University of Manitoba

AN ALGORITHM FOR TRANSIENT FINITE ELEMENT THERMAL ANALYSIS OF INCREMENTALLY CONSTRUCTED MASS CONCRETE DAMS

by

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AN ALGORITHM FOR TRANSIENT FINITE ELEMENT THERMAL ANALYSIS OF INCREMENTALLY CONSTRUCTED MASS CONCRETE DAMS

BY

TERRANCE JOHN ARMSTRONG

A Thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Dedicated to my Mother and Father

ABSTRACT

The use of mass concrete in dams includes special considerations for controlling the thermal behaviour of the concrete, particularly at the construction stage of a project. Heat generated by the hydration of cement causes thermally induced stresses and may result in severe cracking and poor performance of a completed structure. For the purpose of accurately predicting the transient thermal behaviour of the concrete at a young age, a finite element modelling algorithm is developed for incrementally constructed dams. The variable and dynamic construction factors influencing the thermal response of a structure such as the sizes of constituent lifts, use of multiple types of concrete, the placing schedule and prevailing ambient conditions at a project site are systematically accounted for in the algorithm. A case study of a recently constructed typical mass concrete dam with records of in situ temperatures is carried out to test the developed algorithm. The dam was constructed over a 2 year period in an area of severe climatic conditions. Results indicate that the algorithm is effective in predicting the behaviour of a mass concrete dam. The general purpose finite element program ANSYS is utilized as the numerical tool for the work. A series of simple steady state and transient thermal problems are solved to check the individual components of the program. A generic "pilot model" is used to design the algorithmic details.

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1 INTRODUCTION

1.1 General

Concrete used in the construction of dams, large bridge piers, structure foundations and the like is often referred to as "mass concrete". Mass concrete is differentiated from other kinds of concrete in civil engineering by its thermal behaviour. American Concrete Institute (ACI) Committee 116[1] defines mass concrete as "any volume of concrete with dimensions large enough to require that measures be taken to cope with generation of heat from hydration of the cement and attendant volume change to minimize cracking." In Manitoba, mass concrete is used primarily for the construction of dams.

Because of the large physical dimensions typical of most concrete dams, the most practical approach to construction is to build a structure incrementally from many smaller concrete pours, or "lifts". Large lift dimensions and sizable volumes of concrete may still be required for the individual lifts that make up a dam. A consequence of large individual lifts is that the heat produced by cement hydration can result in thermally induced stresses. As concrete is a poor conductor of heat, the lifts of a dam may set with the interior at an elevated temperature due to cement hydration and the periphery at some lower temperature due to exposure to prevailing ambient conditions. Stresses may be generated by restrained shrinkage of the warmer core of the dam with cooling that takes place slowly over time. The severity of these stresses varies according to several factors, such as the total amount of the temperature drop during cooling, the rate and timing of cooling, the amount of restraint offered to shrinkage, the concrete material properties, and so on. Consequently, it is possible that significant stress levels can be present in a concrete dam even before the structure is placed into service. Should thermal stresses not be controlled, a variety of problems can result, particularly cracking and loss of structural integrity, and remediations are typically expensive.

As a result, the design and construction of concrete dams includes attempting to control the temperature reached inside the concrete due to cement hydration. Prediction of thermally induced stresses in a dam would allow for an evaluation of the degree to which the structure should be designed to tolerate the stresses and the effort that should go into controlling the temperature reached within the concrete during construction. Thus, there is a requirement for a procedure capable of reliably predicting thermal stresses in concrete dams. Since most thermal stress problems originate with the heat of hydration, the procedure would have to focus on the early thermal behaviour of a dam; that is, the construction period and the first few weeks and months following completion of a structure.

The literature contains many suggestions for ways to carry out a stress analysis of this type, and most are based on the finite element method. A possible approach to this problem would be to carry out finite element modelling of a mass concrete dam in two steps by assuming that the nature of heat flow and thermal stresses are independent. The first step would be prediction of the early thermal history of a dam according to assumed construction conditions such as concrete mix designs, the lift placing schedule, lift dimensions, weather conditions, etc. The second step would be calculation of the corresponding stress history of the structure based on the predicted thermal history of step one. The stress history could ultimately be extended to incorporate effects of service loads as well. This thesis is concerned with: i) developing a finite element modelling algorithm for the first of these two steps for analyzing thermal stresses in concrete dams, prediction of the early thermal history of a structure; ii) identifying the level of detail necessary to accurately trace temperature evolution in a young concrete dam; iii) assessing the dominant parameters and factors that contribute to the actual temperature distributions in concrete dams; and iv) addressing the reliability of the current methodology used in designing these structures.

1.2 Objective

The objective of this thesis is to develop and verify a finite element modelling algorithm for the prediction of early thermal behaviour of incrementally constructed mass concrete dams. A commercially available finite element engineering analysis program is utilized for this task. The degree of detail required for this type of analysis and the parameters and factors contributing to actual temperature distributions in young concrete dams are evaluated qualitatively.

1.3 Scope

It is fundamental to this type of problem that the effects of time on the thermal behaviour of a dam are accounted for. Therefore, a transient thermal analysis forms the basis of this work. For simplicity, a two-dimensional procedure is developed, but the principles and routines presented here would be identical for the general three-dimensional case.

The factors that determine temperature patterns in a concrete dam at a young age are essential to this work, and have been included in the developed algorithm. They consist of the following:

i) A time span to be modelled in an analysis is selected such that the period of thermal activity of interest can be observed. The analysis begins at a point in time preceding placement of the first lift of concrete in a dam in order to initiate a temperature distribution in the underlying foundation. This is important since foundation temperature conditions influence the thermal response of the first few lifts of concrete in a structure. Analysis takes place through the period of lift placement in a dam allowing the thermal behaviour and interactions between the various concrete lifts to be observed. The analysis is ended once the period of interest has been modelled.

ii) Proper account is taken of the changing geometry of a dam over time due to lifts of concrete being added during the construction process. The developed algorithm presents procedures to ensure that the historical evolution of the temperature distribution in a dam is cumulative throughout the time span modelled.

iii) Consistent with a transient analysis forming the basis of this work, changing thermal boundary conditions over time are included as well. The boundary conditions applied are specified nodal temperature values, varying rates of internal heat generation, and convections to varying ambient conditions during the modelling period. The effects of earthfill materials placed against a dam are included as well. These are all incorporated into the modelling algorithm with proper account taken of changing geometry through time to predict the cumulative thermal response of a young concrete dam.

The organization of this thesis reflects the general series of steps that were followed in carrying out the work. Chapter 2 contains a review of the various factors influencing thermal effects and cracking in mass concrete structures as reported in the open literature. Techniques for modelling important parameters of a thermal analysis of these types of structures is also described in Chapter 2. Chapter 3 presents the developed modelling algorithm, and describes the finite element program and its particular features utilized in analysis execution and for carrying out a case study. In Chapter 4, procedures for formulating a typical finite element model are explained, including a description of assumptions and simplifications. A case study to test the algorithm is presented in Chapter 5. The structure analyzed was constructed over 2 years in an area of severe ambient conditions. Descriptions of the structure, boundary conditions, applied loading, and a comparison of analysis results with in situ data are included. It is demonstrated that the developed algorithm is successful in reproducing observed trends in the structure's behaviour. Finally, a series of conclusions are drawn from the work and recommendations for further effort in this area are identified and documented in Chapter 6.

A number of appendices contain supplementary information related to the work. Development of the detailed procedure for carrying out an analysis is described in Appendix A. A simple finite element "pilot model" with the same characteristics as an incrementally constructed concrete dam is utilized. Verification of the solution capabilities of the finite element program is carried out through use of several steady state and transient thermal problems with analytical solutions in Appendix B. Appendix C is a summary of relevant specification requirements for construction of the case study structure, while construction data for the structure is presented in Appendix D. A description of memory management and file handling operations included as part of modelling the case study is contained in Appendix E. Appendix F is a listing of the program code for the analysis, while Appendix G is a brief explanation of the method used to produce the code. A presentation of comparisons between model results and in situ data for all concrete lifts in the case study structure is made in Appendix H. Finally, a variety of thermal contour plots from the case study analysis are included as Appendix I.

2 LITERATURE SURVEY

2.1 Introduction

Concrete used for the construction of dams does not have high cement contents. Leaner concrete mixes are possible because of the large dimensions involved, and because applied loads on dams may be at least partially resisted by the weight of the concrete elements of the structure. Concrete strength, and thus cement content, may instead be governed by serviceability and durability requirements of a dam.

The large volume of concrete used in the construction of dams still requires control of the thermal behaviour and cracking tendencies. The cracking behaviour of a dam is influenced by concrete properties such as the modulus of elasticity, Poisson's ratio, tensile strength, strain capacity, creep, volume change tendencies, thermal properties and permeability[2]. Various consequences of the cracking of concrete dams are possible, including unacceptable amounts of leakage, and the formation of starting points for deterioration of concrete by freeze-thaw damage. Thermally induced cyclic deformations and accompanying frost penetration have an important influence on the deterioration of concrete strength, particularly for dams in northern regions[3]. The extreme situation is that cracking may cause behaviour different than that intended in design and ultimately threaten the integrity and stability of a dam.

Since most cracking problems in dams are related to the heat of hydration released after concrete placement, it is important to have a general understanding of the heat generation mechanism in concrete. The following section provides a brief introduction to the mechanism as it relates to concrete used in the construction of dams.

2.2 Heat Generation

The source of heat generated within mass concrete is hydration of cementing materials in the mixes, traditionally ordinary Portland cement and, in some cases, materials known as pozzolans. Pozzolans are finely divided siliceous or siliceous and aluminous materials that are not themselves cementitious, but react at ordinary temperatures with moisture and calcium hydroxide produced during the hydration of Portland cement to form strong, stable cementitious compounds. Common pozzolans are fly ash, produced by the burning of coal, and blast furnace slag, produced in the manufacture of steel and iron.

2.2.1 Chemistry of Cement

Ordinary Portland cement (OPC) is comprised of four main compounds that are commonly written with shorthand abbreviations. The compounds are shown in Table 1. Minor amounts of other compounds such as magnesia (MgO) and lime (CaO) are also present.

Compound	Chemical Formula	Shorthand Abbreviation	Typical OPC Composition (%)
tricalcium silicate	$3CaO \cdot SiO_2$	C_3S	55
dicalcium silicate	$2CaO \cdot SiO_2$	C_2S	15
tricalcium aluminate	$3CaO \cdot Al_2O_3$	C_3A	10
tetracalcium alumino ferrite	$4CaO \cdot Al_2O_3 \cdot Fe_2O_3$	C_4AF	8

TABLE 1 - Main Compounds in Ordinary Portland Cement

Through exothermic processes and at different rates, these compounds react with water to produce complex hydrates and calcium hydroxide[4]. The main hydration reactions of OPCs can be summarized as[5]:

$$2\,(3CaO \cdot SiO_2) + 6H_2O \rightarrow 3CaO \cdot 2SiO_2 \cdot 3H_2O + 3Ca(OH)_2$$
$$2\,(2CaO \cdot SiO_2) + 4H_2O \rightarrow 3CaO \cdot 2SiO_2 \cdot 3H_2O + Ca(OH)_2$$
$$2\,(3CaO \cdot Al_2O_3) + 3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 32H_2O + 4H_2O \rightarrow 3\,(3CaO \cdot Al_2O_3 \cdot CaSO_4 \cdot 12H_2O)$$
$$3CaO \cdot Al_2O_3 + Ca(OH)_2 + 12H_2O \rightarrow 4CaO \cdot Al_2O_3 \cdot 13H_2O$$
$$4CaO \cdot Al_2O_3 \cdot Fe_2O_3 + 4Ca(OH)_2 + 22H_2O \rightarrow 4CaO \cdot Al_2O_3 \cdot 13H_2O + 4CaO \cdot Fe_2O_3 \cdot 13H_2O$$

The hydration processes of Portland cement are influenced by the different phases and trace components present in the cement[6]. It is thought that the setting of OPC corresponds to the start of C_3S hydration.

The chemical composition and therefore the heat generation characteristics of OPCs vary according to local manufacturing processes and materials. However, to give an impression of the relative contributions of the compounds to the heat generated by an OPC, a heat generation pattern of the primary compounds of OPC is shown in Table 2[7].

Compound	Heat Evolved at 21 °C (cal/g)				
	3 days	7 days	28 days	90 days	1 year
C_3S	58	53	90	104	117
C_2S	12	10	25	42	54
C_3A	212	372	329	311	279
C_4AF	69	118	118	98	90

TABLE 2 - Heat Evolution Pattern of Main Compounds in Ordinary Portland Cement

Cements have been measured as continuing to generate heat for years, but as shown in the table above, the majority of the total amount is produced in the first few days[8].

The heat of hydration characteristics of a cement depend on the relative proportions of the constituent compounds[9]. Type 10 cement is named normal Portland cement, and is used for general construction purposes. Limitations on the composition of this cement are the least restrictive of all cement types, and thus these cements can have widely variable heat generation characteristics. Type 20 cement is known as moderate Portland cement and is limited to a maximum C_3A content of 7.5% by Canadian Standards Association (CSA) standard CAN/CSA-A5-M88. This cement is designed to have moderate sulfate resistance and a low heat of hydration, and is intended for use in mass concrete structures where temperature control is important. Type 40 cement is low heat of hydration Portland cement also intended for mass structures, and is limited to a maximum C_3A content of 5.5% by the CSA standard. Type 30 cement is high early-strength Portland cement and is not suitable for use in the construction of mass concrete dams. Cements of a particular type can vary much in the amount of heat they produce.

The chemistry of OPC has been found to be different today compared to 50 years ago, particularly with respect to C_3S and C_2S components. It has been reported that cement now tends to produce heat at a rate that is approximately three times what it once was, and that the total temperature rise of in-place concrete appears to be slightly higher[10]. It has also been reported that increased fineness and strengths of cements in the last 30 years has resulted in variable heat generation characteristics of cements[11].

The heat generation pattern of a cement varies according to the conditions under which hydration takes place. Increasing the hydration temperature within ordinary ranges increases heat generation at an early age, but has a negligible effect on the total amount of heat produced by the time hydration approaches completion. A reduction in the water-cement ratio of a mix also increases the rate of initial heat generation, but appears to have little effect on the total amount of heat produced as well[12]. Cement fineness influences heat generation rates more than the total amount of heat produced, with finer cements producing greater amounts of heat at an early age[13].

2.2.2 Concrete Mixes

Many factors affect both the rate and total amount of heat generated within concrete used in the construction of dams. A direct influence on both of these actions is the type and amount of cement used in the mixes. The total amount of heat produced is directly proportional to the amount of cement or the equivalent cement content (cement plus pozzolan) in a mix. The properties of pozzolans vary according to material type and source, but they are typically considered to generate about 40%-50% of the heat that the equivalent amount of Portland cement would generate. The contribution of a pozzolan to the amount of heat produced in a concrete generally increases with the age of the concrete, fineness of the pozzolan in comparison to cement, and with lower heat producing cements[14]. For a concrete containing a pozzolan, early heat generation is primarily from cement hydration, with little contribution from the pozzolan. At later ages, the pozzolan is an increased contributor to heat generation.

Other factors that affect heat generation are admixture use, batching temperature and temperature during hydration. Water reducing and set retarding agents typically affect the temperature rise characteristics of a concrete during the first 12 to 16 hours after mixing, the time that these admixtures have the greatest effect reaction processes. There does not tend to be an effect beyond 24 hours[15]. As the rate of reaction of cement with mixing water is faster at a higher temperature, the greater the mixing temperature the faster the cement hydration process and the greater the amount of heat produced at an early age[16]. The temperature during hydration depends on the placing temperature of the concrete and the rate of heat loss from a structure.

2.3 Concrete Masses

2.3.1 Mix Designs

The goal of proportioning mass concrete mixes is to obtain designs that are economical, meet strength, durability and impermeability objectives, and provide adequate workability and the lowest practical temperature rise after placement using available materials[17]. Admixtures are used to improve workability and control setting, bleeding, segregation and slump loss of a mix while in the plastic state. For hardened concrete, the benefits of admixtures are reduced heat generation, improved strength, durability and abrasion resistance, and decreased permeability[18]. The temperature control aspect of mix designs can take many forms, and some of these are explained in more detail in Section 2.5.

2.3.2 Thermal Properties

There is rarely any flexibility in determining the thermal properties of mass concretes because the majority of the materials for concrete production are usually determined according to local availability. The main factor governing all thermal properties is the mineralogical composition of the aggregate, as aggregate typically makes up 70% to 80% of the volume of a concrete[19]. The conduction coefficient k_c of concrete is only slightly dependent on the hydration rate of the cement[20]. Conductivity of normal to heavyweight concrete is nearly independent of density, and is little affected by changes in temperature. However, void and especially air content, and water contained in a concrete tend to lower the conductivity value[21]. In opposition to this, it has also been reported that the value of conductivity of a concrete depends on the density and temperature of the concrete[22]. The specific heat C_p of concrete also only slightly depends on the hydration rate of the cement[23]. The specific heat value generally varies directly with changes in temperature[24]. The specific heat of a concrete has also been reported as tending to vary only slightly with aggregate characteristics, temperature and other parameters[25].

The increase in temperature of a concrete due to hydration of cementing materials under conditions of no heat gain or loss from the surrounding environment is known as the adiabatic temperature rise of the concrete. The adiabatic temperature rise is a function of mix proportioning, the specific heat of the mix ingredients, and the heat of hydration characteristics of the cementing materials[26]. The adiabatic temperature rise of a concrete mix will increase for a mix with a lower overall specific heat value, and for higher heat of hydration cementing materials.

The composition of the aggregate in a concrete is also the primary factor affecting the coefficient of thermal expansion of a mass concrete. The cement paste tends to have a higher value of the coefficient, and is particularly sensitive to its moisture content. The value of the expansion coefficient is essentially constant through the normal temperature range, but tends to increase with cement content and decrease with age[27].

The reader is directed to reference [28] for a more thorough description of the properties of mass concrete.

2.3.3 Thermal Behaviour

There are many influences on the thermal behaviour of mass concrete. Factors include the size of a member, the properties of the concrete, heat generation and ambient conditions during construction, and long term thermal conditions.

The construction stage of most concrete dams is the most intense period of thermal activity. Higher lift heights during construction results in fewer construction joints in a dam, but also a lower proportion of generated heat being lost through lift surfaces before the addition of subsequent lifts. Lower lift heights mean more construction joints and a greater proportion of heat lost before placement of the next lift[29]. It is possible that natural cooling of some concrete dams to long term temperature conditions may take years.

Once construction temperatures dissipate, a regular periodic temperature pattern gradually emerges in many dams[30]. The pattern is a function of annual temperature cycles, solar radiation input to exposed surfaces, and water temperature patterns for the forebay and tailrace of a dam. A daily temperature pattern would be superimposed over the annual pattern. Significant tensile stresses can result.

Because mass concrete is a poor conductor of heat, there tends to be a delay between changes in thermal boundary conditions and the response of concrete temperatures. The depth within a concrete mass where responses to changing boundary conditions appear increases with an increase in the cycle time of the boundary condition. This is typical of the thermal behaviour of mass concrete structures.

2.4 Cracking Behaviour of Mass Concrete Dams

The most general description of the cause of cracking of mass concrete is that it is initiated by restrained volume changes of the concrete. Restraint that produces tensile stresses in concrete is of concern since this may result in cracking. A uniform volume change will not produce cracking if the change is relatively free to take place in all directions. However, this rarely happens for mass concrete structures such as dams[31]. Some of the causes of volume changes and the nature of restraint on mass concrete structures are discussed briefly below.

2.4.1 Volume Change

2.4.1.1 Shrinkage due to Dissipation of Construction Temperatures

The largest volume change a mass concrete dam experiences is typically the shrinkage of concrete that accompanies the cooling of a dam with dissipation of hydration heat from construction. Changes in temperature gradients after concrete begins to acquire elastic properties causes restrained volume changes in a mass and tensile and compressive stresses. In general, the tendency for concrete to crack is lower when the temperature that the concrete begins to behave elastically is lower[32]. Factors influencing tensile stress development during cooling are temperature differentials and rate of temperature change, the modulus of elasticity and coefficient of thermal expansion, and the degree of restraint[33]. The effects of high temperatures after the setting of concrete are usually mitigated by a low elastic modulus and high creep rates of concrete at early ages.

Form removal can cause a thermal shock to surface concrete. Restraint from interior concrete would resulting in tensile stresses at the surface if the ambient temperature is much less than the concrete temperature when the forms are removed.

2.4.1.2 Annual Thermal Boundary Condition Patterns

Volume changes and thermal stresses in mass concrete dams can also develop from periodic cycles of ambient thermal boundary conditions. Dams in northern regions can have exposed faces subject to significant tensile stresses as a result of annual patterns of temperature distributions in the dam[34]. Daily temperature cycles can produce surface cracking that tends to be shallow in nature. Surface cracks are not a structural threat, but do serve as a starting point for damage by freeze-thaw action.

2.4.1.3 Drying Shrinkage

The drying of mass concrete also causes a volume change and, as far as tensile stresses are concerned, the effect is similar to that caused by a temperature reduction. However, drying shrinkage takes place extremely slowly and is governed by the drying path length and therefore tends to only affect concrete near exposed surfaces. Drying shrinkage cracks also tend to be shallow, and form a random pattern on a concrete surface. Shrinkage is affected by the type of aggregate in the concrete, with low shrinkage concretes tending to contain quartz, limestone, dolomite, granite or feldspar. High shrinkage concretes often have sandstone, slate, or basalt aggregate[35]. Creep tends to reduce the severity of stresses caused by drying shrinkage because of the amount of time involved in the development of the volume change.

2.4.2 Restraint

Restraint to changes in volume of a concrete element can be internal - from the concrete itself, or external - from the foundation of a structure or adjoining structures. Continuous external restraint exists along contact surfaces between concrete and any material that the concrete has been cast against. A concrete member with a uniform tendency to contract but continuously restrained along its base will tend to crack beginning at the base in the area where the restraint is greatest[36]. Formation of cracks causes redistributions of the stresses within a concrete member.

Internal restraint within a mass concrete member occurs when a non-uniform volume change takes place, particularly when interior temperatures are greater than surface temperatures of a block of concrete. The amount of differential volume changes determines the degree of internal restraint, with the effects adding to those that result from external restraint, but not exceeding the effects of complete external constraint[37].

2.4.3 Control of Cracking

Measures implemented to control cracking of a mass concrete structure are largely dependent on the cost of the measures and the consequences of the cracking[38]. Primary techniques for reducing the likelihood of thermal cracking of mass concrete are controlling volume changes by reducing the maximum internal temperature the concrete reaches, managing the rate of cooling after placement, and improving the tensile strength of the concrete. The restraint mechanism can be modified, and reinforcing can be used to distribute and control crack widths.

2.4.3.1 Volume Changes

The main technique for controlling the change in volume of a mass concrete dam is by reducing the amount of the temperature drop between the peak temperature and the long term operating temperature. For reinforced concrete elements, the temperature change that needs consideration is that from the peak temperature due to hydration during construction to the minimum temperature that the element will be subjected to while in service[39]. Insulating surfaces after placement of concrete can be done to reduce thermal gradients within a mass from the interior to the surfaces.

2.4.3.2 Restraint

Controlling the restraint to volume change of a mass concrete dam is done through the installation of contraction joints and by controlling the rate at which a volume change takes place. The restrained lengths of a concrete element can be reduced and thus the tendency to cracking lowered by breaking large blocks into smaller blocks with strategically located contraction joints.

2.4.3.3 Reinforcing

Reinforcing can be used to control cracking by distributing cracks and controlling crack widths. Benefits of controlling crack widths are corrosion protection for reinforcing, leakage prevention and aesthetics[40].

2.5 Methods of Temperature Control

Temperature control on a mass concrete project is primarily done by four means: control of the cementitious materials in the mixes (cement contents and types), precooling concrete ingredients, postcooling in-place concrete, and controlling construction procedures[41]. The following paragraphs describe each of these means in more detail.

2.5.1 Mix Designs

The most direct way to reduce internal temperatures reached inside mass concrete after placement is to lower the cement content of a mix or replace some of the cement by a pozzolan. Poorer concrete workability characteristics that result from lower cement contents can be improved by air entraining and chemical admixtures. Use of pozzolans in a mass concrete mix has advantages of lowering the temperature rise, reducing permeability, improving workability and sometimes increasing later age strength of a concrete[42]. They have been used to help control the interaction between reactive aggregates and high-alkali cements[43]. Along with a reduction in heat generation at a young age, however, there is a corresponding reduction in the early strength of a concrete with a pozzolan compared to a concrete without one. At later ages, strength may be adequate for design loadings, but care is required to ensure that necessary strength for construction loads and early thermal stresses is provided.

2.5.2 Precooling

Cooling coarse aggregate and replacing a portion of the mixing water with ice are practical and effective means of reducing the placing temperature of mass concrete. Lowering the placing temperature of concrete directly lowers the peak temperature reached after placement, but has little effect on the amount of the temperature rise after placing[44]. There is a benefit to long-term strength and durability of mass concretes batched and placed at low temperatures, as long as early strength requirements are not affected[45].

The temperature of batched concrete is influenced by the initial temperature and specific heat of the constituent materials, and the proportion of each in the concrete. Controlling the temperature of the aggregate has the greatest influence on the temperature of a concrete because aggregate occupies the largest volume in a concrete mix. Techniques for temperature control include shading of aggregate piles and chilling coarse aggregate in refrigerated water or by sprinkling. Immersing aggregate into chilled water is effective for cooling, while sprinkling with chilled water has limited benefits. Fine aggregate can be cooled by using chilled water for the classification process[46]. A problem with using water for cooling aggregates is that it introduces the potential for variations in batching characteristics due to residual water from the cooling process[47]. Alternative procedures are chilled air or forced evaporative chilling aggregates.

Lowering the temperature of water is more effective on a per unit weight basis than lowering the temperature of the cement or aggregates. The use of ice for a portion of the batching water is an efficient means of lowering the placing temperature of concrete because of the heat required to melt ice[48]. Substituting crushed ice for all or a portion of the mixing water is common as a means of reducing the placing temperature of a concrete.

Cooling of cement is difficult and has little impact on concrete temperature[49][50]. Other cooling means are usually sufficient, and it is normally not necessary to reduce the cement temperature in order to achieve placing temperature targets[51].

2.5.3 Postcooling

Postcooling of mass concrete involves removing heat from concrete after placement. It is done by embedding pipes within the concrete and circulating cooling water through the system. The most critical time for applying cooling techniques to placed concrete is the first seven days after placement, since this is the period when the most heat is produced[52]. ACI recommends that in the time period before the concrete reaches its peak temperature, postcooling be carried out at a rate equal to the capacity of the cooling system. After this point, cooling should be done until either the rate of cooling of the concrete reaches the maximum recommended rate (about 0.6°C per day), the concrete temperature drops about 17°C below peak, or the temperature reaches the long term average temperature expected for the structure[53]. Postcooling rates should be reduced at later ages because of higher values of the modulus of elasticity as concrete ages[54].

2.5.4 Construction Procedures

Elements of the construction process for a mass concrete dam may be designed to contribute to temperature control of the structure at a young age. Allowable lift thicknesses and delay times between lifts influence the cumulative thermal behaviour of a dam. The amount of heat lost through the top surface of a lift becomes a decreasing percentage of the total amount generated after placement for lift thicknesses greater than about 3 m. Internal temperatures for deep lifts are therefore not significantly affected by the delay time between lifts[55].

Curing procedures can also contribute to temperature control of placed concrete. Use of steel forms for conduction purposes can increase early heat losses, and spraying forms with cool water and shading placed concrete may assist as well[56]. Procedures implemented for a project depend on the consequences of the behaviour being controlled, and cost and schedule implications of measures to reduce thermal effects.

2.6 Thermal Processes

The processes that transport thermal energy are conduction, convection and radiation. The following paragraphs briefly describe each of these processes and the equations that govern their respective effects.

2.6.1 Heat Transfer Mechanisms

To begin, conduction heat transfer within a solid takes place whenever a temperature gradient exists. Fourier's Law of Conduction applies:

$$q = -k_c A \frac{\partial T}{\partial x} \qquad (1)$$

where q is the rate of heat transfer, k_c is the coefficient of thermal conductivity of the material, A the area of heat flow, and $\partial T/\partial x$ the temperature gradient at the point in the solid under consideration. Of course, heat flow occurs in the direction of decreasing temperature.

Convective heat transfer from the surface of a material takes place when the material is exposed to a moving fluid at a temperature different than that of the material. In the case of a concrete dam under construction, the fluid is air that is usually at prevailing ambient conditions. Convection is governed by Newton's Law of Cooling:

$$q_c = -h_c A (T_a - T_s) \qquad (2)$$

where h_c is the convection heat transfer coefficient, A the area of convection, T_a the temperature of the surrounding fluid, and T_s the surface temperature of the material. For concrete structures, the value of h_c varies according to factors such as wind speed, surface roughness and shape of a structure[57].

Radiation effects on concrete dams can be considered in two parts. The first part is solar radiation that reaches the surface of a dam. It is comprised of three components: i) beam radiation, or radiation reaching a dam surface directly from the sun, ii) sky diffuse radiation, radiation reaching a dam face after scattering by the atmosphere, and iii) ground diffuse radiation, radiation reaching a dam after reflection by the ground. Ground cover has a large influence on ground diffuse radiation, particularly for dams in northern regions[58]. Radiation heat input to a dam surface from solar energy I_t is given by:

$$q_s = a A I_t \qquad (3)$$

where a is the solar absorptivity of the surface (the proportion of the energy absorbed) and A the area exposed. The second part is emission of thermal radiation, which is given by the Stefan-Boltzmann Law of Thermal Radiation:

$$q_r = -\epsilon \sigma A (T_a^4 - T_s^4) \qquad (4)$$

where ϵ is the emissivity of the surface ($0 \leq \epsilon \leq 1$), σ is the Stefan-Boltzmann constant independent of the surface, medium and temperature, and is equal to 5.6697×10^{-8} W/m$^{2}\cdot{}^{\circ}$K^{4}, A is area, and T_a and T_s are temperatures of the surrounding air and surface in absolute terms, respectively.

2.6.2 Governing Heat Transfer Equation

The governing classical heat transfer equation is derived from consideration of a control volume in three dimensions. By maintaining heat flow equilibrium and including a term for the storage of heat within the control volume, the following equation is obtained:

$$\rho C_p \frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(k_x \frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y \frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(k_z \frac{\partial T}{\partial z}\right) + q \tag{5}$$

where ρ is the material density, C_p the specific heat, t the time, T the temperature at a point having Cartesian coordinates x, y, z, q the rate of heat generation within the control volume, and the conductivity values k_x, k_y, k_z reflect an anisotropic material. Conditions to be satisfied at the surfaces of a body are:

$$T \,\big|_{S_1} = T_0 \,, \tag{6}$$

and

$$\left(k_x \frac{\partial T}{\partial x} + k_y \frac{\partial T}{\partial y} + k_z \frac{\partial T}{\partial z}\right)\bigg|_{S_2} = q^S \tag{7}$$

where S_1 and S_2 are surfaces on the body, T_0 is the temperature on S_1, and q^S is the heat flow input on S_2.

The finite element method is an effective tool for predicting temperatures within structures that have complex geometry and boundary conditions[59]. Converting the governing equation into matrix form for solution by the finite element method and including the effects of heat transfer mechanisms produces the so-called semi-discrete statement:

$$[C]\{\dot{T}\} + [\bar{K}]\{T\} = \{\bar{Q}\}, \tag{8}$$

where $[C]$ is the specific heat matrix, $[\bar{K}]$ the effective conductivity matrix, $\{T\}$ the matrix of nodal temperature values, and $\{\dot{T}\}$ the time derivative of $\{T\}$. The matrix $\{\bar{Q}\}$ is the effective heat flux vector, and is given by:

$$\{\bar{Q}\} = \{Q_e\} + \{Q_c\} + \{Q_r\} + \{Q_i\} \tag{9}$$

where $\{Q_e\}$ is the applied heat flux vector, $\{Q_c\}$ the convective heat transfer vector, $\{Q_r\}$ the radiation vector and $\{Q_i\}$ the vector of internal heat generation rates. Neglecting radiation allows $\{\bar{Q}\}$ to be evaluated independently of the unknown temperatures[60].

2.7 Modelling Techniques

A finite element thermal analysis of a concrete dam requires proper attention to the characteristics of the dam and the thermal processes governing the temperature distributions within a structure. The following sections briefly describe the important elements of an analysis for realistic modelling of a dam to be carried out.

2.7.1 Constituent Thermal Processes

It is essential that thermal processes influencing the temperature distributions in mass concrete dams during construction are incorporated into an analysis. Fundamental to this is that the physical characteristics of a dam and its environment are built into an analysis so that accurate results can be obtained. The physical nature of a dam is known from initial steps in the design process or from the drawings of an existing structure. The environment that a dam exists in while under construction is reflected by convection coefficient values, ambient air temperatures and solar radiation conditions. Other important factors for thermal modelling are the concrete thermal properties, adiabatic temperature rise characteristics, placing temperatures, structural dimensions and lift thicknesses, and curing[61]. It is also important that initial foundation temperatures and the placing rates (i.e. the construction schedule) are properly accounted for[62].

2.7.2 Internal Heat Generation

2.7.2.1 Adiabatic Conditions

The most important factor to modelling the thermal behaviour of mass concrete is the internal heat generated from hydration of cementing materials after placement[63]. Mass concrete placed in lifts of 1.5 m or greater with lateral dimensions of about 3 m produces conditions within the centre of a lift where the concrete is essentially adiabatic for a brief period[64]. Using an adiabatic procedure to experimentally measure heat evolution within a concrete, such as by adiabatic calorimeter, simulates quite closely the temperature conditions inside the core of large concrete masses where conditions may remain nearly adiabatic for the first few days after placement[65].

The heat of hydration generated in concrete is not only time dependent but also temperature dependent, and strictly speaking should be treated as such in a thermal study. However, in analyzing mass concrete structures, use of data from an adiabatic test of the heat of hydration of a cement provides for reasonably accurate temperature distribution predictions[66]. It has been recommended that for temperature studies of mass structures actual heat generation patterns of the concretes be obtained from laboratory tests and that the tests use actual materials for the project being studied[67]. It should be noted that applying a pattern of adiabatic temperature rise in the prediction of temperature distributions in a structure may not be suitable in all cases. This is particularly true when small structures are involved where the interior conditions are not close to adiabatic[68].

2.7.2.2 Function

In the thermal study of mass structures, the adiabatic temperature rise of the concrete has traditionally been given according to the empirical equation:

$$T(t) = K\left(1 - e^{-\alpha t}\right) \tag{10}$$

where K is a coefficient reflecting the final amount of the adiabatic temperature rise, and α reflects the rate of the temperature rise[69]. The effects of the two coefficients on the temperature rise given by the equation are independent.

The rate of heat generation for concrete under adiabatic conditions and therefore the parameter values for the equation depend on the cement type used, the unit cement content of a mix, and the initial temperature of the materials[70]. The Japanese Concrete Institute (JCI) Committee on Thermal Stress of Massive Concrete measured heat

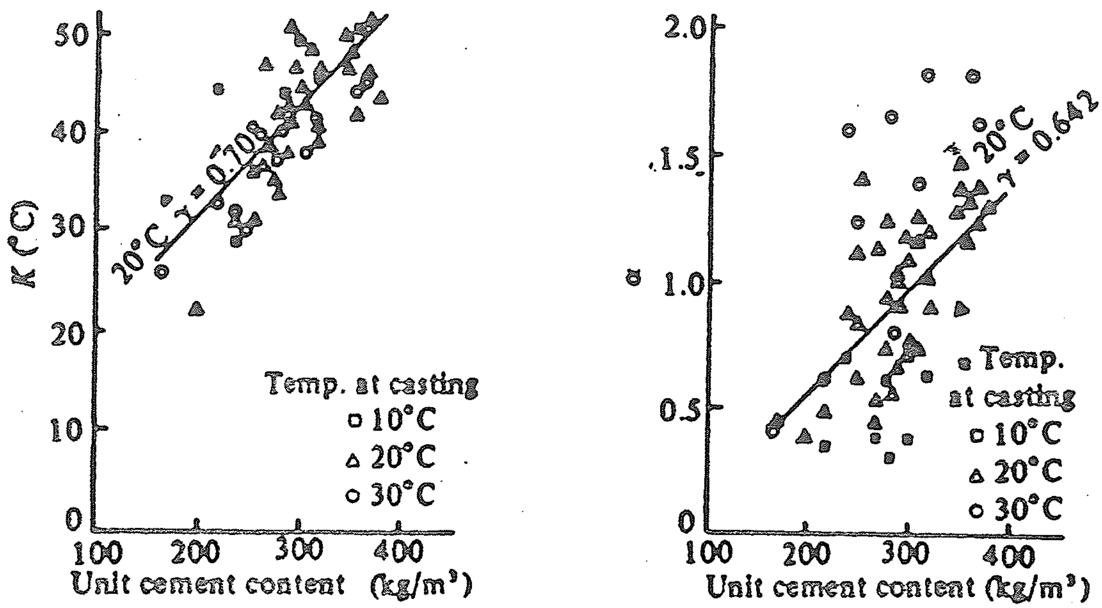

FIGURE 1 - Values of Coefficients K and α for Adiabatic Temperature Rise of Concretes Containing OPC (From Reference [73])

of hydration for cements on the Japanese market and calculated values of these two parameters for each concrete measured[71][72]. Testing included OPC and was done at three different mixing temperatures. Graphs of coefficient values for the OPC measurements are reproduced here in Figure 1 from reference[73]. Values of α are in units of 1/days. As can be seen on the Figure, there is a large variation in the values of both K and α even with approximately equal placing temperatures and cement contents. It is apparent that it is important to obtain concrete-specific adiabatic temperature rise characteristics for use in a thermal analysis.

The effect of placing temperature of the concrete can be reflected in the values of the coefficients to the equation. In general, as the placing temperature rises, K decreases and α increases. The coefficient K does not significantly affect the time to reach the peak temperature in a lift, while α has a significant impact on this response[74].

It has been reported that this empirical equation is not accurate for mass structures at early ages[75]. These authors instead developed their own equations from observations of the behaviour of the actual structure under construction.

2.7.3 Boundary Conditions

Heat is transferred through the boundaries of a concrete dam by conduction at the foundation and by convection and radiation to air and water at exposed surfaces. Because heat transfer into the foundation of a dam begins once concrete is placed, it is important that the initial foundation temperature distribution is estimated as part of a thermal analysis for a structure.

Heat transfer between a dam and the surrounding air depends on temperatures of the air and concrete, wind speed and solar radiation conditions[76]. The convection coefficient between a structure and ambient conditions is very important in obtaining an accurate temperature estimate for a dam. An approximate equation suggested to obtain values of the convection coefficient h_c from a wind blowing parallel to a flat surfaces is[77]:

$$h_c = 3.8\, v + 5.7 \tag{11}$$

where h_c has units of $W/m^2 \cdot {}^\circ K$ and v is the wind speed in m/s. In modelling thermal effects on concrete bridges, empirical equations have been utilized to calculate values of the convective heat transfer coefficient for different exposed surfaces of a bridge as a function of wind speed[78][79]. Values of the coefficient can be obtained experimentally, or a constant value assumed throughout the duration of an analysis. To specify the temperature of the fluid that the convection takes place to, it is common to develop periodic ambient temperature patterns according to prevailing weather at a project site.

Formal treatment of radiation boundary conditions in a transient thermal analysis requires an iterative process. The radiation equation requires a knowledge of the surface temperature to calculate q_r, and is thus non-linear. However, it is possible to account for radiation through the convective loading on a dam by increasing the temperature of the concrete-air interface, or by modifying the value of the convection coefficient. For a transient analysis and considering the temperature differences that typically occur between concrete dams and surrounding air, it is reasonable to modify the radiation equation so that the effects of radiation can be combined with convection, and both heat transfer mechanisms treated together. Equation 4 can be written as[80]:

$$q_r = -h_r \, A \, (T_a - T_s) \tag{12}$$

where

$$h_r = \epsilon \, \sigma \, (T_s^2 + T_a^2) \, (T_s + T_a) \tag{13}$$

and is determined approximately by using previously calculated values of T_s and T_a in absolute terms[81]. It has been reported that the value of h_r is only slightly temperature dependent, and thus the requirement for iterations can be avoided in calculating the temperature solution at each time step in an analysis[82]. The convective and radiative heat transfer mechanisms can then be evaluated by:

$$q_{c+r} = -(h_c + h_r) \, A \, (T_a - T_s) \; . \tag{14}$$

2.8 Previous Work

Thermal and thermal-stress analyses of concrete dams are important in the design process for estimation of tensile and cyclic stresses in a structure. There are many examples of thermal and thermal-stress analyses solved by the finite element method described in the literature. While the objectives of an analysis may be straightforward, it is possible to approach parts of the thermal portion of an analysis using different techniques according to the circumstances of each analysis. In this section, some of these different approaches are noted.

2.8.1 Material Properties

The values of the concrete thermal material properties used during analyses have been reported as assumed to be constant for the temperature ranges encountered during a study[83], and as time dependent in value[84]. The adopted treatment of the material property values would depend on the implications of the range in values expected and the available computer resources to carry out an analysis.

2.8.2 Foundation Conditions

There are two components to the thermal conditions in the foundation portion of a model. The first is the conventional assumption of a constant, uniform temperature value for the invert of the foundation as a boundary condition for the entire duration of an analysis. A measured temperature value can be assigned if available. Without actual data, it is reasonable to adopt a temperature value equal to the mean annual temperature for the project site of a structure being analyzed. This was done in the study reported in Reference [85]. The depth of foundation that is included in a thermal model must be consistent with the assumption of a constant temperature existing throughout the time frame of an analysis.

The second component important for these analyses is that temperature conditions in the foundation at the time of first concrete reflect a transient response to the pattern of ambient temperatures at the project site. For example, a period of thermal loading exceeding one year (to remove any starting influences) on the exposed surface of the foundation for a mass concrete structure was used to establish an initial condition for concrete placement in Reference [86]. In another study, the foundation temperature was determined for the time period prior to placement of the first lift of concrete by exposing the rock surface to a changing ambient temperature for a time period of 2 to 3 years before concrete placement[87].

2.8.3 Convective Boundary Conditions and Adiabatic Surfaces

The two parameters of the convective boundary conditions that require consideration in defining an analysis are the ambient (fluid) temperature and convection coefficient. There are different approaches to determining values of both of these items.

It is possible to use a constant ambient temperature value for the convective fluid temperature when only a slight variation in value is evident at a project site through the time period of an analysis. This was the case in the study described in Reference [88]. When ambient temperatures vary through the duration of an analysis, it is often convenient to use a daily or monthly mean temperature for the project site as a means of avoiding anticipating daily ambient temperature variations and having an excessive number of time steps in an analysis. Examples of these approaches are Reference [89] where the daily median temperature for the project site was used, and Reference [90] where the mean monthly air temperature variations were used for ambient conditions.

There are many approaches evident in the treatment of the value of the convection coefficient. The simplest is the assumption of a uniform, constant value based on previous experience or the average prevailing wind speed at a project site. The coefficient has been determined as a function of evaporative heat losses based on the effects of curing processes on the surfaces of a concrete block[91]. In this case, the evaporative losses were estimated by a relationship that included the effects of wind and moisture conditions in the atmosphere.

A refinement in the treatment of the convection coefficient is incorporation of the effects of formwork on heat losses from the surfaces of new concrete. This has been done in References [92] and [93]. In those studies, the insulating effect of plywood forms was incorporated into the convection coefficient of vertical surfaces for the first 2 days after placement, and of horizontal surfaces (for example, the roof forms for enclosed voids in a structures) for a period of 7 days to simulate what is likely to occur during construction. After this period, the coefficient was determined according to wind speed. Because of the variability of its value through time, an average wind speed was used for external surfaces.

Heat losses through enclosed voids in a structure can be simulated by assuming a wind speed that is much reduced from that outside of a structure. This normally requires engineering judgement to determine a reasonable assumption. Once fully enclosed in concrete, Reference [94] treated structural voids through the use of air elements and unrealistically high values of the conduction coefficient as a means of simulating the combined effect of convection and conduction.

It may be possible to assume that some surfaces of a model do not have heat flow across them during an analysis. For instance, it is common to assume no horizontal heat flow through vertical boundaries of the foundation portion of a model. In modelling a symmetric structure, boundary conditions along the plane of symmetry and on the outside faces of the foundation portion of the model can be left as "adiabatic surfaces", as done in Reference [95].

2.8.4 Solar Radiation

There are various techniques for the treatment of solar radiation as a boundary condition during an analysis, the simplest being to neglect it. This may be justified if solar radiation is felt to be a minor contributor to the thermal response of a particular structure under consideration. If not, incorporation of solar radiation can be estimated as a function of sun height at a project site as was done in References [96] and [97].

An alternate treatment sometimes adopted is to modify the ambient temperature values used for specifying convections to reflect the estimated effect of radiation loading. For instance, the temperature of the surrounding air was increased by 1.7°C during a thermal analysis of a roller compacted concrete (RCC) dam to account for the effect of radiation in the study described in Reference [98]. It must be recognized, of course, that radiation has a greater effect during sunny days than on cloudy days and at night, and thus some error is introduced with this approach.

2.8.5 Internal Heat Generation Loading

It is most reliable to determine functions describing the rates of internal heat generation of concrete by laboratory testing trial mixes of the actual concretes to be used during construction. In one study[99], laboratory testing was carried out on a mix having a lower cement content and the results prorated for actual cement contents of the mixes for the analysis. Without available data, functions can be adopted from previous experience or empirical methods, but with reduced reliability.

In carrying out design studies, internal heat generation loadings and other boundary conditions are typically applied to elements that begin their thermal response from the average placing temperature expected during a project.

2.8.6 Time Steps and Meshes

Defining the sizes of time steps taken during execution of a thermal analysis is normally related to the minimum size of the finite elements. For commercial finite element programs, there is typically a guideline provided in the form of an equation that is recommended by the software authors to relate the two items. It is important to also consider the lift placement pattern used or anticipated to be used during construction. Where lift thicknesses are indistinct because of construction procedures, for instance in the construction of RCC dams, a possible approach is to consider the daily average thickness of material placed during construction in setting the element thickness in a model. In the study described in [100], one element equalled the thickness of RCC placed in one day.

It can be convenient, from a computational point of view, to vary the time step size according to the expected intensity of thermal activity and loading during an analysis. In References [101] and [102], the time steps used varied between the period immediately after placement of a new lift (short time steps) to after the lift had been in place for a few days (longer time steps). This can be utilized as a method of reducing the execution time required to carry out an analysis.

2.8.7 Application of Thermal Analysis Results

Typically, the output from a mass concrete thermal analysis is the time history of temperatures at all nodes in a structure. A benefit to solution of temperatures by the finite element method is that the model mesh and resulting temperature distributions can be applied directly to a structural analysis for calculation of the corresponding stress distributions[103]. Calculated element temperatures were used to determine maturity values of concrete for deriving mechanical material property values as part of the subsequent stress analysis in the study reported in Reference [104].

2.8.8 Benefits of Incremental Types of Analyses

An approach to designing for thermal stresses in mass concrete dams is the application of an assumed temperature difference within a structure that is judged to simulate the effect of heat of hydration thermal stresses. Finite element models that incorporate incremental construction procedures have been found to better estimate stresses that result from the construction process than simpler analysis methods[105].

3 ANALYSIS ALGORITHM

3.1 General

It is best to meet the objective of this thesis with as realistic a modelling algorithm as is practical in order to obtain useful information from a thermal model of a young mass concrete dam. In very broad terms, the essence of the developed algorithm is the solution of the classical heat transfer equation (Equation 5) while satisfying applied boundary conditions and thermal loads for a dam under construction. The modelling algorithm takes proper account of the factors that affect the early thermal behaviour of these kinds of structures. The usefulness of the procedure is improved by utilizing a finite element program that allows convenient specification of model geometry, dynamic boundary conditions and systematic interpretation of analysis results. For this work the commercially available finite element engineering analysis program ANSYS is utilized as a basis for this role.

3.2 Analysis Attributes

Several specific influences unique to the thermal behaviour of mass concrete dams are incorporated into the analysis algorithm. The following sections describe these influences.

3.2.1 Transient Incremental Procedure

The most fundamental attribute of the algorithm is that account is made of the effect of time on the thermal responses and temperature patterns in a dam, and the influences of the incremental nature of the construction process for a dam are properly modelled. This is essential because the cumulative thermal behaviour of a dam is highly influenced by the effects of construction in terms of i) the ambient conditions, ii) the placing schedule, and iii) lift sizes, among other issues to be discussed in subsequent sections. These are incorporated into the algorithm at a detailed level in order that realistic results can be obtained from an analysis.

As a start to modelling these effects, the algorithm includes estimation of the initial foundation temperature conditions at the time the first lift of concrete is placed, since this influences the temperature response of the first lifts in a dam. Thus an analysis begins at a point in time far enough in advance of the first concrete lift to allow a reasonable initial foundation temperature distribution to be determined. The remainder of an analysis takes proper account of the incremental nature of construction to produce cumulative internal thermal interactions between successive lifts of concrete.

3.2.2 Internal Heat Generation Rates

Another fundamental attribute of the analysis algorithm is that realistic, time-dependent internal concrete heat generation rates can be specified as an integral part of the variable forcing functions. Mass concrete dams may consist of several different types of concrete to meet strength, durability, availability and economic objectives. Therefore, there may be several different heat generation patterns for the concretes of a particular dam. There are also a series of different ages of the concretes since lifts are placed at different times in the construction sequence. The algorithm has been developed with the ability to identify every individual concrete type uniquely for assignment of a specific internal heat generation rate at each load step of an analysis.

3.2.3 Constituent Boundary Conditions

Since the goal of the modelling process is the prediction of the thermal behaviour of a dam at a young age, the level of detail for the specification of boundary conditions is consistent with this goal. Boundary conditions incorporated into the algorithm in order to achieve a reasonable degree of accuracy for this type of analysis are as follows.

3.2.3.1 Fixed Temperature at Depth in Foundation

A specific temperature at depth in the foundation is defined as a continuous boundary condition throughout an analysis. This reflects an assumed isothermal reference plane present beneath a dam, and is a common form of boundary condition for these types of analyses. This is a physically admissible condition since there will exist a depth in the foundation of a dam which will be unaffected by the presence of the structure.

3.2.3.2 Convective and Adiabatic Surfaces

To model the effects of prevailing ambient conditions on a dam, the algorithm includes specification of detailed convective boundary conditions on the exposed portions of a dam through time. Related to this, the algorithm allows for no heat loss or gain to be specified to occur across other surfaces in a model, as the simulation being carried out warrants.

Two factors that vary with time are incorporated into the definitions of convective boundary conditions and adiabatic surfaces. The first is that the specific surfaces of a model which are convective to ambient or are adiabatic vary at different points in time as construction progresses. Changes in the convective surfaces occur as new lifts of concrete are added to a dam. Assuming surfaces with earthfill placed against them to behave adiabatically, these surfaces also vary over time as material is placed against existing lifts in the dam. Surfaces of a model which have concrete lifts placed against them are able to be convective for the times that they are exposed to ambient conditions, but then become part of a continuous temperature field for times after concrete placement.

The second factor that varies with time involves changes in the parameters of the rate equation governing convection, Newton's Law of Cooling (Equation 2). Variations in weather conditions at the site of a dam are incorporated into the specification of convections by utilizing ambient temperatures as the fluid temperature, T_a, and daily average wind speeds in determining the value of the convection coefficient, h_c. These parameters both vary over time according to either observed or anticipated weather conditions during construction.

If the level of detail in the modelling process warrants, the algorithm could be modified to accommodate the assignment of different convective loads to different surfaces of a model at the same point in time in the modelling process. This could be done to recognize the differences in the rates of heat loss between completely exposed concrete surfaces and those that may have forms in place against them. Accurate modelling may also require the specification of convective boundary conditions in detail of the level of daily or hourly prevailing conditions. The algorithm could accommodate this approach as well. The practical extent that this could be carried out would depend on the computer resources available to run an analysis.

3.2.3.3 Temperature Initialization of New Lifts

Part of the process of modelling the incremental construction of a dam is recognition that new lifts of the structure begin their thermal behaviour at an initial temperature value equal to the placing temperature. The algorithm therefore allows new lifts of concrete in a model to begin their responses to the various applied boundary conditions and thermal loads from specified temperatures equal to their initial average placing temperatures. Since the effect of initializing the temperature of new lifts is only required for the instant in time that each lift is added (i.e. placed) to a model in an analysis, an initializing temperature boundary condition has no further effect on temperature values in the time beyond the instant the lift is added to a model.

3.3 Detailed Analysis Algorithm

A flowchart illustrating the steps of the algorithm to carry out an incremental thermal analysis is presented in Figure 2. In the Figure, boxes along the right hand side of the flowchart identify locations in the modelling algorithm where structure-specific information is supplied to an analysis, and shaded boxes where boundary conditions and thermal loading are specified. The various steps are introduced in the following paragraphs, elaborated on in Chapter 4, and demonstrated with the case study in Chapter 5.

3.3.1 Step 1

The first step in the algorithm is taken to minimize memory demands during an analysis by suppressing redundant output files generated during execution by the finite element program. This can be done because the program issues nodal temperature solution information to more than one output file during execution, and it is only necessary to save one source of this data for later post-processing.

