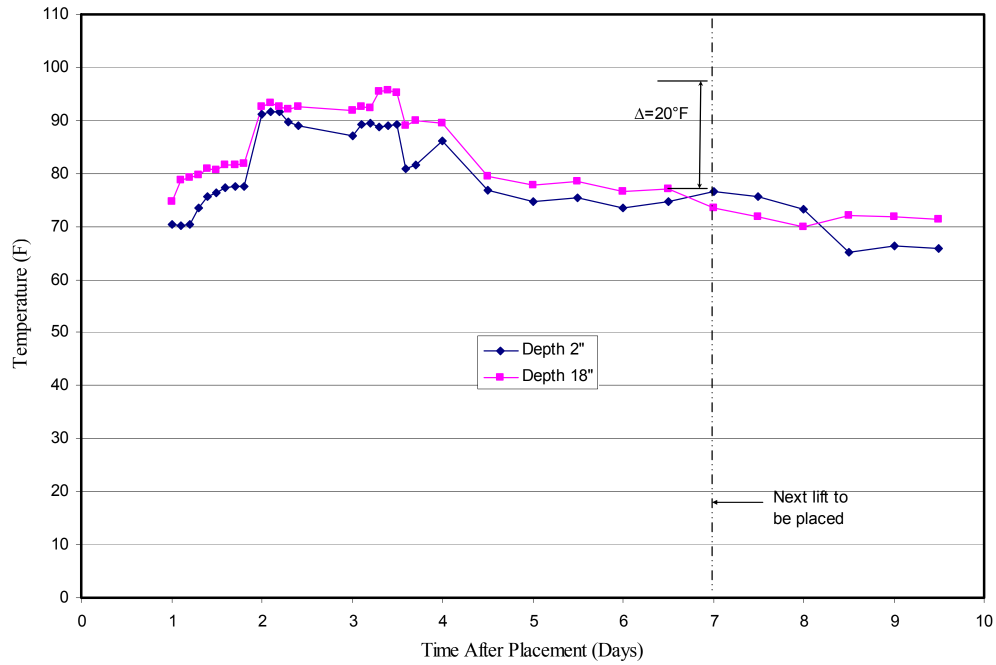


FIGURE 40: LIFT 2 THERMOCOUPLE LOCATION # 13
TEMPERATURE VS. TIME

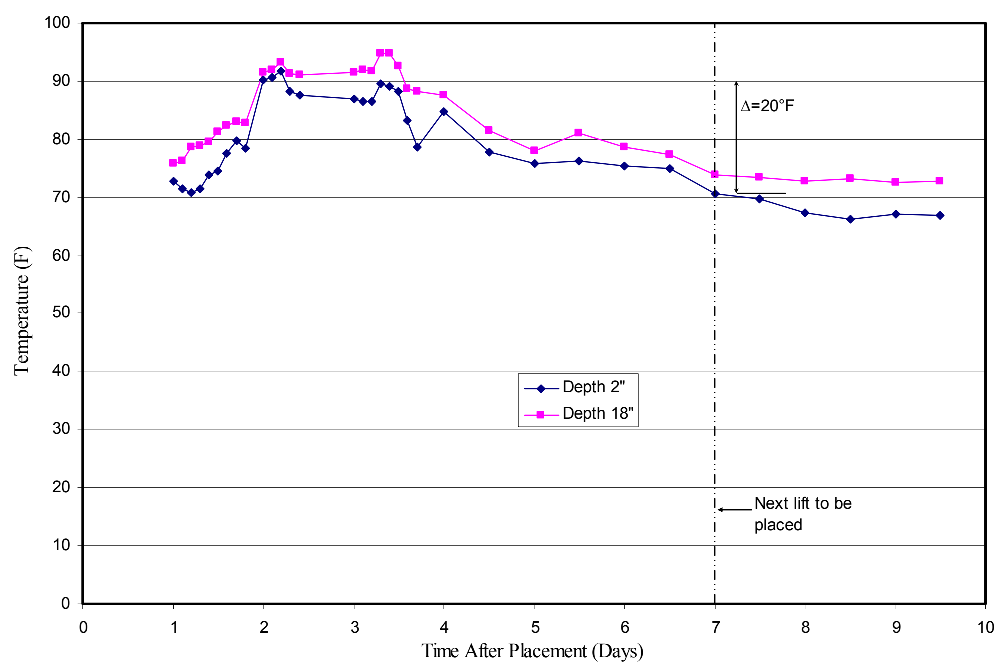


FIGURE 41: LIFT 2 THERMOCOUPLE #14
TEMPERATURE VS. TIME

CHAPTER 5: CONCLUSIONS

5.0 EXPERIMENTAL CONCLUSIONS

The test pad yielded many results before the placement of the mass concrete fill support foundation. From these results, much was learned about the behavior of the concrete mix design proposed. The specified compressive strength of the concrete mix is 2500 psi. The concrete reaches this strength at two to three days. At ten days after placement, the concrete compressive strength has almost reached about 4000 psi. Most mass concrete mix designs are not developed for a high compressive strength because strength is not an essential element in mass concrete (ACI 207.1R-96). The mix design for the project is gaining more compressive strength than what was developed, this behavior is exceptional.