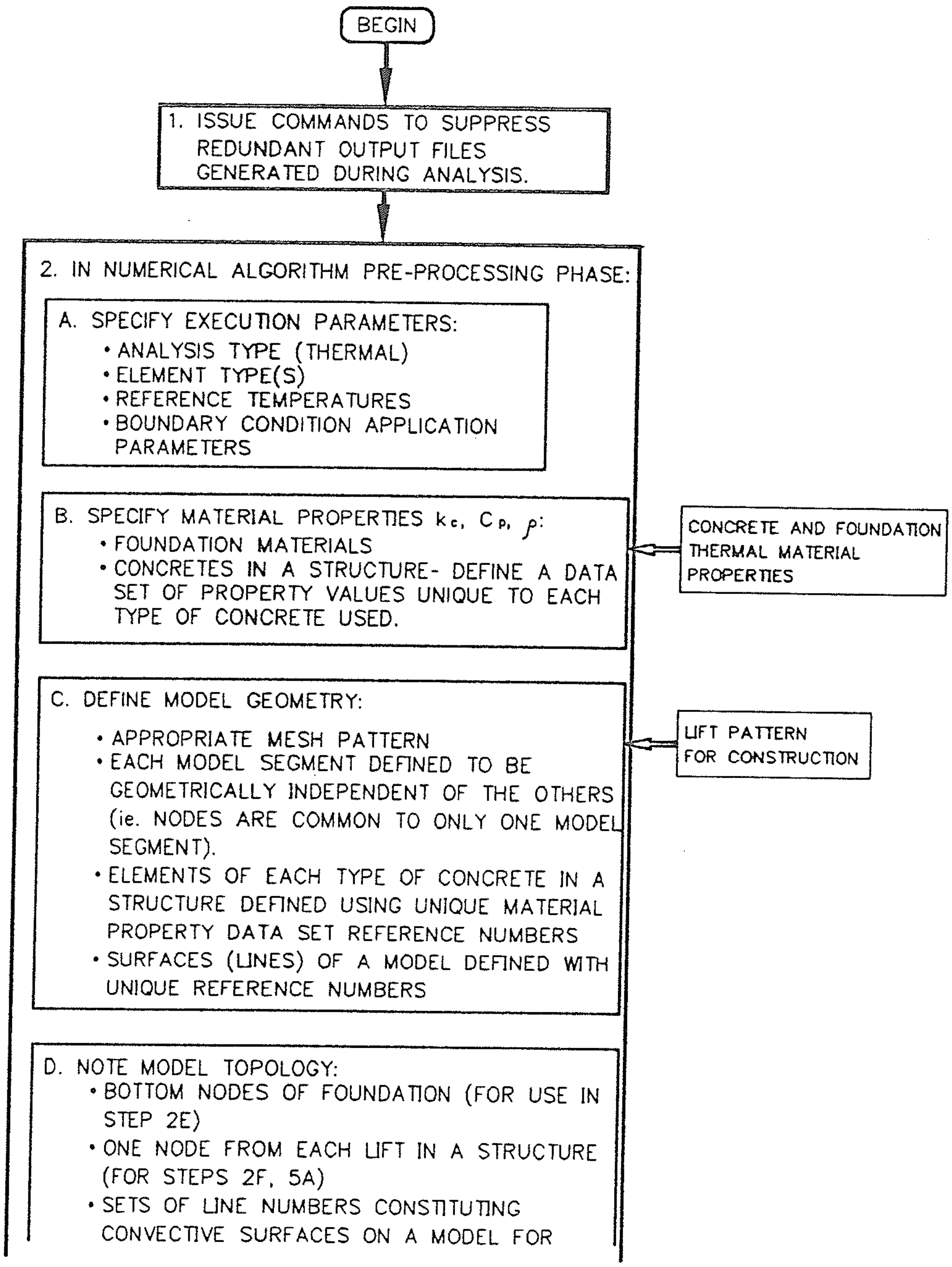

FIGURE 2 - Finite Element Modelling Algorithm for Transient Thermal Analysis of Incrementally Constructed Mass Concrete Dams (Page 1 of 4)

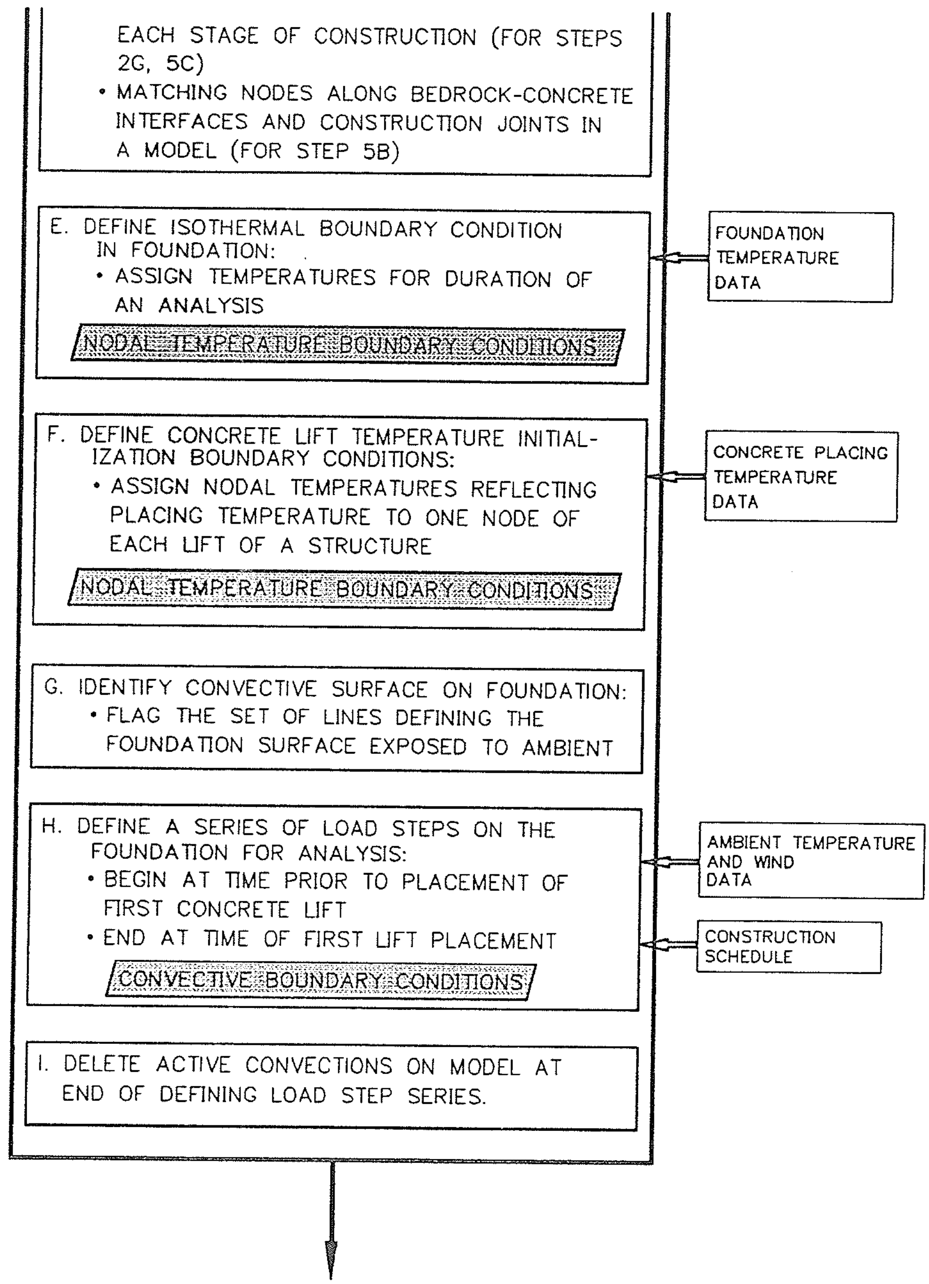

FIGURE 2 - Finite Element Modelling Algorithm for Transient Thermal Analysis of Incrementally Constructed Mass Concrete Dams (Page 2 of 4)

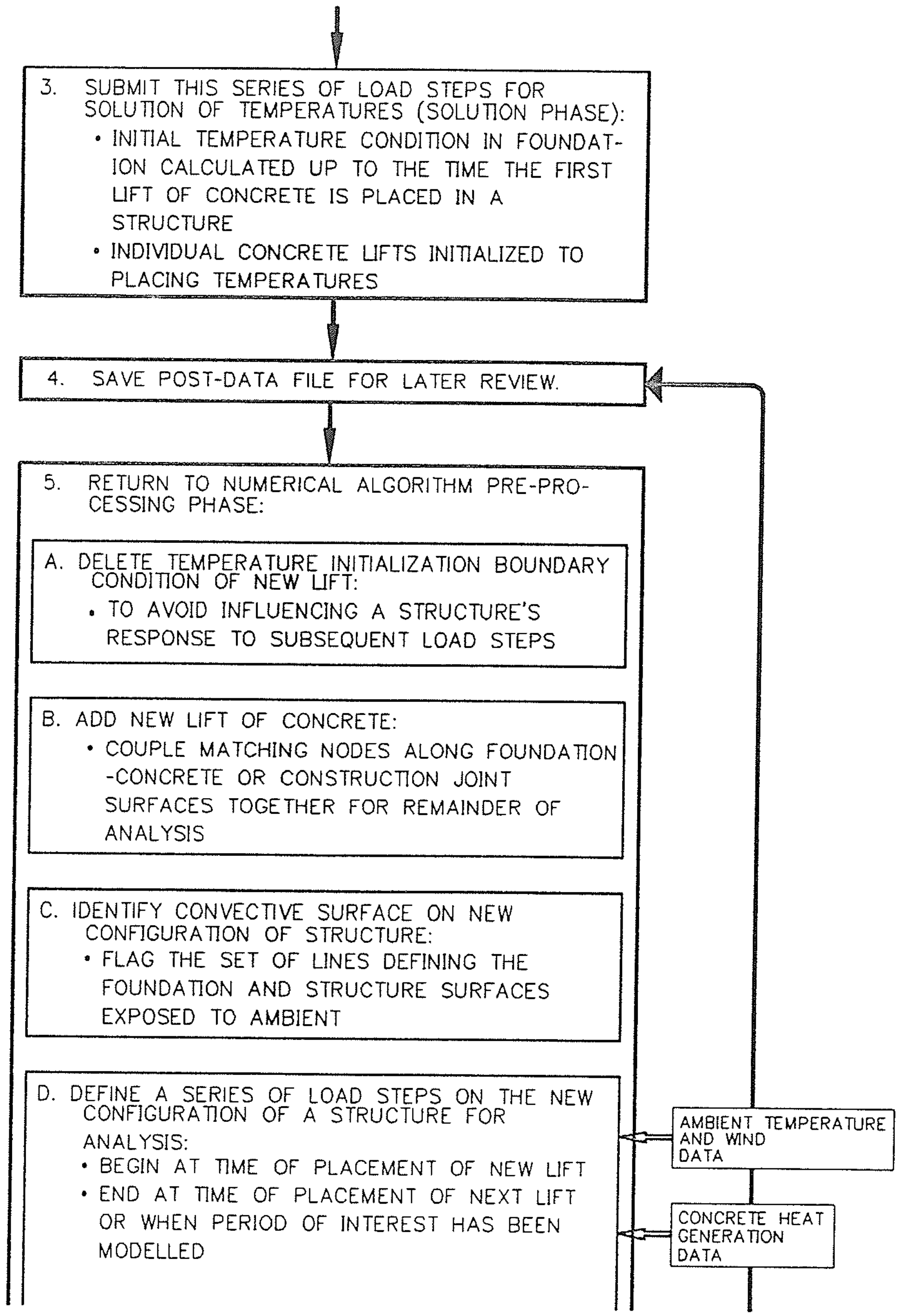

FIGURE 2 - Finite Element Modelling Algorithm for Transient Thermal Analysis of Incrementally Constructed Mass Concrete Dams (Page 3 of 4)

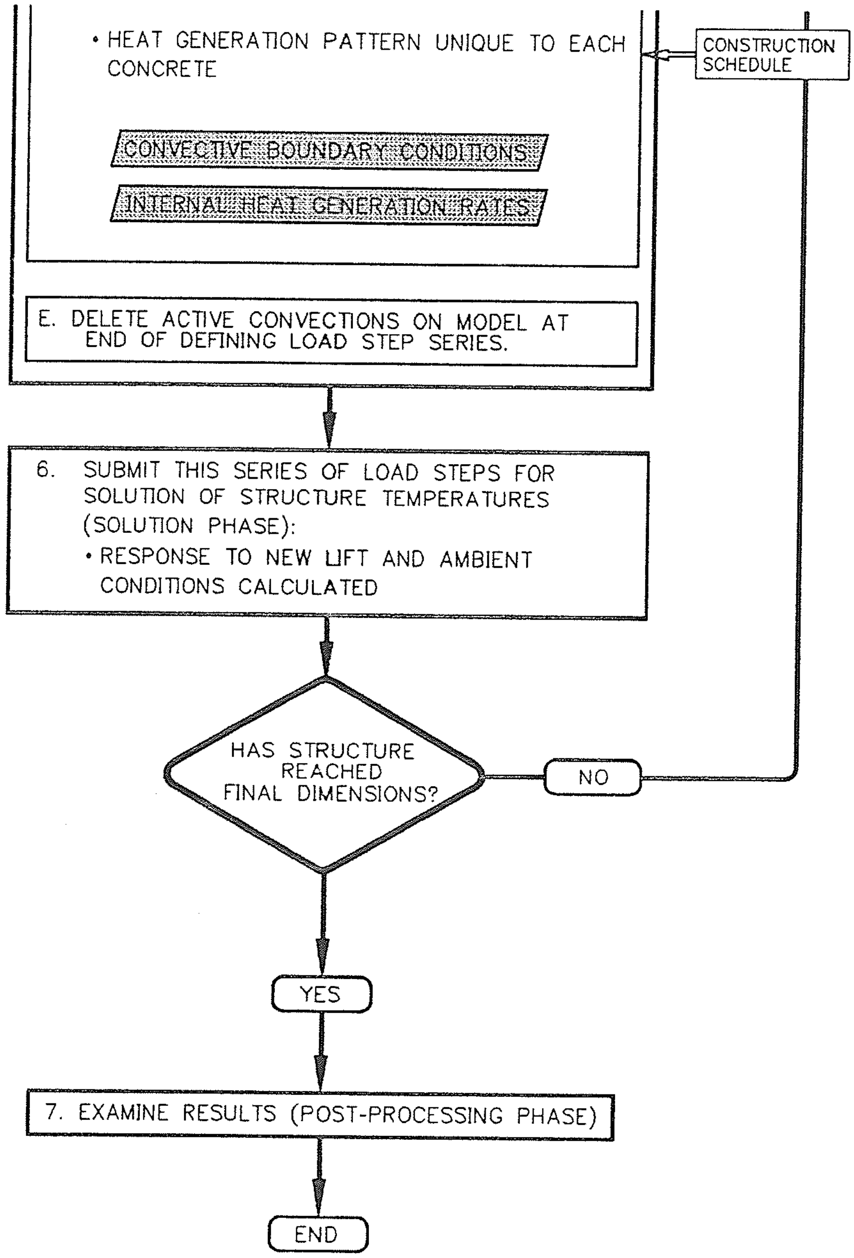

FIGURE 2 - Finite Element Modelling Algorithm for Transient Thermal Analysis of Incrementally Constructed Mass Concrete Dams (Page 4 of 4)

3.3.2 Step 2

The second step is the definition of execution parameters, material properties, model geometry, and initial boundary conditions. The boundary conditions defined in this step are those for the isothermal plane assumed in the foundation, for initializing the concrete lifts of a model to their placing temperatures, and a series of consecutive ambient convection boundary conditions that act on the exposed foundation in the time period prior to the first lift of concrete being placed. Each of these components of the second step are described as follows.

Specification of execution parameters (step 2A on Figure 2) consists of identifying the type of finite element analysis to be performed as thermal, selecting the type of element(s) to be used for a model, and setting some internal switches for application of the boundary conditions and thermal loads on the dam. More details about the internal switches are explained in Chapter 4.

The thermal material properties (step 2B) of the foundation material(s) and each different type of concrete in a dam being analyzed are defined next using either known or assumed property values. The properties needing definition for a transient thermal analysis are the conductivity coefficient k_c, specific heat C_p, and mass density ρ. Specification of material property values in the finite element program is done through the definition of an array consisting of a reference number and set of property values for the different types of materials in a model. Material properties for a dam being analyzed with the developed algorithm must be defined so that the foundation material and each type of concrete (i.e. each individual combination of strength and placing date) have unique material property data set reference numbers, regardless of whether the property values themselves are identical to other foundation materials or concretes in the dam. The reason for this is explained below.

Definition of model geometry is step 2C of the modelling algorithm. The mesh pattern adopted for each lift of concrete must be appropriate for reasonable response of a model to the applied boundary conditions and loads (particularly convections) and the time steps to be taken during execution. An essential feature of the mesh is that each segment of a model (i.e. the foundation and each lift of concrete in a dam) is defined to be "self-contained" with respect to its nodes and elements. This means that model nodes cannot belong to elements of more than one segment of a model, but nodes along bedrock and lift surfaces that concrete is placed against may be defined to have coincident locations. This independence of the finite elements of each segment of a model is important for the process of adding new lifts of concrete to a model at the time they are placed in a dam being modelled.

A component of defining model segments to be self-contained is that model "lines" bounding the various model segments are themselves identifiable by unique reference numbers. Reference numbers are assigned to lines as part of the geometry definition for a model mesh. These are later utilized as part of the process of assigning convective boundary conditions to the dam.

All elements corresponding to each foundation material and concrete type in each lift of a dam must be assigned material properties during mesh definition using one of the unique material property data set reference numbers. The reason for this is also explained below.

Once the complete model mesh has been defined, it is necessary to note the numbering of particular model nodes and lines (step 2D). Node numbers along the invert of the foundation segment of a model are required for assignment of the isothermal boundary condition, and it is necessary to know one node number from each lift of concrete in a model for assigning a nodal temperature boundary condition to initialize the temperature of each lift of concrete to its known or assumed placing temperature. Sets of line numbers used in the model geometry definition that make up exposed surfaces of a dam at each stage of construction must be noted for use in the assignment of convections at each stage of the construction process. Finally, node numbers along surfaces of a model that have concrete placed against them (i.e. foundation contacts and construction joints) are required for adding new lifts of concrete to a model, and they must be noted for use later in the algorithm.

Assignment of the initial set of boundary conditions on a dam begins with specification of temperatures for nodes along the invert of the foundation segment of a model in step 2E. This boundary condition is left in place for the duration of an analysis, reflecting the isothermal condition assumed at depth. In step 2F, individual node numbers noted from each concrete lift in a dam are used to specify nodal temperature boundary conditions reflecting the known or assumed placing temperatures for the concrete.

The final set of boundary conditions defined as part of step 2 are a series of consecutive load steps for a period of time before the first lift of concrete is placed in a dam. In a transient thermal analysis, a load step is a configuration of thermal boundary conditions and loads acting on a model at a discrete point in time. For the series of load steps acting on the foundation segment of a model, each load step consists of a convective boundary condition based on known or assumed ambient conditions. Load steps begin at a point in time that allows the temperature distribution in the foundation when the first lift of concrete is placed to reflect a reasonable transient response to the load steps defined over that time period. The load steps end at the point in time the first lift of concrete is placed.

Defining these load steps begins in step 2G with commands to flag the set of model line numbers that constitutes the exposed foundation surface. Line numbers defined as part of mesh creation for the bedrock segment of a model are used here. The set of flagged line numbers is left intact until all load steps with convections acting on this surface have been defined. The definition of a load step consists of a command to specify the time that the configuration of boundary conditions and loads acts, commands to specifying the boundary conditions and loads (in this case, a convection on the exposed foundation surface), and a command to end definition of the load step. Once all load steps are defined, the convective boundary condition is deleted from a model and all flagged lines "un-flagged" in step 2I. This is done so that a model is left without remnant convective boundary conditions and no flagged lines for the start of definition of the next series of load steps.

3.3.3 Step 3

The initial set of boundary conditions and the series of load steps acting on the foundation segment of a model are submitted for solution up to the time of the last load step specified. The transient response of the foundation temperatures is calculated up to the time the first lift of concrete is placed. The individual lifts of concrete in a dam are also initialized to their placing temperatures upon solution of the first load step, since the nodal temperature boundary condition assigned to the single node of each lift is the only boundary condition on each lift, and the lifts are numerically isolated from all other segments of a model.

3.3.4 Step 4

During execution, temperature solutions are written to a post-data file. On execution of subsequent series of load steps for other configurations of the dam while under construction, temperature solutions would be written to the same post-data file. Therefore, to avoid the solution results from being overwritten and becoming unavailable for later review, the post-data file must be saved either through being renamed or copied to another file.

3.3.5 Step 5

After solution of the series of load steps acting on the foundation, the first lift of concrete is added to a model and load steps acting on that configuration of the dam are defined. The first step to this process is the deletion of the nodal temperature boundary condition used to initialize the temperature of the first lift of concrete to its placing temperature (step 5A). This is done to remove any further influence of this boundary condition from the thermal response of the lift to subsequent applied loadings. The new lift is added to a model in step 5B by coupling degree of freedom values for nodes along the surface of the lift to corresponding nodes of model segments that the concrete is placed against. This forces the temperature values of foundation and concrete nodes along the foundation contact to have identical values for the rest of an analysis. The temperature field then becomes continuous across the boundaries of the different model segments that are coupled together.

Load steps for this configuration of the dam are specified beginning at step 5C. The set of model mesh definition lines that constitutes the exposed surface of a model with the first lift of concrete in place are flagged. Load steps of boundary conditions and thermal loads on the dam for the time period between placement of this lift and the next lift are specified next in step 5D. With concrete placed in the dam, each load step now includes rates of internal heat generation for the concrete as well as a convection to ambient conditions on the exposed surface of the dam. The internal heat generation rate is assigned to specific elements representing a type of concrete by flagging elements according to the material property data set reference number before issuing a command to specify the heat generation rate. Finally, after defining all load steps for this series, the convection on the dam surface is deleted and all lines un-flagged to set up the definition of the next series of load steps (step 5E).

3.3.6 Step 6

This series of load steps for the dam is submitted for solution of internal temperatures up to the time of the last defined load step. Temperature solutions within the dam for this time period are written to the post-data file for later reference.

Steps 4 to 6 of the analysis algorithm are repeated until the dam being analyzed has reached final dimensions or the time period of interest to the analyst has been covered. Once an analysis is complete, results can be examined through a post-processing routine utilizing the post-data files generated during an analysis.

The detailed steps of the algorithm were developed through a series of trial analysis runs using a typical "pilot model" to simulate a dam to be analyzed. This series of pilot runs is explained in detail in Appendix A.

A number of features of the finite element program make it convenient to execute several of the steps of the analysis algorithm. The next section briefly introduces the program, identifies the particular features, and describes how they are utilized.

3.4 Finite element program

The general purpose finite element engineering analysis program ANSYS is used to execute the analysis algorithm and carry out the case study to test the procedure. A very general description of the program is outlined in the following paragraphs.

3.4.1 General Capabilities

The program is capable of solving several different types of engineering analysis problems (e.g. static, modal, transient dynamic, magnetic, fluid, etc.) for linear and non-linear structures. To state the obvious, the thermal capabilities of the program are used for this work.

There are three main phases of the program that are typically utilized in defining and solving most problems: pre-processing, solution and post-processing. All three of these are used at different points in the modelling algorithm and in carrying out the case study. A brief description of the use of these phases for this work is as follows[106].

i) The pre-processing phase is where element types, material properties, model geometry, load options and configurations of boundary conditions are defined for an analysis. Steps 2 and 5 are performed using the pre-processing phase of the program.

ii) The solution phase of the program is used to assemble and solve the simultaneous equations (according to what was defined in the pre-processing phase) to advance the solution in time. A frontal equation solver is used to simultaneously assemble and solve the global set of simultaneous equations[107]. The process includes back substitution to determine the values of the degrees of freedom of the problem. This is done in steps 3 and 6.

iii) Finally, the post-processing phase is used to examine particular items from the set of full analysis results. Plots can be created of analysis results over time or at discrete points in time in the transient analysis. Step 7 utilizes the program's post-processing capabilities.

The thermal capabilities of the program allow for conduction, convection and radiation to take place within a model. There are 14 different element types whose sole degree of freedom is temperature that are available to be used in carrying out a thermal analysis. Of these, six are two-dimensional elements. Use of non-linear (i.e. temperature dependent) and non-isotropic material properties are possible in the program, as are the effects of phase changes.

Thermal boundary conditions that can be specified are nodal temperatures, heat flow rates, convections and heat generation rates[108]. Either specified temperatures, heat flow rates, or convections can be specified on a model boundary. The program allows the deletion of boundary conditions at intermediate points within an analysis.

A transient thermal analysis can have an unlimited number of load steps defined through time for which solutions can be calculated. Within each defined load step, solutions of the problem can be computed at intermediate points in time between the current and the preceding load steps. These solutions are known as "iterations". The use of iterations in the modelling algorithm is described in Chapter 4.

Examining the results of a transient thermal analysis can be done with two different post-processing phases of the program. The first, POST1, allows for result listings, displays, and mathematical operations to be carried out at discrete points in time of an analysis. The other, POST26, allows for listings and displays of results as they vary over time for an analysis.

In order to ensure reliability of the finite element program, a progressive series of six simple one-dimensional thermal problems were solved analytically and by the finite element method using ANSYS, and the solutions compared. These problems are described in Appendix B.

3.4.2 Features Utilized in the Algorithm

This finite element program includes many features that make defining, solving and examining results for finite element analyses convenient. Briefly, the particular features utilized in the developed algorithm are as follows.

3.4.2.1 Solid Modelling

The "solid modelling" capabilities of the program allow for automated generation and numbering of model nodes, elements, line segments, etc. needed for a model mesh. Included in the model geometry definition process is assignment of material properties and element types through the use of unique data set reference numbers. These details for model definition are utilized for the assignment of boundary conditions in defining load steps on a dam in steps 2H and 5D.

It is not necessary to specify units of measurement anywhere in the material property or loading details for an analysis, as the program assumes the use of a consistent set of units by the analyst.

3.4.2.2 Element Type

This work uses the two-dimensional, isoparametric, four-node quadrilateral thermal solid element (ANSYS STIF55). The element has the ability to have an assigned average internal heat generation rate, and all element surfaces have convection capabilities.

3.4.2.3 Selection Capabilities

The finite element program has model attribute selection capabilities that allow the user to flag subsets of full model populations of various components for particular modelling operations. For example, sets of lines within a model are selected for assignment of convective boundary conditions in steps 2G and 5C, and material property reference numbers are used to select specific elements of a model to specify internal heat generation rates in each load step in step 5D. It is possible to modify the particular set of model attributes that are flagged if required. This is done at various points in time in the modelling algorithm to account for changing model geometry and other effects (steps 2I, 5D and 5E).

3.4.2.4 Load Step and Iteration Controls

The finite element program's allowance of an unlimited number of load steps and the ability to control the number of iterations to be executed for each load step are utilized in different ways in the modelling algorithm as described in Chapter 4. The first load step of an analysis is solved as a steady state problem according to defined boundary conditions at that load step. Subsequent load steps have varying numbers of iterations according to the requirements of the process being modelled. All load steps and iteration solutions after the first of an analysis include the transient effects of the various boundary conditions defined for the load steps.

3.4.2.5 Deletion of Boundary Conditions

The algorithm allows for the deletion of boundary conditions at certain times during an analysis, and this is utilized in steps 2I and 5E to account for varying model geometry with the addition of new lifts of concrete to a dam.

3.4.2.6 Coupling of Degree of Freedom Values

It is possible with the finite element program to specify the value of a particular degree of freedom in a model to be a function of another degree of freedom elsewhere in a model. This capability is used in the coupling operation of step 5B as part of the process of adding new lifts of concrete to a dam for further analysis. Coupled nodal temperature values are forced to be identical but can respond to additional applied loads in the rest of an analysis. This degree of freedom coupling capability forms the basis for the algorithm being able to produce results that are cumulative throughout an incremental analysis.

3.4.2.7 Analysis Restarts

Restarting an analysis for additional load steps after temporarily halting execution at a particular point in time in a transient problem is possible with the program. This feature is also utilized as part of adding new lifts of concrete to a model for further analysis.

3.4.2.8 Adiabatic Surfaces

It is convenient that the finite element program numerically treats surfaces without specified boundary conditions as adiabatic. An adiabatic surface has no heat flow across it. This is used for vertical surfaces of the foundation segment of a model, and as a means of reflecting an assumed insulating effect of earthfill placed against a dam during construction.

3.4.2.9 Ramping of Boundary Condition Parameters

Boundary conditions for the solution of iterations between load steps can be interpolated or "ramped" between the two defined sets of conditions for the load steps. This is also a convenient feature for this type of analysis as it is utilized to simulate an assumed continuous change in ambient weather conditions from one day to another as part of convective boundary conditions, and the continuously varying rates of internal heat generation. This feature determines some of the command details of adding a new lift of concrete to the active portion of a model.

3.4.2.10 Post-Data Control

The algorithm allows the user detailed control over which results obtained from iteration and load step solutions of an analysis are written to the cumulative results file. This capability is used to manage the total memory requirements necessary for execution of an analysis by reducing the number of iteration and load step solutions that are written to the post-data file.

Detailed procedures for the proper definition of a finite element model to carry out a thermal analysis of a dam using the algorithm are outlined in Chapter 4.

4 MODEL FORMULATION

Formulation of a model of a mass concrete dam using the developed algorithm involves special consideration of many components of the modelling process. This chapter is a detailed description of the components that require attention in order for the algorithm to provide useful results.

4.1 Assumptions and Simplifications

It is not possible to carry out an analysis of this type without assumptions to simplify the work. The following sections describe the assumptions and simplifications involved in the algorithm for analyzing a dam.

4.1.1 Material properties

It is necessary in defining an analysis to assume values for the thermal properties k_c, ρ and C_p of the materials in a model. The finite element program is capable of incorporating temperature dependent (i.e. non-linear) material properties in the solution procedures. In this algorithm, it has been assumed that the thermal properties of the constituent materials are constant with time and temperature and are isotropic. Furthermore, concrete property values in the case study have had no direct account taken of any particular mix additives, and they are assumed to be the same for all types of concretes used in the structure. This is not quite correct, as concrete properties typically vary to a degree depending on mix ingredients and proportioning.

It is important that actual values of material properties be used where available from material-specific laboratory test results, since there can be some range in values according to the characteristics of the materials[109]. Should properties for site-specific materials not be available, what are felt to be representative values (i.e. values for materials closest to those known to be used in construction of a dam being studied) should be used. It must then be remembered that some degree of variation in the true behaviour of a dam from the results of an analysis is likely to occur.

It must be ensured that whatever form the units for the material property values take, that they are uniform and consistent throughout for correct use in the finite element program.

4.1.2 Structure Geometry

The algorithm is based upon adoption of a two-dimensional analysis of a dam. This simplifies the modelling effort and reduces computer resources necessary to carry out an analysis when prediction of the behaviour being investigated is not unreasonably compromised. Of course, an error is introduced with a two-dimensional analysis for three-dimensional behaviour.

4.1.2.1 Foundation

It would usually be required to make assumptions, to some extent, about the geometry of the foundation material beneath a dam, especially if it is an excavated bedrock surface. This is done as part of the case study to test the algorithm. Foundation surfaces may not get constructed as designed due to inherent variations in the material found in the field when construction work is carried out. Furthermore, the in situ foundation geometry may never be recorded in great detail once excavation is completed. For these reasons it would usually be necessary to simplify the foundation geometry into a set of straight lines.

As part of defining the foundation geometry, horizontal and vertical limits to the extent of the foundation material included in a model must be adopted. The vertical limit has an assumed isothermal boundary condition assigned to it, and thus must be set at a depth that makes such a boundary condition reasonable. The horizontal limits must be set such that the thermal behaviour of the dam being modelled is not unreasonably affected by the adopted foundation boundaries, but also so that the scope of the model geometry does not become impractical. The vertical surfaces of the foundation segment are assumed to be left without any assigned boundary conditions, and therefore are treated numerically as adiabatic surfaces. This is a reasonable assumption for such surfaces in this kind of model.

4.1.2.2 Concrete

If construction procedures require several small preliminary lifts at the beginning of the placing sequence before a standard lift thickness can be adopted, it may be necessary to combine some or all of the preliminary lifts into a single lift in a finite element model. This is a reasonable simplification if the extent of the preliminary lifts cannot be predicted until construction of the foundation surfaces is completed, or the preliminary lifts are not well defined from when a dam was built. With this kind of assumption is likely to be some element of a three-dimensional effect, since not all preliminary lifts may coincide with the location of the plane of a two-dimensional model. It is possible that the algorithm could be used to specifically examine the effects of preliminary lifts on the temperatures inside a dam early in the construction process. In this case, the geometry of these initial lifts could be assumed to be something comparable to what may be encountered in the field.

There may be several different types of concrete used in the construction of a dam being modelled. In reality, the exact locations of the particular mixes will vary somewhat from designed locations because of placing methods used during construction. The line of separation between different concrete types in a lift will never be straight. Therefore, it is necessary to assume idealized locations within the various lifts of concrete in a dam for where the different concrete mixes are in place.

4.1.3 Internal Heat Generation Rates

Because of variations in cement characteristics and the variety of types of coarse and fine aggregates, there is a range to the patterns of internal heat generation rates for mass concretes. Strictly speaking, the heat generated in concrete due to cement hydration is a function of both time since batching and the prevailing temperature at the location within the concrete. For this work, the heat generation rate patterns have been assumed to be a function of time only, and do not include consideration of the temperature in the concrete either initially or during the time period of heat generation. This is a conventional assumption made in these types of thermal studies.

The form of equation used in the algorithm as a basis for internal heat generation rates is that shown as Equation 10 in Chapter 2. It is repeated here:

$$T(t) = K\left(1 - e^{-\alpha t}\right) . \tag{15}$$

Adoption of this equation as a basis for developing internal heat generation rates automatically assumes that use of an adiabatic function of temperature rise is a reasonable means of describing this function for modelling mass concrete dams. Because the equation describes the total temperature rise over time within a concrete under adiabatic conditions, it must be modified into a form giving the unit rate of heat generation under adiabatic conditions. This is done by multiplying by $(C_p \cdot \rho)$ to get the total amount of heat generated per unit volume,

$$Q(t) = C_p \rho T(t) = K C_p \rho \left(1 - e^{-\alpha t}\right) \tag{16}$$

and then differentiating with respect to time to get the rate of heat generation:

$$R(t) = \frac{\partial Q}{\partial t} = \alpha K C_p \rho e^{-\alpha t} . \tag{17}$$

This is the form of equation assumed in the algorithm for estimation of the internal heat generation rates for concretes placed during the construction of a dam. With the presence of C_p and ρ in the equation, it becomes important for the realistic specification of this function that actual property values for particular concretes of a dam be used if they are available. Therefore, accurate modelling requirements may justify a laboratory testing program specifically to obtain thermal material property values and heat generation data for use in an analysis.

The finite element program requires that an internal heat generation rate be specifically deleted when it is no longer needed as a load on a model. Thus in the definition of load steps in the algorithm, the internal heat generation rate load for a concrete must be deleted once the equation describing the rate of heat generation reaches a point in time where $R = 0$.

4.1.4 Boundary Conditions

It would not be possible to avoid assumptions associated with defining the boundary conditions for an analysis. Several have been made specifically for this work, and they are described below.

4.1.4.1 Radiation

For convenience purposes, the effects of radiation as a transfer mechanism for thermal energy has been neglected in the algorithm. There are no solar effects, no account of clouds, hours of sunlight, and so on included. The decision to include or exclude radiation in an analysis would depend on the degree to which this type of boundary condition was felt to contribute to the early thermal behaviour of a dam. It is possible that some studies of mass concrete dams would require inclusion of this type of boundary condition in the thermal loading applied. If this was the case, actual data from the site of a dam should be utilized in defining the loading.

4.1.4.2 Specified Temperatures

There are two forms of specified temperature boundary conditions utilized in the algorithm. The first is the assignment of the constant, uniform temperature at depth in the foundation of a model to simulate an isothermal condition. For this assumed condition to as realistic as possible, the temperature value used should be reflective of a foundation's long term mean temperature at depth, and should remain assigned to the bottom nodes of a model throughout an analysis.

The second use of specified temperatures is for the initialization of each lift of concrete making up a dam to its placing temperature for the instant that each lift is added, or placed, to a model. This boundary condition ensures that each concrete lift begins its thermal response to applied loadings at a suitable initial temperature condition. The boundary condition is deleted as part of the process of adding a new lift to a model to allow free response of nodes in a lift to the forcing functions and boundary conditions of an analysis in subsequent load steps. This lift initialization creates the assumption that each entire lift of a dam starts its thermal behaviour at the temperature value used to reflect the average placing temperature. In reality, the concrete placing temperature is likely to vary within a lift due to the weather and construction factors such as equipment capabilities and performance, other placing operations ongoing at a project site, etc. As well, since placement of concrete for one lift can proceed over several hours or even days, and since internal heat generation begins when the concrete is batched, this temperature initialization assumes each entire lift begins thermal response at a single discrete point in time in an analysis. This is, of course, not the case in prototype dams.

4.1.4.3 Convective and Adiabatic Surfaces

For this work, there have been several simplifications made in the specification of convective boundary conditions on exposed portions of a dam in an analysis. The first is that the insulating effect of formwork on concrete is ignored. As well, the influence of concrete curing procedures on the rate of heat loss from concrete surfaces is neglected. In reality, the extent and effect of curing may not be well known in advance or be suitably documented in project records. The insulating effect of snow on the top or against the sides of a dam is neglected altogether as this condition is difficult to define or is even unknown during the construction of a dam.

No convections are specified along the vertical edges of the foundation segment of a model in this algorithm, since this would not be a realistic condition for these surfaces. Thus, these boundaries are assumed to be and are numerically treated as adiabatic surfaces.

While loading the dam during the time when it has not reached final dimensions and thermal service conditions, some assumptions are likely necessary to define the extent of a model exposed to the prevailing convective boundary conditions for each load step. This is particularly necessary when construction of the dam involves placement of earthfill materials against the concrete. The top portion of a model exposed to a convection is easy to identify as it is simply the top surface of the most recently placed lift of concrete. Should ongoing earthfill placement be involved in the construction process, the algorithm requires an assumed average earthfill elevation reached for each time span covered by a series of load steps applied to a model. If available, information on earthfill progress through time at the locations of all faces of a dam should be utilized for identifying the exposed portion of concrete in a model. Selection of model lines making up the exposed concrete surfaces of a dam for assignment of convections (lines above the assumed level of earthfill) leaves unselected lines as being assumed to act as adiabatic surfaces. The earthfill material is therefore assumed to be a perfect insulator. The extent of the error introduced with this assumption will vary with the fill material used in construction of a dam. For example, the assumption is more reasonable for impervious materials, but less so for granular or rockfill materials.

Another assumption made in this work is that it is reasonable to utilize daily median air temperatures at a project site as the fluid temperature for the assigned convective boundary conditions. If warranted, the level of detail of the convections could be increased such that both the daily low and high temperatures, or even temperatures in between, could be used in separate load steps to define the convective boundary conditions. It is possible with the finite element program to specify convections in as fine a detail as desired. By using only the daily median temperature, it is assumed that the ambient convective conditions acting on a dam can be adequately simulated in a model through use of this one daily temperature value.

The value of the convection coefficient h_c is assumed to be reasonably determined through the use of an empirical equation relating h_c and a wind speed value[110]. The relationship is of the form

$$h_c = h_n + h_f \tag{18}$$

where, for concrete surfaces, the average value of h_n can be taken as $h_n = 6\ W/(m^2 \cdot {}^\circ C)$, and the value of h_f is related to the wind speed v approximately as $h_f = 3.7\ v$ (v in units of m/sec). For increased accuracy of an analysis, wind data specific to a project site should be utilized here. It is assumed in the algorithm that the equation can be applied to bedrock foundation surfaces as well.

The case study utilizes the daily average wind speed in calculating a value of h_c that is assumed to apply uniformly for an entire day's convective heat losses. This implies that the convection coefficient for heat loss from a dam's surfaces is constant for the span of time covered by each load step. It is further assumed that the calculated value of h_c applies equally well to all exposed surfaces of a model - vertical, horizontal or sloping - and that wind direction has no effect on the value of h_c, as it has been neglected in the algorithm. Also ignored is any effect neighbouring structures at a project site may have on either sheltering or channelling wind on a dam being studied.

It is possible that some of these assumptions and simplifications for convective boundary conditions could be eliminated through more rigorous treatment of convections in a more detailed version of this algorithm.

4.1.4.4 Load Steps

The pattern of load steps assumed in the modelling algorithm directly affects the level of detail in the thermal loading on a model of a mass concrete dam. A complete analysis requires a number of series of consecutive load steps to define the forcing functions and thermal boundary conditions acting on a dam through the time span of interest to the analyst. A load step may consist of any combination of internal heat generation rates and boundary conditions including specified nodal temperatures, convections, and heat flow rates. The following paragraphs describe the assumptions and simplifications involved in specifying load steps to carry out an analysis using the algorithm. A conceptual presentation of load step and iteration use in the algorithm is shown as Figure 3.

The first load step in an analysis is for a single iteration and is at a specified time of 0.0 time units. Using a time value of 0.0 causes the finite element program to calculate a steady state solution according to the boundary conditions in effect for the load step. A different starting procedure not suitable for beginning an analysis of this type would be followed should the time value be greater than 0.0.

The first load step must include the lift initializing nodal temperature boundary conditions. Including these as part of the first load step causes all nodes in a lift to adopt the assumed placing temperature value since the nodal temperature boundary condition is the only thermal load on each lift of concrete for this load step.

Remaining load steps in an analysis are defined sequentially at discrete points in time after the start time of the analysis. In this algorithm, it is assumed that the first series of load steps are those that apply thermal loads to the foundation of a dam prior to any lifts of concrete being placed. The particular time span to be covered with these

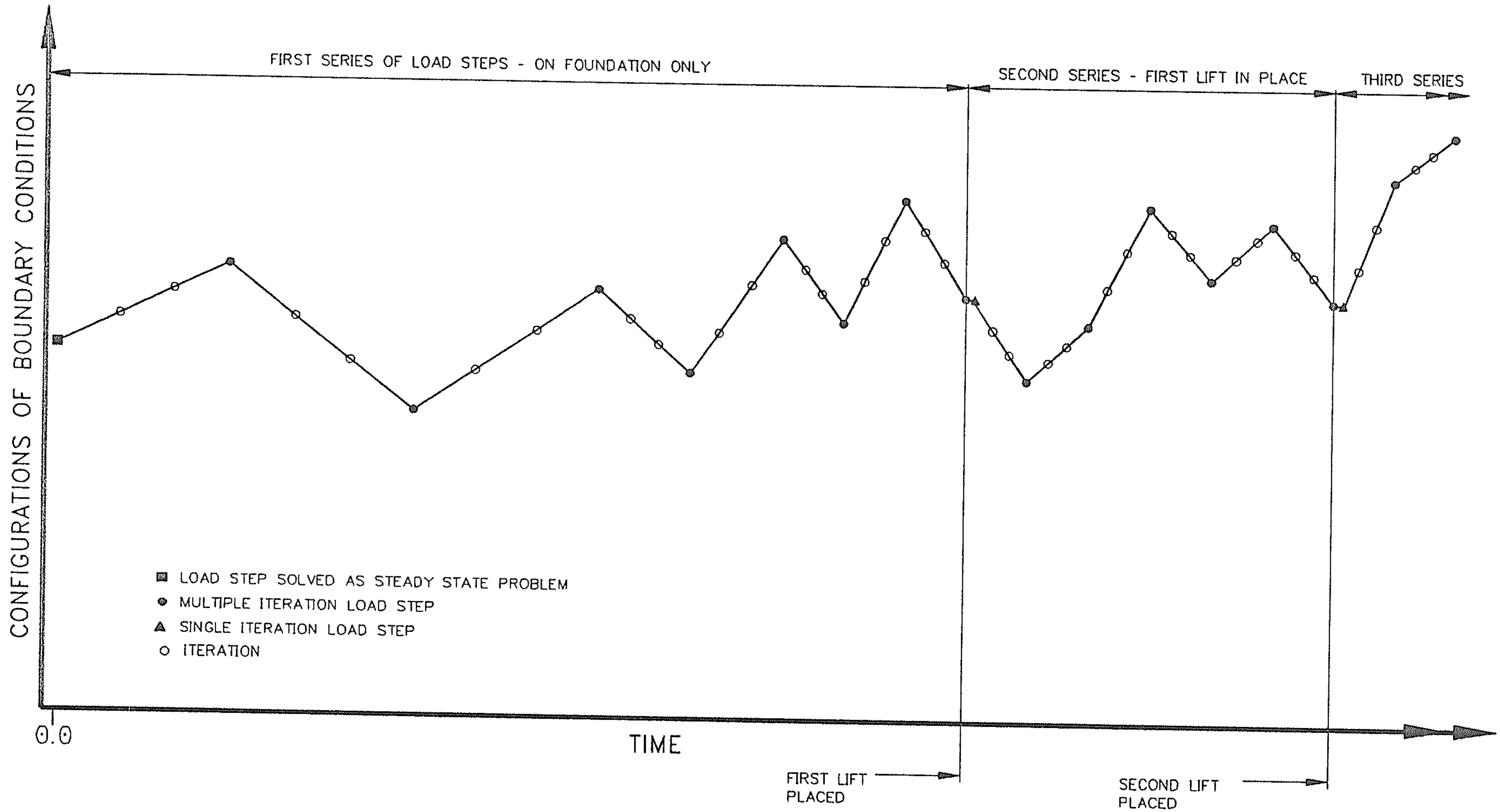

FIGURE 3 - Conceptual Presentation of Load Step and Iteration Pattern for Developed Incremental Thermal Modelling Algorithm

load steps depends on the construction sequence being modelled. Two factors to be considered in selecting a time frame are the timing of foundation construction and the pattern of ambient weather conditions at the site of a dam. The total number of load steps used in carrying out foundation loading can be reduced by adopting a pattern of varying time intervals between specified load steps. The pattern used would depend on the construction conditions of a modelled dam, the level of detail required from the modelling process, and the computational resources available. Engineering judgement is required to come up with an approach that produces reasonable results.

Once concrete placement begins and thermal activity in a structure is most intense, the algorithm utilizes a uniform time spacing of the load steps. The particular spacing adopted for a dam should account for the intensity of the applied thermal loads, and the same factors as are considered in determining the time intervals between load steps on the foundation. Again, engineering judgement is required to determine a sensible approach to the load step pattern.

The algorithm requires that load steps on a dam be defined in sets, where each set begins at the time a lift is placed and continues to the point in time that the next lift is added to a model. The geometry of a model is thus constant through the time covered by a series of load steps. Solution of the problem is stopped at points in time corresponding to when lifts are placed so that commands necessary for a new lift to be incorporated into a model can be executed. The analysis is then restarted with the new lift in place for the next series of load steps.

For an application of the modelling algorithm where the period of interest of thermal behaviour extends beyond the times of lift placement and intense thermal activity due to heat of hydration, a time stepping pattern that uses increased time intervals between load steps may be re-adopted. This decision once again requires engineering judgement to determine a reasonable pattern, and should take account of the objectives of an analysis being carried out.

4.1.4.5 Iterations

The finite element program can be told to compute a single solution of the assigned boundary conditions at the time specified for each load step in an analysis, or it can be made to calculate intermediate iteration solutions at times between load steps, as well as the solution at the specified time of a load step. Both single and multiple iteration solutions for load steps are used in the developed algorithm.

The single iteration per load step approach to solutions of model temperatures must be used in two instances. One already described is that for the first load step in an analysis to accommodate a steady state solution. The second use is for the first load step defined immediately after a new lift of concrete is added to a model. This is done for the following reason.

It is reasonable for the types of thermal loads involved in this kind of analysis to assume that internal heat generation rates and boundary condition parameters change linearly between load steps. This can be imagined as reflecting continuous changes in ambient temperatures and the rates of internal heat generation of the concrete. The modelling algorithm thus incorporates the interpolation of boundary condition parameters for iterations solved between load steps. For this to occur properly, solution of each load step requires the previous load step's boundary condition parameter values. When execution of an analysis is restarted after the addition of a new lift of concrete, the program uses zero as one of the interpolation points should more than one iteration be specified for the first load step after the restart. To avoid this inconsistency with the other load steps of an analysis, the first load step after a restart must be specified to be for one iteration only. The load step must include the same internal heat generation rates and boundary conditions as were specified for the last load step before an analysis was suspended, as well as any new heat generation rates that come with the new lift of concrete in a model. The convection to ambient conditions should be applied to the new configuration of exposed surfaces to account for the new model geometry. Intermediate iterations of the second load step after the restart will then interpolate properly between values of boundary condition parameters. The finite element program does not interpolate the value of the convection coefficient h_c for iterations between load steps, but rather uses the specified value for the load step for all intermediate iterations as well.

There are also particular requirements for the value of time specified for the first load step after restarting an analysis. Since this load step must incorporate internal heat generation rates and boundary conditions from the last load step before suspending execution to add a new lift, it is most realistic to set the value of time to the same value used in the last load step before execution was stopped. However, the finite element program would then solve this first load step as a steady state problem (see Appendix A) and lose the temperature patterns calculated to that point in an analysis. This is avoided in the algorithm by assuming a time for this load step that is slightly greater than the time of the last load step before execution was suspended. This way, the error introduced by not using the same time as the last load step is minimized and analysis results are cumulative through the restarting procedure. More details about the assumptions and procedures of adding new lifts of concrete to a model are explained in the next section.

Multiple iterations can be used for all other load steps in the algorithm. The number of iterations per load step in an analysis is ultimately determined by engineering judgement. Factors involved in determining a number to use include the behaviour being modelled, the number of load steps and time interval between them, the degree of accuracy desired of the solution, and the available computer resources to carry out an analysis.

To reduce solution time for transient or non-linear problems, the finite element program has a time-step optimization capability that can be used to minimize the number of iterations for each load step according to user-specified parameters. The routine is not activated in the algorithm, however, since the nature of this problem - analyzing a dam through a given time span with known or assumed configurations of internal heat generation rates and boundary conditions (e.g. ambient temperatures) - makes it desirable to calculate solutions at regularly spaced, discrete points in time rather than letting the program increase the time steps during periods of reduced thermal activity in a model.

4.1.5 New Lifts of Concrete

Between each set of load steps making up an analysis, the commands to add a new lift of concrete to a model are executed. There are several simplifications and assumptions involved with this process as well. They are described in the next few paragraphs.

The steps to include a new concrete lift in a model take place at a single, discrete point in time in an analysis. This creates the assumption that a model's placing operation for the concrete of that lift takes place instantaneously, where in reality placement may proceed over several hours or even days should the lifts of a dam be so large. It is thus necessary when defining an analysis to select discrete points in time to be used as the assumed placing time for each lift.

If desired, the geometry of individual concrete lifts in a dam could be defined in multiple segments that could be added to a model in a pattern that simulates the progress of the placing operations. However, this would involve a more tedious model definition and analysis, but would be possible to carry out, if required.

The operation at the heart of the process to add a new lift of concrete to a model is coupling of the temperature degree of freedom values of nodes on the edges of the lift being added to those of the supporting material for that lift in a model. Coupled nodes are free to respond to the various internal heat generation rates and boundary conditions applied to a dam in subsequent load steps, but they are just forced to have identical values for the rest of an analysis. This is reasonable behaviour to impose on interface nodes of a model since it is similar to what occurs in reality when new concrete is placed on top of another material. In following the modelling algorithm, it is assumed that node numbers for nodes along coupled surfaces of a model are known in advance of specifying the commands for an analysis. This is necessary so that the coupling of nodes can take place using proper sets of node numbers.

Upon execution of a coupling command, the finite element program assigns the nodes being coupled a temperature value equal to the average of the temperature values of the nodes immediately before the coupling operation (again, refer to Appendix A). This procedure duplicates what can be assumed to occur in reality when concretes at different temperatures are connected. This is convenient for the modelling algorithm since it replaces what would have been assumed in the behaviour of the nodal temperatures upon coupling had the command not worked this way.

4.2 Finite Element Model Definition

There are several features of the finite element mesh that are required for the algorithm to be implemented properly. The following sections describe these requirements.

4.2.1 Geometrically Independent Model Components

It is essential for the developed algorithm that the finite element model of a dam being analyzed has the foundation material and each lift of concrete making up the dam defined such that each is geometrically independent of the others. That is, all nodes in a model are common to finite elements in only one segment of a modelled dam. Nodes along surfaces of a model at locations of construction joints or foundation interfaces can be coincident, however. Since these nodes do not belong to elements in more than one model segment, there is no interaction between segments until the coupling of nodal degree of freedom values takes place at the time corresponding to placement of the lifts in a model.

This geometrical independence and the coupling operation is what permits the applied boundary conditions to act on only a portion of the total number of segments that make up a model of a mass concrete dam.

4.2.2 Mesh Pattern

The mesh pattern used in a model must be suited to the boundary conditions that are applied in carrying out an analysis. In this algorithm, nodal temperature boundary conditions are minor considerations in selecting a mesh pattern because of their particular role in an analysis (bottom nodes of the foundation portion of a model and lift temperature initializations). The mesh pattern is therefore created primarily to accommodate responses to applied convective boundary conditions and the coupling operations for adding new lifts of concrete, with consideration of the suitability for internal heat generation rates as well. A part of this, of course, is the additional factor of an analysis being transient, and the time steps taken between solutions of temperatures in a model.

4.2.2.1 Surfaces Exposed to Convections

The basis for developing the mesh pattern is an equation presented by the finite element program authors that is recommended as a guideline to matching minimum element sizes for areas where the greatest thermal gradient acts and the time steps for solution of transient problems[111]. The equation is of the form

$$ITS = \frac{\delta^2}{4\alpha} \tag{19}$$

where *ITS* is the integration time step, δ is the conducting length of an element in the area where the largest gradient acts and, in this case, α is the thermal diffusivity of the material. The equation is therefore used here to relate the size of elements adjacent to ambiently exposed surfaces in a model and the time steps taken between iteration solutions. Both temporarily exposed surfaces, such as the top of lifts that get poured-back, and permanently exposed surfaces are treated equally for this algorithm.

Selecting an element size and corresponding *ITS* value again requires an account of the intensity of applied boundary conditions, the detail of behaviour sought in an analysis, and the computer resources available to solve the problem. Engineering judgement is needed to select a reasonable combination of values.

Once a time step and minimum element size is selected, the complexity of a mesh can be simplified by adopting an element pattern that decreases in density as the distance

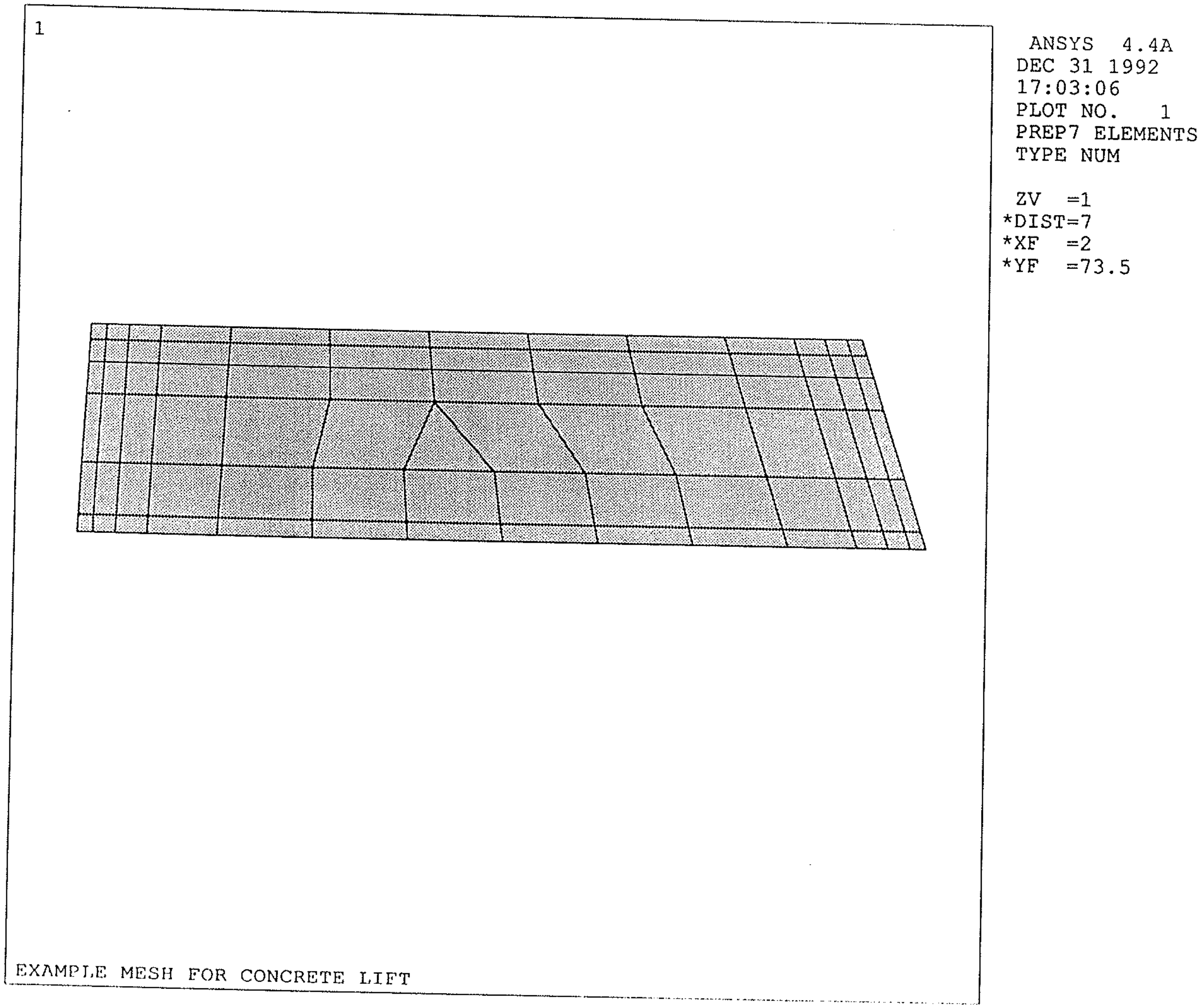

FIGURE 4 - Example Finite Element Mesh for a Lift of Concrete for the Developed Algorithm

from exposed surfaces on a model increases. The element size at the exposed surfaces would be that given by the above equation. An example pattern for a 3 m thick concrete lift exposed on three sides is shown in Figure 4. The mesh pattern is capable of accommodating the convective boundary conditions applied to model surfaces during an analysis period but also reduces the total number of elements in a model. The element pattern along exposed surfaces of a model is especially important for cases where severe ambient conditions may act on a dam being modelled.

If an analysis being undertaken warrants, the analyst may carry out an exercise to compare finite element solutions to a problem using a variety of element mesh patterns to solutions obtained by analytical means. A problem that could be used is a semi-infinite solid convectively exposed to either a step change or periodic variation in fluid temperature. The pattern that produces the minimum error in the solution can be adopted for the exposed surfaces of a mass concrete model.

4.2.2.2 Surfaces for Coupling

A new lift of concrete in a model may have an initial temperature quite different from that of the surface nodes of the supporting materials, and the materials may therefore experience a thermal shock upon placement. Where the surface of one of the materials has previously been exposed to ambient convections and thus has had a mesh defined according to those requirements, the mesh pattern is assumed to be adequate to respond to the nodal temperature coupling during placement of a new lift. Surfaces that have not previously been exposed to ambient convections require a similar but less acute mesh pattern to that of convectively exposed surfaces. The bottom surface of the material shown in Figure 4 is an example of a mesh for this purpose. The exact mesh adopted again requires engineering judgement to select a pattern suitable for the problem being examined.

The corresponding nodes of different segments of a model that lie along a surface to be coupled must have identical locations. This ensures that the coupling operation between nodes of a new lift and those in supporting segments of a model is realistic in that coupled nodes are at common geometrical locations. This applies to both foundation and concrete nodal patterns.

4.2.3 Provisions for Assignment of Thermal Loads

It is assumed in the algorithm that the finite element model of a dam is defined using the finite element program's solid modelling capabilities. The mesh for a model is automatically generated according to particular "keypoints", model line segments, two-dimensional areas bounded by keypoints or line segments, material property data sets and so on, all as defined by the analyst. These items are assigned unique reference numbers during mesh definition that make specifying the internal heat generation rates and boundary conditions in the load steps of an analysis extremely convenient. The next sections describe requirements of the finite element model for assignment of the thermal loads in the algorithm.

4.2.3.1 Specified Temperatures

Specific node and element numbers of a finite element model can be used for the assignment of thermal loads in an analysis. Node numbers are used in two instances in the algorithm. The first is to assign the isothermal boundary condition to nodes in the foundation segment of a model, and the second is the use of a single specific node number from each concrete lift for the placing temperature boundary condition as described in Section 4.1.4.2. All other thermal loads are assigned through the use of the solid modelling parameter reference numbers as follows.

4.2.3.2 Convections

Line numbers from the mesh definition for a model are used in the process of defining convections on exposed surfaces of a dam. Immediately before defining a series of load steps on a model, line selection commands are executed to flag a subset of the total lines present in a model for additional operations. In this case, the additional operation is the assignment of a convection to ALL selected lines as part of the boundary conditions of each load step. This avoids commands to assign convections to individual element faces that are exposed to ambient conditions for each load step of an analysis. The set of flagged lines is left intact until all load steps for a series are defined, when they are then unselected ("un-flagged") so that line selection for the next series of load steps begins without any lines flagged. By defining each segment of a dam to be geometrically independent, any of the surfaces of the foundation or concrete lifts can be used for specifying convections during the construction process. It is necessary for the analyst to know the sets of line numbers that make up the different configurations of convective surfaces in advance of defining the load steps in an analysis.

4.2.3.3 Internal Heat Generation Rates

The assignment of internal heat generation rates to elements is also done utilizing a model parameter selection routine. The finite element program allows a subset of total model elements to be selected according to a variety of parameters related to element definitions (e.g. coordinate values, element types, etc.). In the algorithm, elements are selected according to the material property data set reference numbers used in defining a model mesh. Since there may be many concretes in a dam generating heat at the same time, the algorithm requires that elements representing each type of concrete in each lift of a dam be defined using a unique material property reference number. This must be done even if property values are assumed to be the same for more that one type of concrete in a model.

The elements of a concrete generating heat at the time of each load step are flagged according to the material property reference number. The particular heat generation rate for that concrete is assigned to ALL selected elements, and then the elements are unselected to allow the next internal heat rate to be defined. The selection, heat assignment and un-selection command pattern must be repeated for each concrete producing heat in each load step. This routine avoids commands to assign a heat generation rate to the individual elements making up each concrete for each load step of an analysis.

All of these procedures for formulating and carrying out an analysis of a mass concrete dam are demonstrated in detail in defining and executing the case study. Chapter 5 is the documentation of this portion of the work.

5 CASE STUDY

This chapter presents a case study carried out to test the modelling algorithm. Some background information about the modelled dam is described and the development of the finite element model is explained. At the end of the chapter, the predicted thermal behaviour from the model is compared to measured in situ data from the project site.

5.1 Project

The mass concrete dam modelled in the case study is a component structure of the Limestone Generating Station on the Nelson River in northern Manitoba. The generating station is owned by Manitoba Hydro. Construction of this dam took place between 1985 and 1992. The site for the generating station is in a zone of sub-arctic climate, where the daily maximum temperatures in summer can be above 35°C and the daily minimum temperatures in winter can be below -50°C. There are approximately 100 frost-free days per year at this location.

The generating station is a low head, high discharge, run-of-river type plant comprising gravity structures. The width of the river at the axis of the dam is approximately 1040 m, and the riverbanks are high (over 30 m) and steep. The river is spanned with a combination of concrete and earthfill structures. Most concrete placement for the project took place during the non-winter months (April to October) of the years 1986, 1987 and 1988. Beginning in the winter of 1988-1989, concrete placement was possible during the winter months inside a partially completed portion of the powerhouse. Most of the mass concrete work, however, was carried out between 1986 and 1988.

5.2 Structure Modelled

The component of the generating station selected for the case study is a non-overflow, gravity section called the "north transition structure." It is located between the service bay of the generating station and the north earthfill dam connecting the concrete structures to the north bank of the river. The north transition consists of two adjacent gravity blocks, each 23 m in length and separated by a contraction joint, and is shown in Figure 5. The block farthest from the service bay is denoted as north transition-1, or "NT1", and the other block NT2. The case study specifically models the NT2 block. The structure includes a small room inset into the downstream face of NT2 for chlorine storage and a gallery at the upstream end of the base of the structure for foundation grouting, drainage and inspection purposes. There is a roadway at deck level.

As the north transition acts as a termination point for the north dam, there are earthfill materials in place against both the upstream and downstream faces of the structure. On the downstream side, the earthfill forms part of a "transmission tower spur", which supports transmission line towers, some operation and maintenance facilities, and a parking lot. Earthfill placement against the structure was carried out concurrent with, but trailing behind, concrete placement in the north transition. Photograph 1 shows progress on the two blocks of the north transition, the service bay and earthfill placement for the north dam from the upstream side of the dam.

5.2.1 Selection Rationale

NT2 was selected for the case study for several reasons. The first is that the north transition has the simplest cross-sectional geometry of the component structures making up the generating station. It is thus a suitable starting point to begin testing the modelling algorithm.

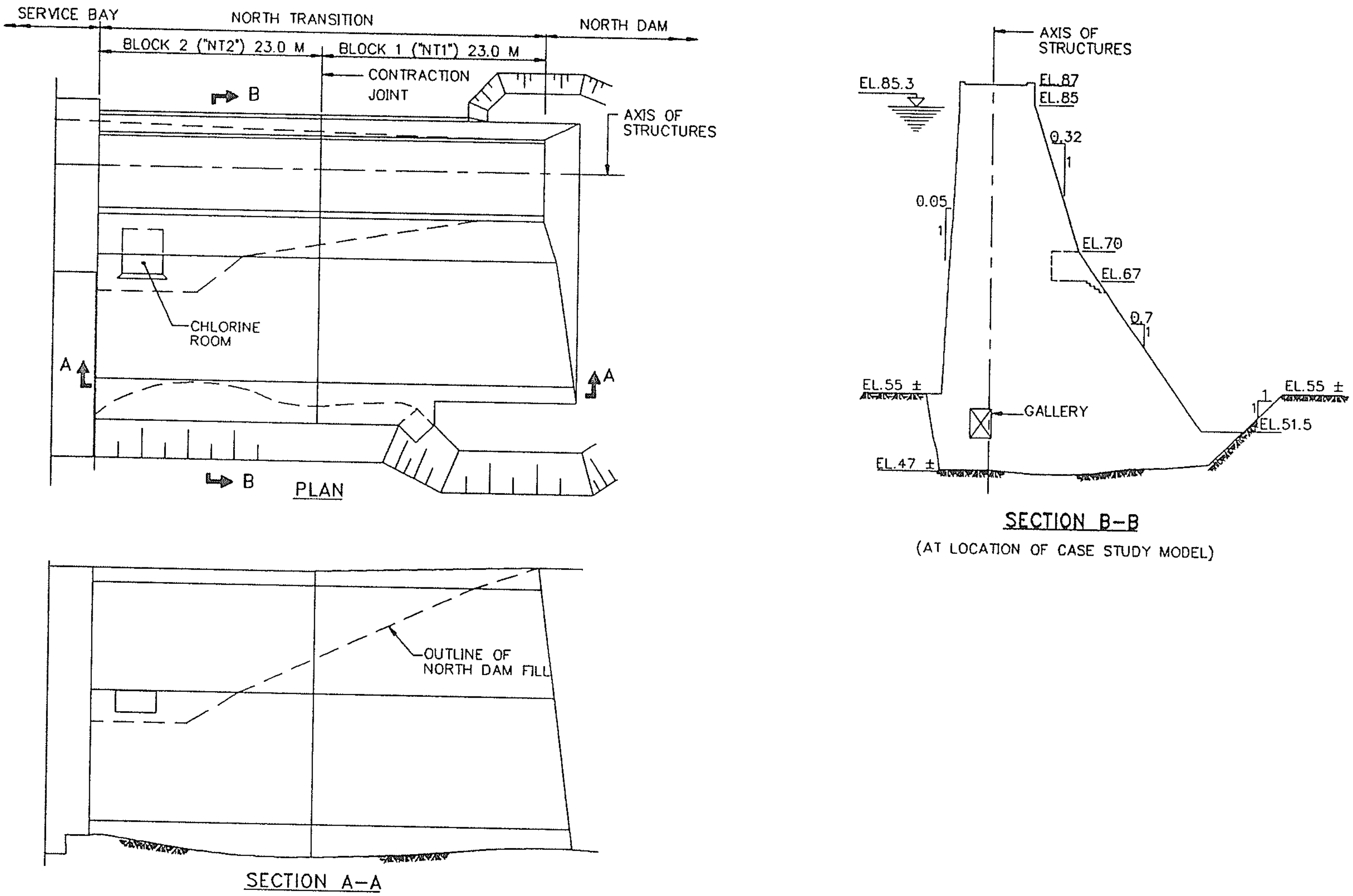

FIGURE 5 - Plan, Elevation and Sectional Views of Incremental Thermal Analysis Case Study Structure

PHOTOGRAPH 1 - Upstream View of North Transition Blocks 1 & 2, Service Bay Blocks 1 & 2 and North Dam During Construction (May 1987)

Secondly, during construction of the project, progress on concrete placement for NT2 lagged behind that of NT1 and the first block of the service bay (see Photograph 1). If these two neighbouring structures are considered to offer more resistance to heat loss from NT2 than exposure to ambient conditions, then the thermal behaviour of NT2 is closer to two-dimensional than if progress on NT2 lead NT1 and/or the service bay. This improves the correlation between a two-dimensional analysis of the structure and its true thermal behaviour as reflected in the measured in situ concrete temperature values. NT2 has minimal complicating features in the geometry of the structure (the chlorine room and gallery) that result in additional assumptions in the modelling process and added effort to model definition and analysis. Finally, a reason essential to this work is that the constituent lifts of NT2 were among those of the project that were instrumented with embedded thermocouple wires for the purpose of monitoring internal concrete temperatures after placement. Each lift generally had two thermocouple wires installed which were read and recorded on a periodic basis. Because of the thermocouple use, there is a record of in situ temperature readings for the different lifts of NT2, beginning with the day each lift was placed.

5.2.2 Design

The north transition was designed considering the various loads that act on the structure[112]. The cases evaluated involved load combinations of the structure's self weight, forebay water pressures, tailrace water pressures, upstream horizontal ice loads, and hydrostatic uplift pressures. A series of parameters were computed at the foundation level and particular intermediate points in the structure to ensure adequate stability. These included the vertical stress at the upstream face, stress at the downstream face parallel to the slope of the structure, location of the resultant force acting on the structure, and sliding, shear friction and floatation factors of safety. As the north transition has unbalanced lateral earth loads, these parameters were again evaluated with earthfill effects included. A series of limiting criteria for the parameters were adopted for evaluating the design of the structure. The design was carried out to meet the requirements of ACI Standard 318-71, and the Canadian Standards Association (CSA) Standard CAN3-A23.3-M77.

For design purposes, concrete for the structure was assumed to have a compressive strength of 20 MPa, but several different types of concrete were used in the construction of the structure.

5.2.3 Concretes and Lifts

Manitoba Hydro specified the mix designs used for construction of the north transition and all other component structures of the project. A variety of classes of concrete were defined for use in different areas of the structures according to prevailing service conditions. Mix classes generally included designs that ranged from mass concrete mixes with 80 mm maximum size aggregate (MSA) for unreinforced sections, to mixes with 20 mm MSA for heavily reinforced sections. The principle classes of concrete used on the project are shown in Table 3[113].

Concrete Class	Use Criteria	MSA (mm)	Approximate Cement Content (kg/m^3)	Specified 28 Day Compressive Strength (MPa)
A	Areas subjected to severe exposure conditions in service.	20, 40, 80	270-320	35
B	Areas subjected to freezing and thawing in a saturated or near-saturated condition except where required to be class A.	20, 40, 80	240-285	30
C	Water passage surfaces within the intake and powerhouse; interior structural concretes.	20, 40, 80	200-240	25
D	Interior reinforced mass concrete not required to be class C.	40, 80	180-200	20
E	Interior non-reinforced mass concrete.	80	150	15

TABLE 3 - Concrete Mix Classes for Case Study Project Construction

The objective of defining many different mix designs was to be able to utilize economical and durable concretes that met the designer's strength requirements for the various structures making up the generating station. Figure 6 shows the "as-built" mix classes used in construction of the north transition according to the above mix use criteria.

Concrete placement in NT2 took place over two years, 1986 and 1987, with the structure left exposed to ambient conditions through the winter in between. The individual concrete lifts that were placed in the construction of NT2 are shown below in Table 4.

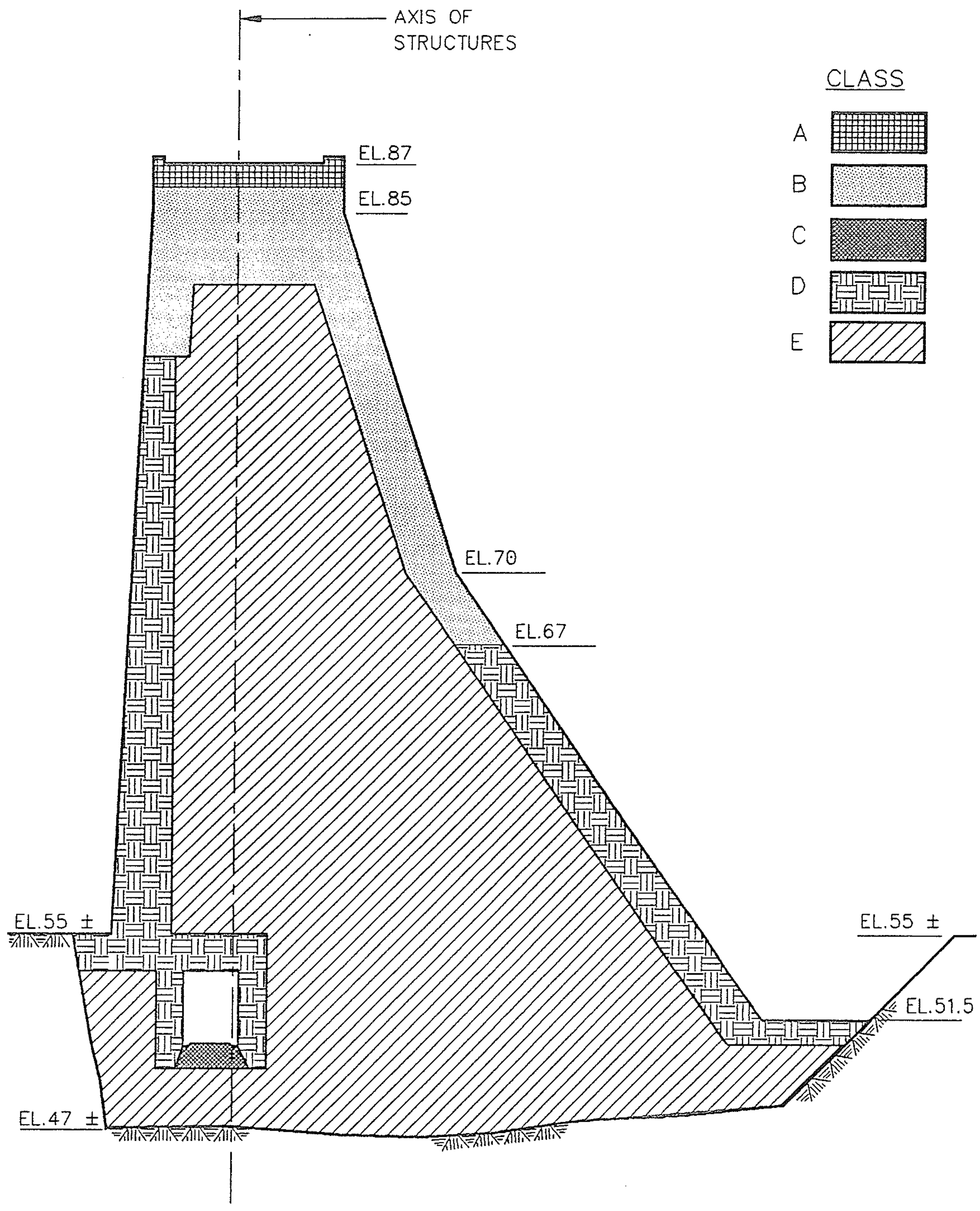

FIGURE 6 - As-Built Concrete Mix Classes for Case Study Structure

Lift Number	Batched Volume (m^3)	Elevation From (m)	Elevation To (m)
NT2-1c	25.0	Rock surface	45.50
NT2-1b	55.0	Rock surface	46.25
NT2-1a	203.0	Rock surface	47.00
NT2-1	813.0	45.50	48.50
NT2-2	1 546.0	48.50	50.60
NT2-3a/b	1 685.0	50.60	53.60
NT2-4	852.0	53.60	55.00
NT2-5	1 644.0	55.00	58.00
NT2-6	1 483.5	58.00	61.00
NT2-7	1 365.0	61.00	64.00
NT2-8a	606.0	64.00	65.50
NT2-8b	562.0	65.50	67.00
NT2-9	985.0	67.00	70.00
NT2-10-1	240.0	70.00	70.75
NT2-10-2	221.0	70.75	71.50
NT2-10-3	437.0	71.50	73.00
NT2-11	825.0	73.00	76.00
NT2-12	750.0	76.00	79.00
NT2-13	664.0	79.00	82.00
NT2-14	606.0	82.00	85.00
NT2-15	360.0	85.00	87.00
NT2-16a/b (curbs)	10.0	87.00	87.20

TABLE 4 - Concrete Lifts Placed During Construction of Case Study Structure

Specification requirements for the manufacture and placement of concrete in the structure are summarized in Appendix C. Additional data related to the construction of NT2, including information about earthfill placement progress for the north dam, is provided in Appendix D.

5.3 In Situ Concrete Temperature Surveillance

Thermocouple wires were embedded in the concrete of each lift of NT2 beginning with the first regular lift after the shallow lifts at the foundation level. A "hot wire" was placed at the approximate centre of each lift to allow monitoring of the core temperature, and a "cold wire" was placed at a location within about 15 cm of the forms, typically in a corner of the lift, to permit monitoring of the near-surface concrete temperature. The hot wires were continually

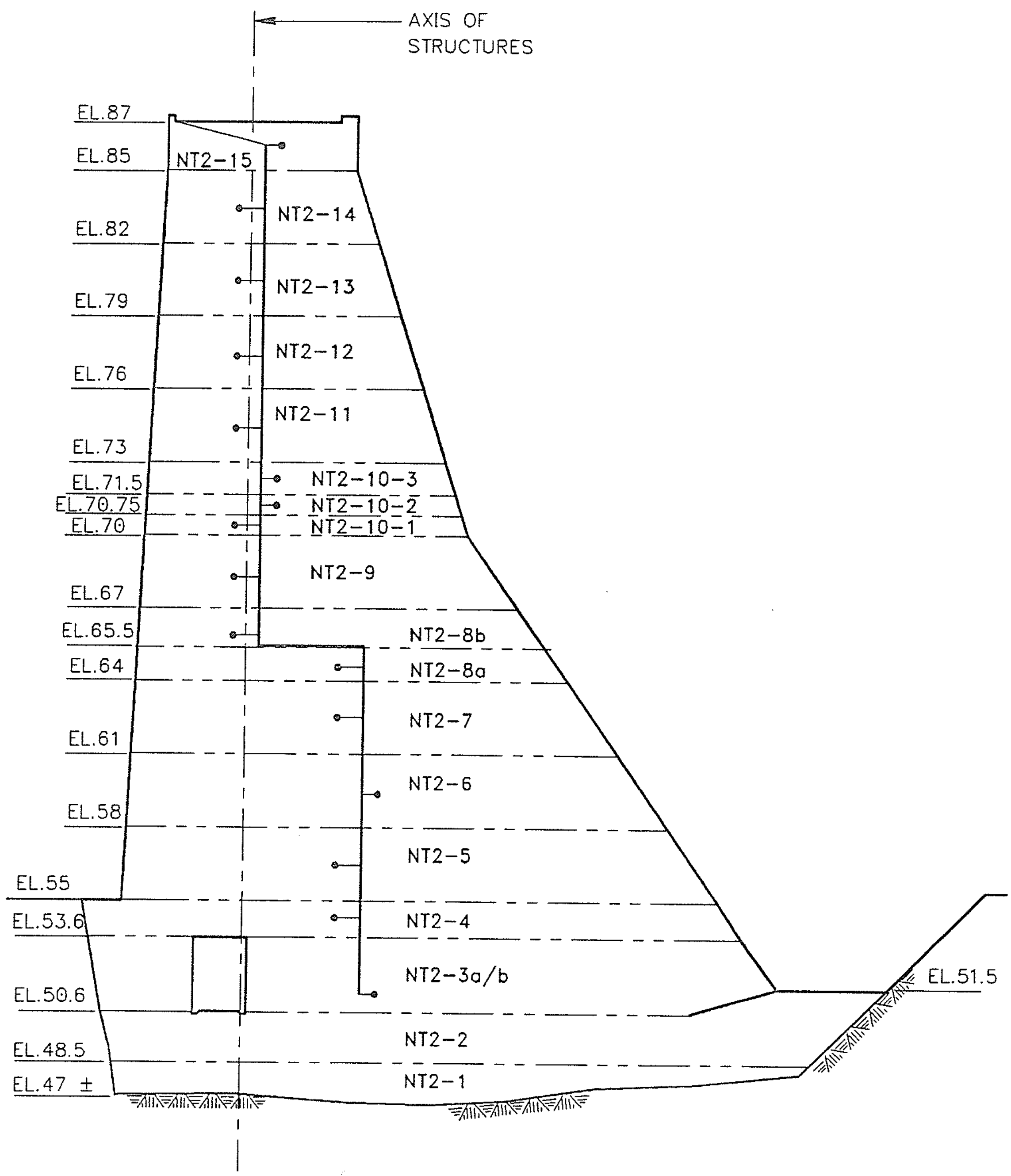

FIGURE 7 - Approximate Locations of Internal Thermocouple Wires in Case Study Structure

extended up through the structure as new lifts of concrete were placed, and eventually reached deck level. This allowed the interior in situ concrete temperature of any lift to be obtained at any time after installation of the thermocouple. The approximate locations of most hot wires installed in NT2 are shown in Figure 7[114]. The locations are approximate since the thermocouple positions were not surveyed during construction.

5.3.1 Monitoring Program

Cold wires installed in each lift were typically monitored on a daily basis for a period of only about one week after placement and were then abandoned. There are two reasons why monitoring of these thermocouples did not extend for a longer period of time[115]. One is that cold wires were used to obtain a measure of the maximum temperature difference between the core of a lift and the surface, and this generally occurred within one week of placement of a lift. The second reason is that in the spring and fall when ambient temperatures were low, the cold wire temperature value was used to ensure that specification requirements for maintaining concrete temperatures after placement were being met. These requirements are explained in Appendix C.

The hot wires for each lift were incorporated into a site-wide program of periodic in situ temperature measurements that continued at intervals that varied with the age of each lift. Monitoring was done on a daily basis for anywhere from two weeks to two months after placement, after which the wires were read on a weekly basis. As construction activities at the site wound down, the reading frequency became monthly. Data was collected up to approximately September, 1992. This work relies solely on the information collected from these hot wires to compare with the model results later in this chapter.

5.3.2 Temperature Observations

A summary of the data collected from the hot wires of each lift of NT2 is shown in Table 5[116]. The location of the thermocouple is listed in terms of the concrete in which the wire is embedded, where the letter denotes the mix class, and the number the MSA of the mix used. The location of the thermocouple wire for lift NT2-9 is in conflict with what is shown in Figure 7. Both sources of this information have equal weight, and it was not possible to determine which is correct.

Lift Number	Thermo-couple Location (mix type)	Average Placing Temperature (°C)	Measured Peak Temperature (°C)	Measured Temperature Rise (°C)	Measured Days to Peak Temperature
NT2-1	E-80	10	28	18	2.5
NT2-2	E-80	14	38	24	3.0
NT2-3a/b	E-80	9	36	27	4.5
NT2-4	E-80	12	27	15	2.5
NT2-5	E-80	12	38	26	3.5
NT2-6	E-80	13	38	25	3.5
NT2-7	E-80	11	40	29	4.0
NT2-8a	E-80	12	18	6	1.5
NT2-8b	E-80	11	22	11	3.0
NT2-9	B-80	9	35	26	3.0
NT2-10-1	E-80	12	17	5	1.0
NT2-10-2	E-80	13	14	1	2.5
NT2-10-3	E-80	11	24	13	2.0
NT2-11	E-80	11	37	26	6.5
NT2-12	E-80	10	40	30	5.0
NT2-13	E-80	10	41	31	5.0
NT2-14	B-80	7	51	44	3.0
NT2-15	B-80	12	53	41	3.5

TABLE 5 - Summary of Measured Thermocouple Data for Constituent Lifts of NT2

The internal temperatures recorded for lifts of NT2 placed in 1986 are plotted in Figure 8, and those for 1987 lifts in Figure 9. The influence of placement of subsequent lifts on the internal temperatures of underlying lifts can be seen in the Figures.

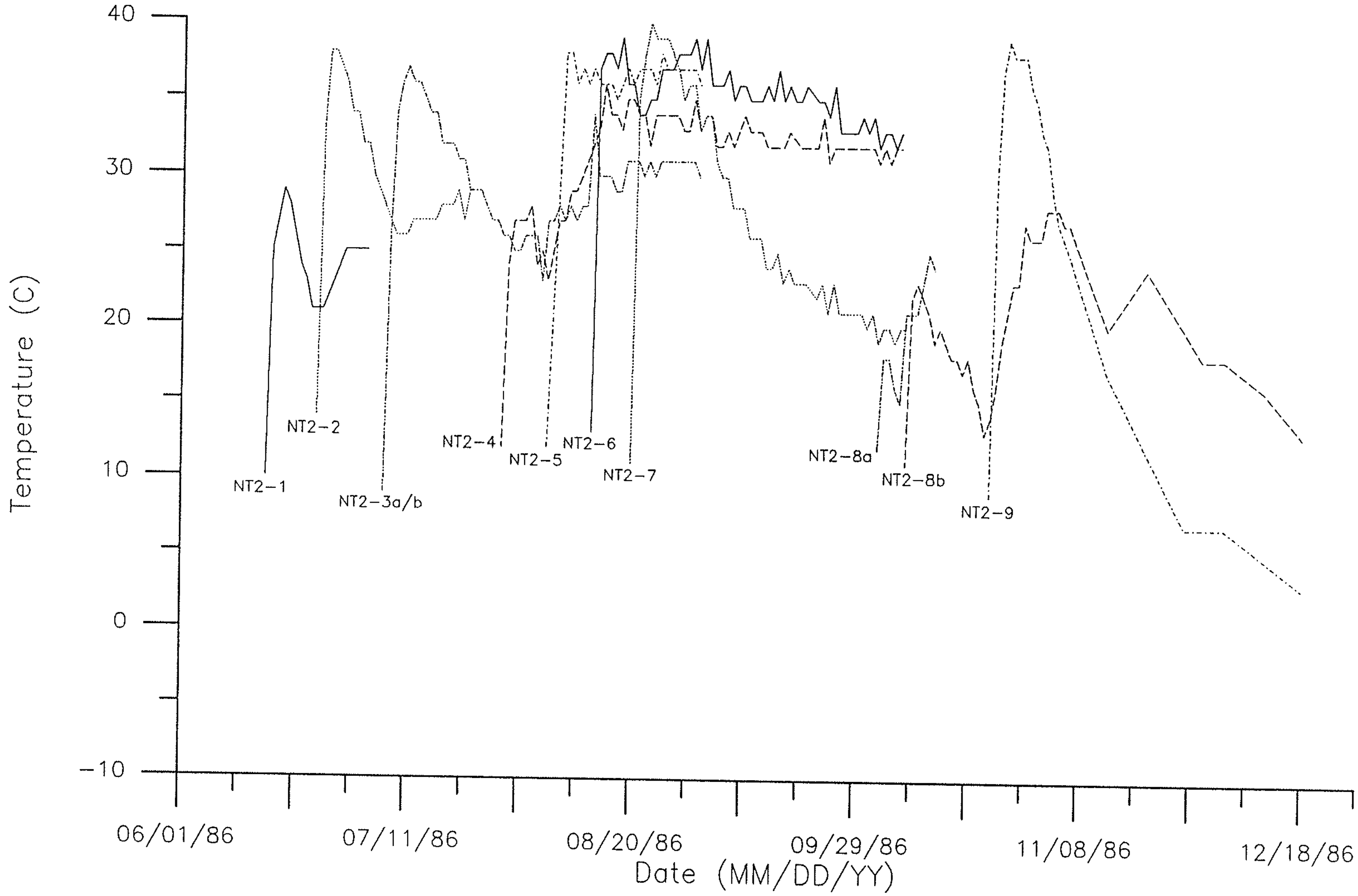

FIGURE 8 - Measured Thermocouple Responses for Concrete Lifts of NT2 Placed in 1986

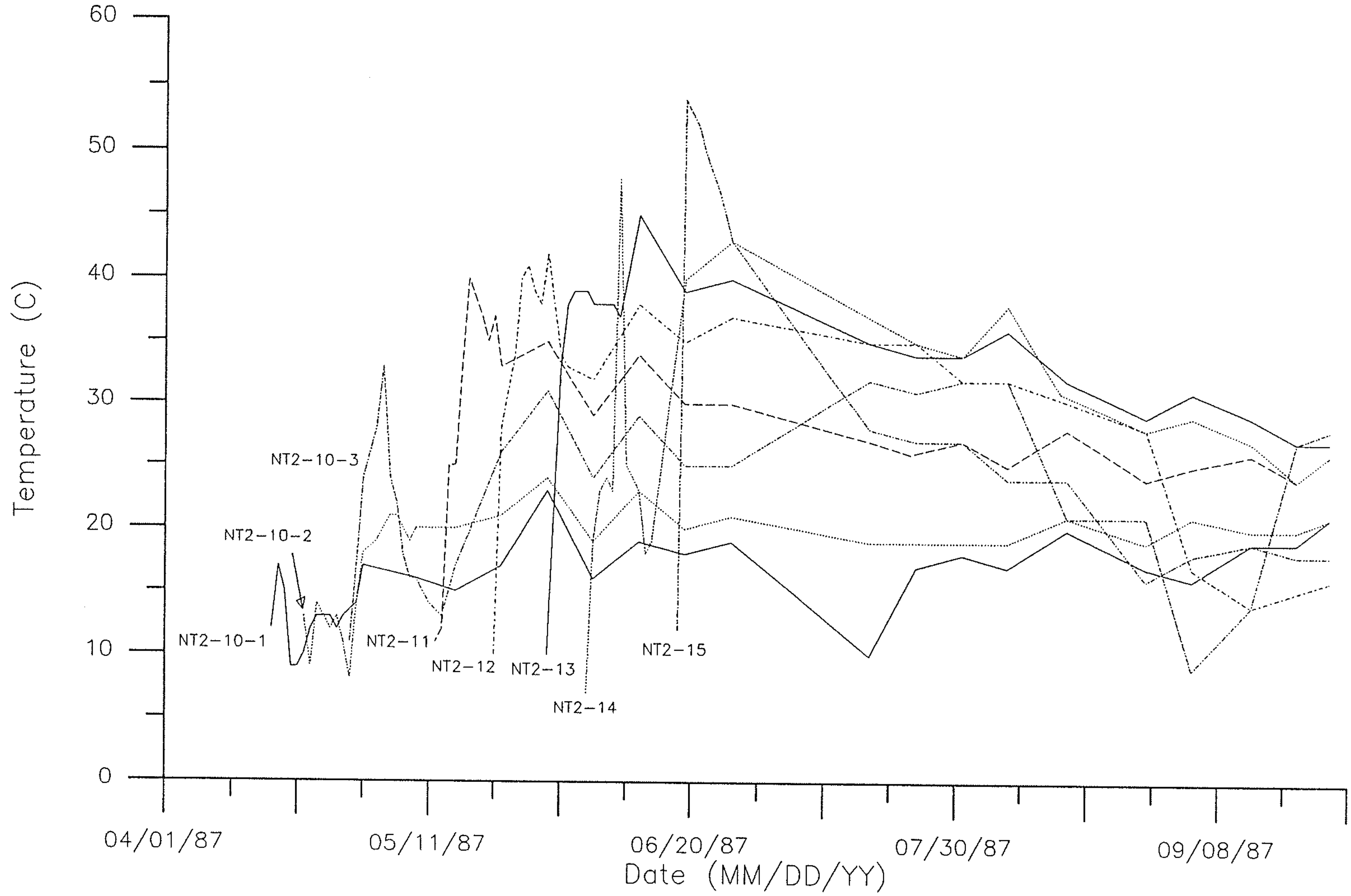

FIGURE 9 - Measured Thermocouple Responses for Concrete Lifts of NT2 Placed in 1987

5.3.3 Thermocouple Realities

The extent of the information collected from some of the different thermocouples is limited and some readings in the records may be in error possibly due to any of an assortment of reasons. There can sometimes be problems encountered with the site thermocouples due to various activities and procedures that take place during construction. Occasionally, wires may get severed by being hit with aggregate during concrete placement, or they may get damaged accidentally during preparations for subsequent lift placement. The multiple splices required to extend the wires to deck level introduce opportunities for the thermocouples to become dysfunctional. The size of the project site presents the potential for damage due to vandalism. The interpreting device used to obtain readings can sometimes give erroneous readings. Generally, however, data collected from the thermocouples provides a reasonable indication of the temperature conditions at the locations of the thermocouples. The data plotted in Figures 8 and 9 have had only the obvious errors in the readings corrected to what is estimated to be more likely values.

5.4 Finite Element Model

For the purpose of defining the finite element model for the analysis, the geometry, lifts, and concrete locations for the structure are assumed to be as shown in Figure 10. The following paragraphs explain more about each component of the finite element model.

5.4.1 Foundation Geometry

Two assumptions about the foundation of NT2 are reflected in the case study. First, the bedrock geometry has been simplified into a series of straight lines, and there are no surface

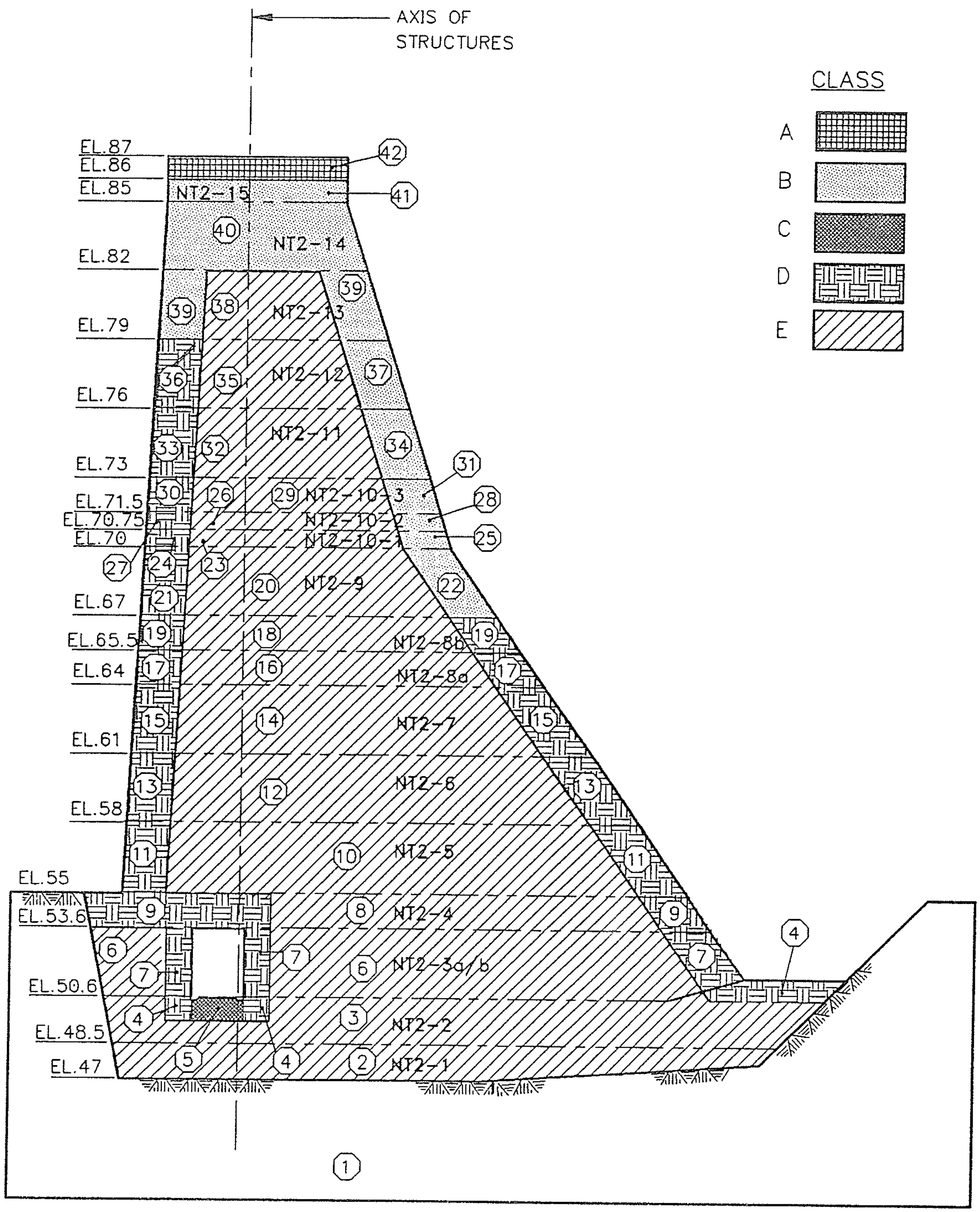

FIGURE 10 - Assumed Structure Geometry and Concrete Locations for Definition of Case Study Analysis Finite Element Model

irregularities invariably present in a real excavation included in the model. The second is that the excavation of the foundation material is assumed to have been completed in the fall of the year before concrete placement began in NT2. The surface of the foundation is thus assumed to have been exposed to ambient conditions from the fall of 1985 through to the spring of 1986.

The bottom of the foundation portion of the finite element model was selected to be el. 40 m, seven meters below the assumed invert of the excavation. This depth was judged to be a reasonable spacing between the bedrock surface and its exposure to convective boundary conditions through the winter, and the isothermal plane assumed to exist in the foundation. The upstream limit of the foundation was set 5.4 m from the most upstream edge of concrete in the dam, and the downstream limit 5 m beyond the downstream edge of the foundation excavation. These distances were estimated to be suitable spacings between the adiabatic vertical faces of the bedrock portion of the model and sloping surfaces of the foundation excavation.

5.4.2 Structure Geometry

Some assumptions have been made with respect to the geometry of NT2 in formulating the finite element model. To begin, the first four concrete lifts of the structure have been combined into a single Lift 1. This has been done for several reasons. The three lifts prior to lift NT2-1 are small (see Table 4) and not well defined in their locations. These lifts also likely lie at least partially off the plane of the model. There is an error introduced because of this since three lifts have been merged into a fourth, and because of the two-dimensional treatment when the lifts may include a third dimensional effect in reality.

The locations within the structure for where the different concretes are located have been assumed to be those shown in Figure 10. Actual locations will generally be close to that assumed here, but may be quite different in local areas due to placing procedures and construction conditions at the time of placing the different lifts.

Two additional general simplifications of the model geometry have been made for the case study. The chlorine room present in the downstream face of the structure at el. 67 m lies slightly off the plane of the model and is therefore neglected in the analysis. This introduces a slight error, but it is generally a local effect that is missed. Finally, for simplicity's sake, the curbs of the roadway at deck level are also neglected in defining and carrying out the analysis.

5.4.3 Material Properties

To accommodate the requirement for a consistent set of units, the base units of measurement for both material properties and degree of freedom values for the case study are as shown in Table 6.

Quantity	Units of Measurement
Heat	kcal
Mass	kg
Time	days
Temperature	°C
Distance	meters

TABLE 6 - Base Units of Measurement for Case Study Analysis

In defining the case study, actual values for thermal material properties were used where available. Otherwise, what were felt to be representative values (i.e. values for materials closest to those of the case study) were adopted in their place. The values for mass densities of the bedrock and the different concretes used in the structure were obtained from project exploration programs[117] and the concrete laboratory testing program[118][119], respectively. Values for conduction and specific heat for the foundation and the concretes were not measured at the project site, and have therefore been extracted from the literature for this analysis. The values for the material properties are shown in Table 7. The material property data set reference numbers used to later select specific concretes in the model for internal heat generation rate assignment are included in the table as well. These numbers are also shown on Figure 10.

5.4.4 Mesh Definition

To define the geometry and mesh of the model, the origin of the coordinate system was set at the intersection of sea level and the axis of the dam. Positive y is up, and positive x is in the downstream direction. This is a convenient selection since concrete lifts are designated in terms of elevations, and dimensions of the structure are typically measured with respect to the axis of the dam.

An exercise was carried out using a problem with an analytical solution to relate the mesh pattern for exposed surfaces to the time-step size, while satisfying the ANSYS guideline equation shown previously as Equation 19. From this came a general mesh pattern for the direction perpendicular to exposed surfaces that is used for the one meter thickness of material adjacent to exposed surfaces. This pattern is the "general purpose" pattern for temporarily and permanently exposed concrete surfaces in the model.

For surfaces along which coupling takes place, a similar but less dense perpendicular mesh pattern is adopted to accommodate the shock loading that results from the coupling process. This is applied to the one meter thickness of material along those concrete surfaces of the model that are not exposed to ambient but have to respond to a coupling operation. This pattern was also used as the primary pattern for the mesh along the exposed surfaces of the foundation

Model Segment	Concrete Class	Property Set Reference Number	Conductivity k_c (kcal/m·day·°C)	Specific Heat C_p (kcal/kg·°C)	Mass Density ρ (kg/m³)
Bedrock	--	1	55.2	0.22	2650
Lift NT2-1	E	2	62.4	0.225	2319
Lift NT2-2	E	3	62.4	0.225	2319
	D	4	62.4	0.225	2324
	C	5	62.4	0.225	2298
Lift NT2-3a/b	E	6	62.4	0.225	2319
	D	7	62.4	0.225	2324
Lift NT2-4	E	8	62.4	0.225	2262
	D	9	62.4	0.225	2284
Lift NT2-5	E	10	62.4	0.225	2262
	D	11	62.4	0.225	2284
Lift NT2-6	E	12	62.4	0.225	2276
	D	13	62.4	0.225	2285
Lift NT2-7	E	14	62.4	0.225	2276
	D	15	62.4	0.225	2285
Lift NT2-8a	E	16	62.4	0.225	2276
	D	17	62.4	0.225	2285
Lift NT2-8b	E	18	62.4	0.225	2276
	D	19	62.4	0.225	2285
Lift NT2-9	E	20	62.4	0.225	2276
	D	21	62.4	0.225	2285
	B	22	62.4	0.225	2291
Lift NT2-10-1	E	23	62.4	0.225	2258
	D	24	62.4	0.225	2285
	B	25	62.4	0.225	2303
Lift NT2-10-2	E	26	62.4	0.225	2258
	D	27	62.4	0.225	2285
	B	28	62.4	0.225	2303
Lift NT2-10-3	E	29	62.4	0.225	2258
	D	30	62.4	0.225	2285
	B	31	62.4	0.225	2303
Lift NT2-11	E	32	62.4	0.225	2258
	D	33	62.4	0.225	2285
	B	34	62.4	0.225	2303
Lift NT2-12	E	35	62.4	0.225	2258
	D	36	62.4	0.225	2285
	B	37	62.4	0.225	2303
Lift NT2-13	E	38	62.4	0.225	2264
	B	39	62.4	0.225	2317
Lift NT2-14	B	40	62.4	0.225	2317
Lift NT2-15	B	41	62.4	0.225	2305
	A	42	62.4	0.225	2331

TABLE 7 - Material Properties for Case Study Finite Element Model

bedrock. This was used instead of the pattern for the exposed surfaces of the concretes since the foundation's exposure to ambient conditions is limited, convection on the foundation is not as critical as with the concrete elements, and this served to reduce the total number of elements in the model. The pattern also forms the basis for the mesh along the walls of the gallery. Lifts shallower than the regular 3 m thickness were meshed using the above pattern modified to suit the thickness of the lifts.

In order to have corresponding nodes along coupled surfaces at coincident locations for realistic coupling, nodal patterns on matching surfaces are defined to be identical. This has been done along the bedrock surfaces as well as concrete surfaces. A reasonable range of aspect ratios for the elements was maintained in selecting the number of elements along the tops and bottoms of lifts of concrete.

When the number of elements along the bottom of a lift differed from that along the top of the lift due to the tapering of the thickness of the dam with increasing elevation, the 1 m core of each of the 3 m thick lifts of the dam was used as the area where the mesh was adjusted. Thus, the interiors of the lifts typically consist of both triangular and quadrilateral elements as a transition from the nodal pattern at the bottom of a lift to that of the top of the lift. The typical mesh pattern applied to two lifts of the structure is shown in Figure 11, and the full model mesh for the case study is shown in Figure 12. Figure 13 shows the model nodes, and Figure 14 the various lines defined as part of creating the model mesh shown in Figure 12. There are 450 keypoints, 685 lines, 255 areas, 2177 nodes and 1798 elements in the model. Note that it is not possible to distinguish surfaces where coupling takes place since nodes at these locations are defined to be coincident.