Collection of temperature data from the test pad was a very important aspect for the mass concrete fill placement. Since the potential for thermal cracking varies directly with increasing temperatures, monitoring the temperature behavior of the proposed mix design was very important. The thermocouples worked out very well, and did not develop any problems. It is very easy to record temperature data from the surface of a concrete mass, but the thermocouples allow for measurements inside the test pad, to evaluate exactly what was happening. The thermocouples also provided an accurate thermal time-history of the secondary rise in temperatures of the lower lift due to the temperature interaction with the second lift. While this behavior was expected, the actual temperature readings were very important. The test pad mass concrete behavior was as expected. The temperatures in the direct center of the section were always the hottest.

The temperatures reduced as the heat dissipated from the center of the mass to the surface. Generally, the highest temperatures were seen two to three days after placement. Once the concrete reached its highest temperatures, it immediately started to slowly cool down. Table 26 is a summary of the results.

Based on the ACI approach, the project specifications state that the maximum temperature gradient between two thermocouples shall not exceed twenty degrees Fahrenheit. The thermocouple data collected from the test pad showed that there was no problem meeting this criterion. The temperature differential between two thermocouples never reached twenty degrees Fahrenheit. The highest differential between thermocouples was fourteen degrees Fahrenheit, as seen in Tables 1 through 8.

TABLE 26: SUMMARY OF RESULTS

Lift	Date	Age (Days)	f'c (PSI)	E (PSI)	ε_t (IN/IN)	ε_m (IN/IN)	ΔT_t (°F)	ΔT_m (°F)
1	02/06/05	2	1570	2.424×10^6	5.701×10^{-5}	7.537×10^{-5}	29.6	48.7
1	02/10/05	6	3235	3.818×10^6	8.757×10^{-5}	6.644×10^{-5}	45.5	28.0
2	02/14/05	3	2140	2.429×10^6	1.007×10^{-4}	6.604×10^{-5}	52.3	46.3
1	02/14/05	10	3800	3.700×10^6	1.256×10^{-4}	5.456×10^{-5}	65.2	22.0
2	02/20/05	9	3300	3.200×10^6	1.293×10^{-4}	5.121×10^{-5}	67.2	20.2
1	02/20/05	16	4400	4.250×10^6	1.249×10^{-4}	3.335×10^{-5}	64.9	27.7

The specification also defined that the maximum temperature gradient between the interior temperature and the surface temperature of the mass concrete shall be thirty-five degrees Fahrenheit within a seven-day curing period. The experimental results for this requirement were not so favorable. At highest temperature for both lifts, the temperature differential between the interior and the surface was about forty-seven degrees Fahrenheit. According to the specification, these temperatures would induce thermal cracking. The data for lift one (day two) supports the possibility of cracking because the measured strain is greater than the strain capacity. However, as the compressive strength increases with time, the theoretical temperature differential that creates a potential for cracking increases. For example, the theoretical temperature differential for lift one (day six) was 45.5°F. This value is much higher than the thirty-five degrees outlined in the specification, but the results conclude that there is no potential for cracking due to the higher compressive strength. The highest theoretical temperature differential, which would create a potential for cracking, was sixty-seven degrees Fahrenheit for lift two (day nine). This temperature is much higher than the thirty five degrees in the specification. The higher the theoretical temperature differential that yields a potential for cracking, the less likely cracking would occur. The experimental results reflect this behavior. The only time a potential for cracking existed in the test pad was at lift one high temperature (day two). During this time period the compressive strength was at its lowest,1570 psi, and the temperature differential measured from the test pad was the highest, 48.7°F.