After definition of the mesh for the finite element model, a reordering of element numbers is executed in the y-direction to reduce the size of the solution wavefront and thereby

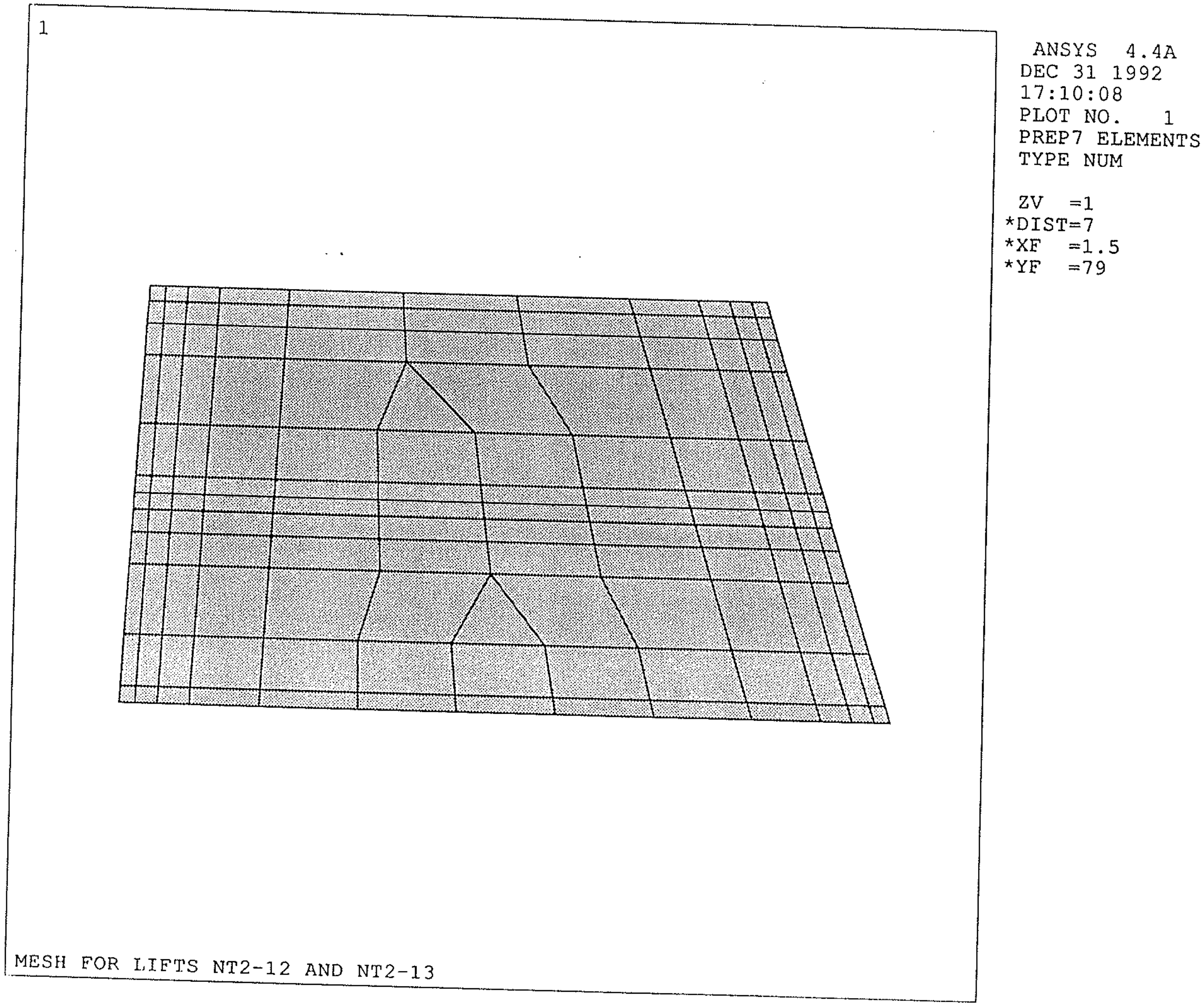

FIGURE 11 - Typical Mesh Pattern of Two Concrete Lifts for Case Study Finite Element Mesh

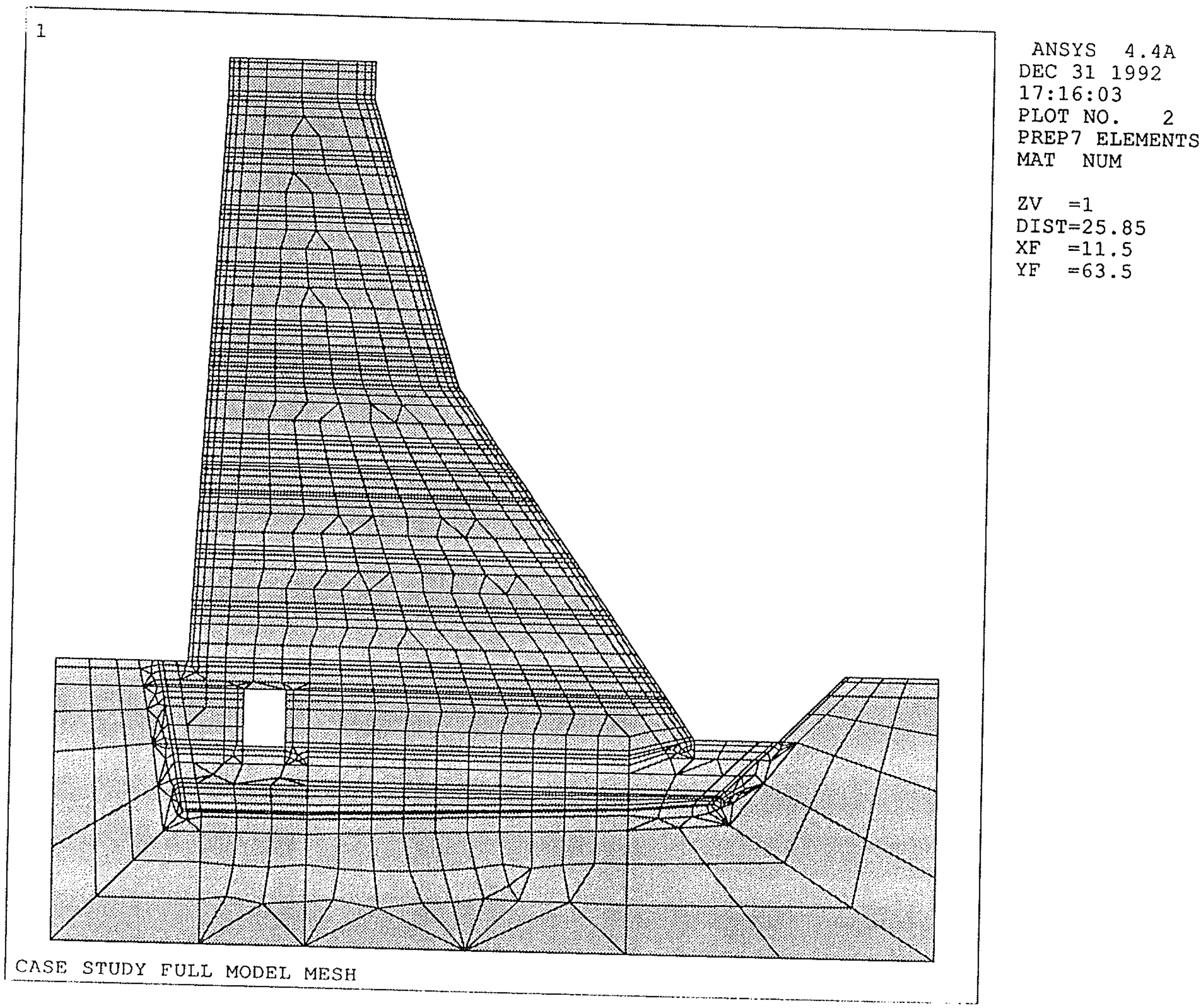

FIGURE 12 - Full Model Finite Element Mesh for Case Study Analysis

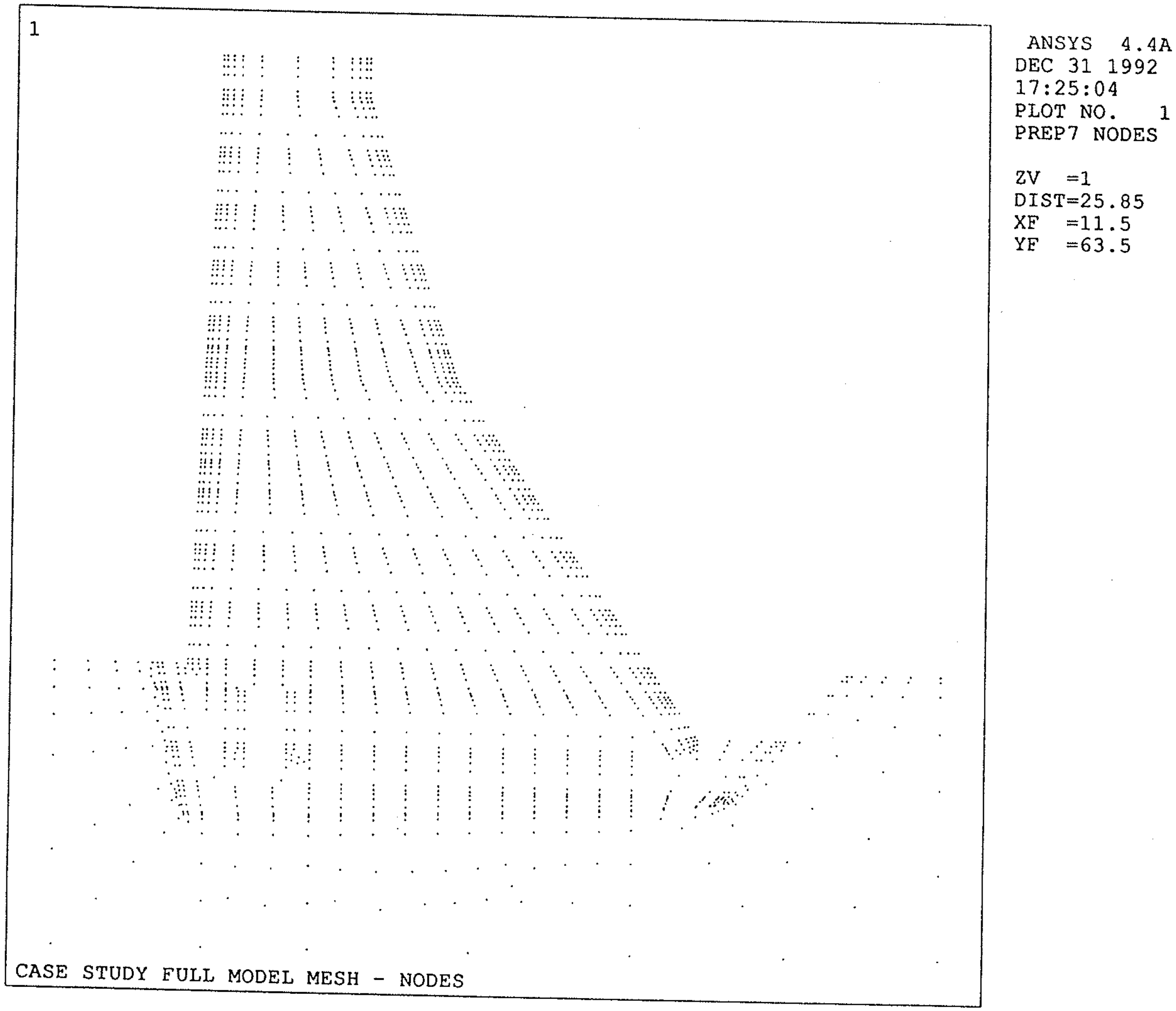

FIGURE 13 - Case Study Analysis Finite Element Model Nodes

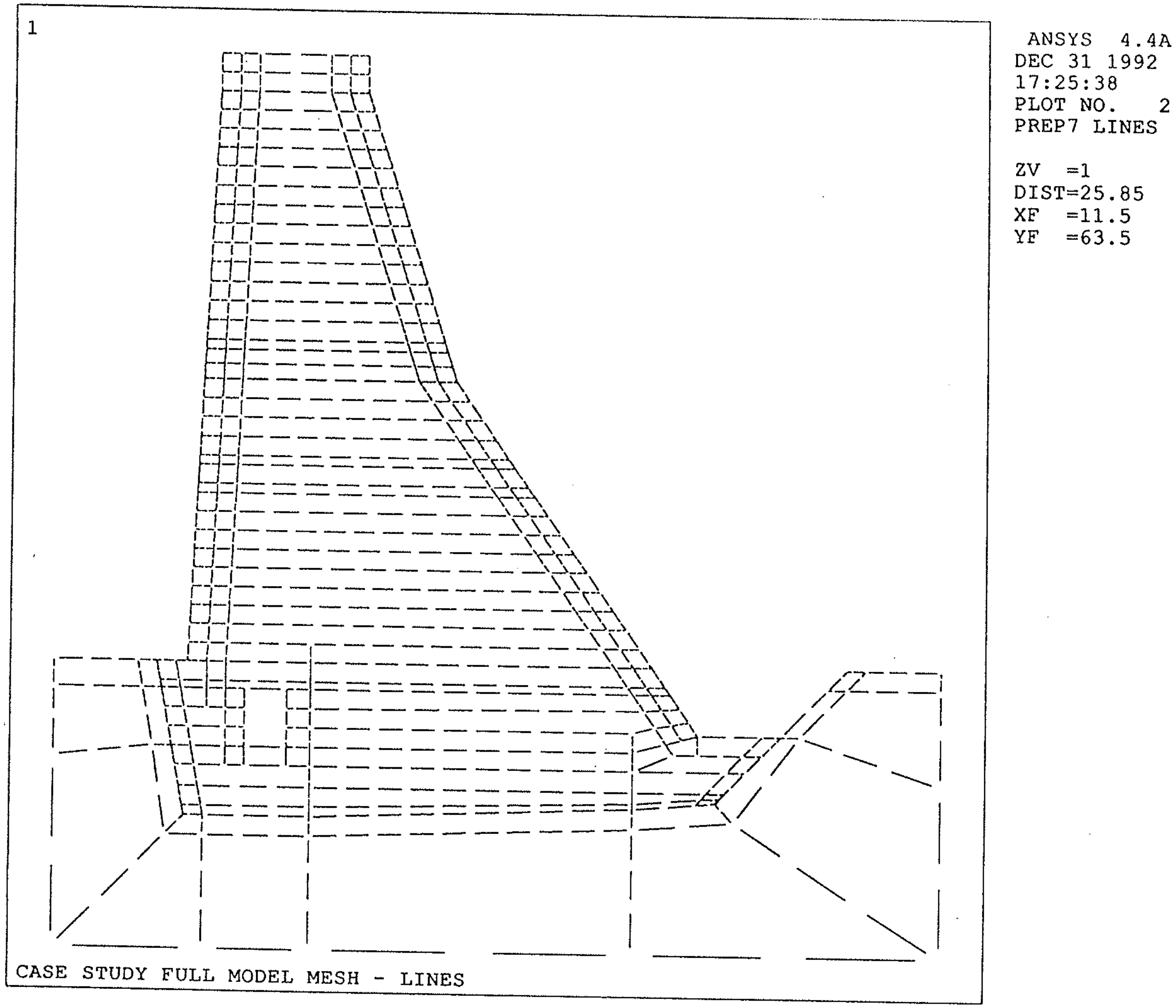

FIGURE 14 - Case Study Analysis Finite Element Model Lines

decrease computational time requirements to perform the analysis. Also after definition of the mesh, one node number from each lift of the structure was identified for the initializing nodal temperature boundary condition, and coincident node numbers along coupled surfaces were determined so the proper coupling can be assigned during the analysis. Nearly all the coupling that happens in the case study involves pairs of nodes, but there are four instances where three nodes form a coupled set. This happens where the intersection of the top of one concrete lift and the bottom of another lies against the foundation bedrock. Three such occurrences are along the upstream slope of the foundation (Lifts NT2-1 and NT2-2, NT2-2 and NT2-3a/b, and NT2-3a/b and NT2-4) and one on the downstream slope (Lifts NT2-1 and NT2-2).

All elements in the case study are ANSYS element type STIF55, the thermal two-dimensional isoparametric solid element.

5.5 Internal Heat Generation Rates

Adiabatic heat of hydration data for a sample of the Type 10 cement used to batch concrete for the project was used as the basis for defining the internal heat generation rates in the case study. The data is shown in Table D.1. This information was utilized to determine values of the two coefficients K and α in Equation 10 for each concrete in the structure. For each data point of heat generation for the cement sample, a corresponding adiabatic temperature rise for the concrete was calculated according to its material properties shown in Table 7. The temperature rise is calculated by:

$$H \cdot C \cdot 0.23901 \times 10^{-3} \cdot \frac{1}{C_p} \cdot \frac{1}{\rho} = T\ (^\circ C) \qquad (20)$$

where H is the heat generated to a particular point in time (J/g) and C is the cement content of the concrete mix (kg/m^3). Values for K and α were determined by trial and error according tothe criteria of minimizing the sum of the errors squared between the temperature rises calculated from the heat generation data and that predicted from Equation 10 using different assumed values of K and α. Parameter values for the heat generation rate equations used for the case study are shown in Table 8. Mix labels include a version specifier for each particular concrete. The values of α are nearly identical for all concretes because the shape of the heat generation data curve (Figure D.1) is common to all concretes. Example plots of the adiabatic temperature rise of some of the concretes using the above parameter values are shown as Figure 15.

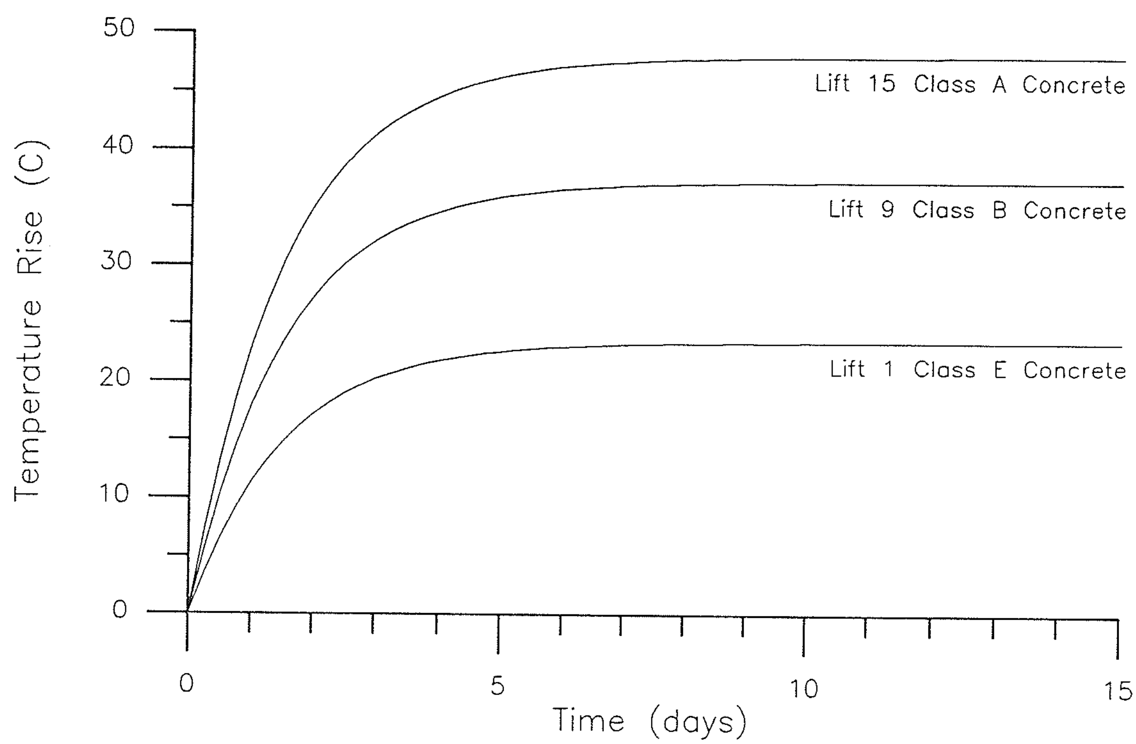

FIGURE 15 - Example Adiabatic Temperature Rise Curves for Case Study Analysis Concretes

Lift Number	Concrete Mix	Cement Content (kg/m^3)	K (°C)	α (1/days)
NT2-1	E-80-01	150	23.5	0.66
NT2-2	E-80-01	150	23.5	0.66
	D-80-01	180	28.2	0.65
	C-80-01	205	32.4	0.66
NT2-3a/b	E-80-01	150	23.5	0.66
	D-80-01	180	28.2	0.65
NT2-4	E-80-02	150	24.1	0.66
	D-80-02	175	27.9	0.65
NT2-5	E-80-02	150	24.1	0.66
	D-80-02	175	27.9	0.65
NT2-6	E-80-03	155	24.8	0.66
	D-80-03	180	28.7	0.65
NT2-7	E-80-03	155	24.8	0.66
	D-80-03	180	28.7	0.65
NT2-8a	E-80-03	155	24.8	0.66
	D-80-03	180	28.7	0.65
NT2-8b	E-80-03	155	24.8	0.66
	D-80-03	180	28.7	0.65
NT2-9	E-80-03	155	24.8	0.66
	D-80-03	180	28.7	0.65
	B-80-00	235	37.3	0.66
NT2-10-1	E-80-04	155	25.0	0.66
	D-80-04	185	29.5	0.65
	B-80-01	250	39.5	0.66
NT2-10-2	E-80-04	155	25.0	0.66
	D-80-04	185	29.5	0.65
	B-80-01	250	39.5	0.66
NT2-10-3	E-80-04	155	25.0	0.66
	D-80-04	185	29.5	0.65
	B-80-01	250	39.5	0.66
NT2-11	E-80-04	155	25.0	0.66
	D-80-04	185	29.5	0.65
	B-80-01	250	39.5	0.66
NT2-12	E-80-04	155	25.0	0.66
	D-80-04	185	29.5	0.65
	B-80-01	250	39.5	0.66
NT2-13	E-80-05	160	25.7	0.66
	B-80-02	260	40.9	0.65
NT2-14	B-80-02	260	40.9	0.65
NT2-15	B-80-03	255	40.3	0.655
	A-80-02 and A-40-04	308 (Avg.)	48.0	0.66

TABLE 8 - Heat Generation Rate Equation Parameter Values for Case Study Analysis

5.6 Applied Boundary Conditions

Thermal loading applied as boundary conditions during the analysis, and the basis for their definition, are as follows.

5.6.1 Radiation

The effect of radiation on the case study structure has been assumed to be negligible, and so is left out entirely of the analysis.

5.6.2 Specified Temperatures

The nodes along the bottom of the foundation segment of the model are assigned a temperature of 2°C for the entire length of time analyzed in the case study[120]. The only other specified temperatures used as boundary conditions are for initializing each lift of concrete in the dam to its placing temperature. The temperature values used are those shown in Table D.2 of Appendix D.

5.6.3 Convections

Each load step in the analysis includes a convection assigned to the exposed surfaces of the model. Two types of weather data collected either at or near the project site during construction are incorporated into the specification of convective boundary conditions. The daily median temperature as calculated from daily low and high temperatures measured by Manitoba Hydro at the site during construction is used as the fluid temperature. The median temperatures for the time period of the case study analysis are shown plotted in Figure 16.

The convection coefficient for each load step was derived using wind data collected by Environment Canada at a weather station at Gillam, Manitoba 56 km southwest of the project

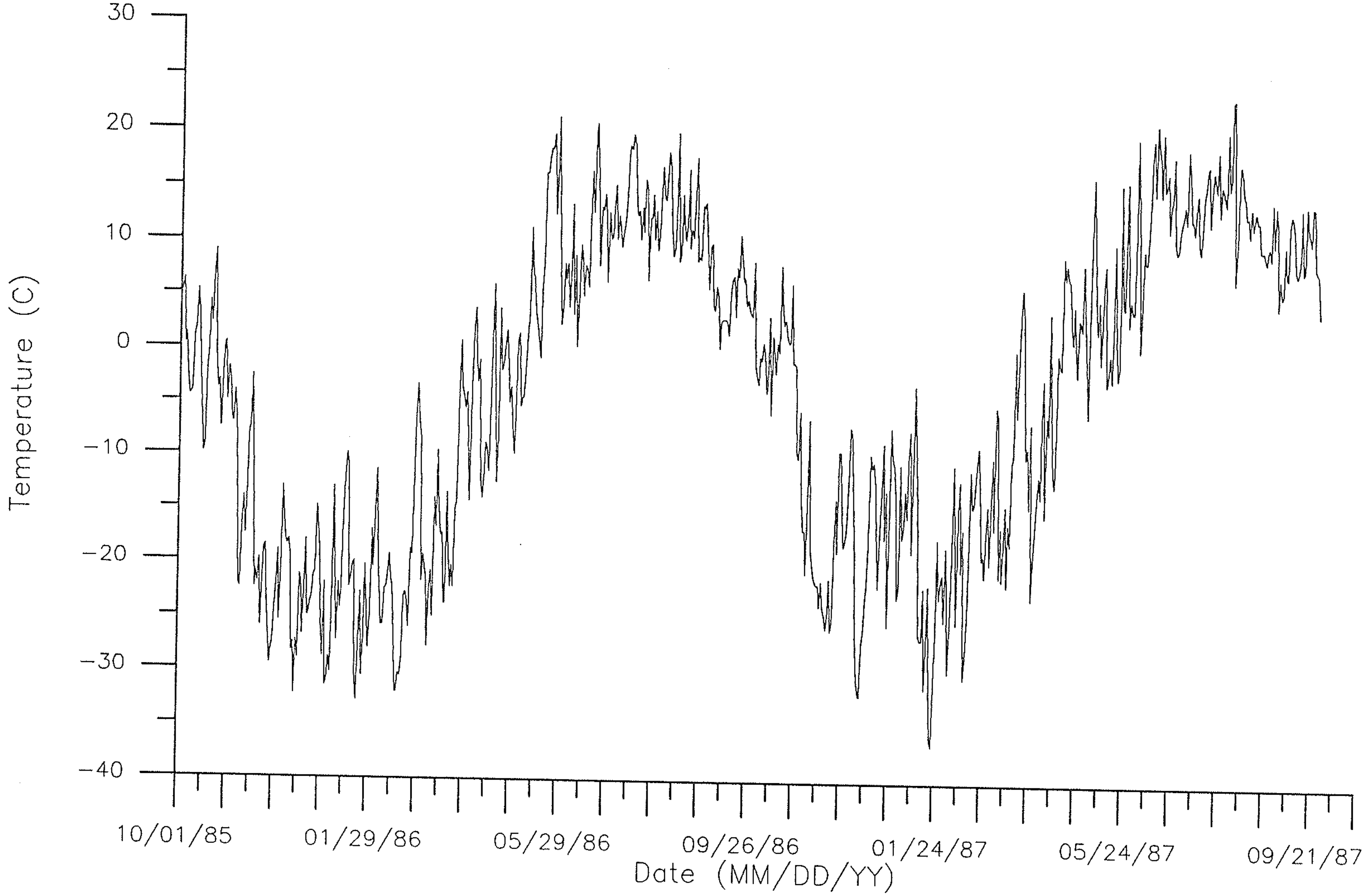

FIGURE 16 - Median Ambient Temperatures Used for Case Study Convective Boundary Condition Definitions

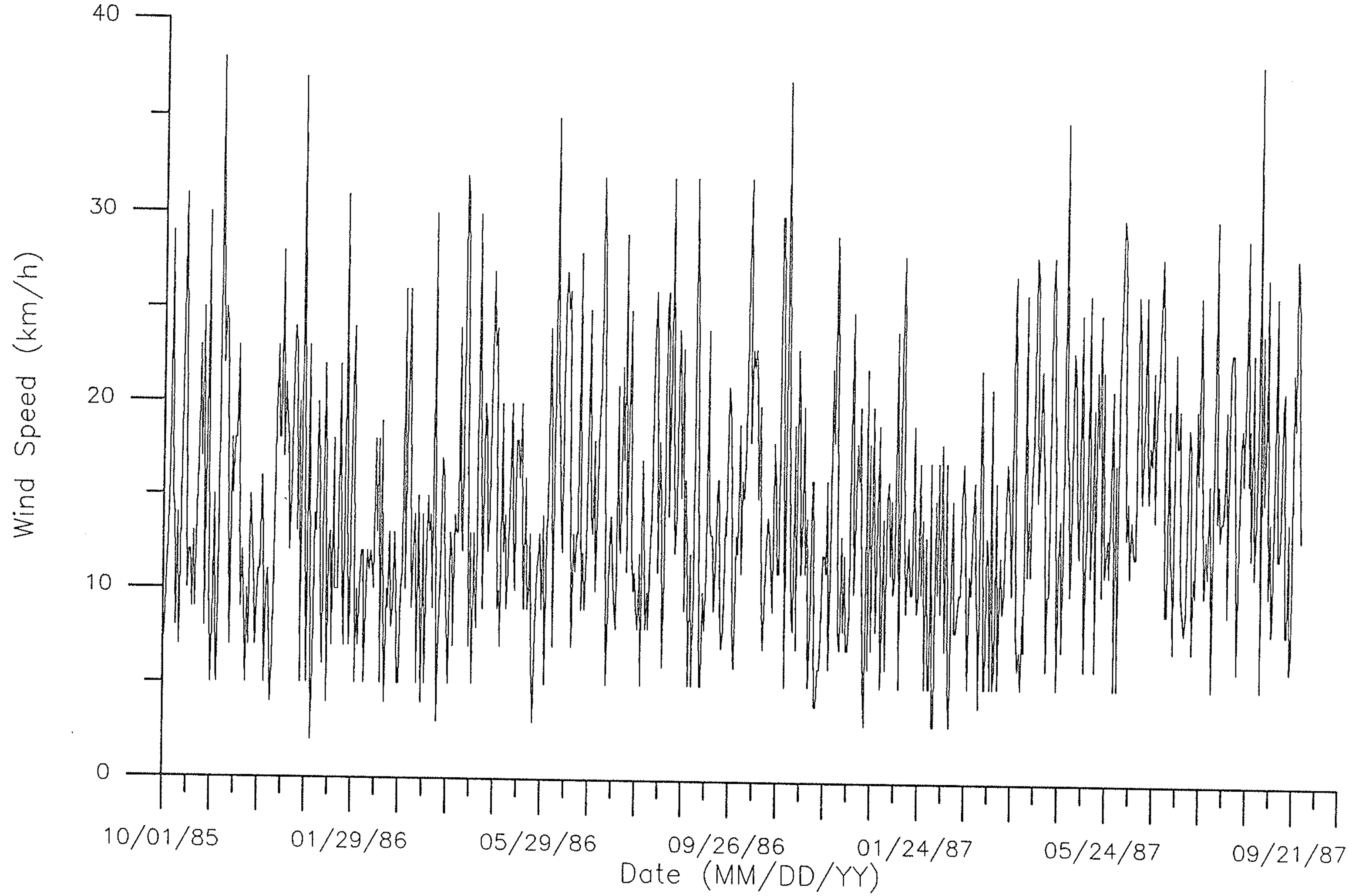

FIGURE 17 - Daily Average Wind Speed Used for Case Study Convective Boundary Condition Definitions

site, and the empirical relationship shown as Equation 18. This weather station was the closest location with measured wind data, as this information was not recorded at the construction site. The data is in the form of an average wind speed on a daily basis. Values for the period of the analysis are shown plotted in Figure 17. Some of the data in the Environment Canada listing was coded as "missing," typically on the last day of the month for months that have 31 days, and occasionally on other days as well. When this is encountered, a wind speed is assumed that results in a convection coefficient value of 240 kcal/m^2·day·°C. This converts to a wind speed of approximately 5.5 km/hr. This particular value of h_c has been used in other thermal studies of mass concrete structures as a constant convection coefficient throughout the entire time span of an analysis. No account of the direction of the wind or the effects of neighbouring structures has been taken in the case study analysis in any way.

5.6.4 Adiabatic Surfaces

Adiabatic surfaces are built into the model along the vertical edges of the foundation segment of the model, and also where earthfill is placed during progress on concrete work on the dam. Earthfill placement data shown in Appendix D was utilized to adopt an "average earthfill elevation reached" for each series of load steps on the model. The earthfill elevation was determined by interpolating between the known data points of earthfill progress, and then rounding to a discrete model line number from the mesh definition. At the location of the plane of the model (assumed to be the centre of the NT2 block), the maximum elevation of earthfill is approximately el 68.1 m. Adopting an average elevation was done to simplify the configuration of convective surfaces in effect on the model during each series of load steps. A slight error is introduced because of this simplification since material placement may be ongoing during the time covered by a load step series. However, the impact of this is minor because the time spans involved are typically short. The assumed elevations of earthfill placement for each portion of the case study are shown in Table 9. A small error is introduced because the face of the earthfill material along the north transition is in fact on a slope. This has also been neglected in this case study.

Newest Segment of Model	Average Earthfill Elevation Reached (m)	Earthfill Elevation Used on Model (m)
Bedrock	--	0
NT2-1	--	0
NT2-2	--	0
NT2-3a/b	--	0
NT2-4	--	0
NT2-5	--	0
NT2-6	--	0
NT2-7	54.05	54
NT2-8a	63.75	64
NT2-8b	65.83	66
NT2-9	66.7	66
NT2-10-1	66.7	66
NT2-10-2	66.7	66
NT2-10-3	66.7	66
NT2-11	66.7	66
NT2-12	66.7	66
NT2-13	66.7	66
NT2-14	66.7	66
NT2-15	68.1	68

TABLE 9 - Earthfill Elevations Reached for Load Step Series on the Case Study Structure

There is only one other occurrence of adiabatic lines in the case study model, and that is the surfaces of the gallery in lift NT2-3a/b after lift NT2-4 is placed. It is possible that the gallery may or may not have been exposed to air temperatures close to ambient at various times, or the forms may have been left in place inside the gallery for an extended period of time, and so on. During the winter of 1986-1987, the gallery was unventilated and air temperatures followed the that of the adjacent concrete[121]. No other reasonable information was available about the prevailing ambient conditions inside the gallery to use for defining convections. Neglecting convection on the gallery also simplifies the number of convections that are specified for each load step.

Convective boundary conditions are deleted at the end of each series of load steps so that definition of the next series can be started with no convective loads existing on the model. Illustrations of the boundary condition configurations on the model for six different series of load steps are shown on node plots in Figures 18 to 23 for lifts NT2-1, NT2-3a/b, NT2-7, NT2-9, NT2-11 and NT2-15, respectively. On the figures, triangles are shown where nodal temperature boundary conditions are assigned and lines where convections are applied. Specified internal heat generation rates are not shown. The presence of earthfill materials can be seen beginning with lift NT2-7 (Figure 20). Lift initializing nodal temperature boundary conditions are applied to bottom nodes of each concrete lift and so appear to coincide with the convective surface.

5.7 Load Steps and Iterations

The case study starts with a series of load steps on the foundation portion of the model to establish a temperature distribution in the bedrock for the time the first lift of concrete is placed. Time 0.0 is taken to be October 1, 1985, so that the foundation can be loaded through the winter prior to the start of concrete placement. The first load step includes the foundation isothermal and lift temperature initializing boundary conditions, and a convective load on the bedrock to an ambient temperature of 0°C. The measured median ambient temperature on this date was 5°C, but 0°C is used since it is felt that the 5°C value would result in an artificially warm foundation to begin the analysis. The frequency of load steps during foundation loading varies as a way of reducing execution time, and is as shown in Table 10. In all cases during foundation loading, there are four iteration solutions of temperatures in the model per load step.

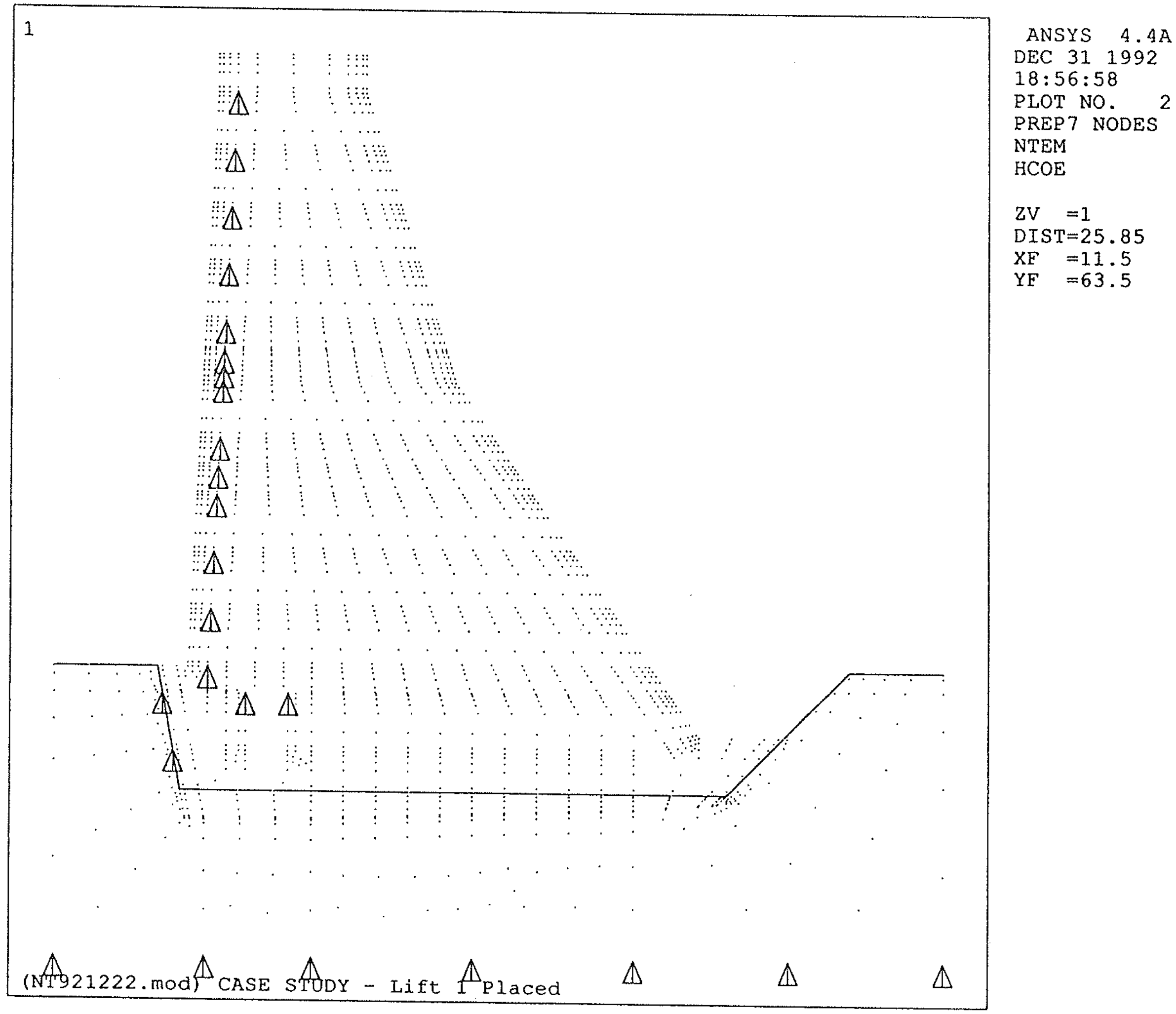

FIGURE 18 - Boundary Condition Configuration for Case Study Analysis Load Step Series With Lift NT2-1 in Place

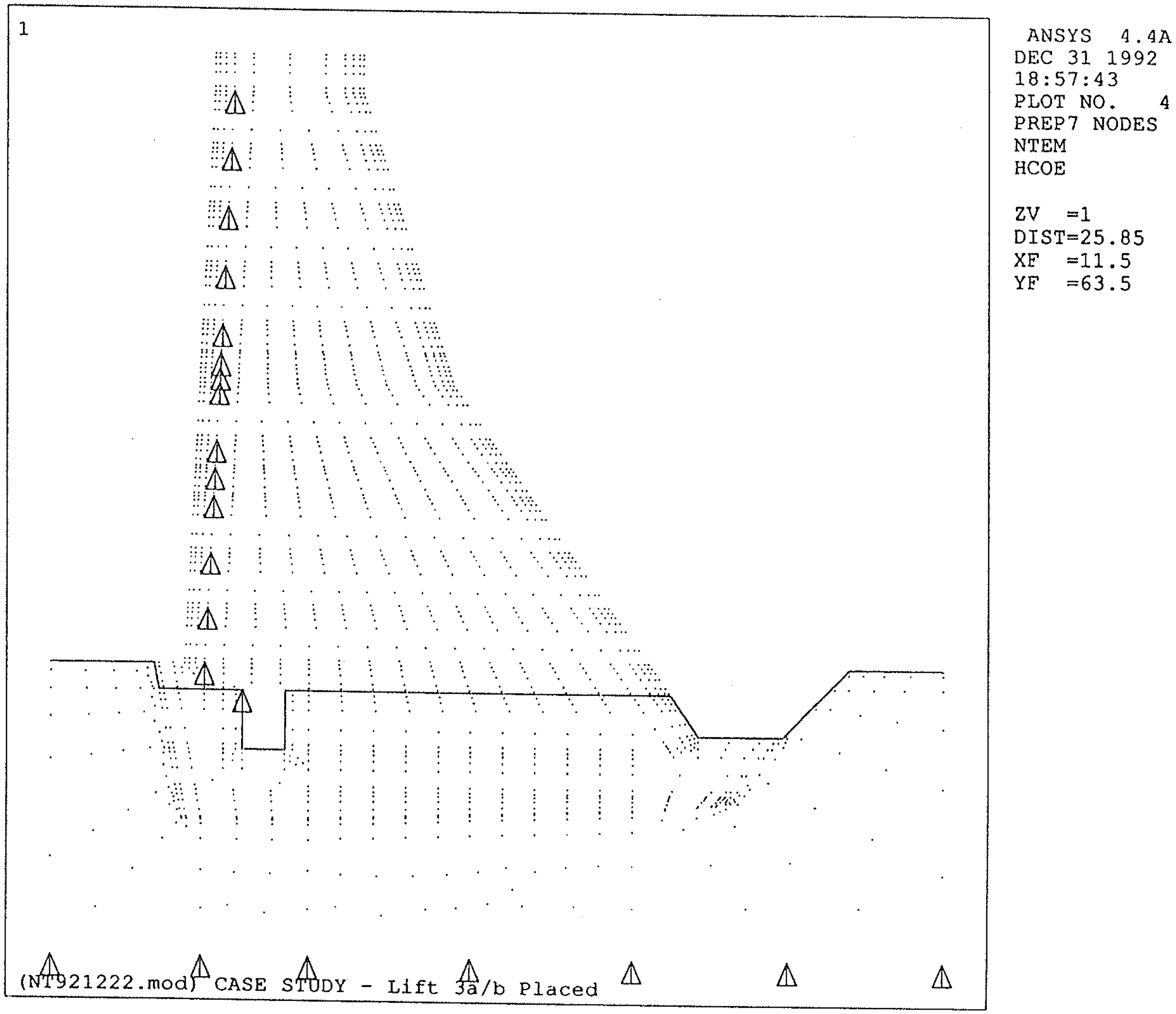

FIGURE 19 - Boundary Condition Configuration for Case Study Analysis Load Step Series With Lift NT2-3a/b in Place

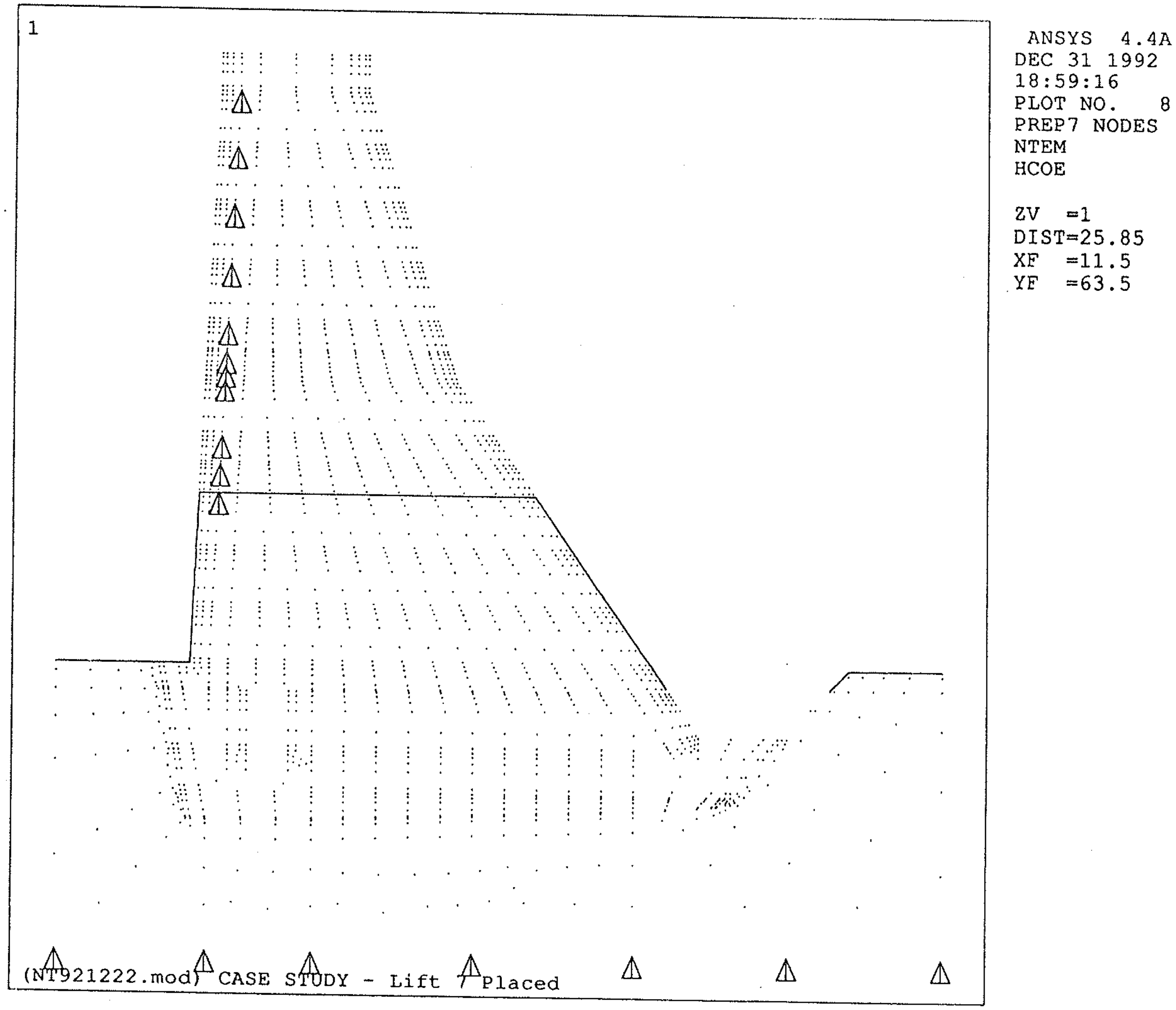

FIGURE 20 - Boundary Condition Configuration for Case Study Analysis Load Step Series With Lift NT2-7 in Place

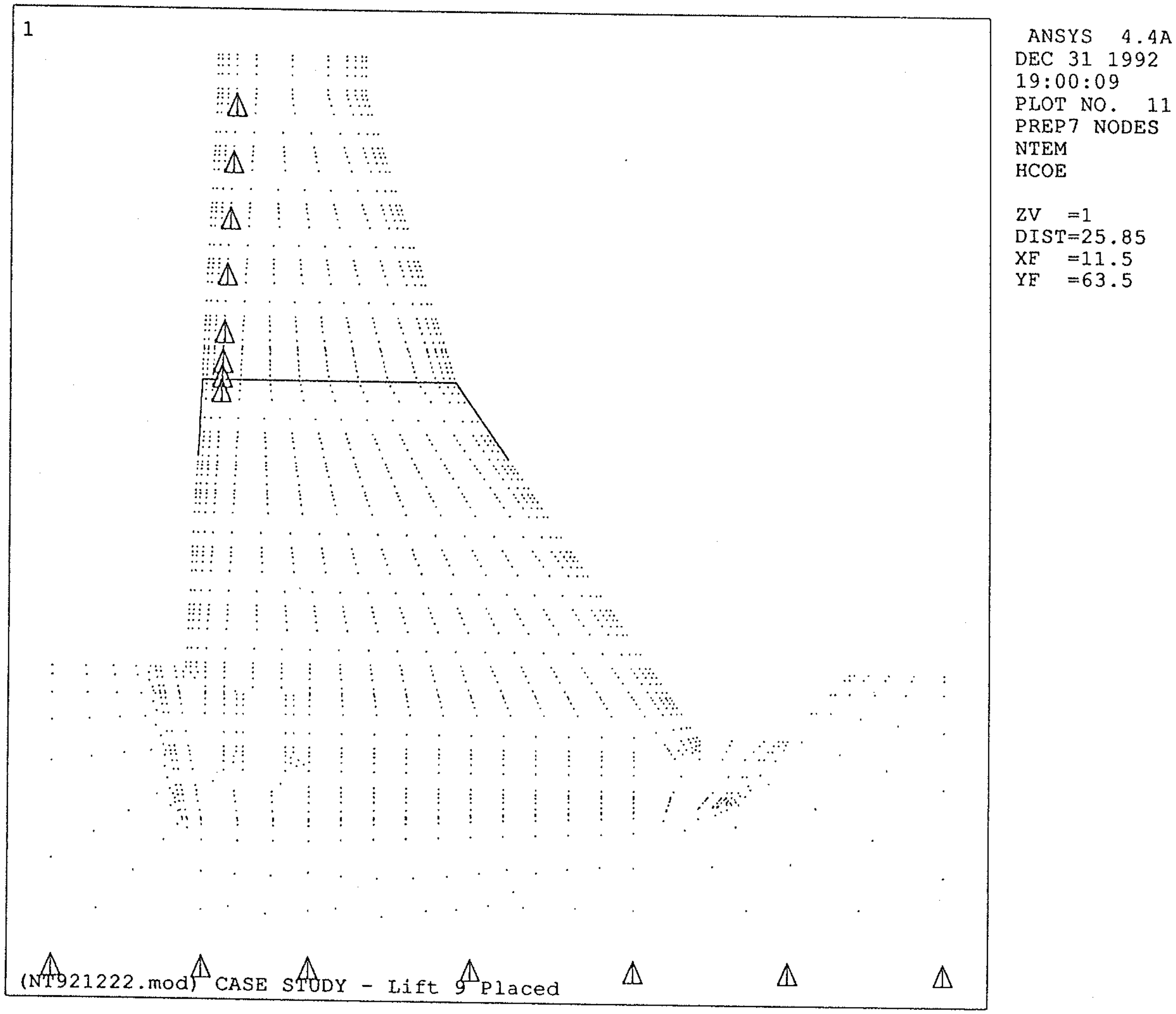

FIGURE 21 - Boundary Condition Configuration for Case Study Analysis Load Step Series With Lift NT2-9 in Place

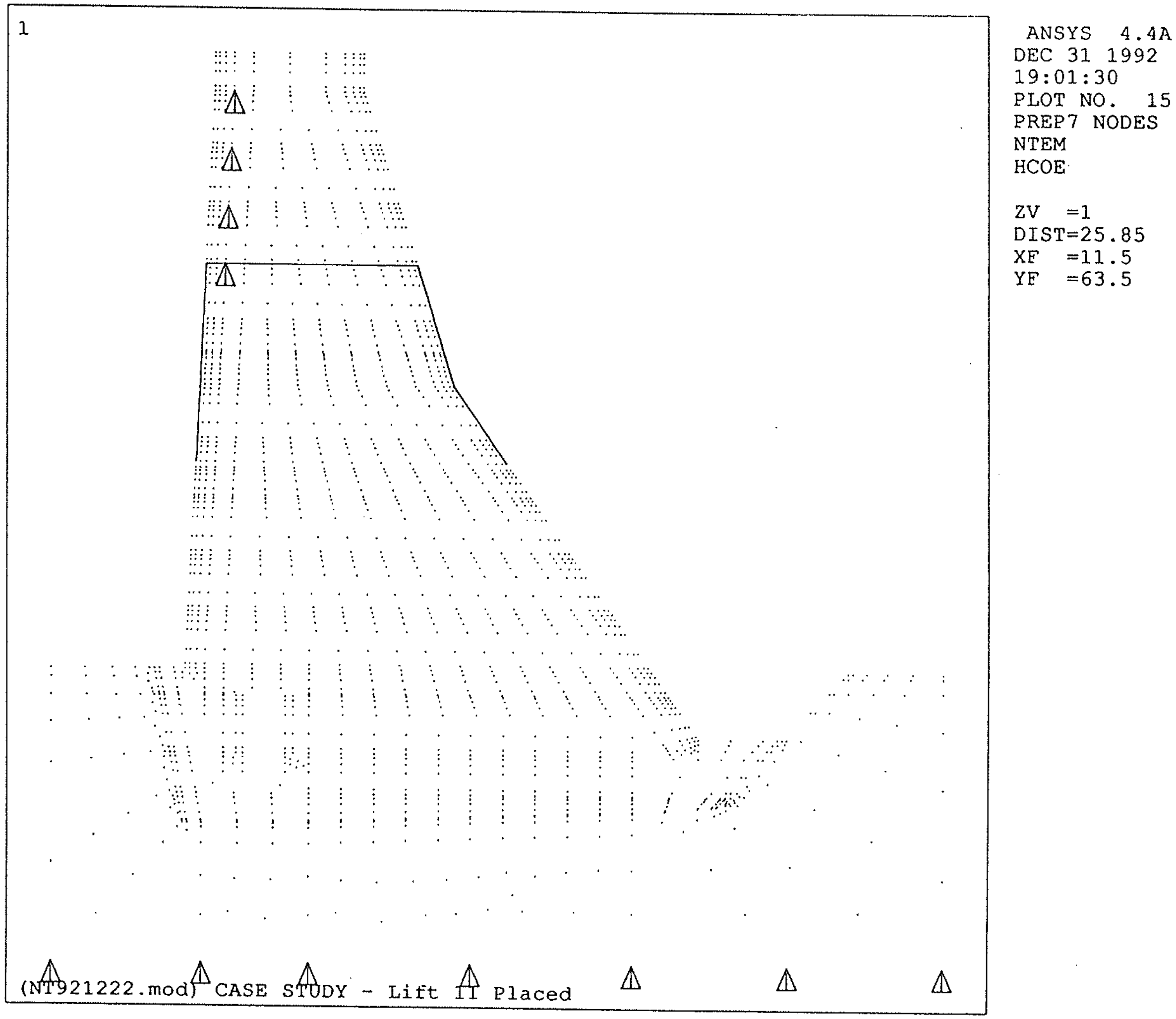

FIGURE 22 - Boundary Condition Configuration for Case Study Analysis Load Step Series With Lift NT2-11 in Place

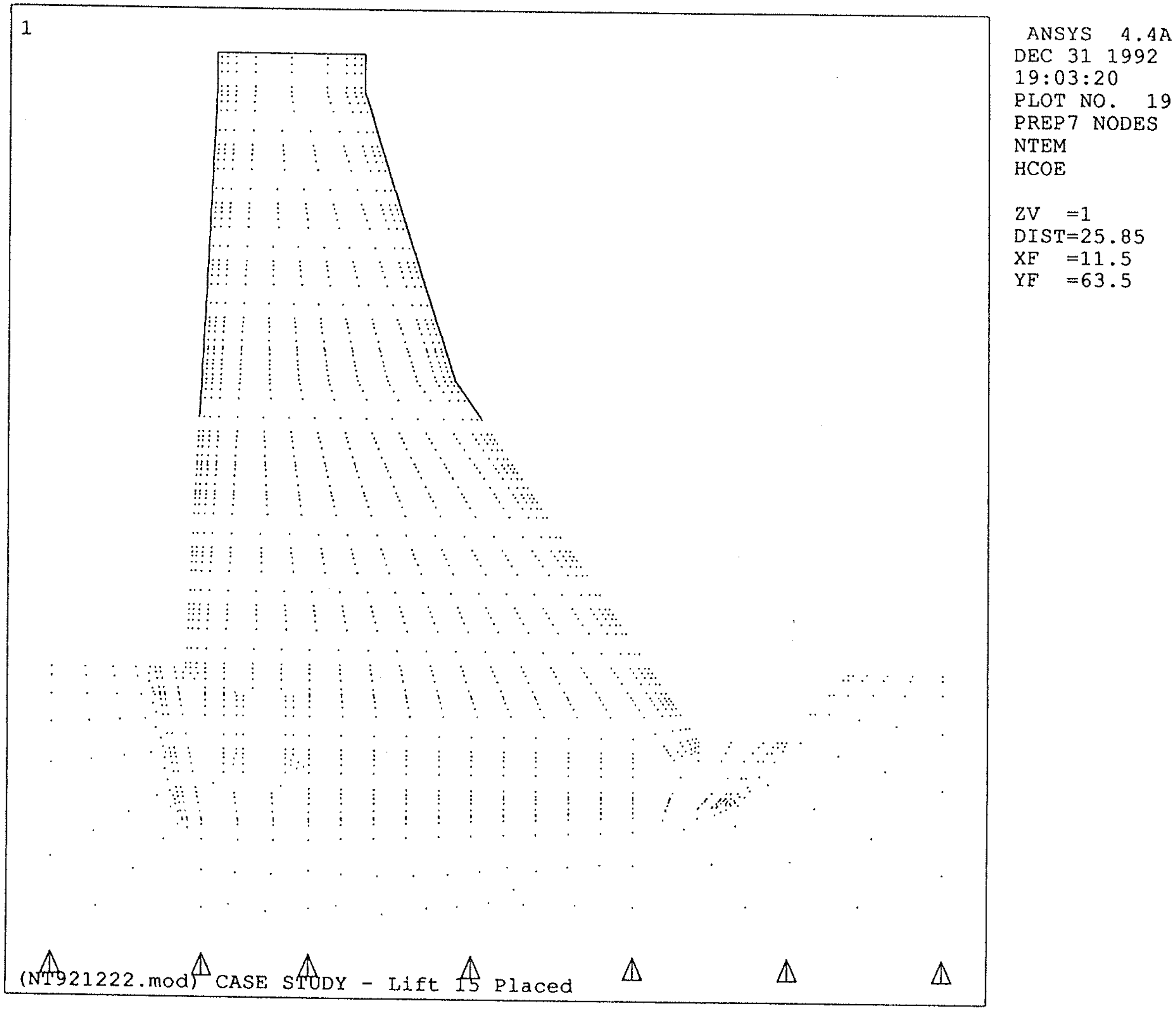

FIGURE 23 - Boundary Condition Configuration for Case Study Analysis Load Step Series With Lift NT2-15 in Place

Time Period	Frequency of Load Steps
October 1, 1985 to April 22, 1986	One per week
April 26, 1986 to May 20, 1986	One every four days
May 22, 1986 to June 11, 1986	One every two days
June 12, 1986 to June 16, 1986	One per day

TABLE 10 - Frequency of Load Steps for Foundation Loading During the Case Study Analysis

The remainder of the case study consists daily load steps defined with four iterations per load step. This, of course, translates into the calculation of a temperature solution for the dam every six hours through the two summers of construction activity and the intervening winter. The only exception to this load step and iteration pattern occurs when the analysis is stopped to add a new lift of concrete, and the first load step after the restart is specified at 0.1 days later than the previous load step to ensure that interpolation of boundary condition parameters takes place properly. This load step is solved for only one iteration.

The assumed placing dates for lifts of concrete in the case study are shown in Table 11. These times are selected as being those closest to the centroid of the placing operations as shown in Table D.2 of Appendix D.

5.8 Execution and Output Control

The case study includes two commands inserted near the start of the code defining the analysis to avoid the occurrence of an ANSYS "Class 3" error. This type of error causes numerical variations in calculation results, but is non-fatal to analysis execution. The two commands used to avoid the error are recommended by the authors of the finite element program. They are TREF for assigning a reference temperature for model calculations, and TUNIF for

Lift	Model Time Placed (days from 851001)	Model Date Placed (YYMMDD)
NT2-1	258	860616
NT2-2	267	860625
NT2-3a/b	279	860707
NT2-4	301	860729
NT2-5	308	860805
NT2-6	316	860813
NT2-7	323	860820
NT2-8a	368	861004
NT2-8b	372	861008
NT2-9	387	861023
NT2-10-1	563	870417
NT2-10-2	568	870422
NT2-10-3	575	870429
NT2-11	588	870512
NT2-12	597	870521
NT2-13	605	870529
NT2-14	610	870603
NT2-15	624	870617

TABLE 11 - Lift Placement Dates Assumed for Case Study Analysis

assigning a uniform temperature to model nodes. These commands are not required as part of an analysis and, other than avoiding the Class 3 error, have no effect on the thermal loading on the structure.

As a means of reducing total memory requirements to run the analysis, only selected iteration solutions are written to the post-data file, file12.dat, for later reference. In general, beginning with load step series on concrete lifts of the structure, the first load step solution is written to the file, and then the fourth iteration solution of every second load step is also written to file. The solution to the last iteration of the last load step in a series is also written to file12.dat to be available for later reference during post-processing. A detailed description of the memory management and post-data file handling operations carried out as part of the case study is presented in Appendix E.

A complete listing of the program code that defines, executes and post-processes results of the case study analysis is contained in Appendix F. A very brief explanation of the method used to efficiently create the analysis file is described in Appendix G.

5.9 Analysis Results

Results of the analysis are presented here in two forms. The first is comparison of measured in situ temperatures in the dam to temperatures calculated for particular nodes in the model through time. The second form is presentation of model temperature patterns through thermal contour plots at discrete points in time in the analysis. Since the comparisons to in situ data are most valuable for testing the reliability of the algorithm, this form of the analysis results is presented first. Some observations about the model behaviour and results are made in Section 5.10.

5.9.1 Comparison to In Situ Data

For each lift of concrete in the model, interior and exterior nodes were selected for the creation of temperature listings through time after completion of the analysis. The nodes used are shown in Figure 24. Two exterior nodes were identified from each lift, a node on the top surface and at either the upstream or downstream face of each lift, and a near-surface node from the same element as the surface node but diagonally opposite the surface node. The temperature values of the surface nodes can be expected to follow ambient temperatures until the time that the next concrete lift is placed or earthfill materials are placed against the dam. The near-surface nodes should also follow ambient temperatures, but will vary slightly by being set back from the surface of the concrete lift.

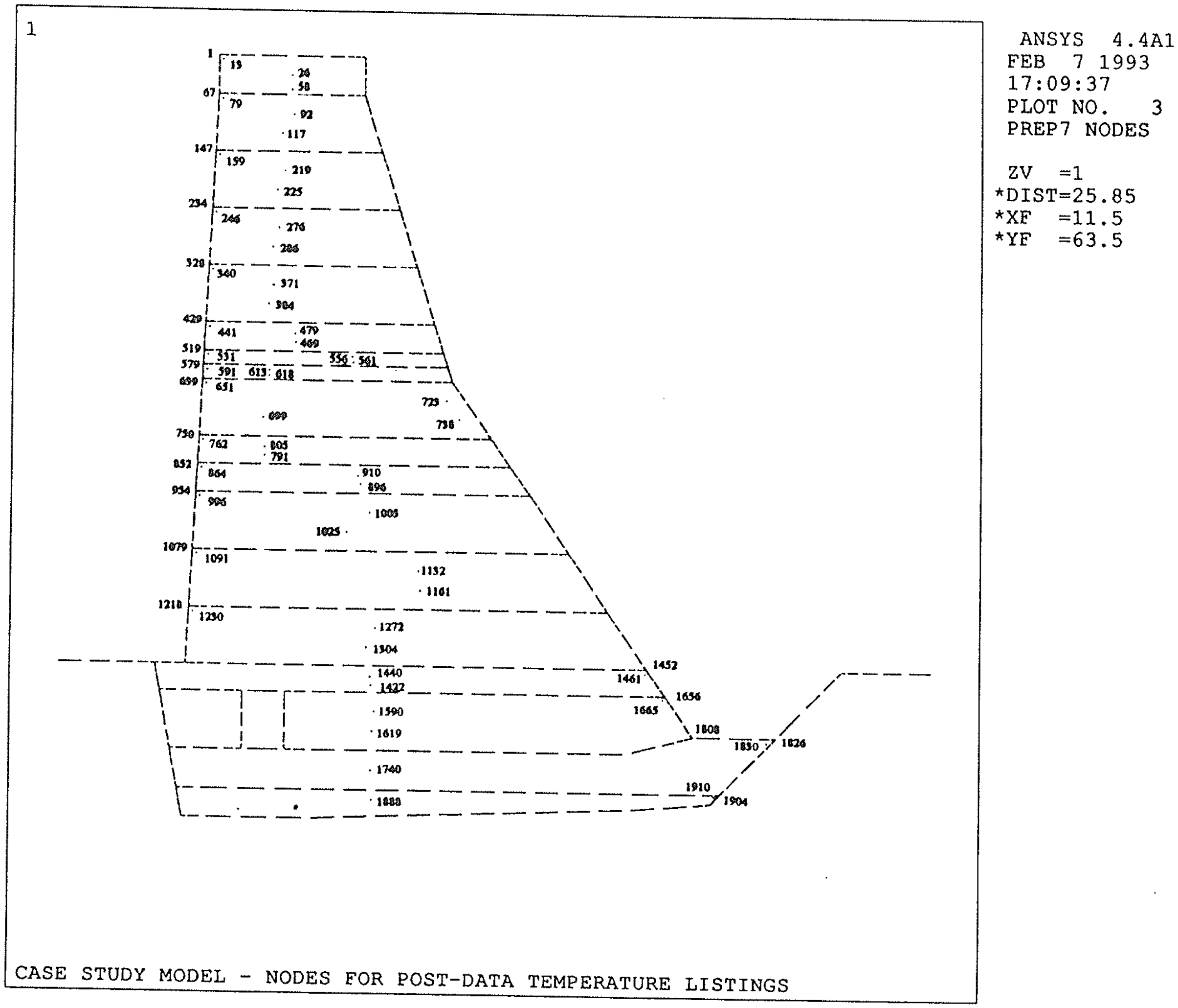

FIGURE 24 - Case Study Model Nodes Used to Create Temperature Listings of Analysis Results

Interior nodes that were judged to be in approximately the same locations as the site thermocouples were also identified for the creation of temperature listings. These nodes are shown in Figure 24 as well. It was not important to obtain a precise correlation between model nodes and the thermocouple locations in the dam. This is because the thermocouple locations are not known in exact terms, and because there is some range in the horizontal direction of locations within the cores of the lifts where thermal behaviour is uniform at early ages. Temperature listings for lifts that are 3 m thick were made for nodes at heights in the lifts of 1 m and 2 m, since the model has no nodes at the mid-height of these lifts. Other lifts were done in a similar manner if mid-height nodes are not present in the lifts. For lift NT2-9, temperature listings were made for nodes both in the core class E concrete and the class B concrete along the downstream face because of the uncertainty in the location of the thermocouple for this lift.

Comparisons between the measured in situ data and the calculated model temperatures for selected lifts of the dam are shown in Figures 25 to 32. A complete set of comparisons for all lifts is contained in Appendix H. A plot of the core temperatures for all lifts placed in 1986 is shown in Figure 33, and for lifts placed in 1987 in Figure 34. The patterns of internal temperatures in Figures 33 and 34 can be compared to those of the thermocouples shown in Figures 8 and 9.

5.9.2 Thermal Contour Plots

A series of thermal contour plots were created at discrete points in time in the analysis to illustrate temperature conditions within the dam during construction. A variety of these plots are included here as Figures 35 to 56. On the Figures, assorted information is listed along the right side of the plot as follows. The parameters STEP, ITER and TIME indicate the particular load step and iteration number, and analysis time that the plot is created from. The minimum

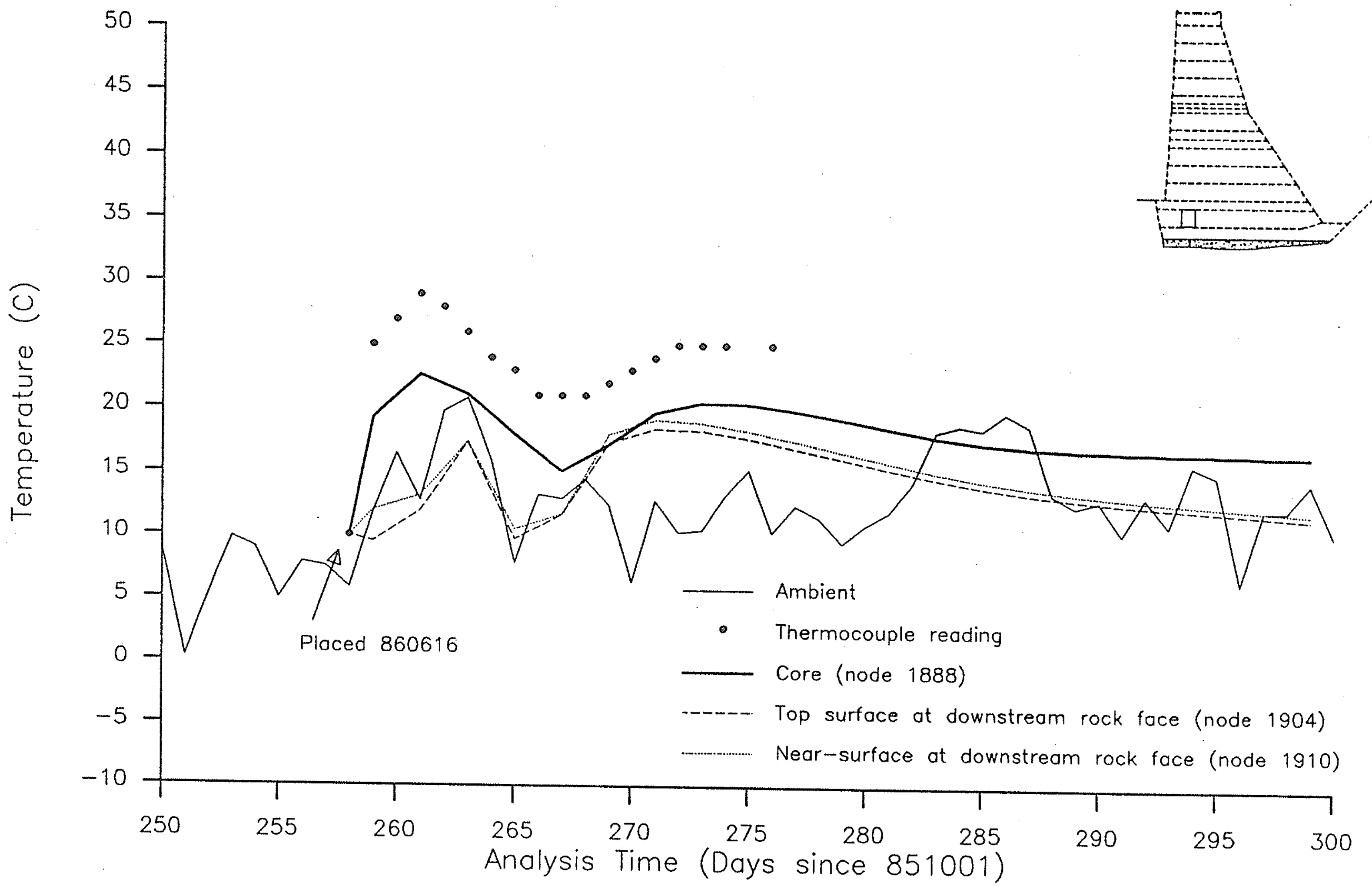

FIGURE 25 - Comparison of Case Study Analysis Results to Measured In Situ Data for Lift NT2-1

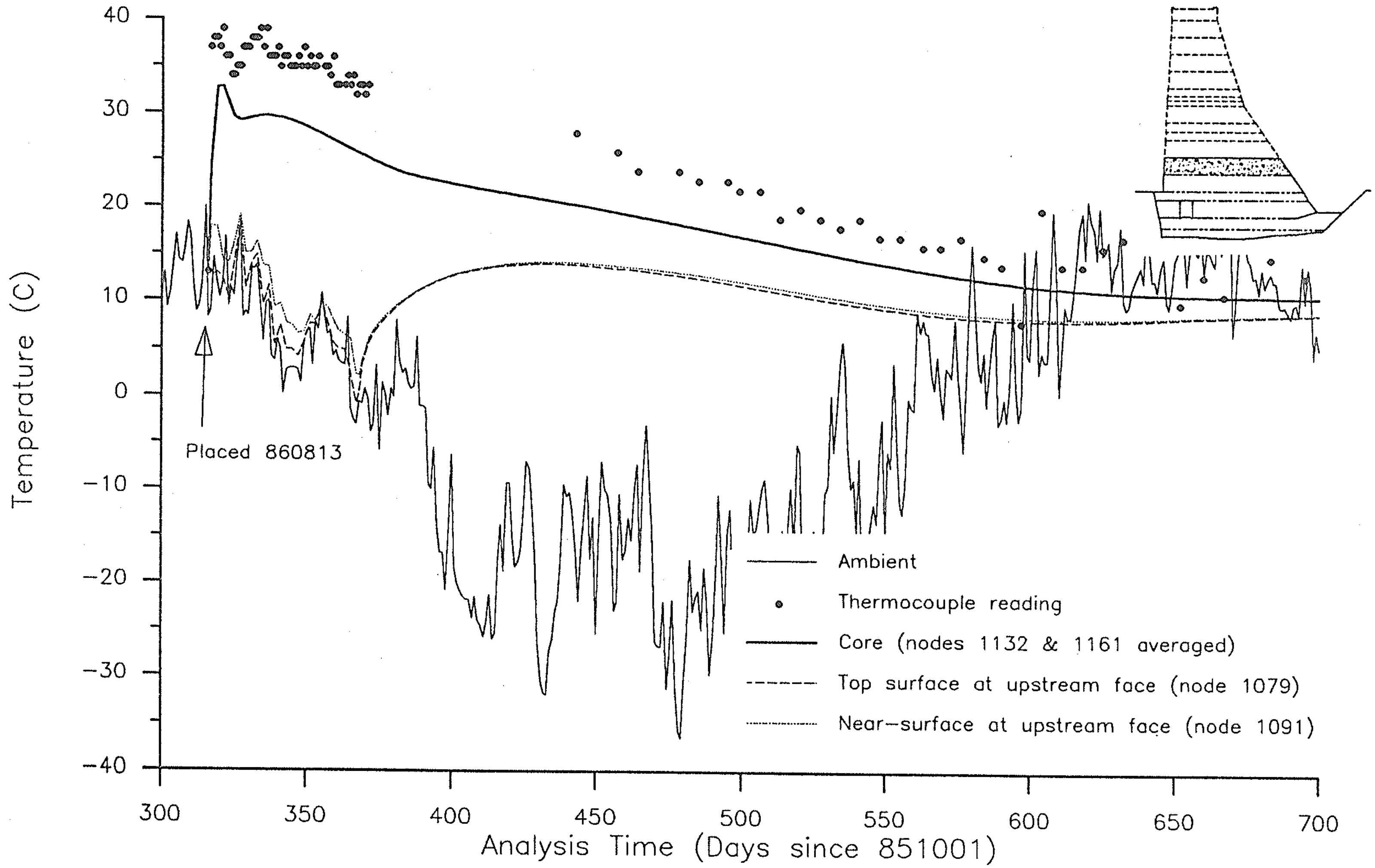

FIGURE 26 - Comparison of Case Study Analysis Results to Measured In Situ Data for Lift NT2-6

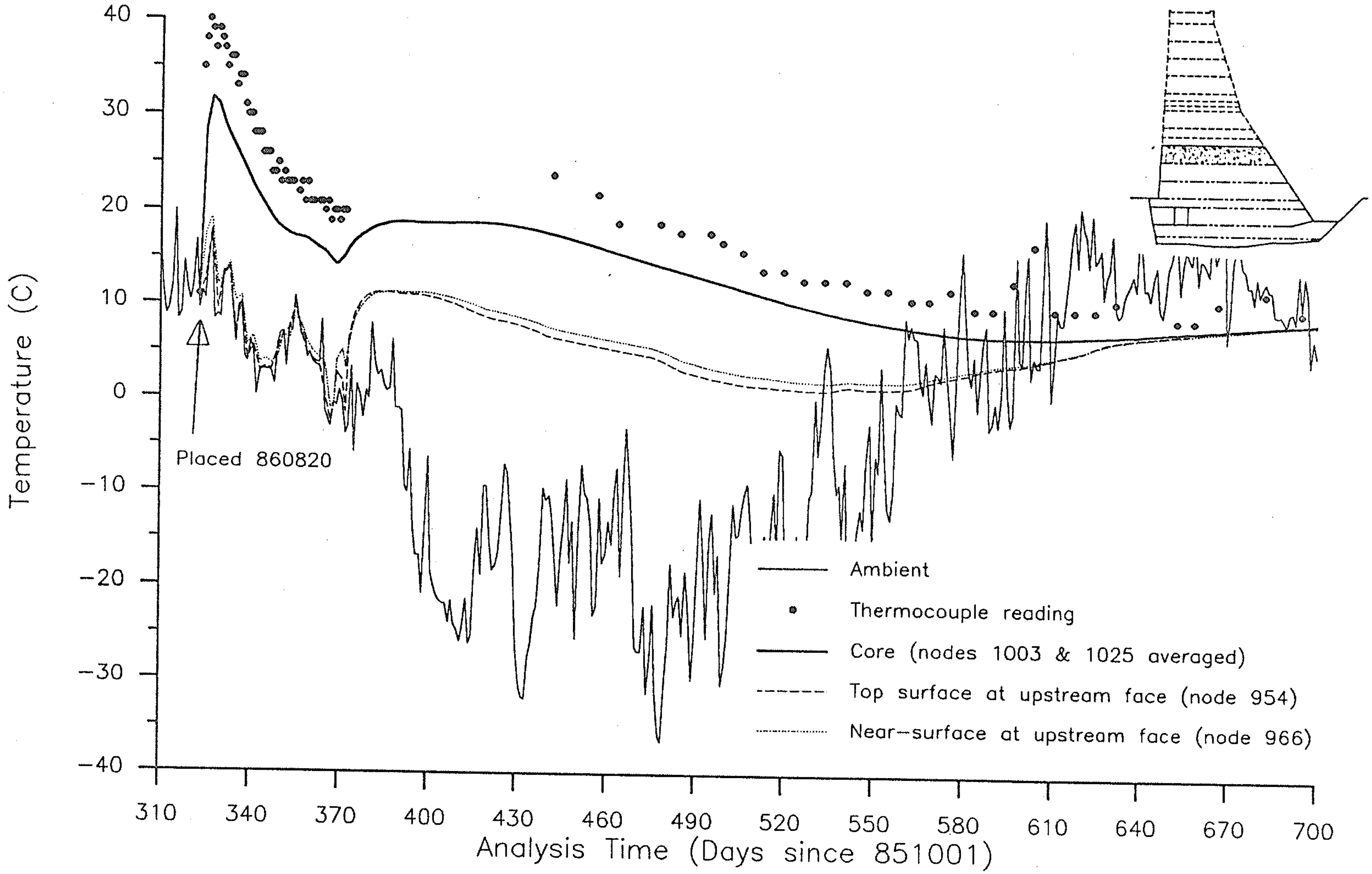

FIGURE 27 - Comparison of Case Study Analysis Results to Measured In Situ Data for Lift NT2-7

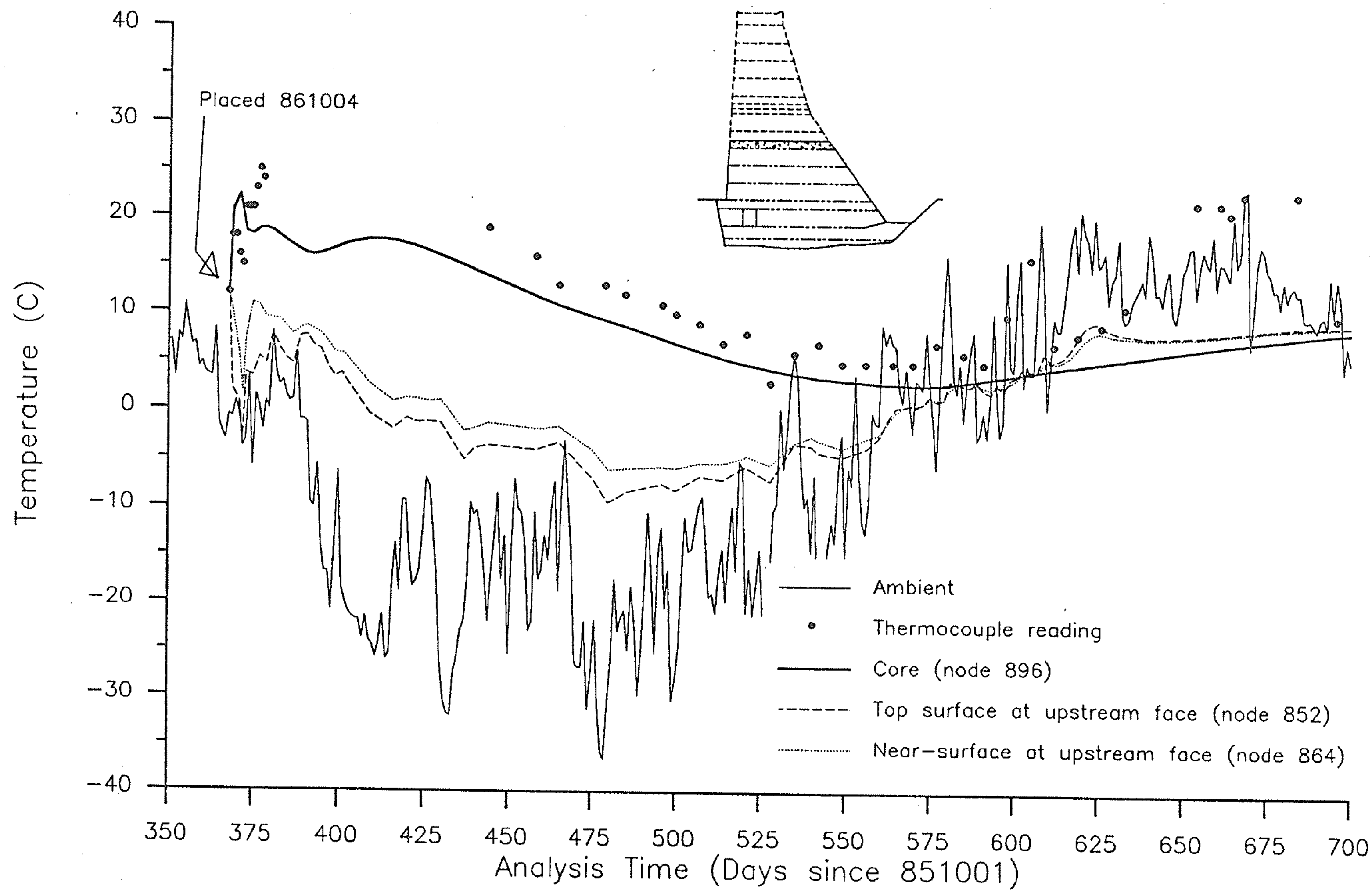

FIGURE 28 - Comparison of Case Study Analysis Results to Measured In Situ Data for Lift NT2-8a

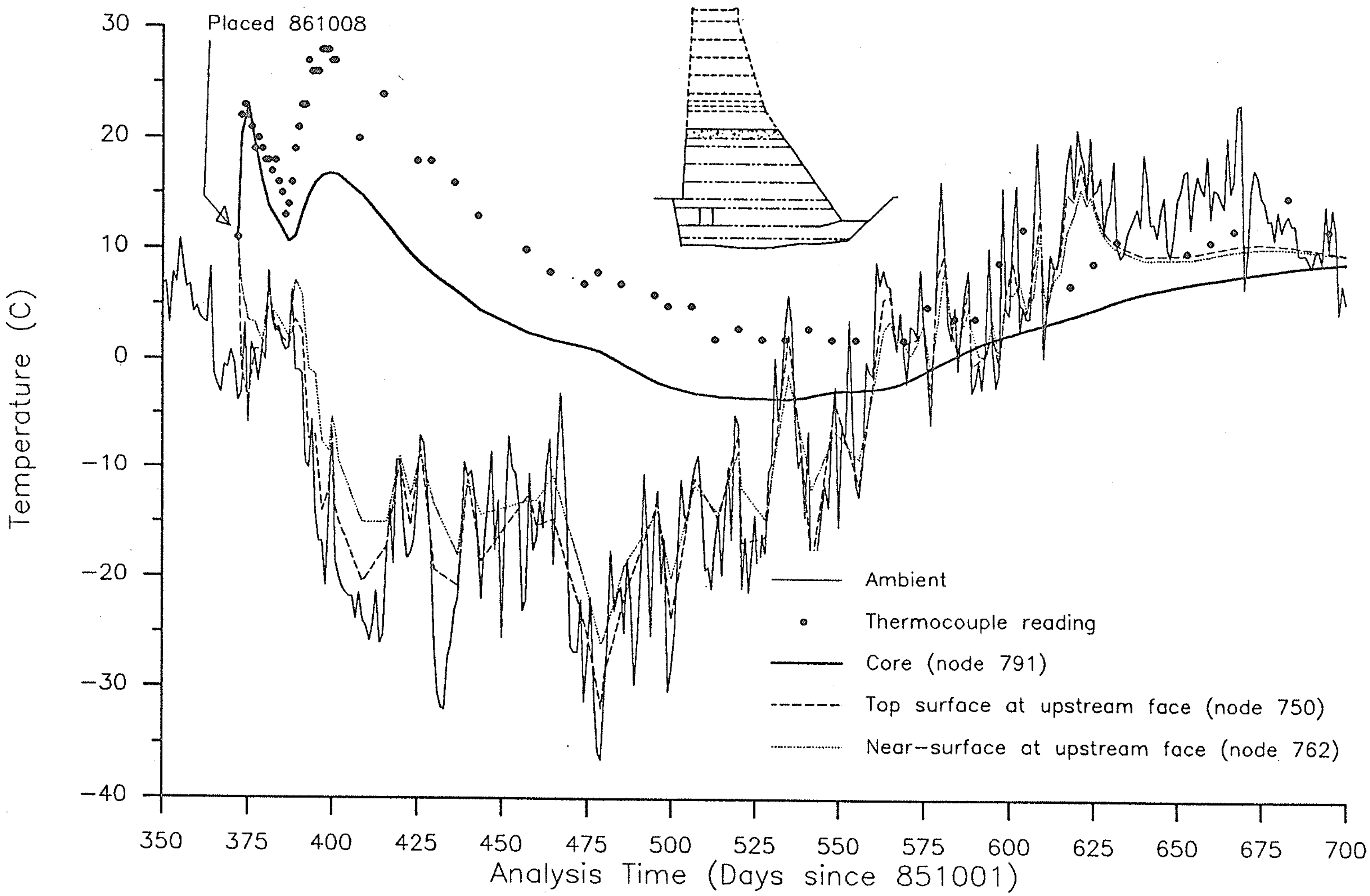

FIGURE 29 - Comparison of Case Study Analysis Results to Measured In Situ Data for Lift NT2-8b

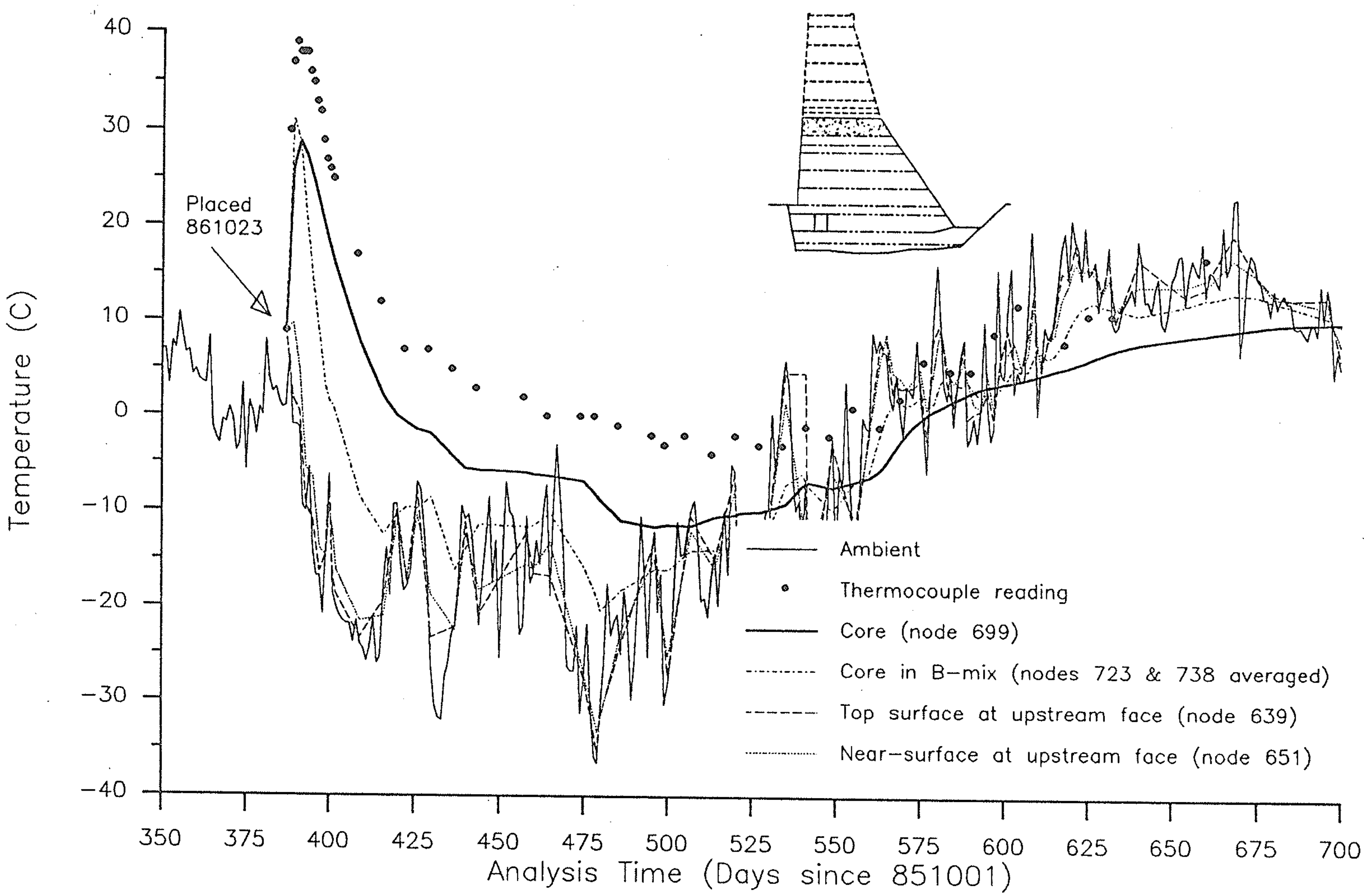

FIGURE 30 - Comparison of Case Study Analysis Results to Measured In Situ Data for Lift NT2-9

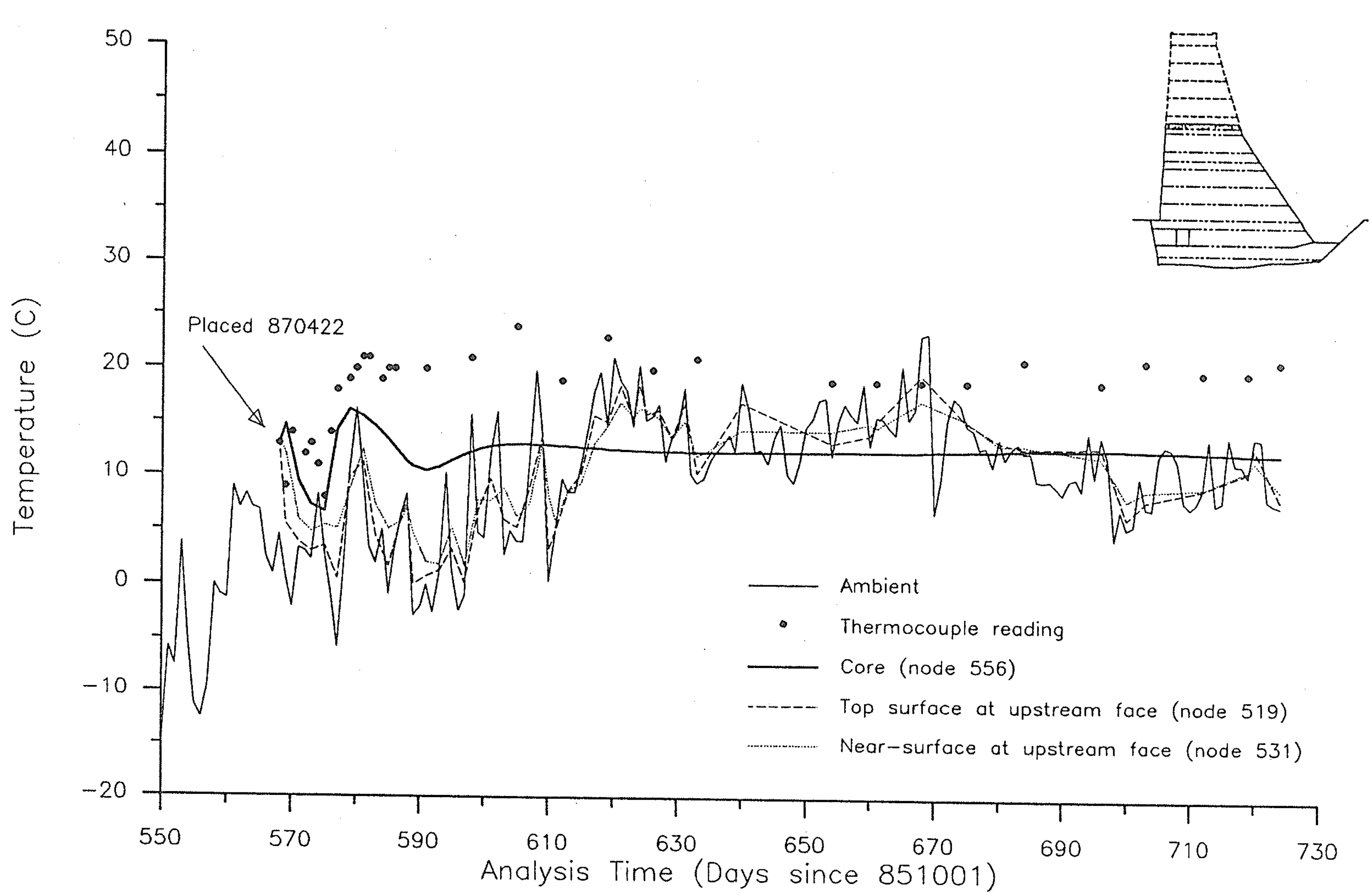

FIGURE 31 - Comparison of Case Study Analysis Results to Measured In Situ Data for Lift NT2-10-2

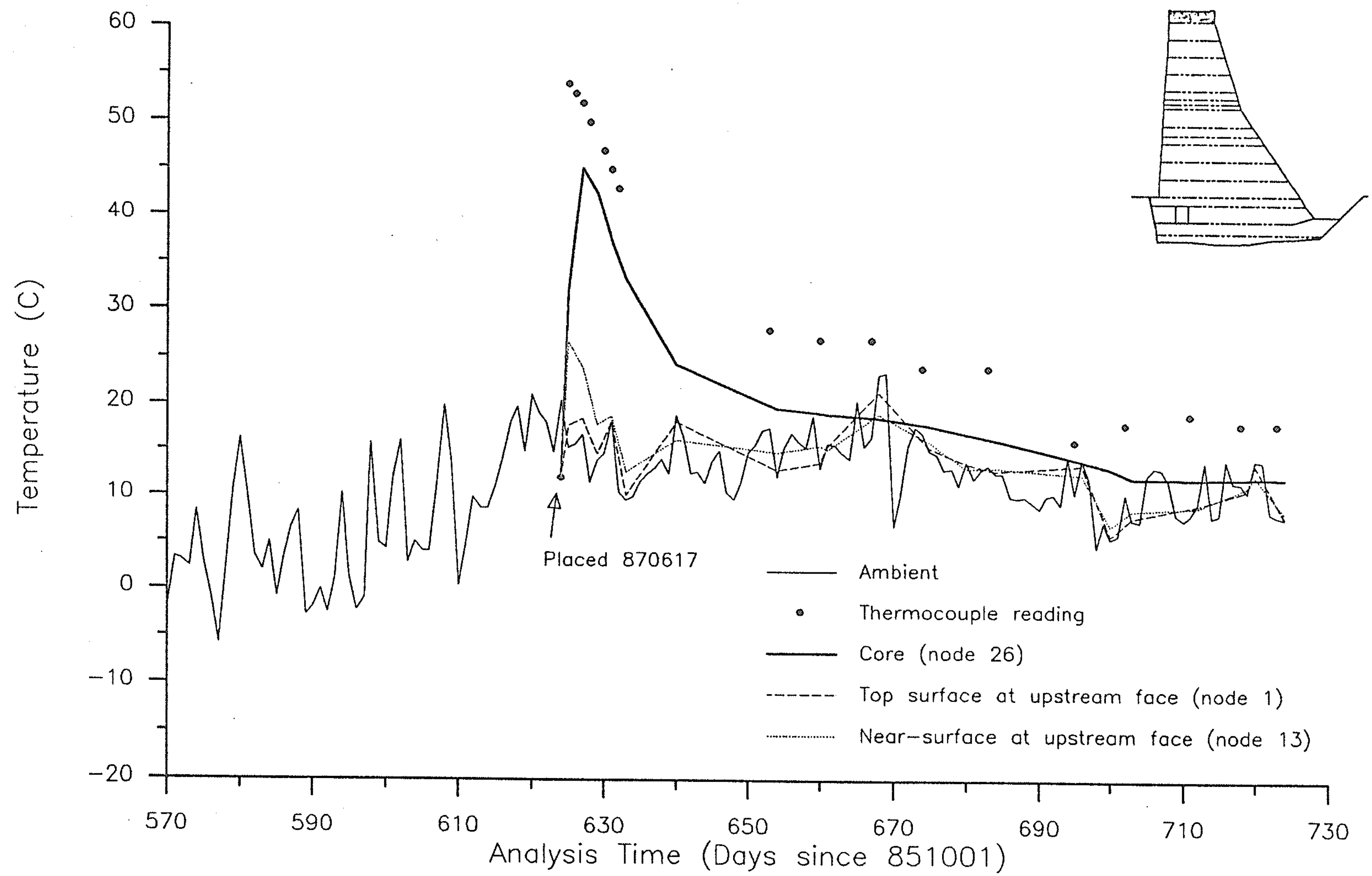

FIGURE 32 - Comparison of Case Study Analysis Results to Measured In Situ Data for Lift NT2-15

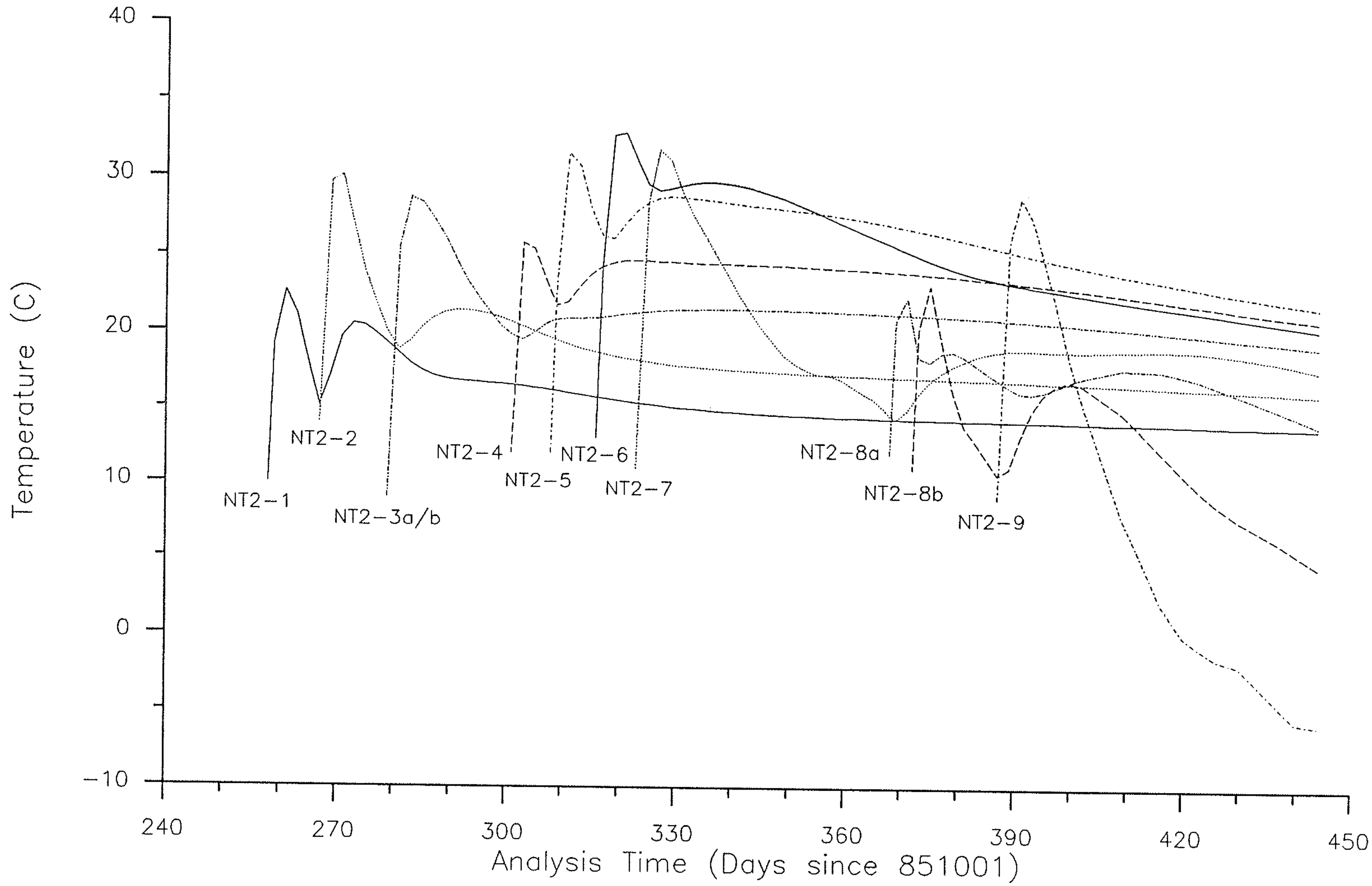

FIGURE 33 - Case Study Analysis Internal Temperatures for Concrete Lifts Placed in 1986

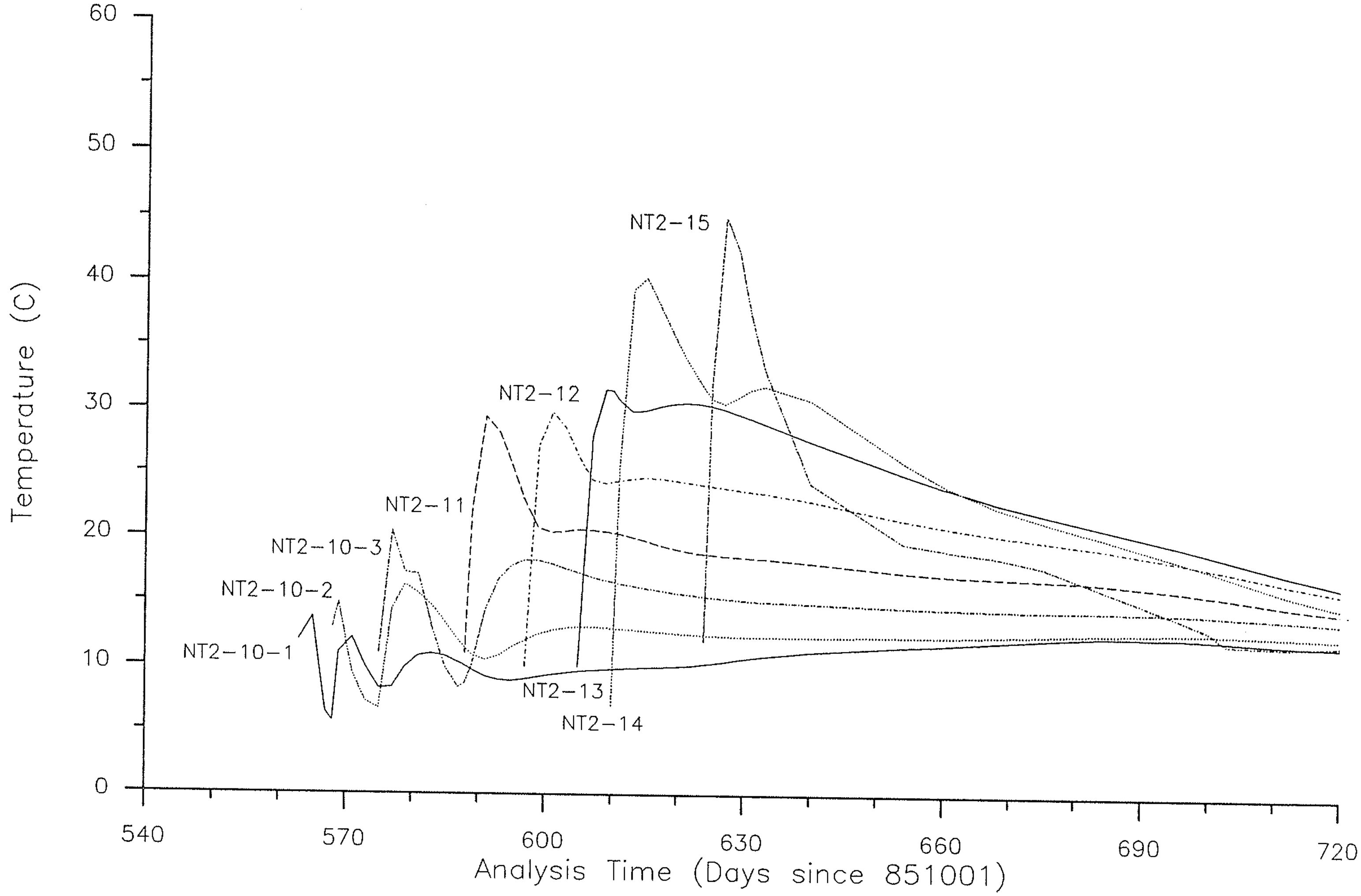

FIGURE 34 - Case Study Analysis Internal Temperatures for Concrete Lifts Placed in 1987

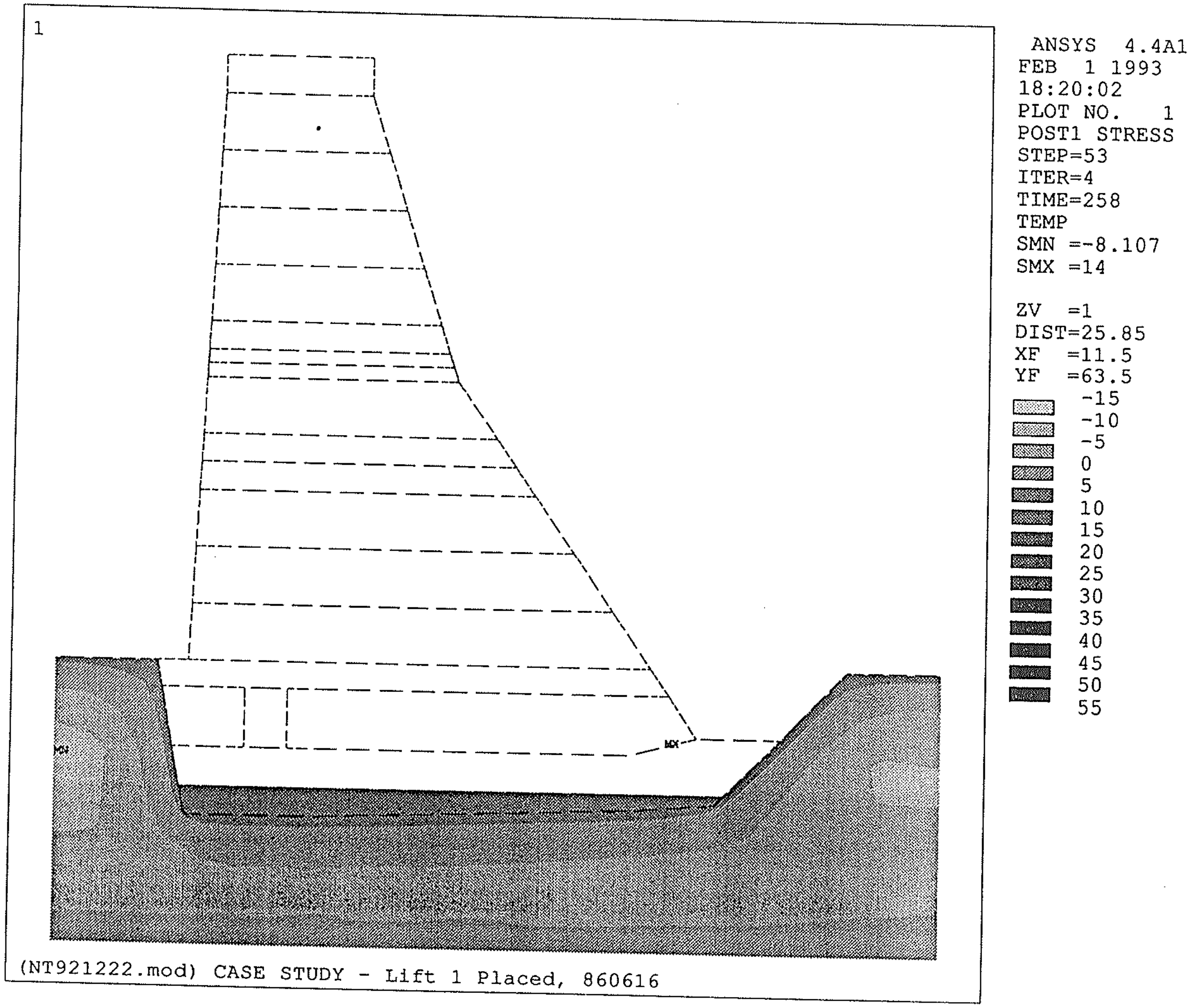

FIGURE 35 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 860616 (Day of Placement of Lift NT2-1)