5.1 ACCURACY OF EMPERICAL METHOD

The empirical equation analysis came directly from the ACI approach. The Liu and McDonald journal article, “Prediction of Tensile Strain Capacity of Mass Concrete”, published the following equation to be used for the prediction of tensile strain capacity of concrete.

$$\varepsilon_t = 410K\frac{(f'c)^{1.85}}{E^2}$$

K = Aggregate Factor (1.0 for angular, 0.74 for rounded)
f’c = Compressive strength, psi
E = Modulus of Elasticity, psi
ε_t = Tensile strain capacity under slow loading conditions

Harrison (1981) published the equation below to illustrate the relationship between strain capacity and the temperature differential that creates a potential for cracking.

$$RC\Delta T \geq \varepsilon_t$$

R = Restraint Factor (0.35 typical for internal temperature distribution)
C = Coefficient of Expansion, in/in/°F
ΔT = Temperature change between the center of the mass and the surface, °F
ε_t = Tensile strain capacity under slow loading conditions

Overall, after using these equations with the actual experimental results in the field, the ACI method proved to be an accurate method to use for the development of the project specification. The tensile strain capacity determined by the Liu and McDonald equation was consistently greater than the experimental tensile strain found in actual field conditions, with exception of the high temperature condition of lift one. This behavior indicates the methods used to predict the tensile strain capacity for the project specification were acceptable. The second case analyzed in this research was the

temperature differential that creates a potential of cracking. As the compressive strength of the mass concrete rises, the allowable temperature differential increases. The first allowable temperature differential is twenty-six degrees for lift one (day two) and the last allowable temperature differential is sixty-seven degrees Fahrenheit for lift two (day nine). Therefore, the maximum temperature differential of thirty-five degrees Fahrenheit between the center of mass and the surface per the project specification becomes more conservative as the concrete ages. Overall, the specification restrictions of twenty degrees Fahrenheit between thermocouples and thirty-five degrees Fahrenheit between the center of the mass and the surface are acceptable, but have been shown to be conservative. They reflected good results for all cases analyzed except for one.

In conclusion, the adequacy of the ACI approach was verified with respect to this project. The empirical equations allowed for the development of a concrete mix design and project specification, which yielded good results in the test pad. It is concluded that no alterations should be made to the project specification before the placement of the 50,000 cubic yard mass concrete fill.

5.2 SEVEN-DAY PLACEMENT

Thermocouple data were plotted in Figure 34 and Figure 35 for lift one of the test pad. In reviewing the thermocouple data it is found that the sequential placement of a second lift on top of the first lift increases the temperature of the first lift by about twenty degrees Fahrenheit. This temperature increase brings the first lift back up close to its highest temperature. Ideally, it would be preferable that the temperature increase stay well below its high temperature due to its interaction with a sequential lift. As seen from

the finite element results, the re-increase in temperature of the first lift after the placement of a sequential lift increases the sequential lift temperature above what was seen for the previous lift. If this behavior would continue to happen, the temperatures for each sequential lift would continually become higher than the last. This is illustrated in Figure 36 and Figure 37, which is representative of thermocouple data from lift two of the test pad. If twenty degrees Fahrenheit is added to lift two after the placement of a sequential lift, the temperature increases to approximately ninety degrees Fahrenheit versus the eighty-five degrees Fahrenheit observed for lift two. Theoretically, this is undesirable behavior. However, because of the rise in compressive strength with time and the effect this has on the increased allowed temperature differential, the behavior is acceptable.

The results of this research were taken with a seven-day waiting period between lifts. The most important behavior to be monitored is the temperature differential within the first 72 hours. If each lift of the mass concrete fill is monitored closely during this period, and measures are taken to restrict the initial temperature rise, the waiting period may be decreased slightly.

5.3 SHEAR WAVE VELOCITY

After all the analyses performed on temperature differential and mass concrete behavior, one question still remains. The entire analysis of the test pad was made in order to evaluate the behaviors explained above, but the monitoring of the test pad and the analyses were performed to make sure that a 50 blow count subgrade defined by the Standard Penetration Test (SPT) is the final result for the mass concrete support

foundation. The facility design requires the support foundation to be relatively crack-free in order to attain the shear wave velocity of 6000 fps, which is necessary for acceptable structural behavior during a design basis earthquake. A Spectral Analysis of Surface Wave (SASW) test was performed on the completed mass concrete test pad in order to evaluate the shear wave velocity. The result was a final shear wave velocity of 7500 fps. Therefore, all of the hard work and research for this project, both done preliminary and during the execution of a test pad, was worth it. The project support foundation will meet the facility requirements by means of the current design specifications.

In conclusion, the appropriateness of the ACI approach was verified by the combined use of field data and finite element analyses. Analytical modeling allowed for the input of the real time lab and field data to assess the behavior of the mass concrete, and provide the unique ability to model the sequential construction to capture the time dependent interaction between successive concrete lifts.

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VITA

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Cristina is currently pursuing her masters in Civil Engineering at the University of Tennessee, Knoxville.