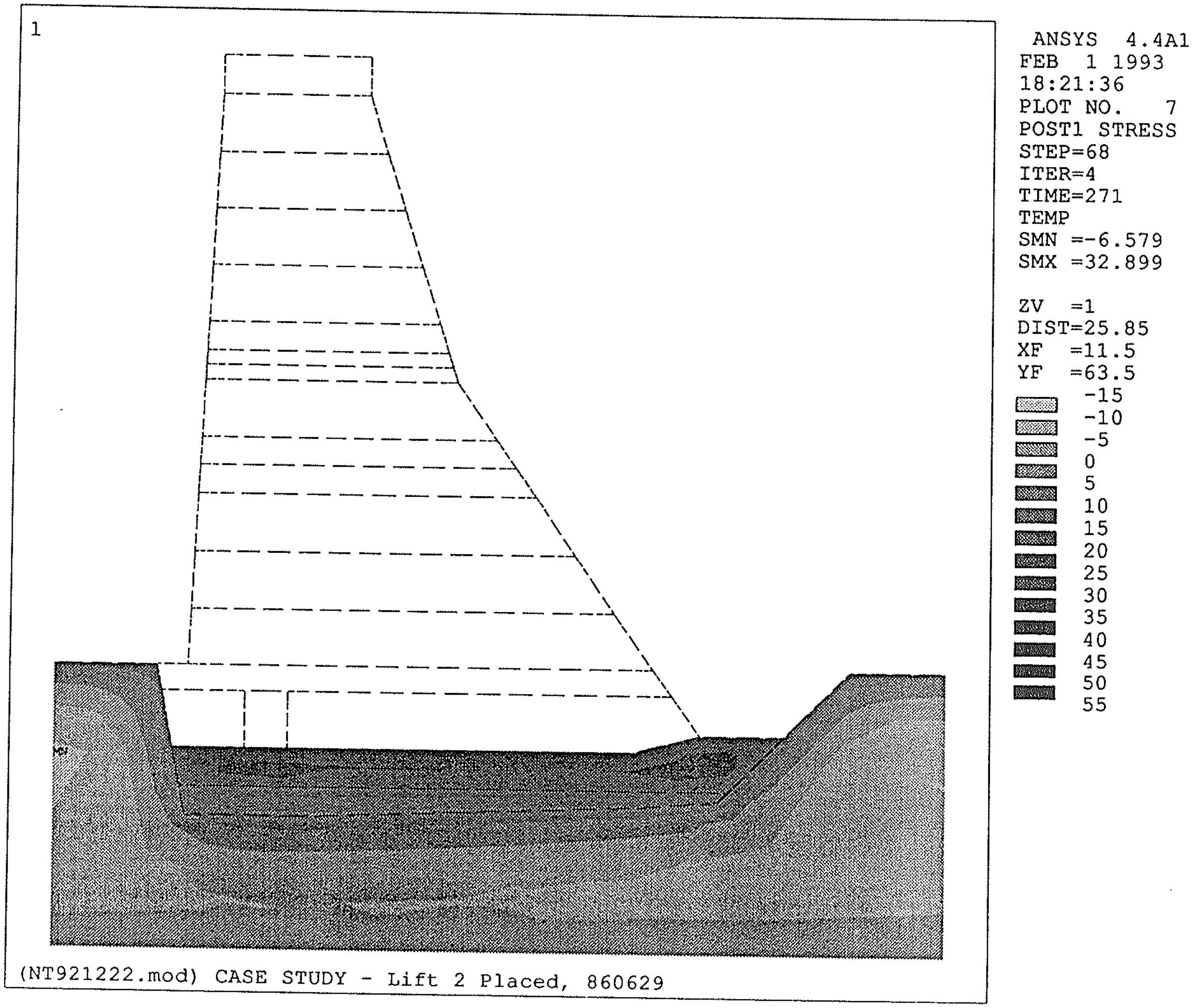

FIGURE 36 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 860629 (4 Days After Placement of Lift NT2-2)

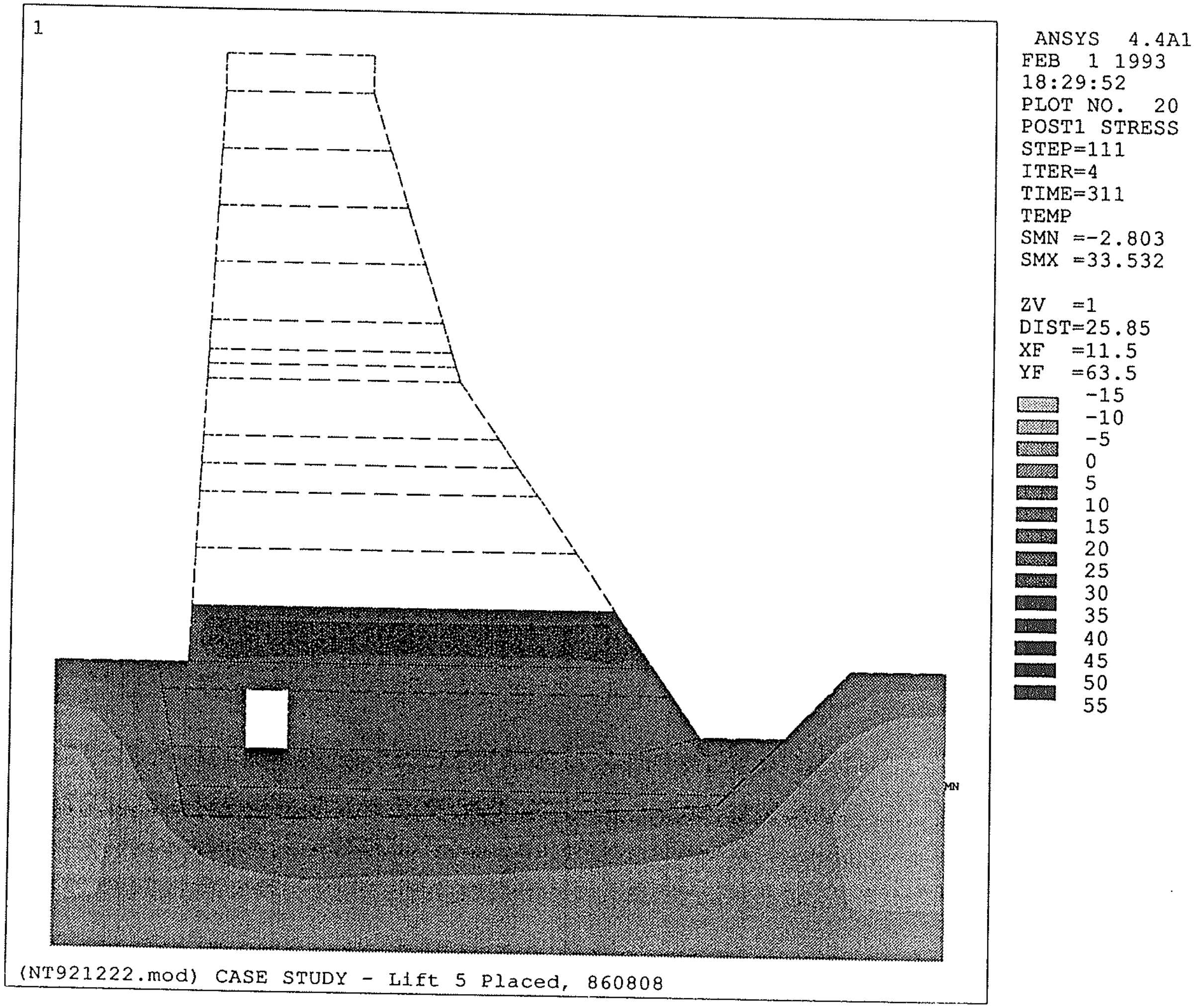

FIGURE 37 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 860808 (3 Days After Placement of Lift NT2-5)

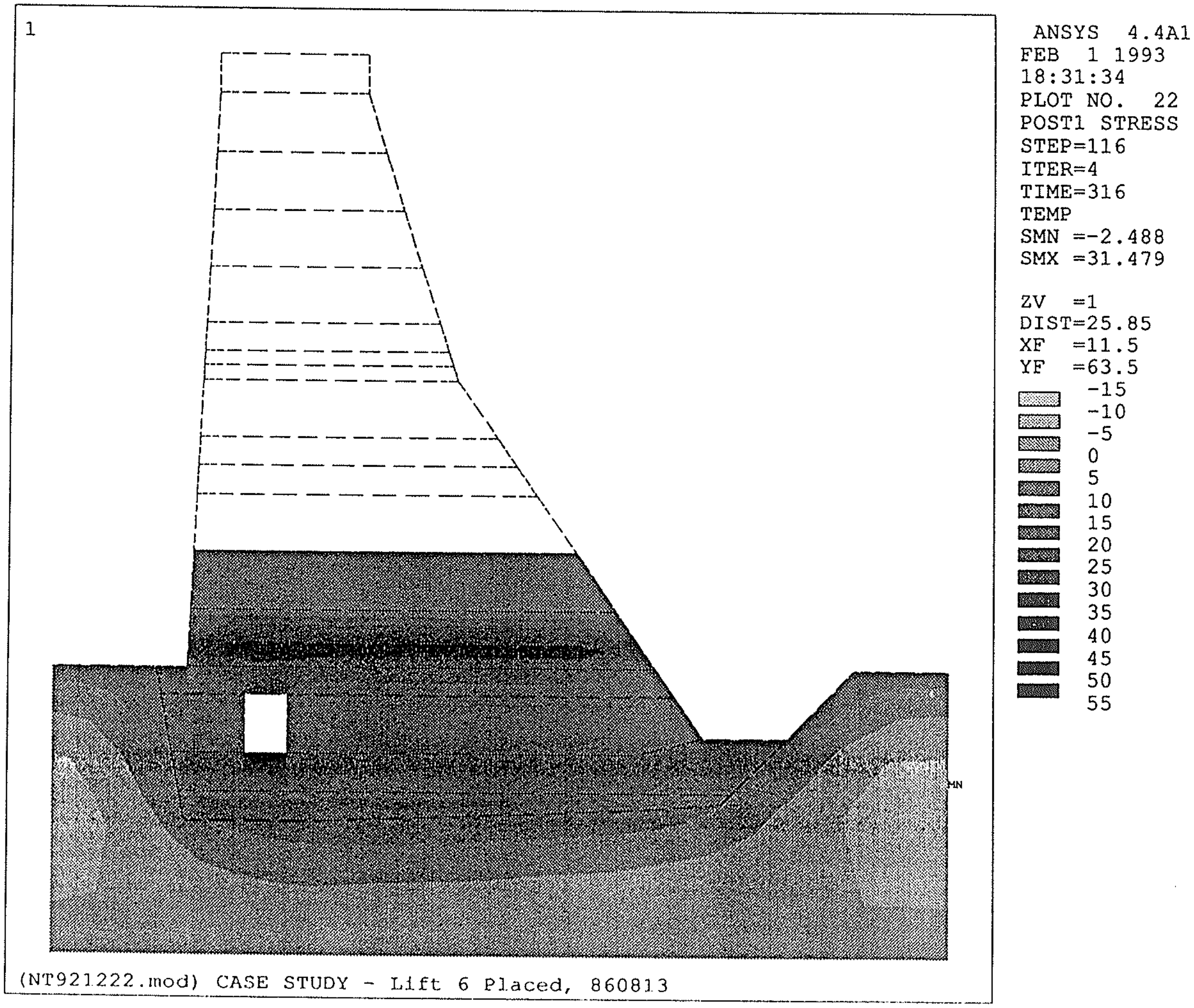

FIGURE 38 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 860813 (Day of Placement of Lift NT2-6)

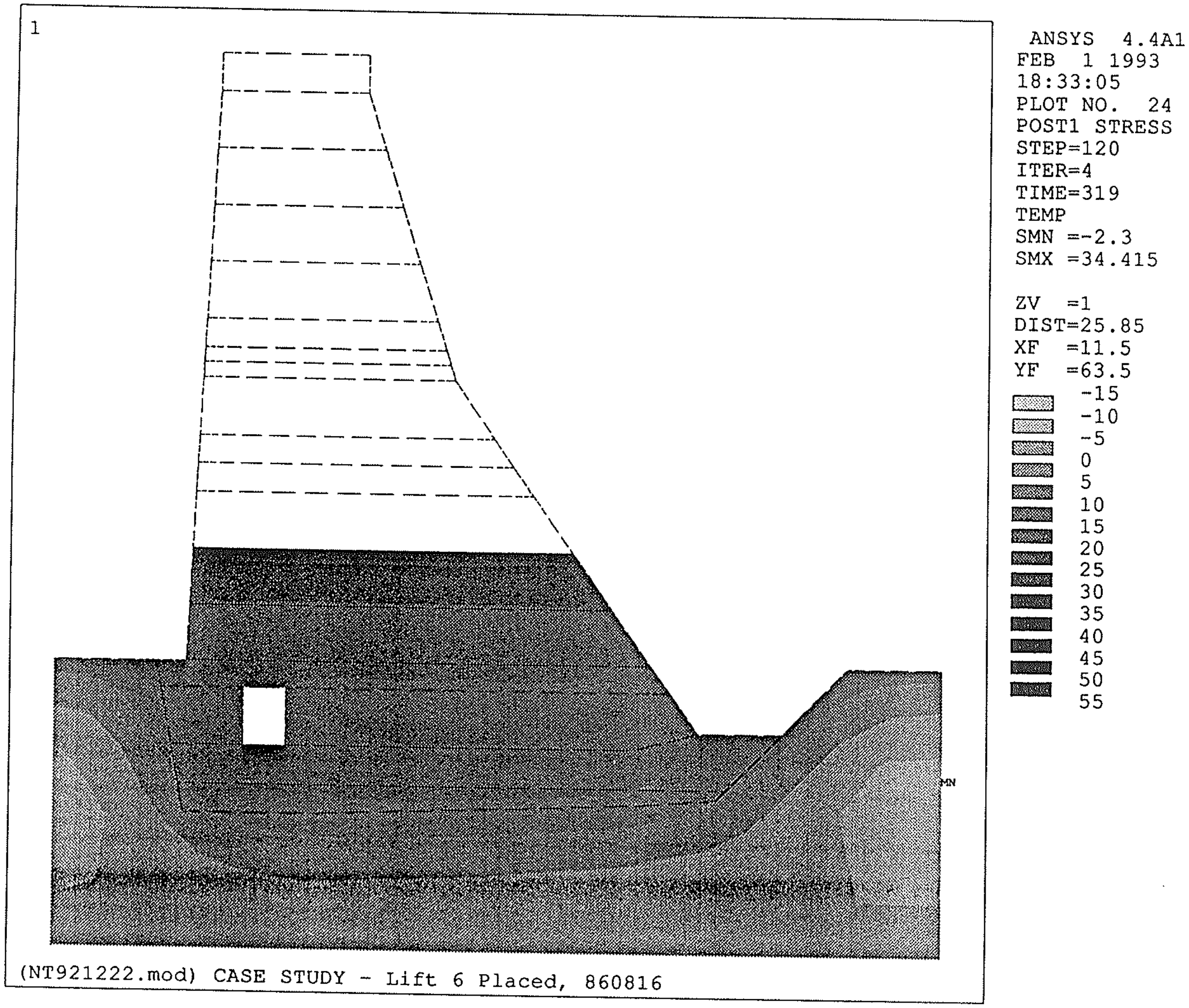

FIGURE 39 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 860816 (3 Days After Placement of Lift NT2-6)

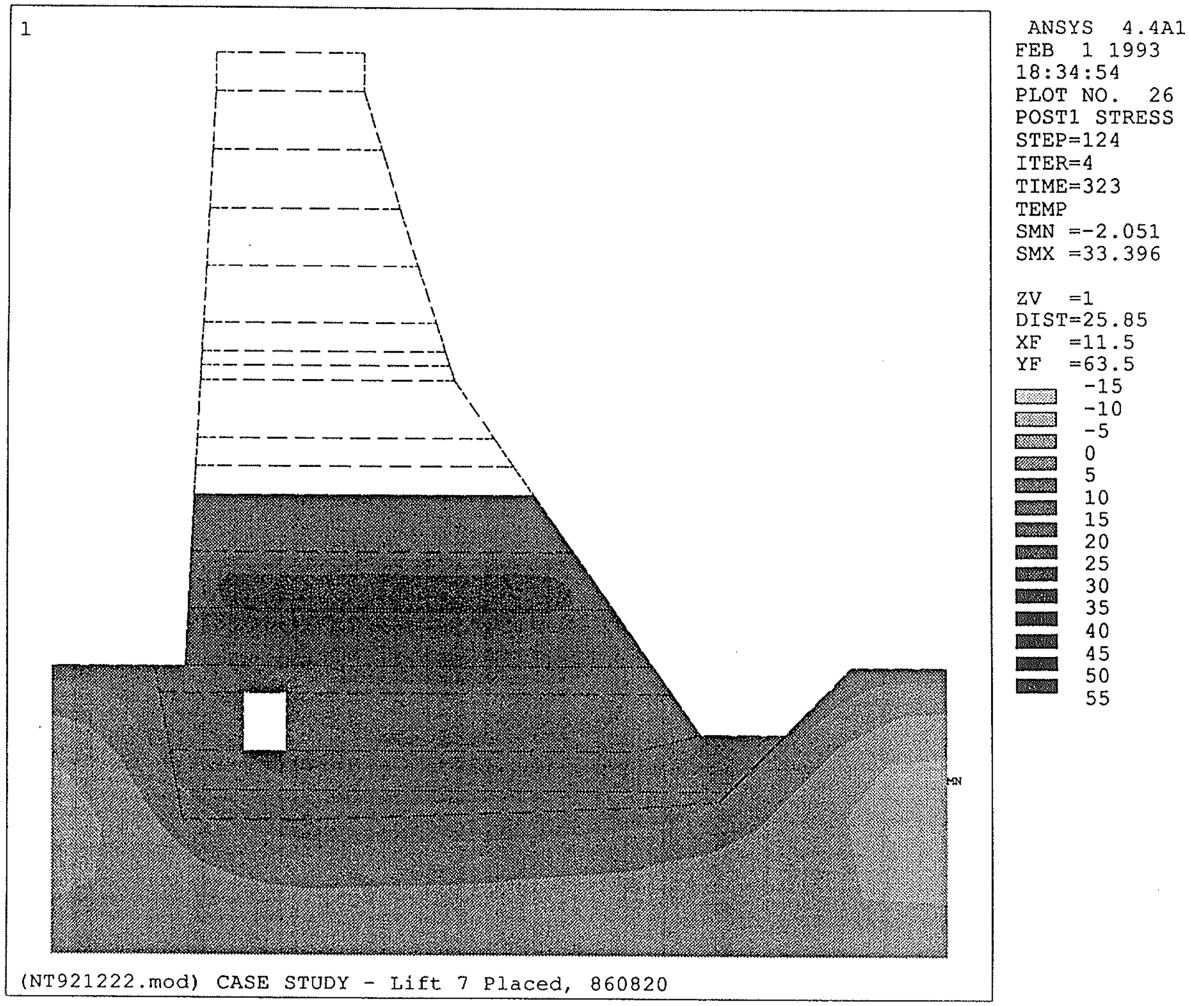

FIGURE 40 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 860820 (Day of Placement of Lift NT2-7)

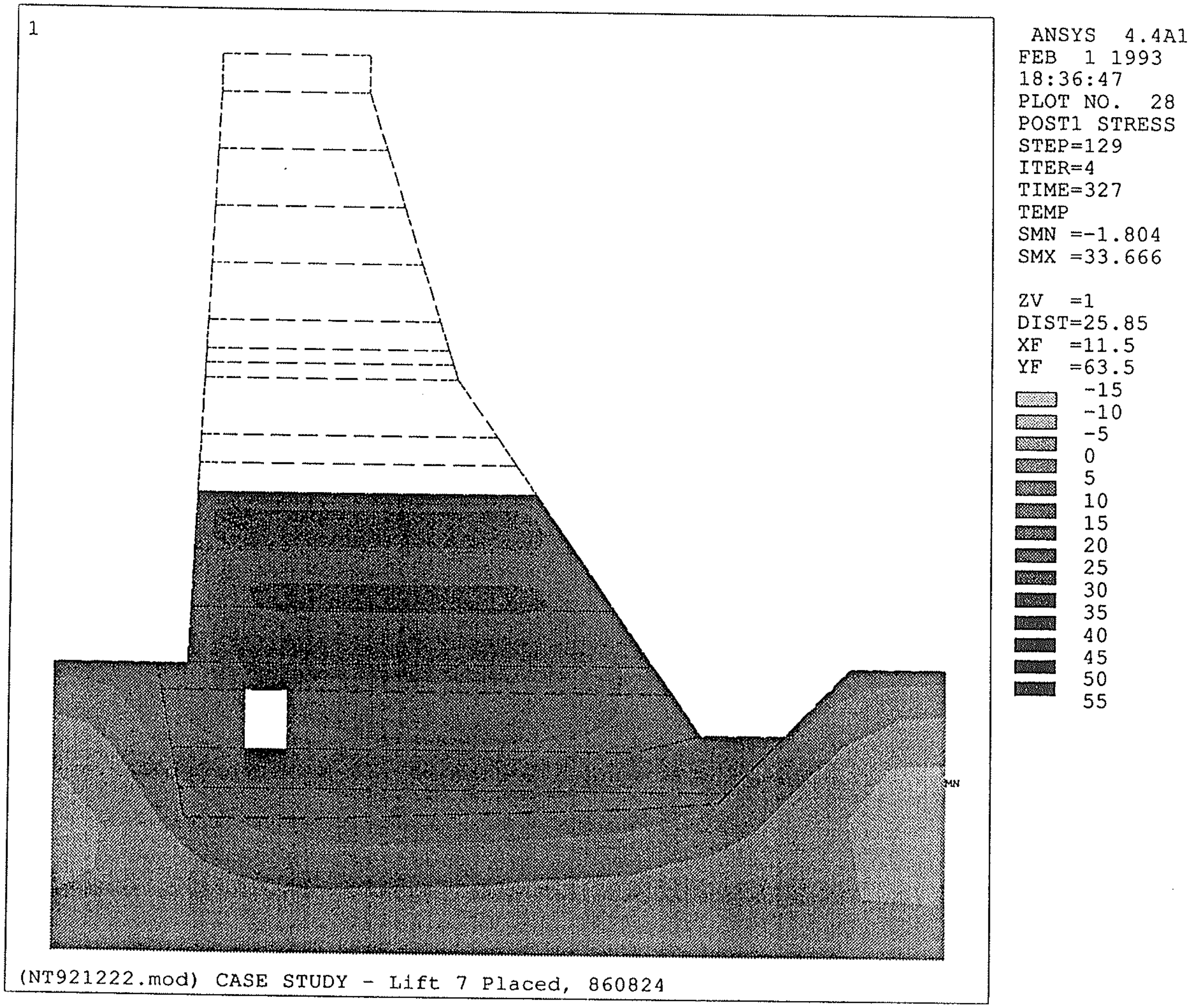

FIGURE 41 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 860824 (4 Days After Placement of Lift NT2-7)

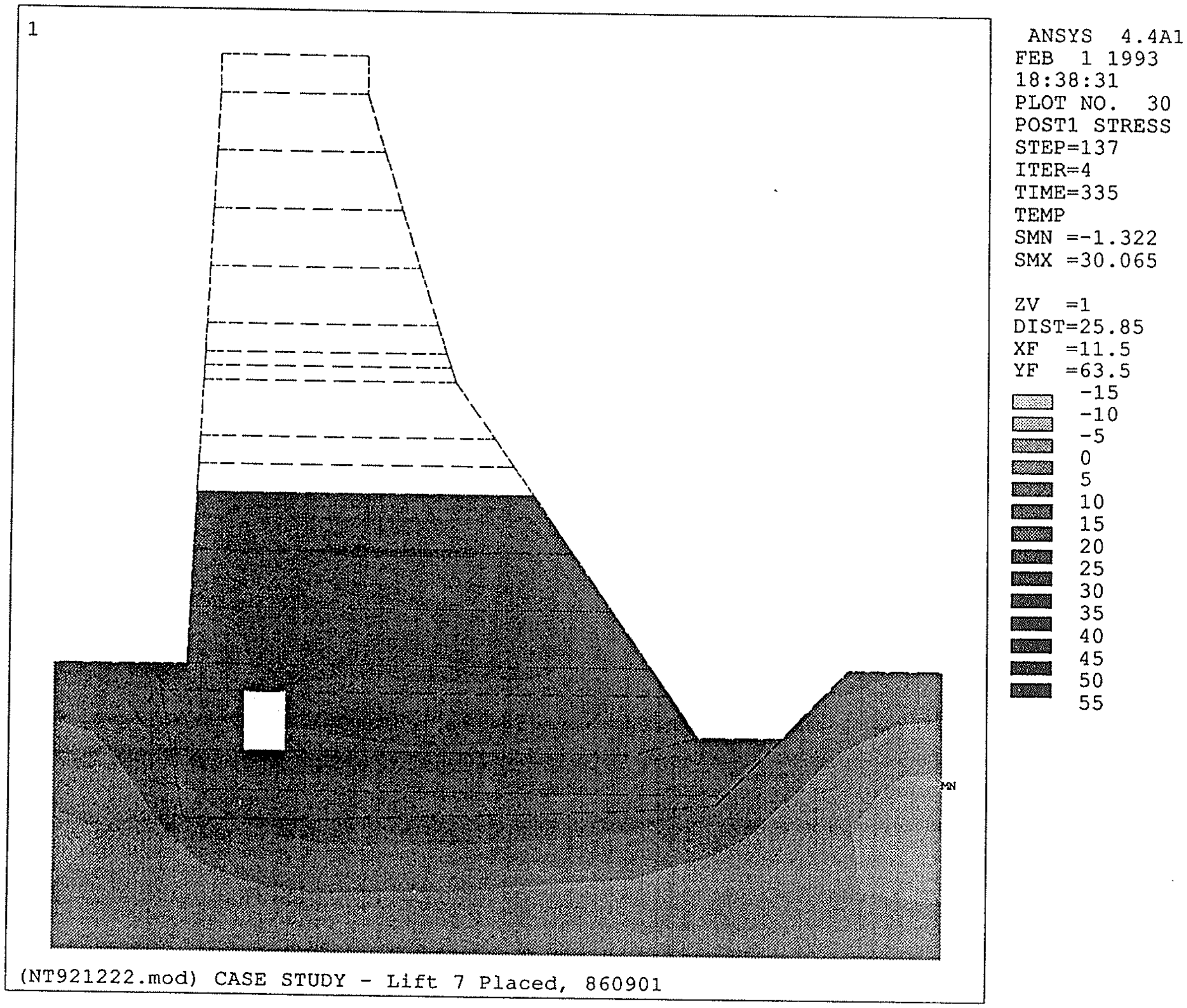

FIGURE 42 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 860901 (12 Days After Placement of Lift NT2-7)

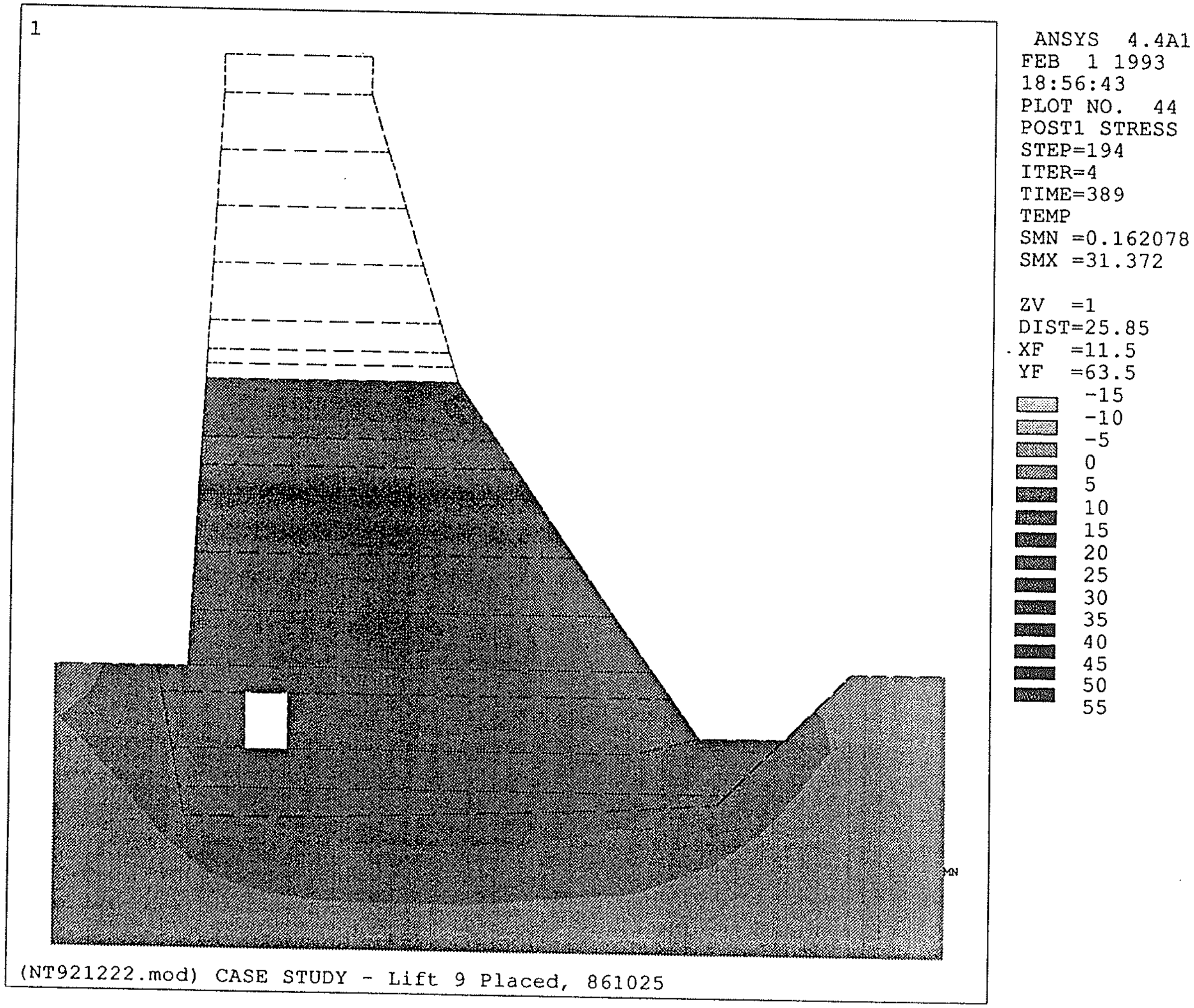

FIGURE 43 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 861025 (2 Days After Placement of Lift NT2-9)

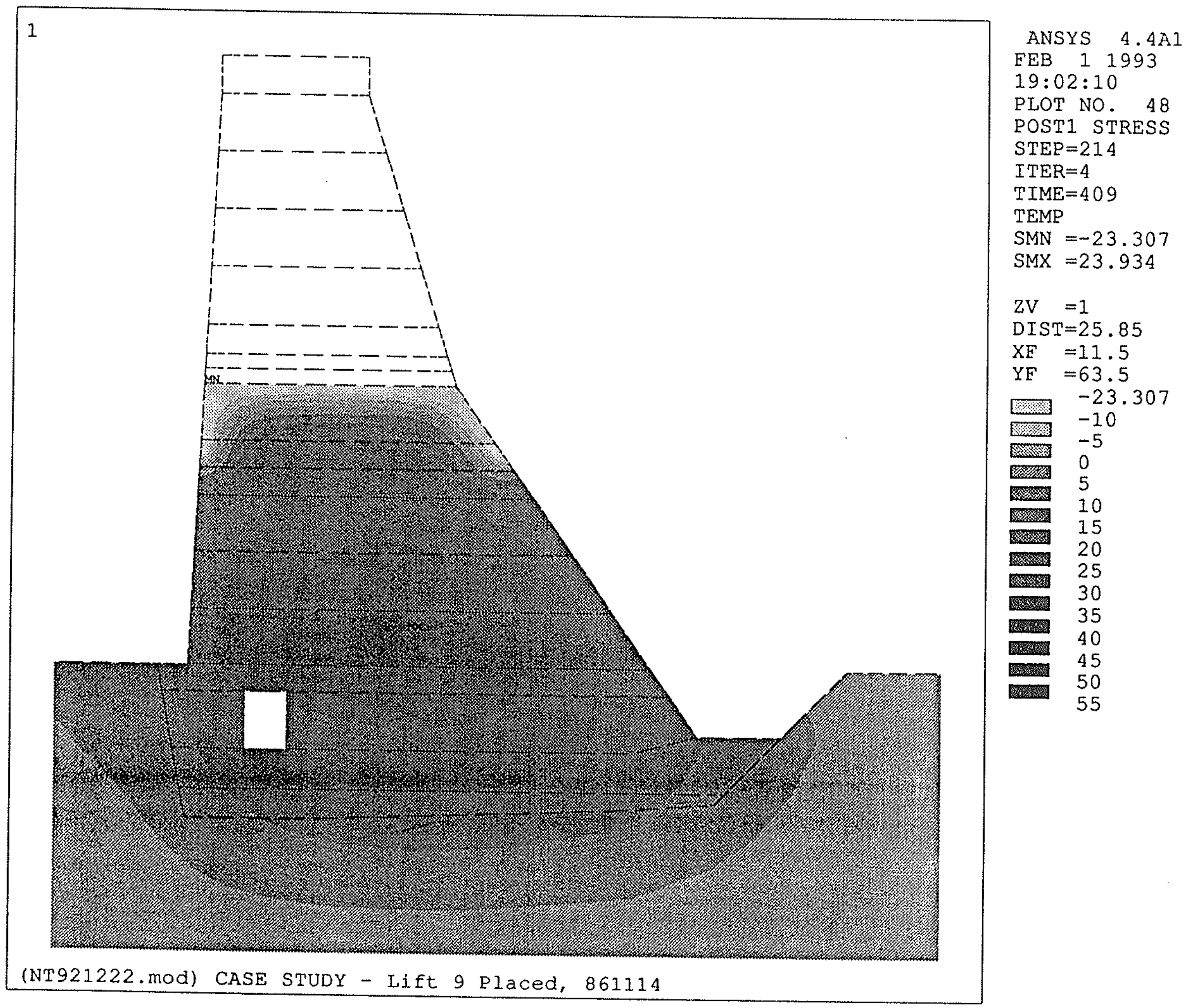

FIGURE 44 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 861114 (22 Days After Placement of Lift NT2-9)

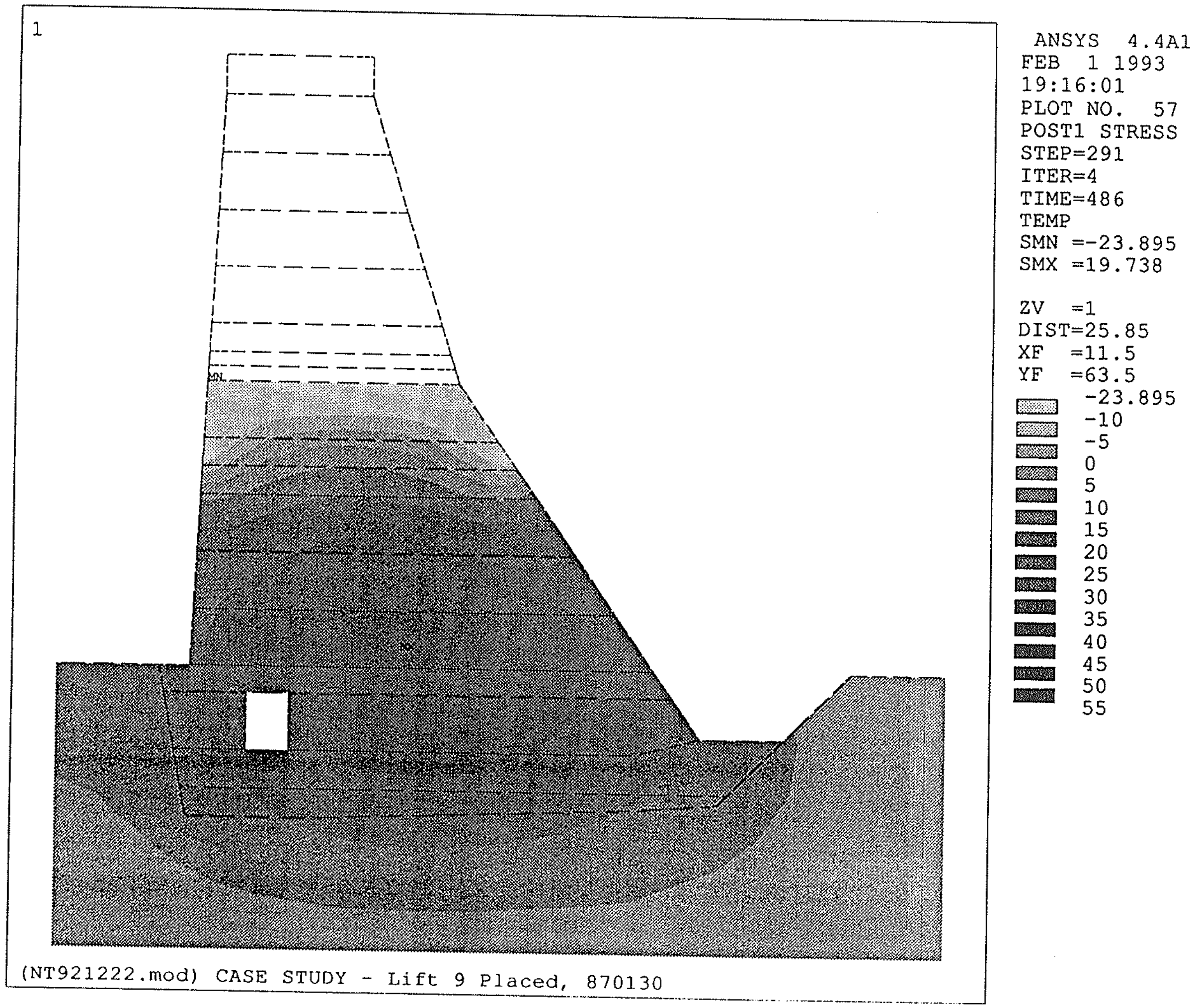

FIGURE 45 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 870130 (99 Days After Placement of Lift NT2-9)

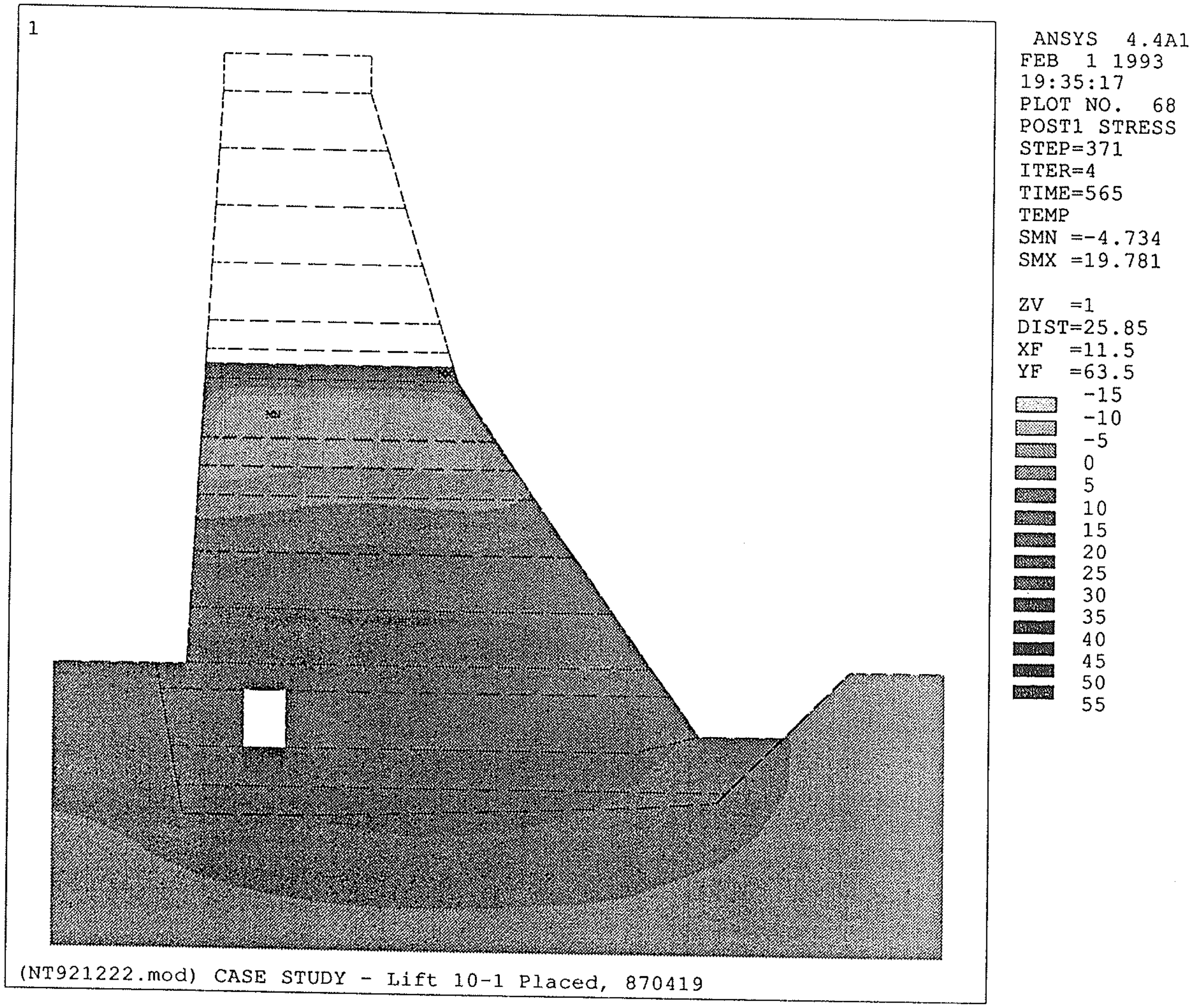

FIGURE 46 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 870419 (2 Days After Placement of Lift NT2-10-1)

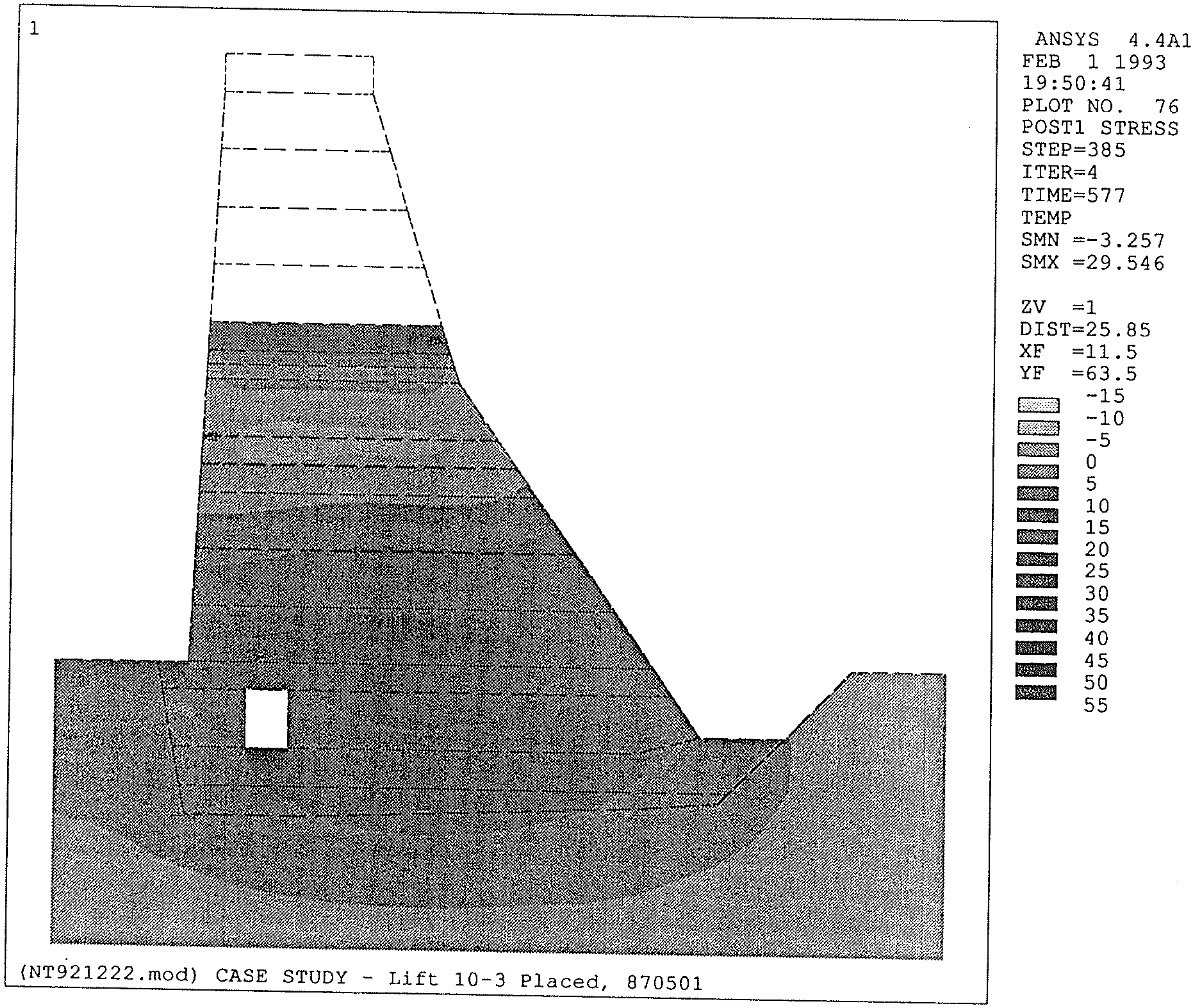

FIGURE 47 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 870501 (2 Days After Placement of Lift NT2-10-3)

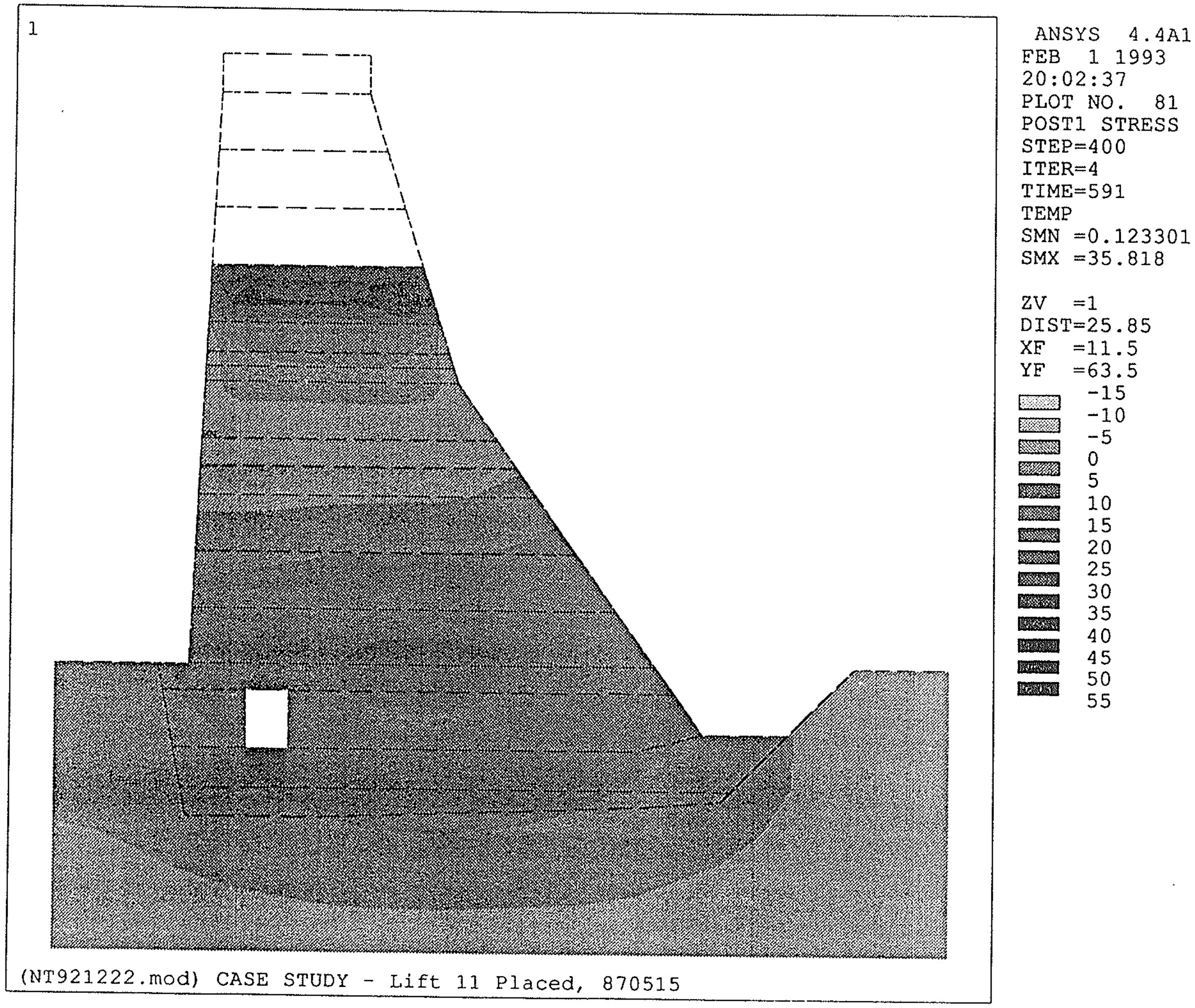

FIGURE 48 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 870515 (3 Days After Placement of Lift NT2-11)

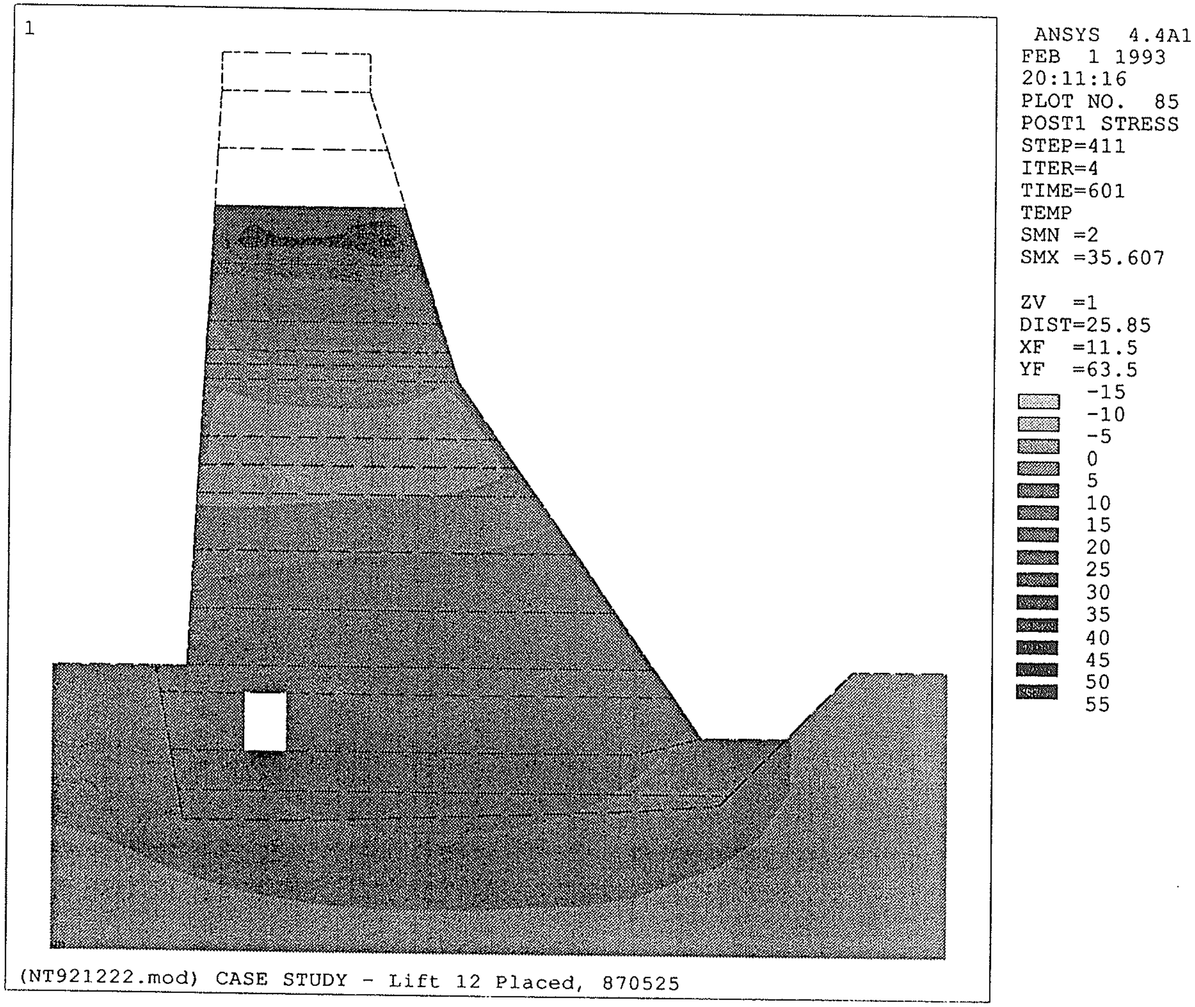

FIGURE 49 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 870525 (4 Days After Placement of Lift NT2-12)

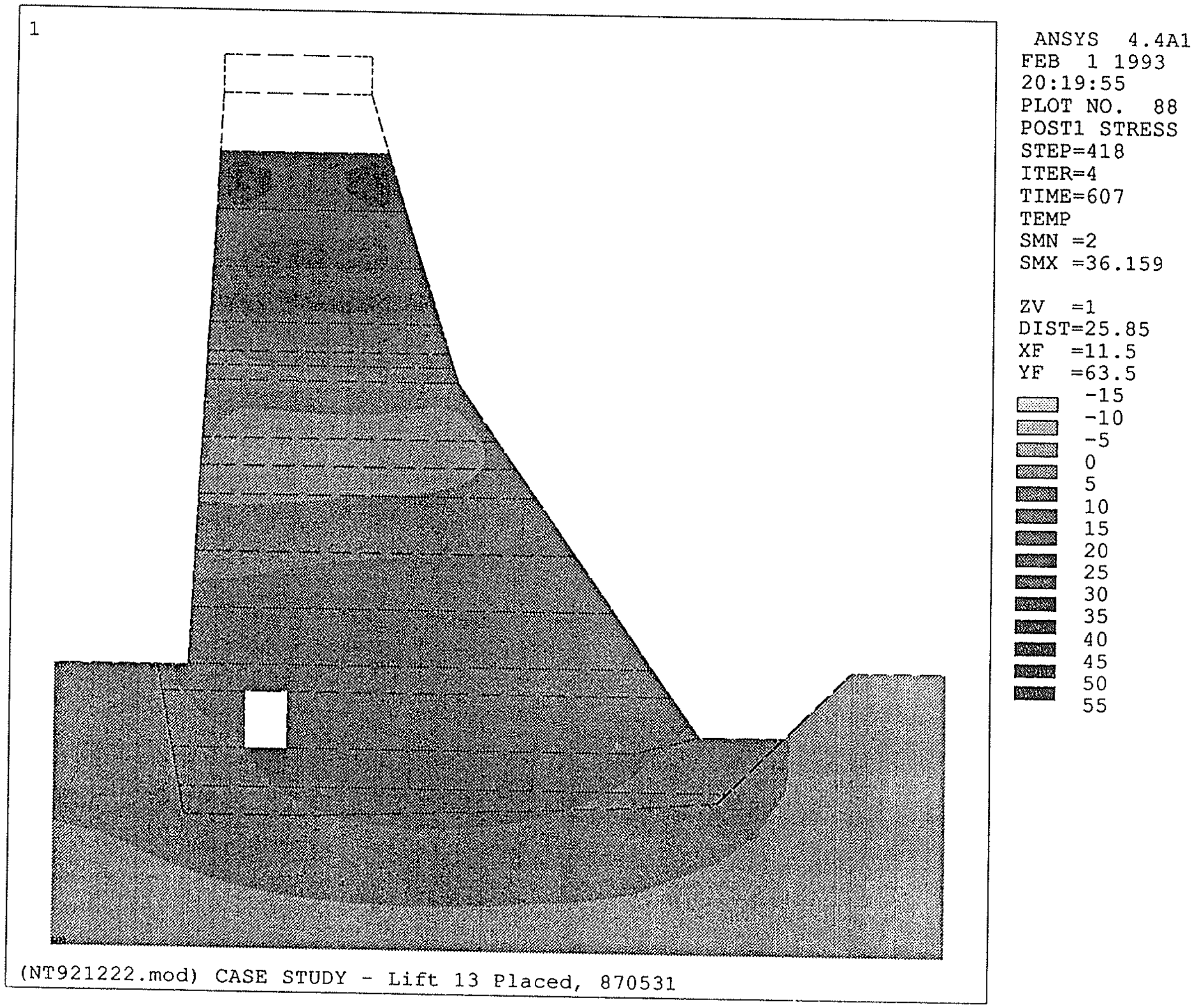

FIGURE 50 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 870531 (2 Days After Placement of Lift NT2-13)

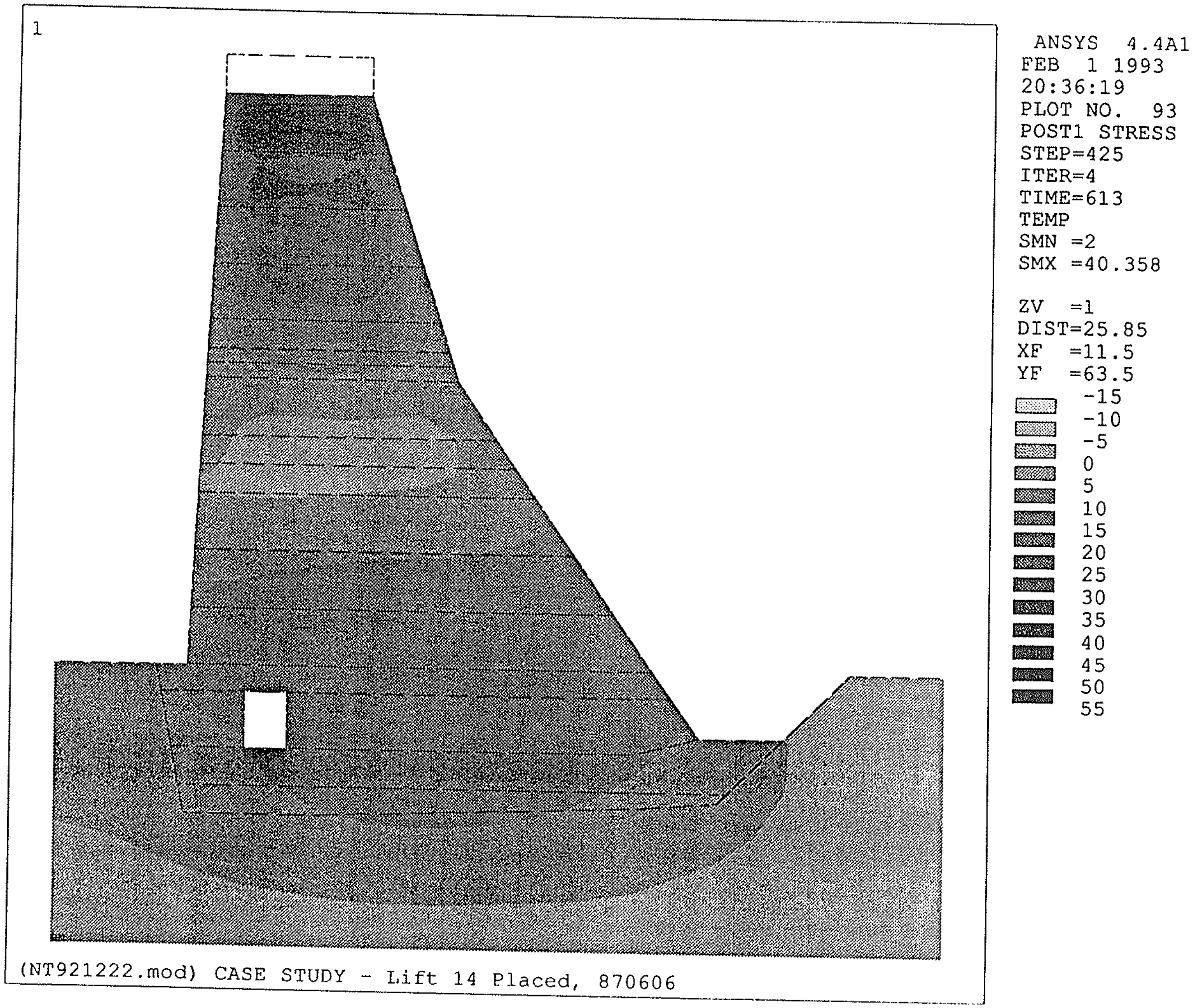

FIGURE 51 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 870606 (3 Days After Placement of Lift NT2-14)

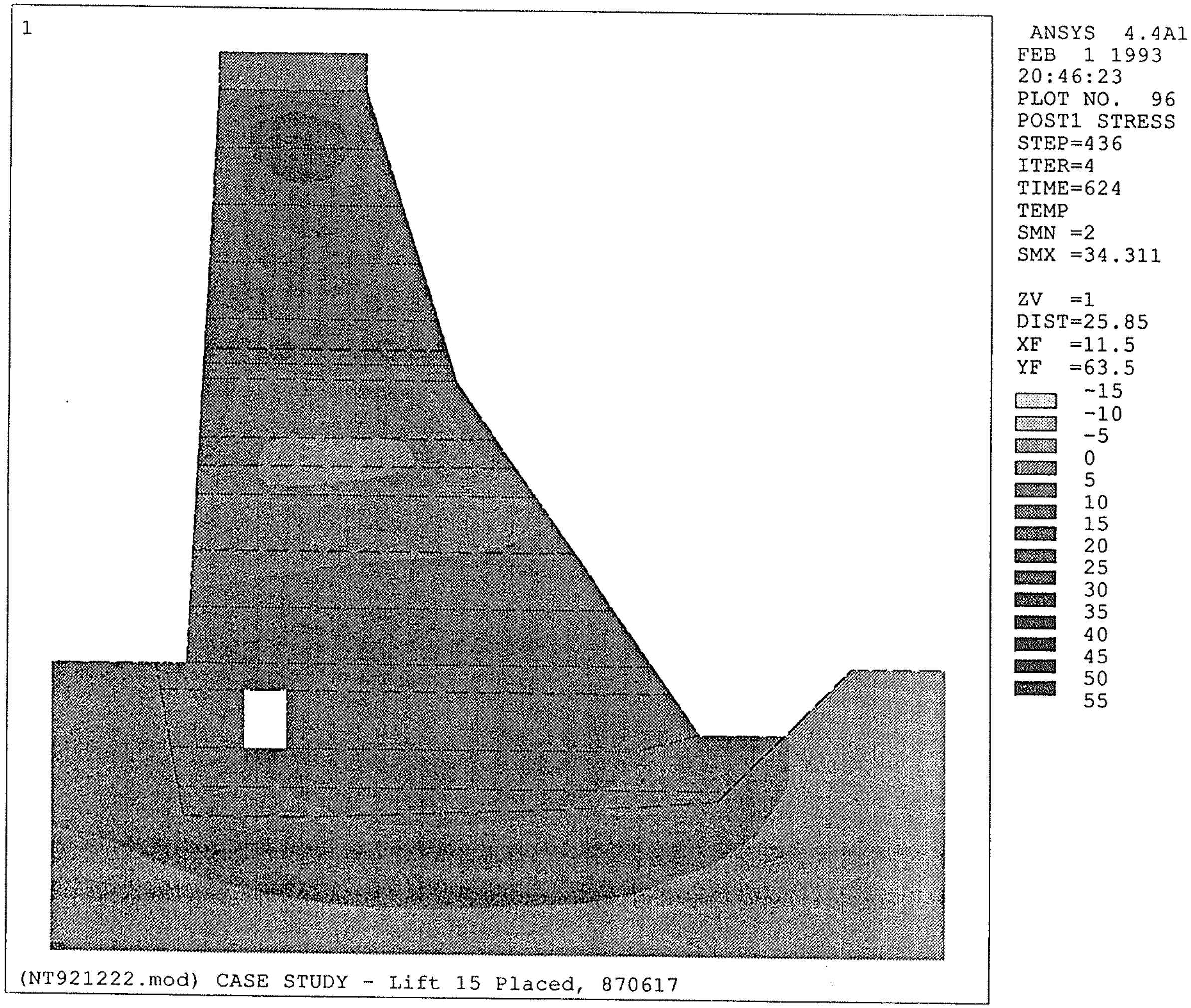

FIGURE 52 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 870617 (Day of Placement of Lift NT2-15)

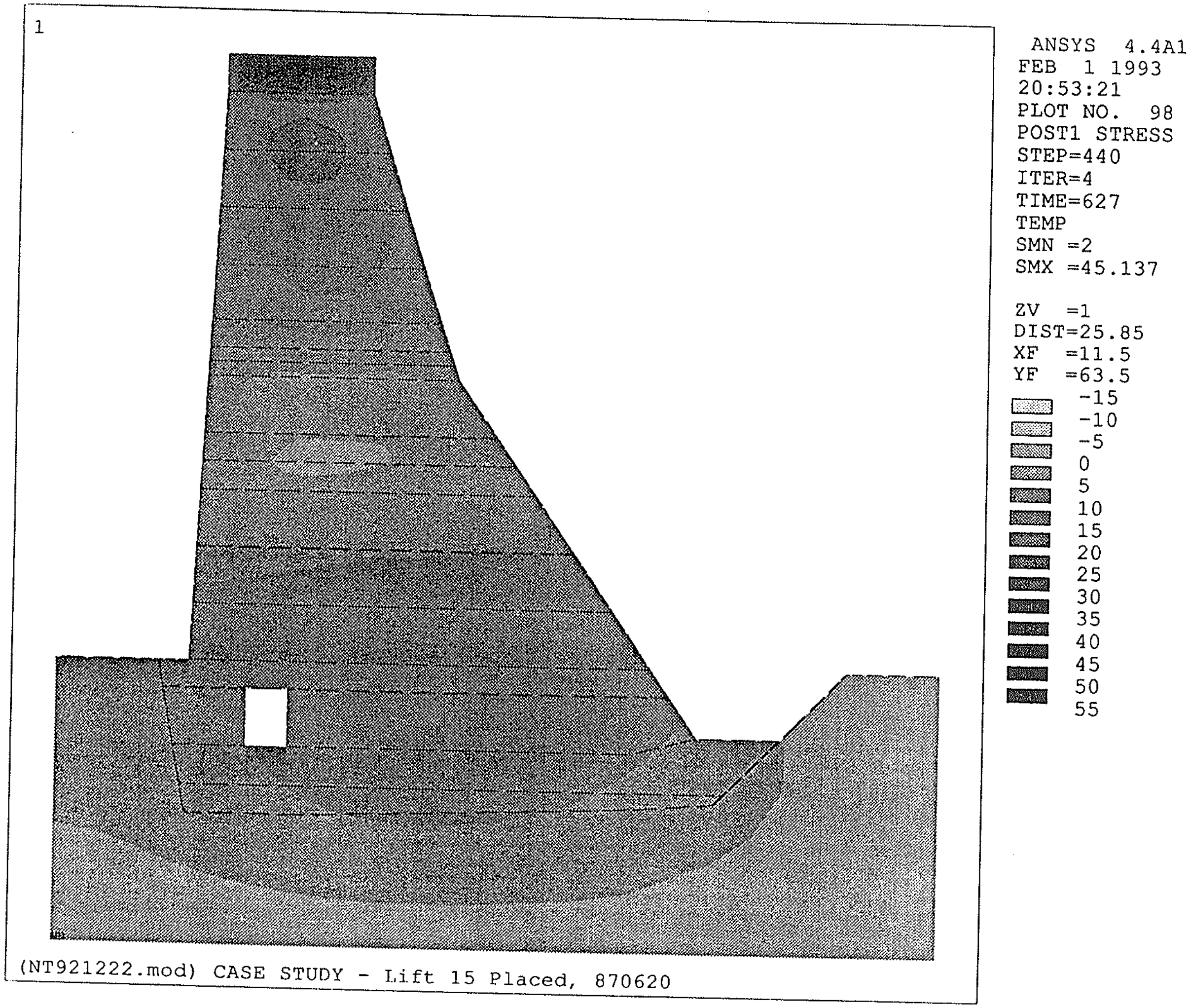

FIGURE 53 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 870620 (3 Days After Placement of Lift NT2-15)

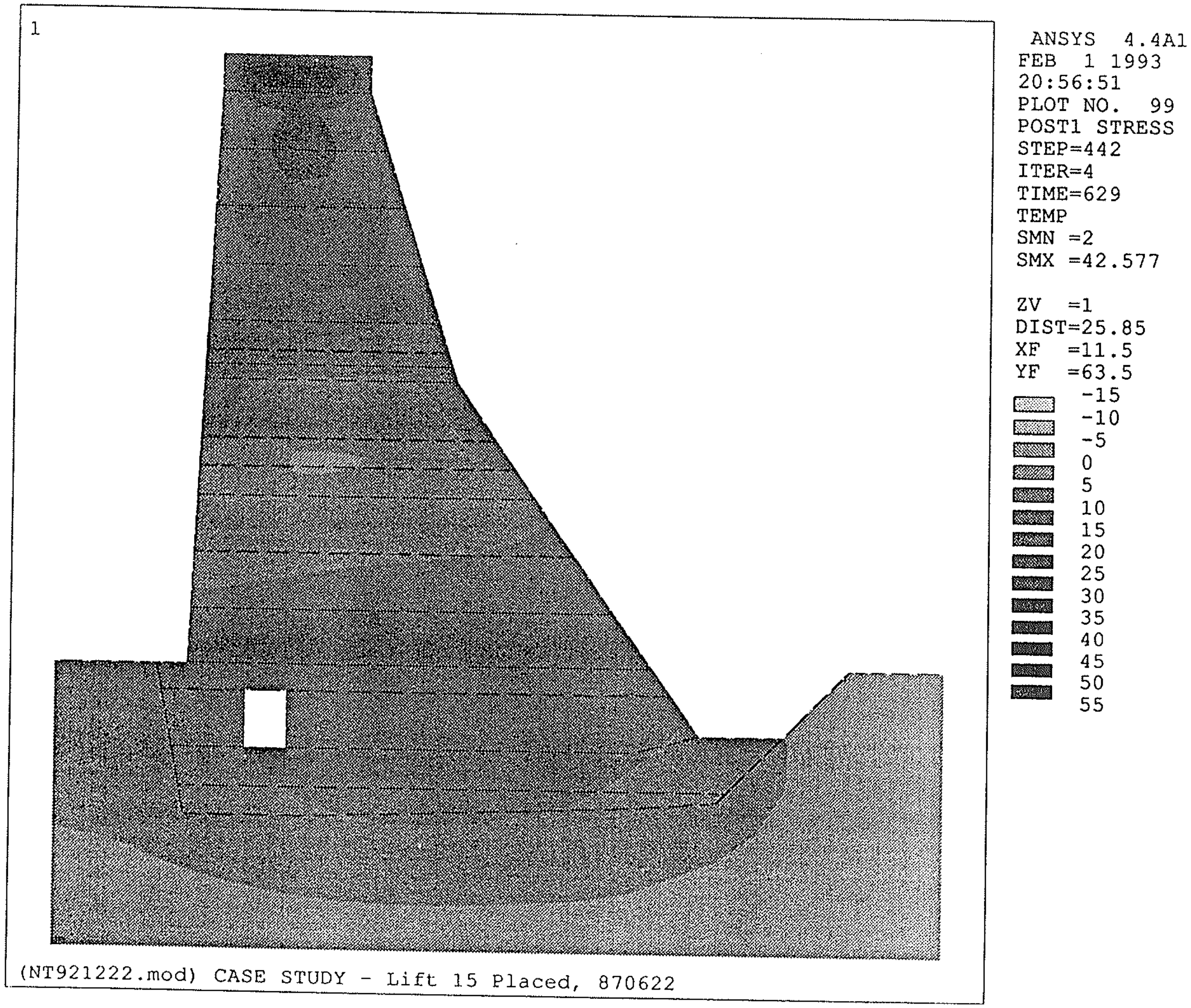

FIGURE 54 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 870622 (5 Days After Placement of Lift NT2-15)

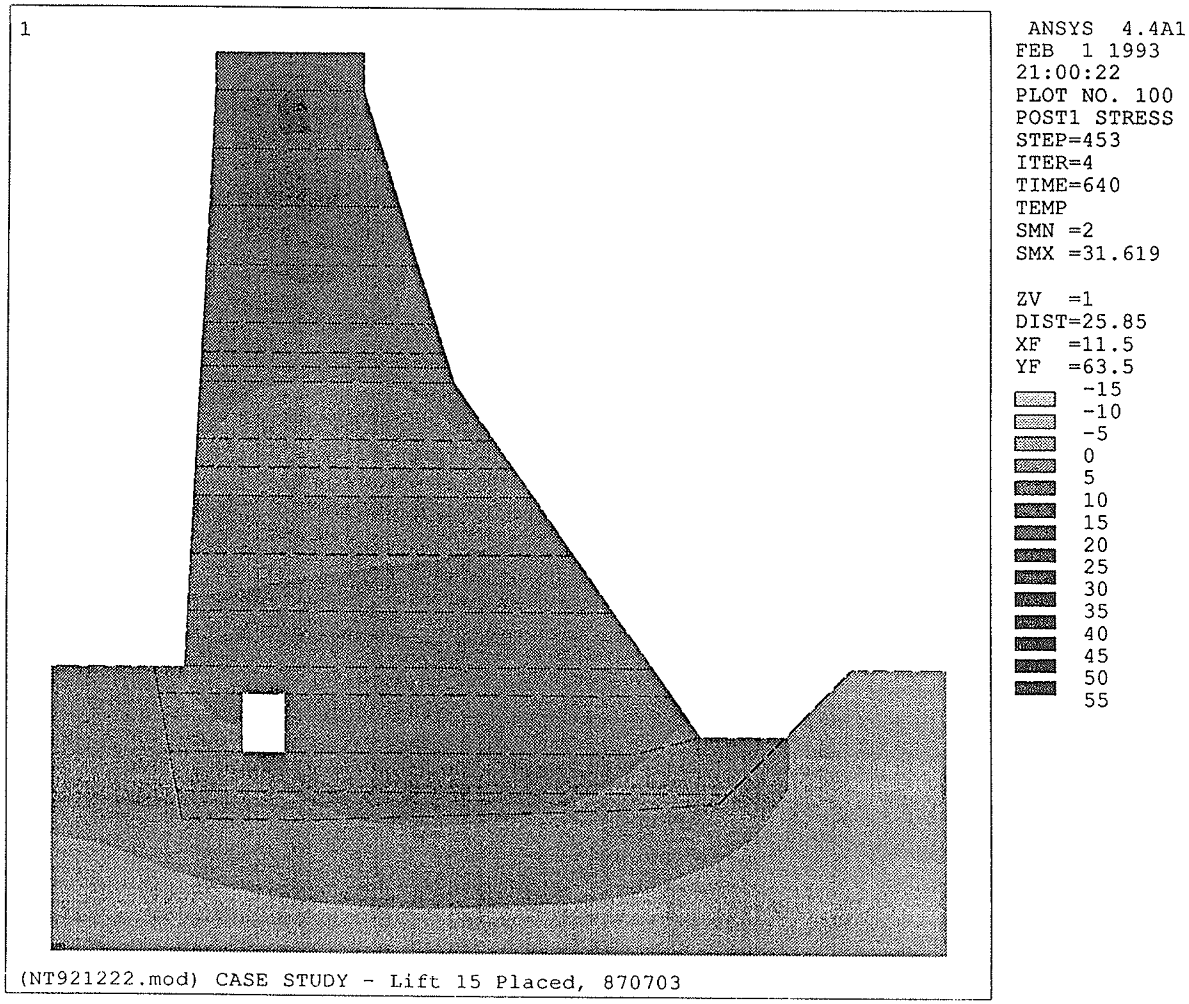

FIGURE 55 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 870703 (16 Days After Placement of Lift NT2-15)

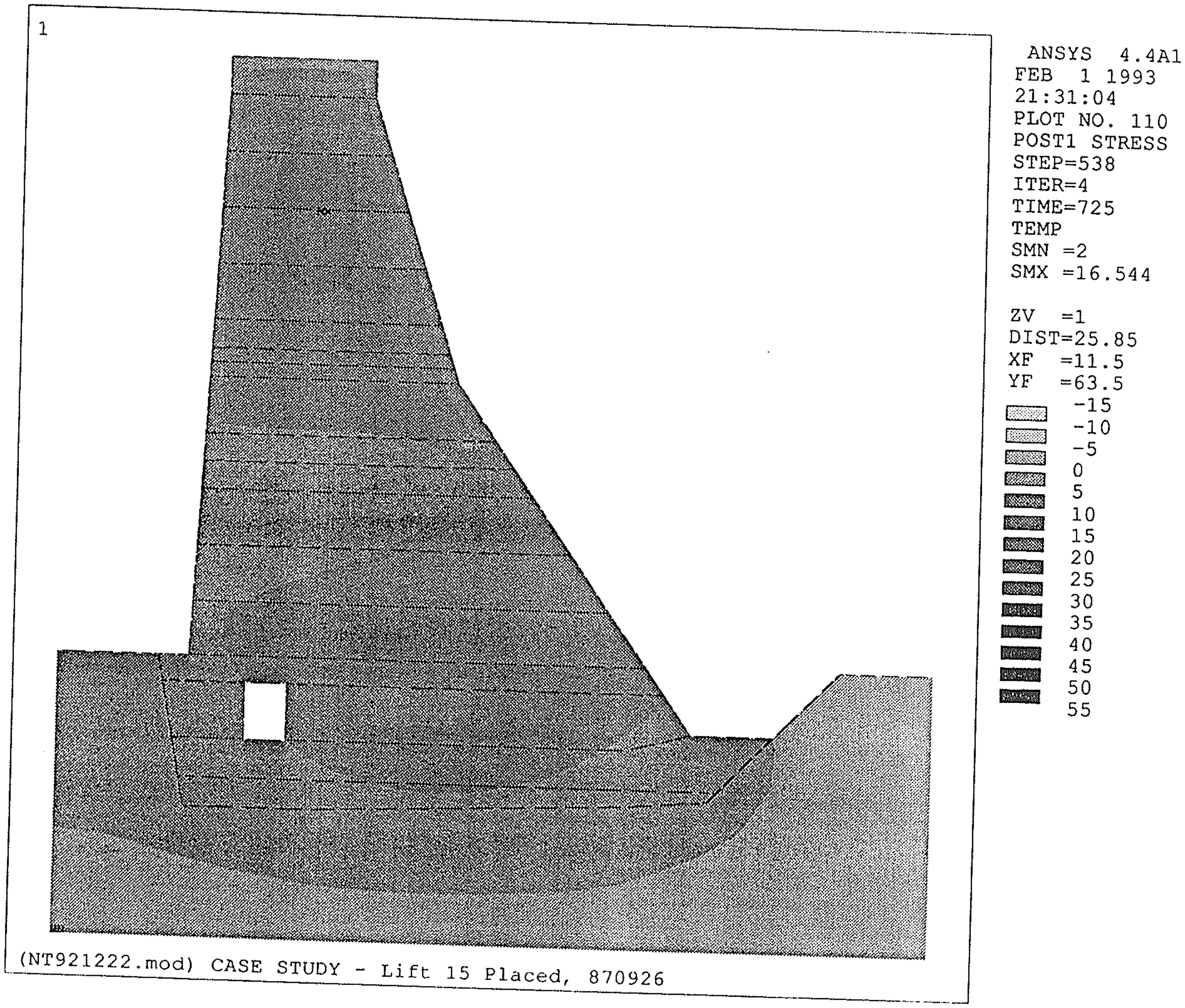

FIGURE 56 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 870926 (101 Days After Placement of Lift NT2-15)

and maximum temperatures in the model for each plot are listed as SMN and SMX, respectively, and their locations shown on the plot by the labels MN and MX. The contour intervals (in degrees Celsius) for the plot are also shown. At the bottom of each plot is a title reflecting the most recent lift of concrete placed in the dam and the date that the plot corresponds to. Only those concrete elements of the model that have been placed at the time of each plot are included in the Figures. A more complete array of thermal contour plots is included as Appendix I.

5.10 Model Behaviour

Some general observations about the behaviour of the case study analysis can be made from the Figures comparing temperatures at model nodes to the measured in situ data. First, the core temperatures of each lift successfully reproduce trends in internal temperatures demonstrated by the measured thermocouple values. These trends typically have an internal temperature rise that is a result of cement hydration in the lift just placed, followed by subsequent increases in temperature that reflect placement of succeeding lifts above. All lifts except lift NT2-9, the last lift placed in the first year of construction of the dam, demonstrate this pattern. Perhaps the most prominent illustrations of this behaviour from the model are lifts NT2-8b (Figure 29) and NT2-10-2 (Figure 31). In Figure 29, the influence of the placement of lift NT2-9 is apparent, and in Figure 31, the effects of placement of lifts NT2-10-3 and NT2-11 are evident.

The second observation made is that the temperature patterns of the surface and near-surface nodes are similar to ambient temperatures in the times before placement of subsequent concrete lifts or earthfill materials against the dam. For lift NT2-1 (Figure 25), the effect of placement of lift NT2-2 is shown by the lack of influence of daily ambient temperature variations on the temperature response of the surface and near-surface nodes after about analysis time 267.

In lifts NT2-6 and NT2-7, the insulating effect assumed for the earthfill materials is clearly visible on the temperatures of the surface and near-surface nodes (Figure 26 and 27).

The thermal contour plots illustrate various elements of the dam's thermal behaviour. Figure 35 shows the temperature condition in the foundation at the time of first concrete in the model. The depth of frost penetration into the bedrock appears to be unrealistic, likely a result of the starting procedure at time 0.0, assuming excavation work as being completed in the fall before the start of construction, and neglecting the insulating influence of snow cover at the surface. These effects contribute to the first concrete lift's temperatures being lower than if the foundation condition was more reasonable. In Figure 36, the effect of the richer concrete in the gallery floor is apparent, as is the larger lift dimension at the downstream end of lift NT2-2. The typical temperature patterns within new lifts and their effect on underlying lifts is shown in Figures 37 through 42 for the placement of lifts NT2-6 and NT2-7. In Figure 43, the richer class B concrete along the downstream face of the dam in lift NT2-9 appears as an area of warmer temperatures than the rest of the lift. The effect of the insulating earthfill materials against the dam is shown in Figures 44 and 45. Figures 48 to 50 all show the richer concretes along the upstream and downstream faces as being the warmest areas of the lifts. The temperature patterns due to the addition of the last lift of the dam are shown in Figures 51 to 55. Finally, the temperature distribution in the dam on the last day of the case study analysis is presented in Figure 56.

The behaviour of the model is not precisely consistent with data collected from the thermocouples. There are several factors that contribute to this. The thermal material properties C_p and k_c are assumed from the literature since actual values for the concretes used in the dam were not measured. The preliminary concrete lifts at the foundation level in the dam were combined into a single lift (NT2-1) to begin the analysis, and thus their effect as in the prototype dam was not reflected in the model. This in combination with an unreasonable initial foundation condition at the time of first concrete affects the temperature response of the first lifts in the model.

A major contributor to model behaviour is the parameter values for the heat generation equations. With the source heat generation data for the cement only covering a period of one week, the least squares parameter fitting exercise generated values that reflected one week of heat generation. In reality, heat generation continues in mass concrete for well beyond one week. This effect appears in the core temperatures of nearly every lift, with peak model temperatures being consistently lower than that shown by the thermocouples. It would be best to have heat generation data that is based on measurements taken on the concretes themselves for extended periods, rather than just the cement used in the mixes for a short period.

Assumptions involving the application of boundary conditions also contribute to the behaviour shown in the model. There is little uncertainty involved with the nodal temperature boundary conditions. However, neglecting curing effects would tend to make the model warmer, and ignoring radiation loading would tend to make the model colder, particularly during summer daylight hours. Approximations incorporated into the application of convections on the dam (e.g. adiabatic surfaces) and the placing times for the lifts also affect the model temperature response.

Finally, the comparisons between the model nodal temperatures and that of the thermocouples must be kept in perspective. Model nodes do not exactly coincide with thermocouple locations, and thermocouple locations are not known in precise terms. For 3 m thick lifts, the two nodes selected for the core temperature listings may not be at locations that capture the maximum temperature reached within the lifts, assuming that this occurs at the mid-height of the lifts. However, it is clear from the results of the case study analysis that the modelling algorithm is reliable when definition of a finite element thermal model of a dam using project-specific data (e.g. structure geometry, construction sequence and schedule, material properties, heat generation data and ambient conditions) is undertaken.

6 CONCLUSIONS AND RECOMMENDATIONS

It is concluded from this work that the developed modelling algorithm can be used to reliably predict the thermal behaviour of incrementally constructed mass concrete dams. Factors influencing the thermal response of a dam under construction are properly incorporated into the algorithm. These include the effects of time and changing structure geometry on temperature patterns, and time-varying thermal loads and boundary conditions. Best results can be obtained using project-specific information for the formulation of a model for analysis. It has been demonstrated that the algorithm is effective over long time periods and under severe ambient conditions.

It is recommended that this work be followed by the development of a companion algorithm for thermal stress analysis of incrementally constructed mass concrete dams using the developed algorithm as the basis for establishing the thermal history of a structure.

It is possible to refine the modelling algorithm, particularly with respect to the treatment of surfaces of a dam exposed to ambient conditions. The effects of earthfill materials, formwork and curing procedures on heat losses can be improved to better approximate actual behaviour. The algorithm could be modified to include the definition of convections specific to different surfaces of a dam, as well as radiation loading should it be necessary. An analysis can be extended for the prediction of thermal behaviour for time periods beyond the construction of a dam. Using the developed algorithm and the finite element program, the level of detail possible in a finite element model of this kind is only limited by computational resources available to execute an analysis.

There are several potential benefits to the appropriate application of the developed algorithm. Studies can be carried out together with the future companion thermal stress algorithm to investigate opportunities to either relax or enhance specification constraints to construction procedures. For example, construction scheduling and thus project cost benefits would result from elimination of the requirements for limited lift heights at the foundation level or after long delay times between lifts. Such concrete lifts are expensive and time consuming for contractors. Lift thickness rules can be examined and details refined to account for specific structure dimensions, concretes, placing schedules and project sites. There is potential for savings in costs should it be found that some preliminary or intermediate shallow lifts in a dam could be eliminated from the construction sequence. The impact of variations in waiting periods between lifts can be evaluated, and possibly a more aggressive placing schedule made possible. Investigations can be made into the feasibility of allowing higher maximum concrete placing temperatures. More confident design and construction procedures have the benefit of reduced long term costs as well.

Finally, interactions between thermal factors affecting the construction of a dam, and the potential behaviour of a dam for a particular combination of factors could be evaluated directly and in real terms, rather than empirically or strictly by engineering judgement.

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APPENDIX A

DEVELOPMENT OF THE MODELLING ALGORITHM

A DEVELOPMENT OF THE MODELLING ALGORITHM

To establish the detailed procedure for carrying out the incremental thermal analysis, a series of seven preliminary thermal "pilot runs" were developed. The pilot runs incorporate all characteristics of a full model analysis, and thus allow the routine established on the pilot model to be directly transferred to a full scale analysis of a mass concrete dam. The following sections are a description of the pilot model used for the runs, the thermal loadings involved and the seven pilot runs themselves. Explanations are provided as to the objective of each run, the results obtained, and why each model behaves the way it does.

A.1 Pilot Model

The pilot model is a simple one-dimensional band of material consisting of four individual segments: an underlying foundation segment and three segments above representing separate lifts of concrete. The general form of the model and the material properties assigned to each segment are shown in Figure A.1.

A.1.1 Finite Element Model

The finite element form of the model is defined using the ANSYS two-dimensional, four node, isoparametric thermal solid element STIF55. This is the same element type used in construction of the case study model to test the developed algorithm. The model is defined and loaded to behave as a simple, one-dimensional thermal structure. It is one element wide by twenty elements tall, the foundation segment being eight elements tall and each concrete segment four elements tall. The program code to define the model is as follows. Note that throughout the appendix listings of program code, lines of text that begin at the margin with a "$" character

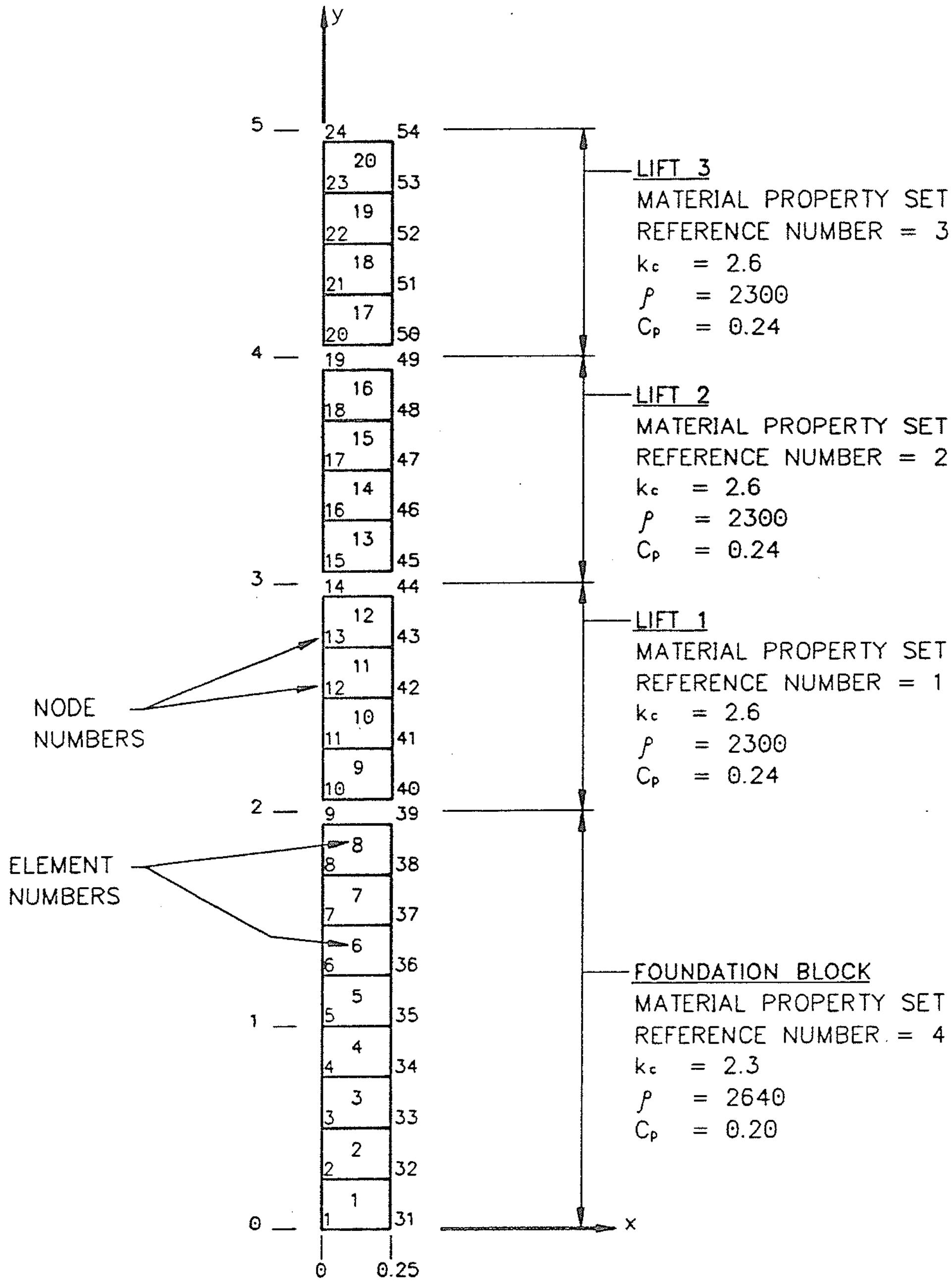

FIGURE A.1 - General Form of the Finite Element Pilot Model are system-level commands.

```
$ansys44a
/prep7
/title,PILOT RUNS - MODEL DEFINITION
kan,-1 $et,1,55 $type,1
mp,kxx,1,2.6 $mp,dens,1,2300 $mp,c,1,0.24    * lift 1 concrete
mp,kxx,2,2.6 $mp,dens,2,2300 $mp,c,2,0.24    * lift 2 concrete
mp,kxx,3,2.6 $mp,dens,3,2300 $mp,c,3,0.24    * lift 3 concrete
mp,kxx,4,2.3 $mp,dens,4,2640 $mp,c,4,0.20    * bedrock
mat,4$n,1     $n,9,0,2 $fill$ngen,2,30,1,9,1,0.25  $e,1,31,32,2  $egen,8,1,1
mat,1$n,10,0,2$n,14,0,3$fill$ngen,2,30,10,14,1,0.25$e,10,40,41,11$egen,4,1,9
mat,2$n,15,0,3$n,19,0,4$fill$ngen,2,30,15,19,1,0.25$e,15,45,46,16$egen,4,1,13
mat,3$n,20,0,4$n,24,0,5$fill$ngen,2,30,20,24,1,0.25$e,20,50,51,21$egen,4,1,17
finish
/eof
```

Figure A.2 shows a picture of the pilot model with elements of each segment numbered according to the material property data set reference number used for model definition. Figure A.3 is a plot showing the node numbers of the model. Some nodes are shown as overlapping because segments of the model (foundation and concrete lifts) are defined to be "self-contained" with respect to their geometry and material properties. Geometrically, nodes on the upper and lower faces of top and bottom elements, respectively, of each segment belong to elements of that segment only. However, nodes at points of contact between segments of the model are defined to have the same locations. This makes it possible to isolate different segments (lifts of concrete) of the model from the thermally active portion of the model until the point in time corresponding to placement of that lift of concrete. Nodes at the bottom of a newly placed lift can then be coupled to the corresponding nodes at the top of the underlying segment of the model, to incorporate the new lift into the active portion of the model.

Each segment of the model is assigned its own thermal material property values with a unique material property data set reference number even though the actual material property values of a segment of the model may be identical to those of another segment of the model.

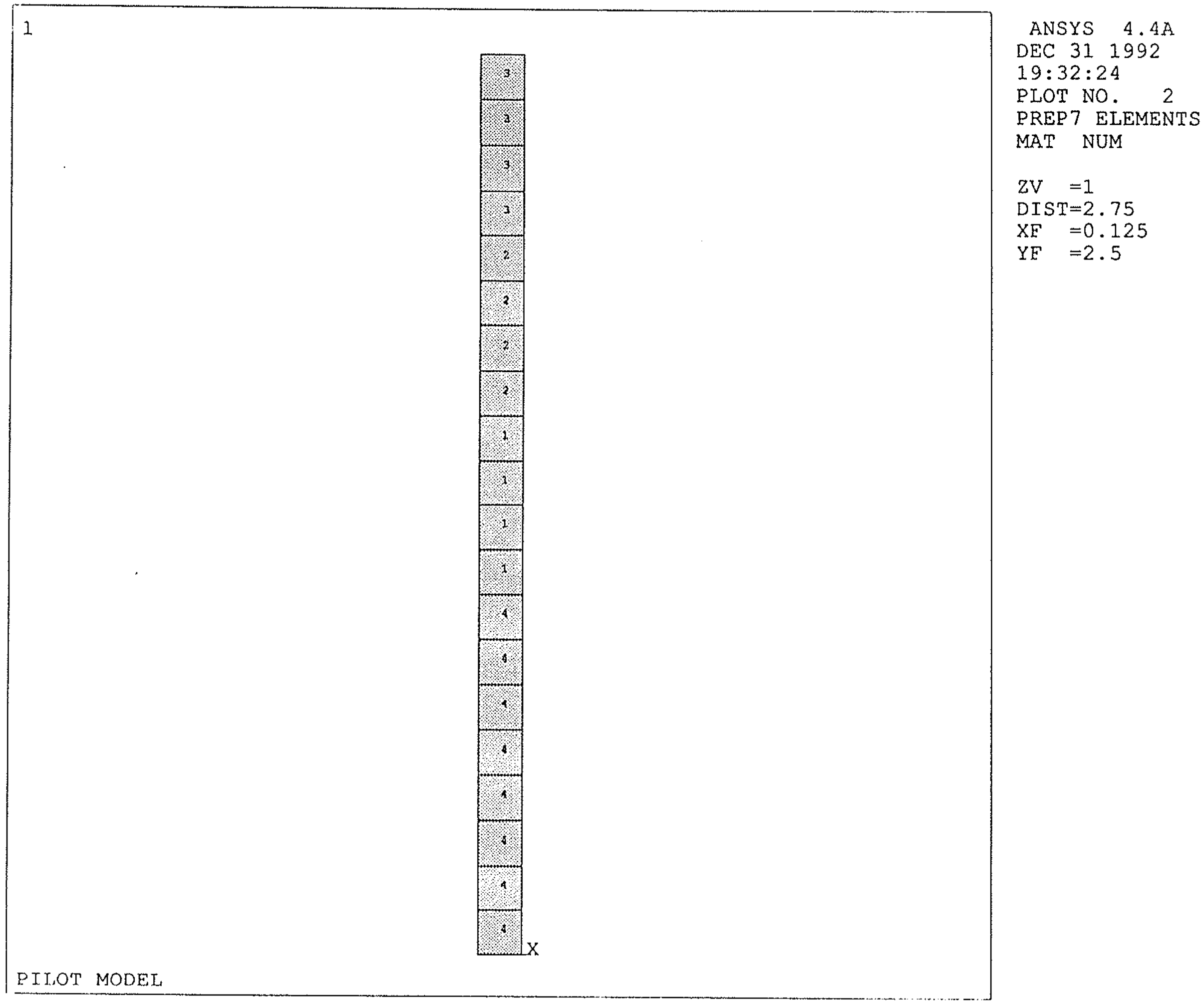

FIGURE A.2 - Pilot Model Showing Material Property Set Reference Numbers

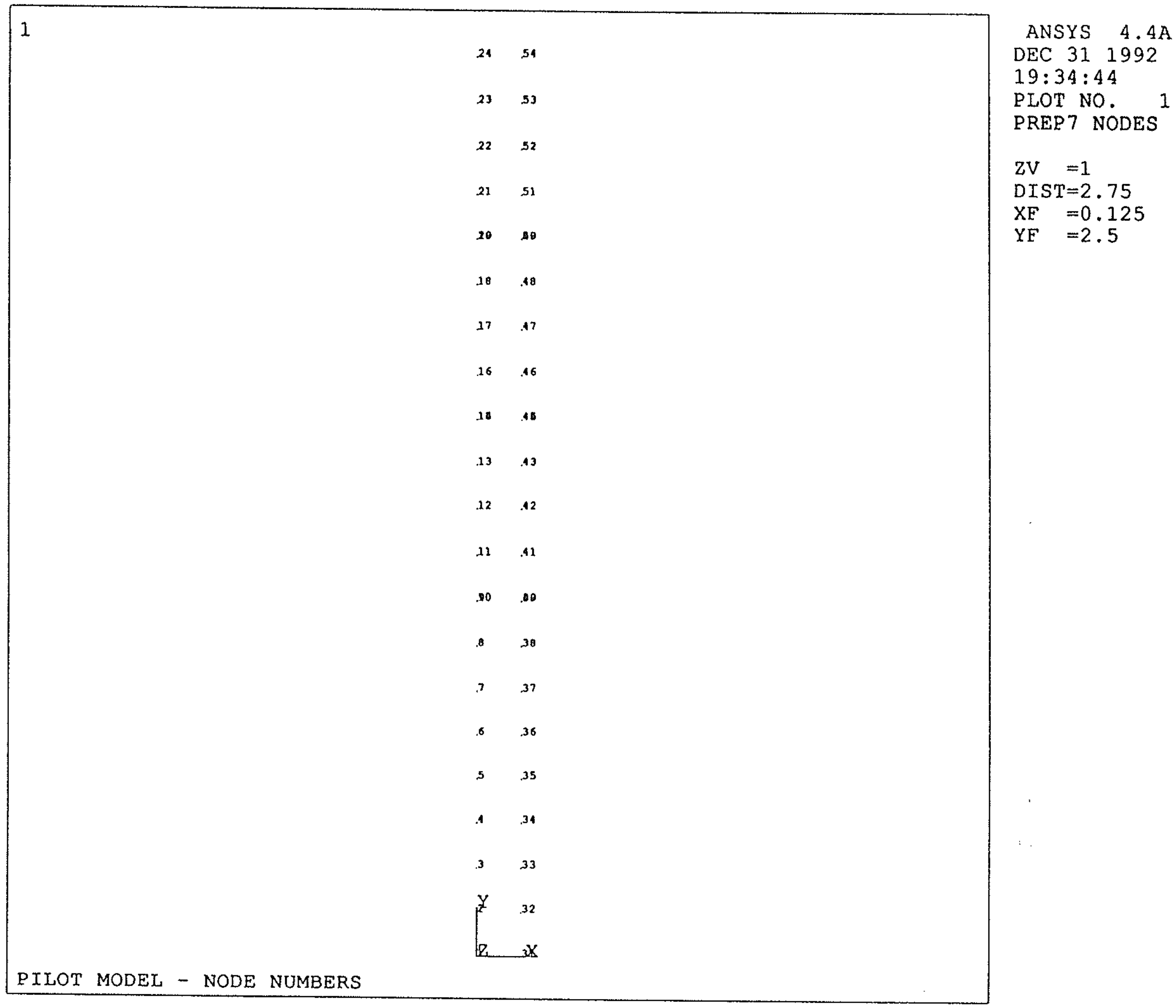

FIGURE A.3 - Pilot Model Node Numbers

This allows the elements corresponding to each lift of concrete to be uniquely identified for assignment of the internal heat generation rates. This is demonstrated in detail in pilot run seven.

A.1.2 Thermal Loading

The thermal loading on the pilot model consists of internal heat generation rates and the boundary conditions identified in Chapter 3 as being those important for an analysis of this type. The first form of boundary condition is the assignment of a fixed temperature value to bottom nodes of the foundation segment of the model to reflect an isothermal plane assumed to be present at depth. This boundary condition is common to all pilot runs - the bottom two nodes of the bottom foundation element are set equal to a temperature of 2° for the entire duration of each of the runs. In later pilot runs, specific nodal temperature boundary conditions are used to initialize the temperatures of different concrete lifts of the model prior to their placement in the construction process. In these cases, the boundary condition is deleted just before the start of loading on that segment of the model, leaving the nodal temperatures free to respond to the loading as applied in subsequent load steps.

The second type of boundary condition included in the pilot runs is transient convective loading applied to exposed surfaces of the model. In these pilot runs, the convective load is applied to the top surface of the top element of the highest active segment of the model. The heat transfer coefficient is left constant, and the fluid temperature is varied to simulate a changing ambient temperature condition.

Finally, internal heat generation rates are applied on a per unit volume basis to elements in the concrete segments of the model in the last pilot run. It is the specification of this load which is made convenient by being able to identify elements of the different segments of the model by the unique material property data set reference numbers.

Side surfaces of all elements in the model are left unloaded, which the finite element program treats as adiabatic surfaces. The pilot model is thus one-dimensional in its thermal behaviour. The different features of the transient incremental thermal analysis developed in each of the separate pilot runs are described in the paragraphs that follow.

A.2 Pilot Run 1

The first pilot run was carried out with the time-varying convective boundary condition applied to the top surface of the foundation segment of the model. For the moment, the three segments of the model that simulate lifts of concrete are "left out" of the active portion of the model. This run was completed to establish a reference thermal behaviour of the foundation for pilot runs two, three and four which develop the detailed procedure for restarting a transient thermal analysis after stopping execution at a certain point in time to add a new lift of concrete to the model. The code to carry out pilot run one is as follows.

```
$ansys44a
/prep7
/title,PILOT RUN 1 - CONVECTIVE LOADING ON BEDROCK, NO RESTART
kan,-1 $et,1,55 $type,1
mp,kxx,1,2.6 $mp,dens,1,2300 $mp,c,1,0.24    * lift 1 concrete
mp,kxx,2,2.6 $mp,dens,2,2300 $mp,c,2,0.24    * lift 2 concrete
mp,kxx,3,2.6 $mp,dens,3,2300 $mp,c,3,0.24    * lift 3 concrete
mp,kxx,4,2.3 $mp,dens,4,2640 $mp,c,4,0.20    * bedrock
mat,4$n,1     $n,9,0,2 $fill$ngen,2,30,1,9,1,0.25  $e,1,31,32,2  $egen,8,1,1
mat,1$n,10,0,2$n,14,0,3$fill$ngen,2,30,10,14,1,0.25$e,10,40,41,11$egen,4,1,9
mat,2$n,15,0,3$n,19,0,4$fill$ngen,2,30,15,19,1,0.25$e,15,45,46,16$egen,4,1,13
mat,3$n,20,0,4$n,24,0,5$fill$ngen,2,30,20,24,1,0.25$e,20,50,51,21$egen,4,1,17
c****************************************************************************
kbc,0 $ktemp,-1 $tref,20 $tunif,20 $nt,1,temp,2,,31,30
time,  0 $iter,1,,1 $cv,9,39,10,  7.5 $lwrite  * Ld.step 1
time, 12 $iter,6,,1 $cv,9,39,10,  0.5 $lwrite  * Ld.step 2
time, 24 $iter,6,,1 $cv,9,39,10, 15.0 $lwrite  * Ld.step 3
time, 36 $iter,6,,1 $cv,9,39,10,  6.0 $lwrite  * Ld.step 4
time, 48 $iter,6,,1 $cv,9,39,10, 26.0 $lwrite  * Ld.step 5
time, 60 $iter,6,,1 $cv,9,39,10,  2.5 $lwrite  * Ld.step 6
time, 72 $iter,6,,1 $cv,9,39,10, 13.5 $lwrite  * Ld.step 7
afwrite $finish
/input,27 $finish
/eof
```

The responses of selected nodes in the model are shown in Figure A.4. Nodes 1 to 9 belong to foundation elements and react to the changing fluid temperature of the convective boundary condition. Node 10, one of the two bottom nodes of the bottom element of the first lift of concrete above the foundation, remains at 0° throughout the duration of the analysis since this segment of the model has been left uncoupled from the active foundation portion of the model. Node 1, at the bottom of the foundation, remains at the specified 2° temperature value throughout the run as specified by the boundary condition.

The finite element program requires that the first load step of a transient thermal analysis be for one iteration only. The program will calculate a steady state solution for this load step if the value of time is specified to be zero. Thus the temperatures shown in the Figure at time = 0 are steady state values for the convective boundary condition in the first load step. Subsequent iterations and load steps after this time are solved with the transient behaviour incorporated. This response pattern is evident in the plot of results for this run.

A.3 Pilot Run 2

For a full incremental thermal analysis to be carried out properly, it is necessary to stop the analysis at points in time when new lifts of concrete are placed so that new segments of the model corresponding to lifts of concrete can be coupled into the active portion of the model. Thus, a procedure for restarting the analysis without loosing the existing temperature distribution must be established. The second pilot run was carried out to test a possible command sequence for restarting a thermal analysis that has been suspended.

The transient loading applied to the pilot model in the first run is again applied to the model for the second pilot run, with the exception that the analysis is stopped and then restarted at a time equal to 36 time units. It is desirable to have the times before and after the restart be

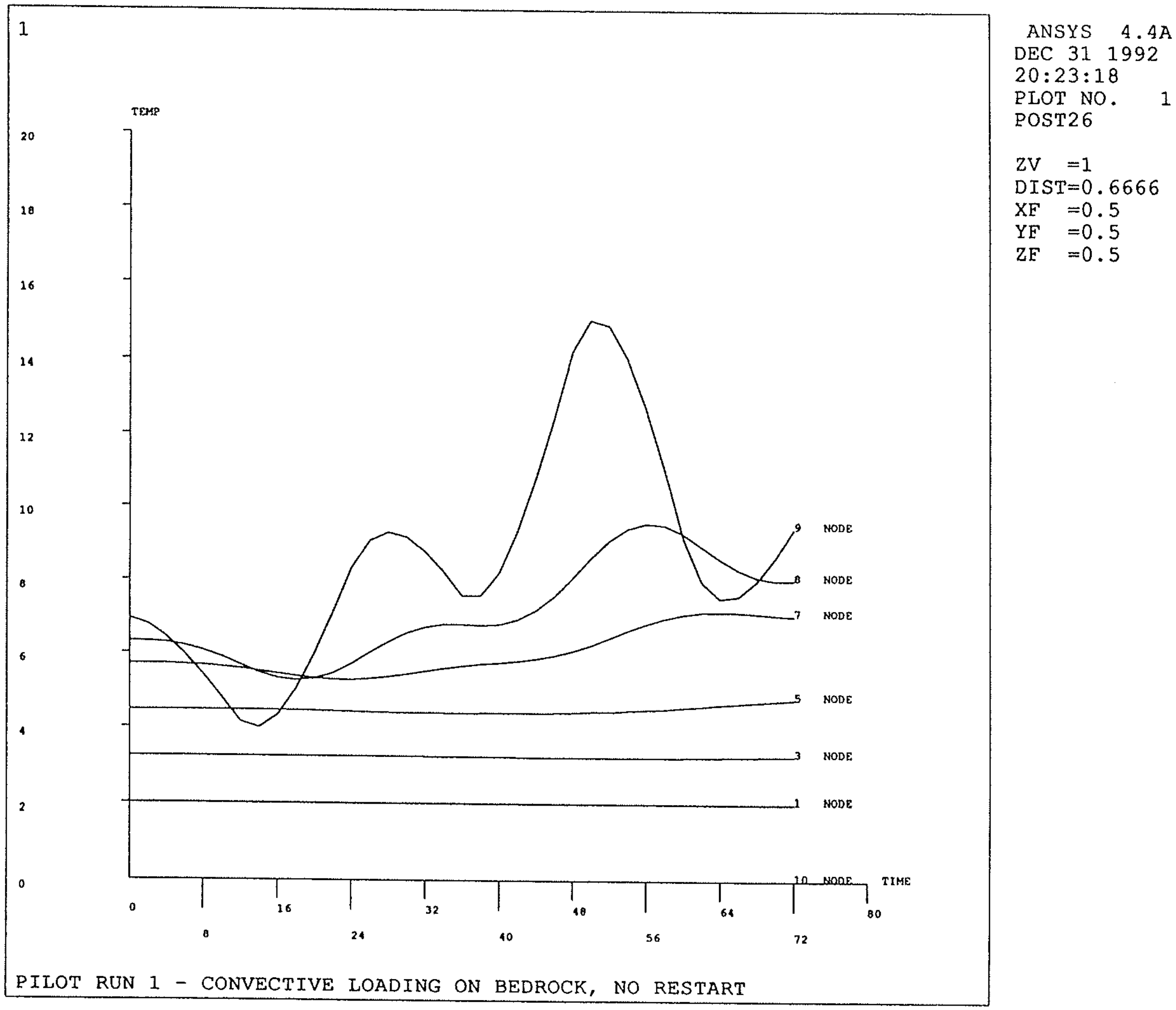

FIGURE A.4 - Nodal Temperature Responses for Pilot Run 1

the same so that the interpolation of the fluid temperature value of the convective boundary condition for iterations between load steps takes place properly. The code for this pilot run is shown below. The last few commands combine output files from the two separate execution steps carried out into a single output file to do post-processing of results from.

```
$ansys44a
/prep7
/title,PILOT RUN 2 - CONVECTIVE LOADING ON BEDROCK WITH RESTART AT TIME = 36
kan,-1 $et,1,55 $type,1
mp,kxx,1,2.6 $mp,dens,1,2300 $mp,c,1,0.24    * lift 1 concrete
mp,kxx,2,2.6 $mp,dens,2,2300 $mp,c,2,0.24    * lift 2 concrete
mp,kxx,3,2.6 $mp,dens,3,2300 $mp,c,3,0.24    * lift 3 concrete
mp,kxx,4,2.3 $mp,dens,4,2640 $mp,c,4,0.20    * bedrock
mat,4$n,1      $n,9,0,2 $fill$ngen,2,30,1,9,1,0.25  $e,1,31,32,2  $egen,8,1,1
mat,1$n,10,0,2$n,14,0,3$fill$ngen,2,30,10,14,1,0.25$e,10,40,41,11$egen,4,1,9
mat,2$n,15,0,3$n,19,0,4$fill$ngen,2,30,15,19,1,0.25$e,15,45,46,16$egen,4,1,13
mat,3$n,20,0,4$n,24,0,5$fill$ngen,2,30,20,24,1,0.25$e,20,50,51,21$egen,4,1,17
c***************************************************************************
kbc,0 $ktemp,-1 $tref,20 $tunif,20 $nt,1,temp,2,,31,30
time,  0 $iter,1,,1 $cv,9,39,10,  7.5 $lwrite  * Ld.step 1
time, 12 $iter,6,,1 $cv,9,39,10,  0.5 $lwrite  * Ld.step 2
time, 24 $iter,6,,1 $cv,9,39,10, 15.0 $lwrite  * Ld.step 3
time, 36 $iter,6,,1 $cv,9,39,10,  6.0 $lwrite  * Ld.step 4
afwrite $finish
/input,27 $finish
/eof
$rename file12.dat file39.dat
$ansys44a
/prep7 $resume $krstrt,4
time, 36 $iter,1,,1 $cv,9,39,10,  6.0 $lwrite  * Ld.step 5
time, 48 $iter,6,,1 $cv,9,39,10, 26.0 $lwrite  * Ld.step 6
time, 60 $iter,6,,1 $cv,9,39,10,  2.5 $lwrite  * Ld.step 7
time, 72 $iter,6,,1 $cv,9,39,10, 13.5 $lwrite  * Ld.step 8
afwrite $finish
/input,27 $finish
/eof
$rename file12.dat file40.dat
$ansys44a
/inter,no
/aux1 $copy,39,12 $copy,40,12
finish
/eof
```

The plot of temperature responses over time for some of the nodes in the model is shown in Figure A.5. Again, nodes 1 to 9 begin from a steady state solution of the first load step at time = 0 and then respond to the varying convective load on the top of the foundation. Node 10

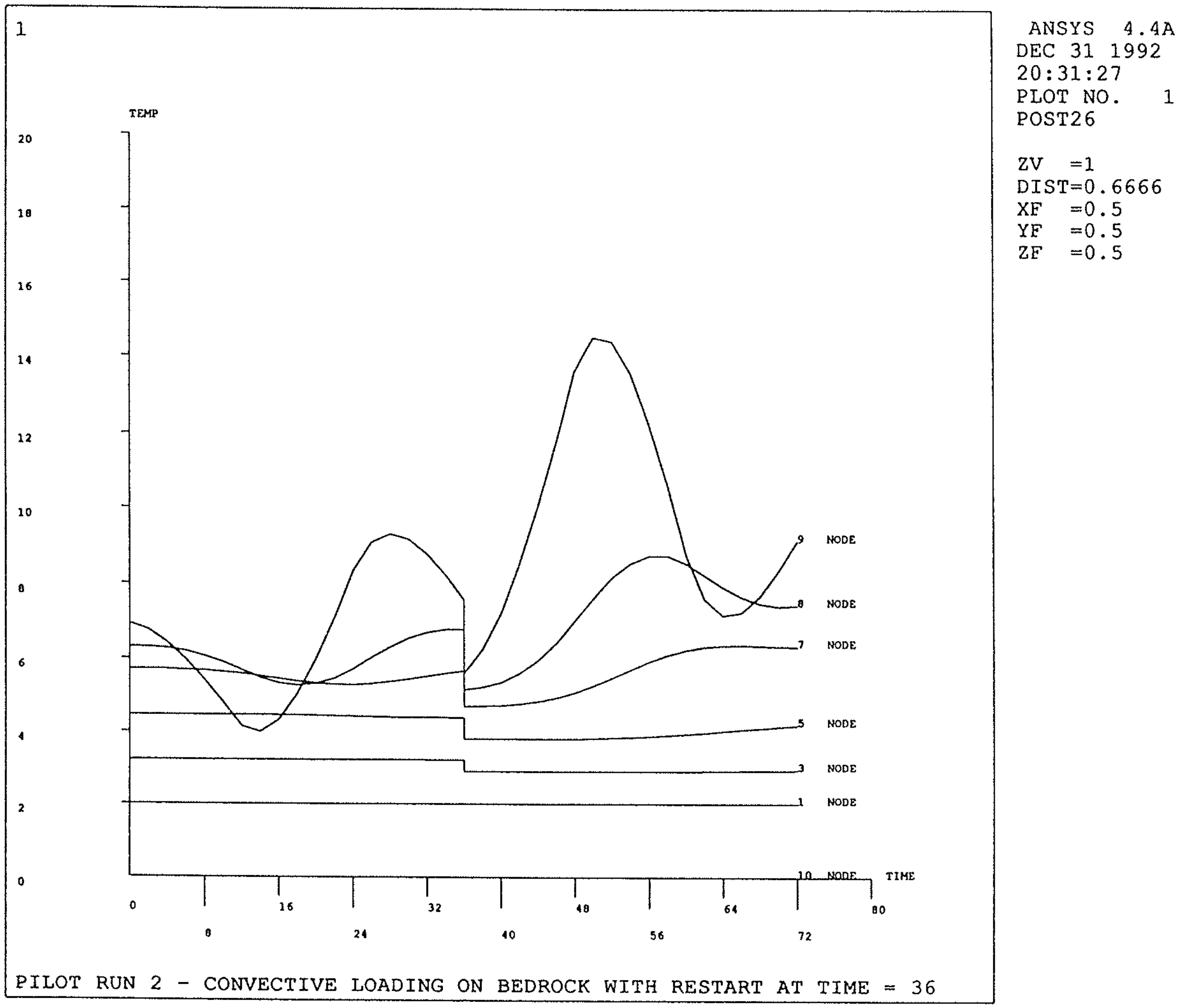

FIGURE A.5 - Nodal Temperature Responses for Pilot Run 2

remains at 0° throughout the analysis since it belongs to an inactive segment of the model, and node 1 remains at the nodal temperature boundary condition value of 2°. However, the temperature distribution in the model obtained from solution of the load steps up to time 36 is lost upon restarting the analysis. The nodal temperatures at the time of the restart again begin from a steady state condition. Thus, this particular restart command sequence in essence produces two sequential independent transient thermal analyses, both starting from a steady state condition, on the same model. The reason for this is that a restart of a transient analysis that uses the KRSTRT command must have the value of time for the first load step specified after the restart be greater than the last load step time prior to the stopping the analysis. The effect of this detail can be seen in the results of the third pilot run.

A.4 Pilot Run 3

The third pilot run is exactly identical to the second, except that the time for the first specified load step after the restart is 36.1, 0.1 time units later than the last time specified prior to stopping the analysis. All other commands are the same as for pilot run two. The program code for this run is shown below.

```
$ansys44a
/prep7
/title,PILOT RUN 3 - CONVECTIVE LOADING ON BEDROCK WITH RESTART AT TIME = 36.1
kan,-1 $et,1,55 $type,1
mp,kxx,1,2.6 $mp,dens,1,2300 $mp,c,1,0.24    * lift 1 concrete
mp,kxx,2,2.6 $mp,dens,2,2300 $mp,c,2,0.24    * lift 2 concrete
mp,kxx,3,2.6 $mp,dens,3,2300 $mp,c,3,0.24    * lift 3 concrete
mp,kxx,4,2.3 $mp,dens,4,2640 $mp,c,4,0.20    * bedrock
mat,4$n,1     $n,9,0,2 $fill$ngen,2,30,1,9,1,0.25  $e,1,31,32,2  $egen,8,1,1
mat,1$n,10,0,2$n,14,0,3$fill$ngen,2,30,10,14,1,0.25$e,10,40,41,11$egen,4,1,9
mat,2$n,15,0,3$n,19,0,4$fill$ngen,2,30,15,19,1,0.25$e,15,45,46,16$egen,4,1,13
mat,3$n,20,0,4$n,24,0,5$fill$ngen,2,30,20,24,1,0.25$e,20,50,51,21$egen,4,1,17
c*****************************************************************************
kbc,0 $ktemp,-1 $tref,20 $tunif,20 $nt,1,temp,2,,31,30
time,  0 $iter,1,,1 $cv,9,39,10,  7.5 $lwrite  * Ld.step 1
time, 12 $iter,6,,1 $cv,9,39,10,  0.5 $lwrite  * Ld.step 2
time, 24 $iter,6,,1 $cv,9,39,10, 15.0 $lwrite  * Ld.step 3
time, 36 $iter,6,,1 $cv,9,39,10,  6.0 $lwrite  * Ld.step 4
```

```
afwrite $finish
/input,27 $finish
/eof
$rename file12.dat file39.dat
$ansys44a
/prep7 $resume $krstrt,4
time,36.1$iter,1,,1 $cv,9,39,10,  6.0 $lwrite  * Ld.step 5
time, 48 $iter,6,,1 $cv,9,39,10, 26.0 $lwrite  * Ld.step 6
time, 60 $iter,6,,1 $cv,9,39,10,  2.5 $lwrite  * Ld.step 7
time, 72 $iter,6,,1 $cv,9,39,10, 13.5 $lwrite  * Ld.step 8
afwrite $finish
/input,27 $finish
/eof
$rename file12.dat file40.dat
$ansys44a
/inter,no
/aux1 $copy,39,12 $copy,40,12
finish
/eof
```

The plot of nodal temperature responses is shown as Figure A.6. This time the temperature distribution in the model obtained up to the time of the restart is retained for continuation into the restarted portion of the analysis. A comparison of this plot of temperature responses with that obtained from the first pilot run reveals only a slight difference in the temperature of the highest node plotted in the foundation segment of the model in the time immediately after the restart. This difference is due to the short time step required at the beginning of the second series of load steps in the analysis, before the regular time step pattern can be resumed.

The load step that begins the second part of the analysis is only for one iteration, and specifically consists of the same applied boundary conditions as the last load step before the restart. This is done to ensure that boundary condition parameters for iterations within the second load step after the restart are interpolated between the correct specified values. This makes the treatment of boundary condition parameters for iterations within load steps consistent at all times of the analysis.

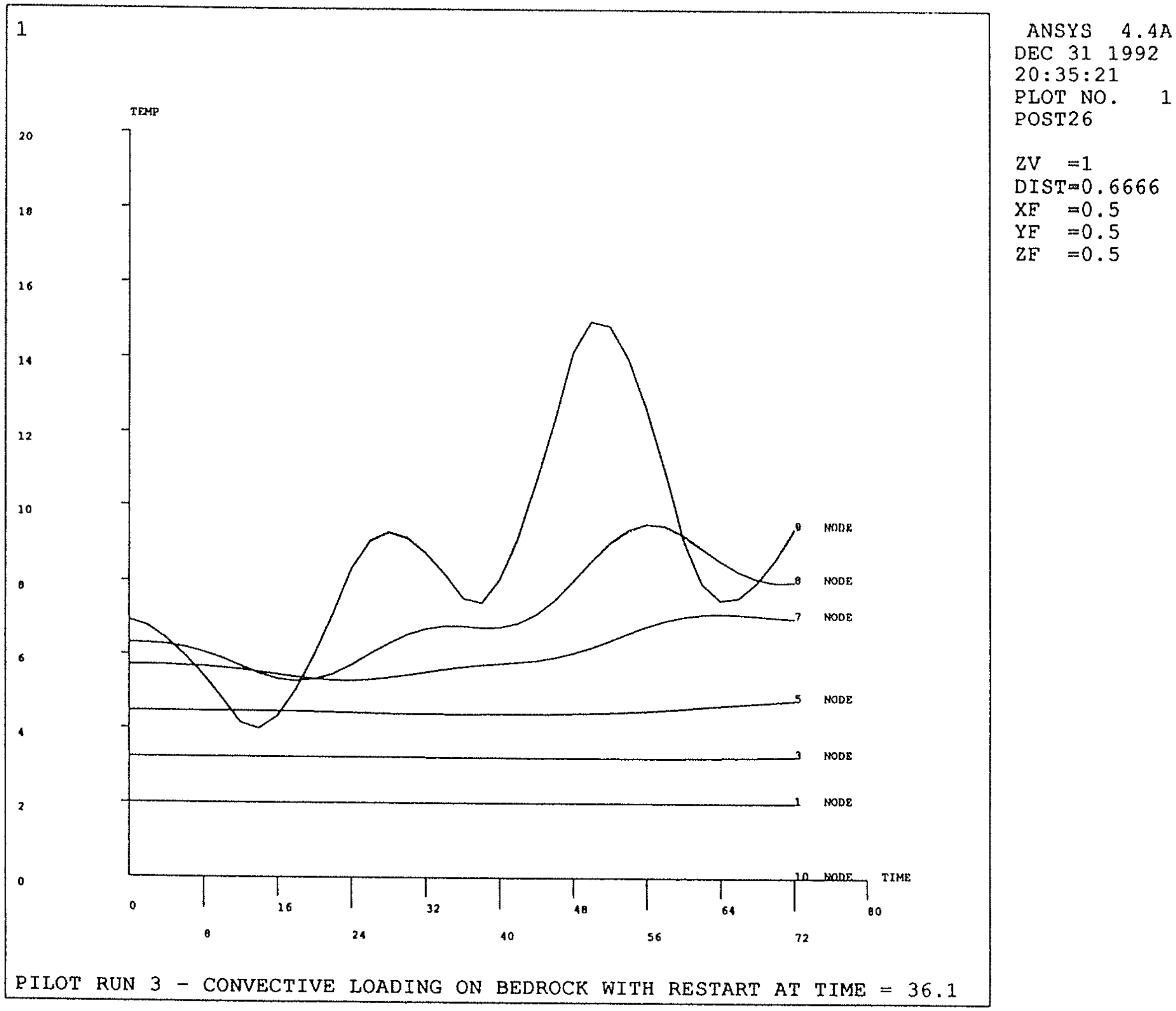

FIGURE A.6 - Nodal Temperature Responses for Pilot Run 3

It is worthwhile to verify the behaviour of the model in the third pilot run by carrying out an identical analysis without the restart. Pilot run four is used to do this.

A.5 Pilot Run 4

The fourth pilot run is a non-restarted form of the third pilot run, with the same load steps from the third run and a single iteration load step at time 36.1. The code for this run is:

```
$ansys44a
/prep7
/title,PILOT RUN 4 - BEDROCK LOADED, NO RESTART, LOAD STEP AT TIME = 36.1
kan,-1 $et,1,55 $type,1
mp,kxx,1,2.6 $mp,dens,1,2300 $mp,c,1,0.24    * lift 1 concrete
mp,kxx,2,2.6 $mp,dens,2,2300 $mp,c,2,0.24    * lift 2 concrete
mp,kxx,3,2.6 $mp,dens,3,2300 $mp,c,3,0.24    * lift 3 concrete
mp,kxx,4,2.3 $mp,dens,4,2640 $mp,c,4,0.20    * bedrock
mat,4$n,1     $n,9,0,2 $fill$ngen,2,30,1,9,1,0.25  $e,1,31,32,2  $egen,8,1,1
mat,1$n,10,0,2$n,14,0,3$fill$ngen,2,30,10,14,1,0.25$e,10,40,41,11$egen,4,1,9
mat,2$n,15,0,3$n,19,0,4$fill$ngen,2,30,15,19,1,0.25$e,15,45,46,16$egen,4,1,13
mat,3$n,20,0,4$n,24,0,5$fill$ngen,2,30,20,24,1,0.25$e,20,50,51,21$egen,4,1,17
c*******************************************************************************
kbc,0 $ktemp,-1 $tref,20 $tunif,20 $nt,1,temp,2,,31,30
time,  0 $iter,1,,1 $cv,9,39,10,  7.5 $lwrite  * Ld.step 1
time, 12 $iter,6,,1 $cv,9,39,10,  0.5 $lwrite  * Ld.step 2
time, 24 $iter,6,,1 $cv,9,39,10, 15.0 $lwrite  * Ld.step 3
time, 36 $iter,6,,1 $cv,9,39,10,  6.0 $lwrite  * Ld.step 4
time,36.1$iter,1,,1 $cv,9,39,10,  6.0 $lwrite  * Ld.step 5
time, 48 $iter,6,,1 $cv,9,39,10, 26.0 $lwrite  * Ld.step 6
time, 60 $iter,6,,1 $cv,9,39,10,  2.5 $lwrite  * Ld.step 7
time, 72 $iter,6,,1 $cv,9,39,10, 13.5 $lwrite  * Ld.step 8
afwrite $finish
/input,27 $finish
/eof
```

Figure A.7 shows that the results of pilot run four are identical to those obtained in pilot run three. Therefore, the restarted analysis can produce the same results as a non-restarted analysis with similar load steps at similar times.

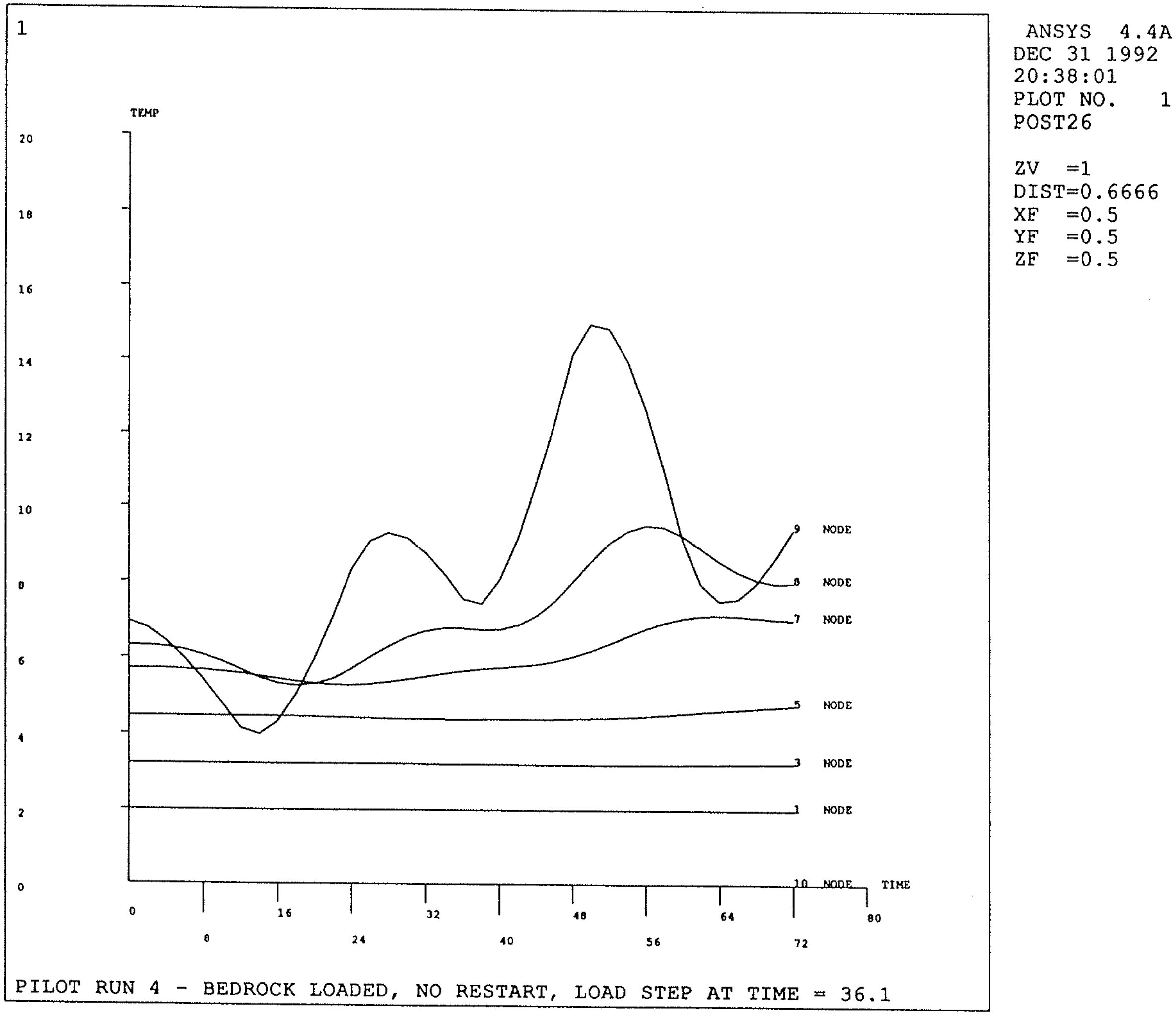

FIGURE A.7 - Nodal Temperature Responses for Pilot Run 4

A.6 Pilot Run 5

In the fifth pilot run, the correct thermal analysis restart command sequence obtained from pilot run three is used to incorporate the segment of the model representing the first concrete lift into the model, coupling it to the underlying active foundation segment of the model. The analysis is stopped after the first series of load steps, the convective boundary condition on top of the foundation is deleted, the new segment of the model is coupled to the previously active portion of the model, and the analysis is then restarted with subsequent convective boundary conditions applied to the top surface of the new lift of concrete. The coupling of nodes at the bottom of the new segment to the top of the previously active segment forces the two segments to respond together to applied loading as a single structure. The code to carry this out is as follows.

```
$ansys44a
/prep7
/title,PILOT RUN 5 - SINGLE RESTART, MATERIAL COUPLING, CONVECTIVE LOAD CHANGE
kan,-1 $et,1,55 $type,1
mp,kxx,1,2.6 $mp,dens,1,2300 $mp,c,1,0.24    * lift 1 concrete
mp,kxx,2,2.6 $mp,dens,2,2300 $mp,c,2,0.24    * lift 2 concrete
mp,kxx,3,2.6 $mp,dens,3,2300 $mp,c,3,0.24    * lift 3 concrete
mp,kxx,4,2.3 $mp,dens,4,2640 $mp,c,4,0.20    * bedrock
mat,4$n,1     $n,9,0,2 $fill$ngen,2,30,1,9,1,0.25  $e,1,31,32,2  $egen,8,1,1
mat,1$n,10,0,2$n,14,0,3$fill$ngen,2,30,10,14,1,0.25$e,10,40,41,11$egen,4,1,9
mat,2$n,15,0,3$n,19,0,4$fill$ngen,2,30,15,19,1,0.25$e,15,45,46,16$egen,4,1,13
mat,3$n,20,0,4$n,24,0,5$fill$ngen,2,30,20,24,1,0.25$e,20,50,51,21$egen,4,1,17
c*****************************************************************************
kbc,0 $ktemp,-1 $tref,20 $tunif,20 $nt,1,temp,2,,31,30
time,  0 $iter,1,,1 $cv,9,39,10,  7.5 $lwrite  * Ld.step  1
time, 12 $iter,6,,1 $cv,9,39,10,  0.5 $lwrite  * Ld.step  2
time, 24 $iter,6,,1 $cv,9,39,10, 15.0 $lwrite  * Ld.step  3
time, 36 $iter,6,,1 $cv,9,39,10,  6.0 $lwrite  * Ld.step  4
afwrite $finish
/input,27 $finish
/eof
$rename file12.dat file39.dat
$ansys44a
/prep7 $resume $krstrt,4
cvdele,9,39 $cp,1,temp,9,10  $cp,2,temp,39,40
time,36.1$iter,1,,1 $cv,14,44,10,  6.0 $lwrite  * Ld.step  5
time, 48 $iter,6,,1 $cv,14,44,10, 26.0 $lwrite  * Ld.step  6
time, 60 $iter,6,,1 $cv,14,44,10,  2.5 $lwrite  * Ld.step  7
time, 72 $iter,6,,1 $cv,14,44,10, 13.5 $lwrite  * Ld.step  8
afwrite $finish
```

```
/input,27 $finish
/eof
$rename file12.dat file40.dat
$ansys44a
/inter,no
/aux1 $copy,39,12 $copy,40,12
finish
/eof
```

The plot of temperature responses for this run is shown in Figure A.8. On the Figure, the temperatures of nodes 5, 7 and 8 show that the temperature distribution in the foundation portion of the model is carried forward into the restarted portion of the analysis. The temperature of the foundation surface node 9 follows the transient convective boundary condition for the time prior to the analysis restart and is then averaged with the temperature of node 10 (0°) at the restart time of 36.1 when the two nodes are coupled together. This averaging of temperature values for a pair of nodes upon coupling is quite convenient for the purpose of this type of thermal analysis, as a similar physical behaviour can be assumed to occur when new concrete is placed on top of an existing material.

Perhaps the most prominent nodal temperature responses shown in the Figure are those of nodes belonging to elements in the new segment of the model after the coupling operation and restarting of the analysis. Nodes 12, 13 and 14 belong to elements in the first lift of concrete above the foundation. Prior to time 36, their temperatures are equal to 0° as this segment is independent of the active portion of the model. After coupling and the restart, they can be seen to begin their response to the transient convective loading from 0°. This occurs because nodal temperature values for inactive segments of the model remain at 0° until they are either set to another value by a boundary condition or are coupled into the model and can respond to the thermal loading. Node 15, meanwhile, is one of the bottom nodes of the bottom element of the second lift of concrete, and its temperature remains at 0° because that segment of the model is yet to be coupled into the active portion of the model.

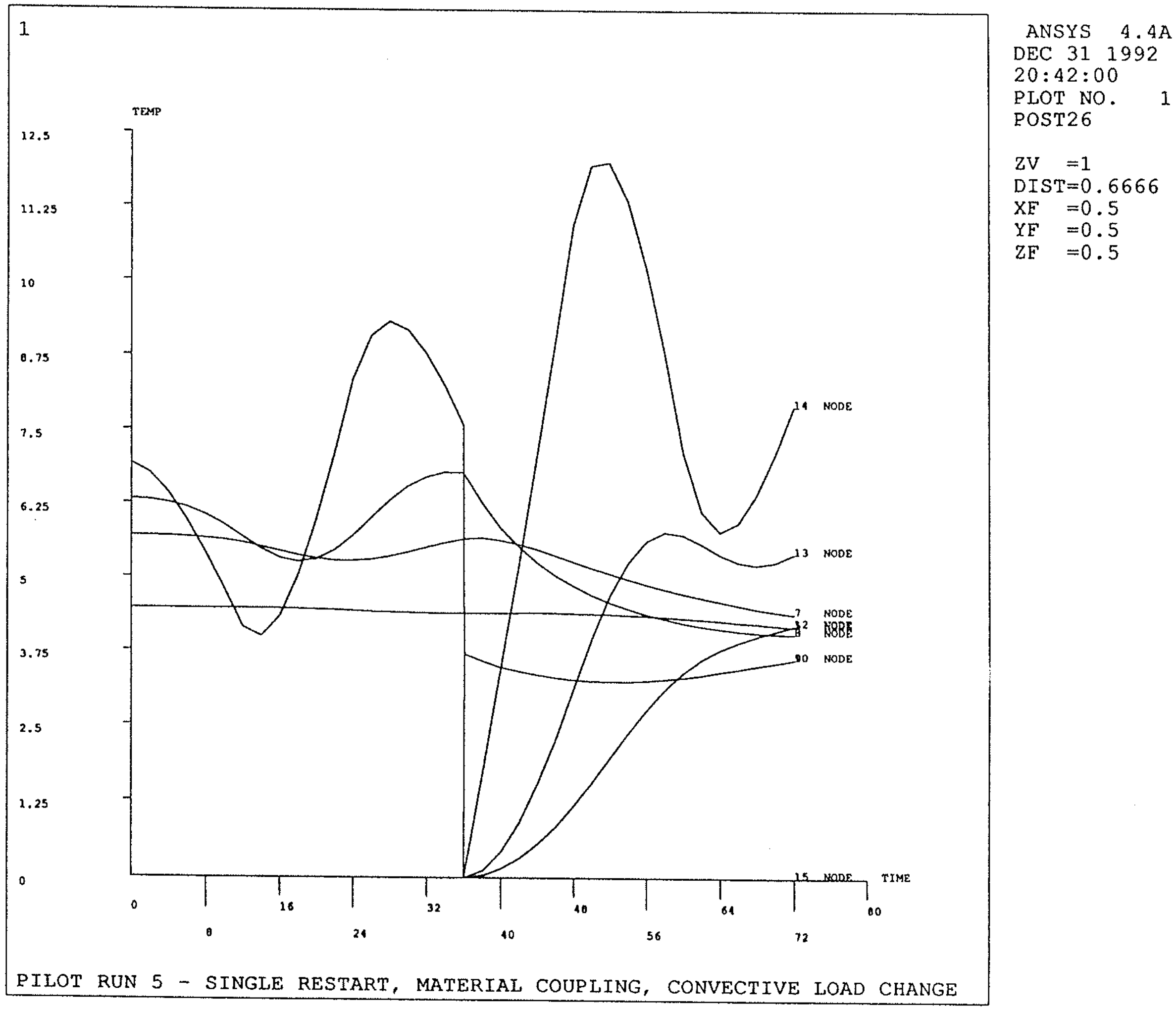

FIGURE A.8 - Nodal Temperature Responses for Pilot Run 5

A.7 Pilot Run 6

In the sixth pilot run, the restart and coupling command sequence is repeated three times, to bring all segments of the model active by the last restart. With this run however, nodal temperatures of inactive segments of the model are initialized to arbitrary temperature values to reflect some sort of placing temperature of the concrete. Temperature initialization is done in the very first load step of the analysis through nodal temperature boundary condition commands applied to one node from each segment of the model. All nodes of a segment of the model will then adopt the specified temperature value because this is the only boundary condition on each segment for the load step that is solved as a steady state problem. No other boundary conditions are applied until a segment is coupled into the active portion of the model. Thus, the entire lift gets initialized to a uniform temperature that can represent a lift's placing temperature.

The nodal temperature boundary condition for each concrete segment is deleted upon coupling of that segment to the rest of the model just prior to applying additional thermal loads. This leaves the nodes in the new segment free to respond to applied boundary conditions, but to begin their reactions from the temperature assigned through the initializing nodal temperature boundary condition.

In this sixth run, each of the three concrete segments of the model were assigned different temperatures: the first lift was set to 10°, the second lift to 11°, and the third to 12°. This allows the nodal temperatures plotted for each individual lift in the model to be observed individually throughout the analysis. The following program code defines and carries out the sixth run.

```
$ansys44a
/prep7
```

```
/title,PILOT RUN 6 - MULTIPLE RESTARTS, NT COMMAND USED FOR INACTIVE LIFTS
kan,-1 $et,1,55 $type,1
mp,kxx,1,2.6 $mp,dens,1,2300 $mp,c,1,0.24    * lift 1 concrete
mp,kxx,2,2.6 $mp,dens,2,2300 $mp,c,2,0.24    * lift 2 concrete
mp,kxx,3,2.6 $mp,dens,3,2300 $mp,c,3,0.24    * lift 3 concrete
mp,kxx,4,2.3 $mp,dens,4,2640 $mp,c,4,0.20    * bedrock
mat,4$n,1     $n,9,0,2 $fill$ngen,2,30,1,9,1,0.25  $e,1,31,32,2  $egen,8,1,1
mat,1$n,10,0,2$n,14,0,3$fill$ngen,2,30,10,14,1,0.25$e,10,40,41,11$egen,4,1,9
mat,2$n,15,0,3$n,19,0,4$fill$ngen,2,30,15,19,1,0.25$e,15,45,46,16$egen,4,1,13
mat,3$n,20,0,4$n,24,0,5$fill$ngen,2,30,20,24,1,0.25$e,20,50,51,21$egen,4,1,17
c*****************************************************************************
kbc,0 $ktemp,-1 $tref,20 $tunif,20 $nt,1,temp,2,,31,30
nt,10,temp,10 $nt,15,temp,11 $nt,20,temp,12
time,  0 $iter,1,,1 $cv,9,39,10,  7.5 $lwrite  * Ld.step  1
time, 12 $iter,6,,1 $cv,9,39,10,  0.5 $lwrite  * Ld.step  2
time, 24 $iter,6,,1 $cv,9,39,10, 15.0 $lwrite  * Ld.step  3
time, 36 $iter,6,,1 $cv,9,39,10,  6.0 $lwrite  * Ld.step  4
cvdele,9,39
afwrite $finish
/input,27 $finish
/eof
$rename file12.dat file34.dat
$ansys44a
/prep7 $resume $krstrt,4 $ntdele,10,temp
cp,1,temp,9,10 $cp,2,temp,39,40
time,36.1$iter,1,,1 $cv,14,44,10,  6.0 $lwrite  * Ld.step  5
time, 48 $iter,6,,1 $cv,14,44,10, 26.0 $lwrite  * Ld.step  6
time, 60 $iter,6,,1 $cv,14,44,10,  2.5 $lwrite  * Ld.step  7
time, 72 $iter,6,,1 $cv,14,44,10, 13.5 $lwrite  * Ld.step  8
cvdele,14,44
afwrite $finish
/input,27 $finish
/eof
$rename file12.dat file35.dat
$ansys44a
/prep7 $resume $krstrt,8 $ntdele,15,temp
cp,3,temp,14,15 $cp,4,temp,44,45
time,72.1$iter,1,,1 $cv,19,49,10, 13.5 $lwrite  * Ld.step  9
time, 84 $iter,6,,1 $cv,19,49,10, 23.0 $lwrite  * Ld.step 10
time, 96 $iter,6,,1 $cv,19,49,10, 17.5 $lwrite  * Ld.step 11
time,108 $iter,6,,1 $cv,19,49,10, 28.5 $lwrite  * Ld.step 12
cvdele,19,49
afwrite $finish
/input,27 $finish
/eof
$rename file12.dat file36.dat
$ansys44a
/prep7 $resume $krstrt,12 $ntdele,20,temp
cp,5,temp,19,20 $cp,6,temp,49,50
time,108.1$iter,1,,1$cv,24,54,10, 28.5 $lwrite  * Ld.step 13
time,120 $iter,6,,1 $cv,24,54,10, 16.0 $lwrite  * Ld.step 14
time,132 $iter,6,,1 $cv,24,54,10, 22.5 $lwrite  * Ld.step 15
time,144 $iter,6,,1 $cv,24,54,10, 18.5 $lwrite  * Ld.step 16
cvdele,24,54
afwrite $finish
/input,27 $finish
/eof
$rename file12.dat file37.dat
$ansys44a
/inter,no
/aux1 $copy,34,12 $copy,35,12 $copy,36,12 $copy,37,12
```

```
finish
/eof
```

The plot of nodal temperatures for this run is shown in Figure A.9. Nodes of the foundation (6, 8 and 9) respond to the applied transient convective boundary conditions until time 36 when the first concrete segment is coupled to the foundation. At that time, the temperature of node 9 is averaged with the temperature of node 10 since these two nodes become a coupled pair, and the two nodes then continue at common temperatures for the rest of the analysis. Nodes 13 and 14 belong to elements of the first concrete segment. Their temperatures remain at the assigned value of 10° until time 36, when the initial nodal temperature boundary condition on that lift is deleted. This segment of the model is then coupled to the foundation and the convective loads are applied to the top of the lift. This remains as the active portion of the model until time 72 when the same procedure is applied to the second segment of the model, representing the second lift of concrete placed. This time, the plot shows nodes 18 and 19 to begin their response to the applied thermal loads from their assigned initial temperature of 11°. Finally, the process is repeated one last time when the top lift of concrete is coupled into the model. The nodal temperature boundary condition on this segment of the model is deleted, and the transient convective loads are applied to the top surface of this last lift of concrete.

The Figure clearly shows that nodal temperatures of individual lifts can be isolated from active portions of the model, and can be held at predetermined temperature values until the time comes to incorporate each lift into the rest of the model. After this point, nodal temperature response begins from the initialized temperature values, and the temperature distribution present in the remainder of the model is carried forward into the rest of the analysis.

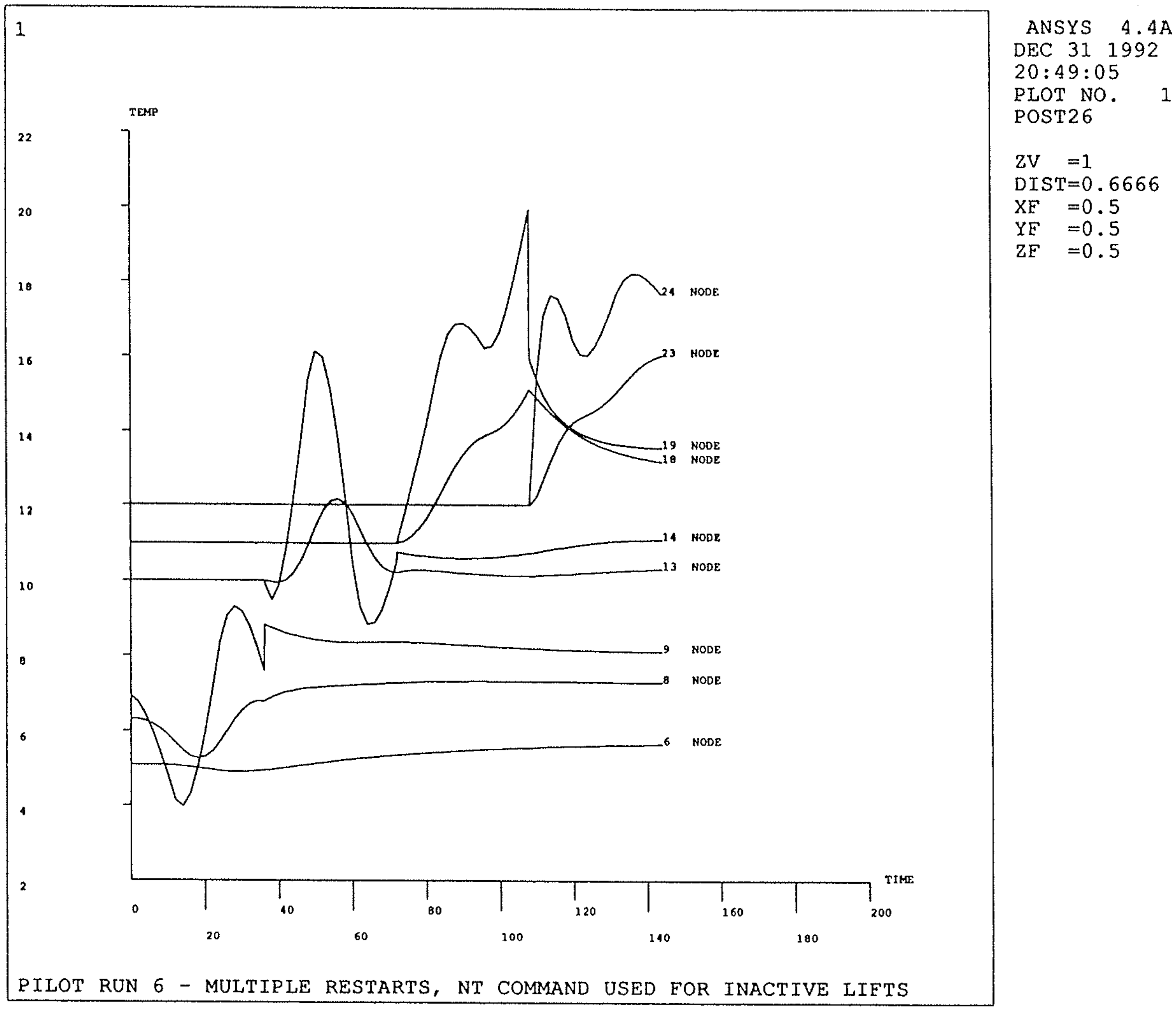

FIGURE A.9 - Nodal Temperature Responses for Pilot Run 6

A.8 Pilot Run 7

The seventh and final pilot run is a repeat of the sixth run, with the addition of an arbitrary pattern of internal heat generation rates being applied as an additional thermal load. This heat generation loading is intended to simulate the hydration of cement in a concrete mix after placement, and is the final type of load required to be incorporated to produce realistic thermal loading on a model simulating a mass concrete dam.

For proper modelling of internal heat generation, a command sequence must be possible that allows either no heat generation rate to be assigned to a group of elements, as in the case of the foundation material, or, since the lifts of concrete are placed at different points in time, various heat generation rates to be assigned in any single given load step. By default, no heat generation is assumed to occur unless specified, which takes care of the foundation situation. To assign specific rates to different concretes in different lifts of the model in the same load step, subsets of all the elements in the model are flagged, or selected, individually. In this type of modelling, it is convenient to do this element selection on the basis of the material property data set reference numbers assigned to sets of elements in the model definition portion of the code. It is for this reason that all elements of a particular segment of the model were assigned their own material property data set reference number, even though the material property values may have been identical to those of other segments of the model.

The pattern of heat generation rates over time was applied to all elements of each concrete segment of the model beginning at the time each lift was placed. The full listing of the code for this pilot run is shown below.

```
$ansys44a
/prep7
/title,PILOT RUN 7 - MULTIPLE RESTARTS WITH INTERNAL HEAT GENERATION LOADING
kan,-1 $et,1,55 $type,1
mp,kxx,1,2.6 $mp,dens,1,2300 $mp,c,1,0.24    * lift 1 concrete
```

```
mp,kxx,2,2.6 $mp,dens,2,2300 $mp,c,2,0.24     * lift 2 concrete
mp,kxx,3,2.6 $mp,dens,3,2300 $mp,c,3,0.24     * lift 3 concrete
mp,kxx,4,2.3 $mp,dens,4,2640 $mp,c,4,0.20     * bedrock
mat,4$n,1      $n,9,0,2 $fill$ngen,2,30,1,9,1,0.25  $e,1,31,32,2  $egen,8,1,1
mat,1$n,10,0,2$n,14,0,3$fill$ngen,2,30,10,14,1,0.25$e,10,40,41,11$egen,4,1,9
mat,2$n,15,0,3$n,19,0,4$fill$ngen,2,30,15,19,1,0.25$e,15,45,46,16$egen,4,1,13
mat,3$n,20,0,4$n,24,0,5$fill$ngen,2,30,20,24,1,0.25$e,20,50,51,21$egen,4,1,17
c***************************************************************************
kbc,0 $ktemp,-1 $tref,20 $tunif,20 $nt,1,temp,2,,31,30
nt,10,temp,10 $nt,15,temp,11 $nt,20,temp,12
time,  0 $iter,1,,1 $cv,9,39,10,  7.5 $lwrite  * Ld.step  1
time, 12 $iter,6,,1 $cv,9,39,10,  0.5 $lwrite  * Ld.step  2
time, 24 $iter,6,,1 $cv,9,39,10, 15.0 $lwrite  * Ld.step  3
time, 36 $iter,6,,1 $cv,9,39,10,  6.0 $lwrite  * Ld.step  4
cvdele,9,39
afwrite $finish
/input,27 $finish
/eof
$rename file12.dat file34.dat
$ansys44a
/prep7 $resume $krstrt,4 $ntdele,10,temp
cp,1,temp,9,10 $cp,2,temp,39,40
time,36.1$iter,1,,1 $cv,14,44,10,  6.0 $esel,mat,1 $qe,all,100 $eall
                                         lwrite  * Ld.step  5
time, 48 $iter,6,,1 $cv,14,44,10, 26.0 $esel,mat,1 $qe,all, 70 $eall
                                         lwrite  * Ld.step  6
time, 60 $iter,6,,1 $cv,14,44,10,  2.5 $esel,mat,1 $qe,all, 40 $eall
                                         lwrite  * Ld.step  7
time, 72 $iter,6,,1 $cv,14,44,10, 13.5 $esel,mat,1 $qe,all, 30 $eall
                                         lwrite  * Ld.step  8
cvdele,14,44
afwrite $finish
/input,27 $finish
/eof
$rename file12.dat file35.dat
$ansys44a
/prep7 $resume $krstrt,8 $ntdele,15,temp
cp,3,temp,14,15 $cp,4,temp,44,45
time,72.1$iter,1,,1 $cv,19,49,10, 13.5 $esel,mat,1 $qe,all, 15 $eall
          esel,mat,2 $qe,all,100 $eall $lwrite  * Ld.step  9
time, 84 $iter,6,,1 $cv,19,49,10, 23.0 $esel,mat,1 $qe,all,  5 $eall
          esel,mat,2 $qe,all, 70 $eall $lwrite  * Ld.step 10
time, 96 $iter,6,,1 $cv,19,49,10, 17.5 $esel,mat,1 $qedele,all $eall
          esel,mat,2 $qe,all, 40 $eall $lwrite  * Ld.step 11
time,108 $iter,6,,1 $cv,19,49,10, 28.5 $esel,mat,2 $qe,all, 30 $eall
                                         lwrite  * Ld.step 12
cvdele,19,49
afwrite $finish
/input,27 $finish
/eof
$rename file12.dat file36.dat
$ansys44a
/prep7 $resume $krstrt,12 $ntdele,20,temp
cp,5,temp,19,20 $cp,6,temp,49,50
time,108.1$iter,1,,1$cv,24,54,10, 28.5 $esel,mat,2 $qe,all, 15 $eall
          esel,mat,3 $qe,all,100 $eall $lwrite  * Ld.step 13
time,120 $iter,6,,1 $cv,24,54,10, 16.0 $esel,mat,2 $qe,all,  5 $eall
          esel,mat,3 $qe,all, 70 $eall $lwrite  * Ld.step 14
time,132 $iter,6,,1 $cv,24,54,10, 22.5 $esel,mat,2 $qedele,all $eall
          esel,mat,3 $qe,all, 40 $eall $lwrite  * Ld.step 15
time,144 $iter,6,,1 $cv,24,54,10, 18.5 $esel,mat,3 $qe,all, 30 $eall
```

```
                                                lwrite  * Ld.step 16
cvdele,24,54
afwrite $finish
/input,27 $finish
/eof
$rename file12.dat file37.dat
$ansys44a
/inter,no
/aux1 $copy,34,12 $copy,35,12 $copy,36,12 $copy,37,12
finish
/eof
```

The resulting plot of nodal temperatures versus time is shown in Figure A.10. The response pattern is somewhat similar to that obtained from pilot run six, but of course differs by the effects of the internal heat generation rate loading applied to the elements.

This seventh pilot run simulates all necessary applied loading and boundary condition effects and modelling features that are needed for realistic thermal modelling of an incrementally constructed dam. The command pattern utilized for this final pilot run forms the basis for the developed algorithm as presented in Figure 2 of Chapter 3, and for carrying out the case study to test the algorithm.

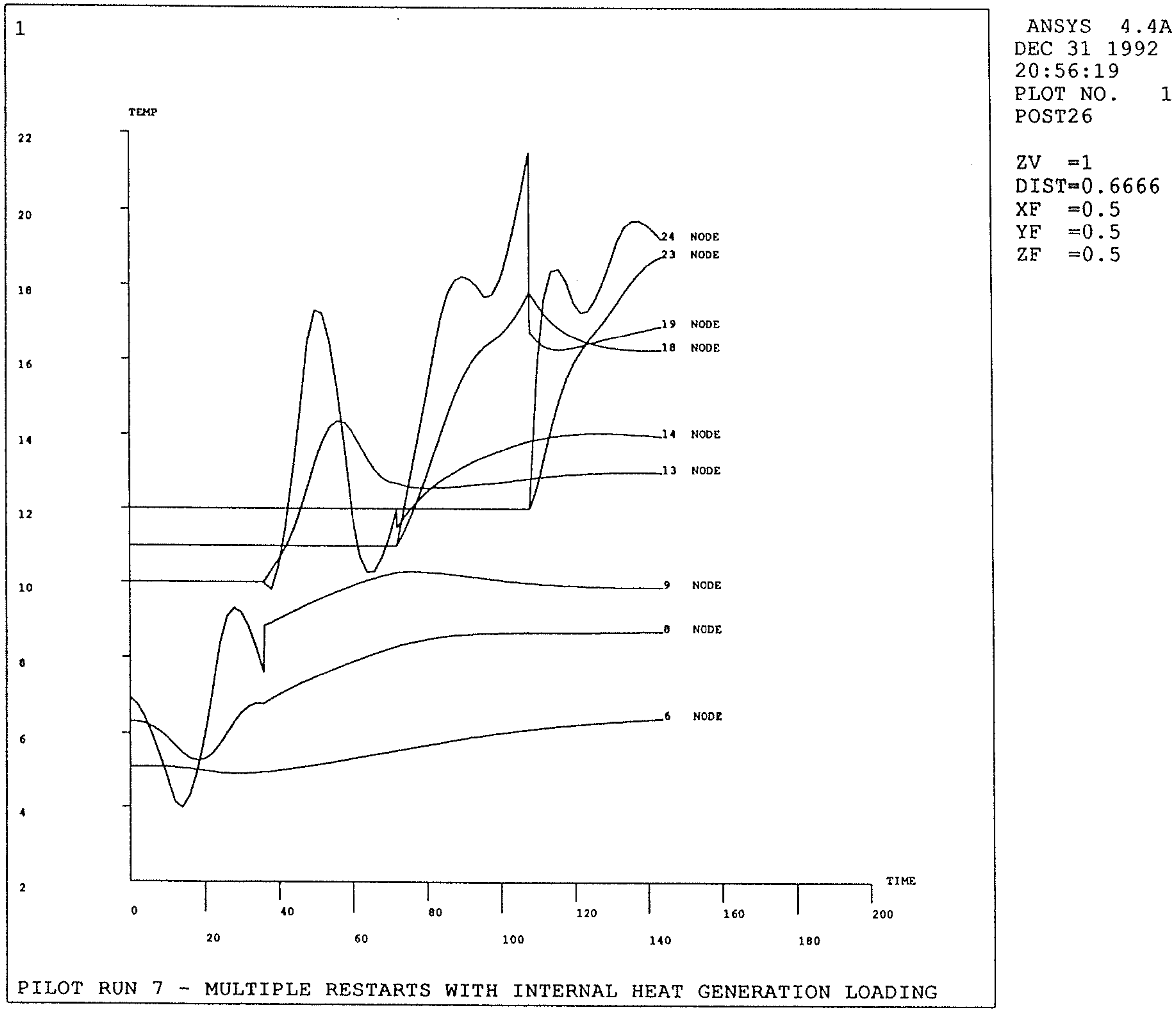

FIGURE A.10 - Nodal Temperature Responses for Pilot Run 7

APPENDIX B

SOFTWARE VERIFICATION PROBLEMS

B SOFTWARE VERIFICATION PROBLEMS

The reliability of the finite element program was tested through the solution of a series of six progressive simple one-dimensional thermal problems. Analytical solutions were used to compare with the finite element solutions of the problems. The process begins with the simple case of steady state conduction in a solid, and progress to a transient analysis of conduction with internal heat generation in a solid.

B.1 Thermal Model

The thermal material properties of the solid used for this exercise are arbitrary in their value and units of measurement. The property values are shown in Table B.1.

Property	Value
Conductivity, k_c	5
Mass density, ρ	700
Specific heat, C_p	2
Convection coefficient, h_c	15

TABLE B.1 - Material Properties for Software Verification Problems

The geometry of the finite element model was defined in two dimensions as shown in Figure B.1 by the following program code.

```
$ansys44a
/prep7
/title,THERMAL VERIFICATION RUNS - MODEL DEFINITION
kan,-1  $et,1,55  $type,1
mp,kxx,1,5  $mp,dens,1,700 $mp,c,1,2
mat,1 $n,1  $n,25,,10    $fill,,,,,,,,0.1 $ngen,2,30,1,30,1,0.15
e,1,31,32,2 $egen,24,1,1
finish
/eof
```

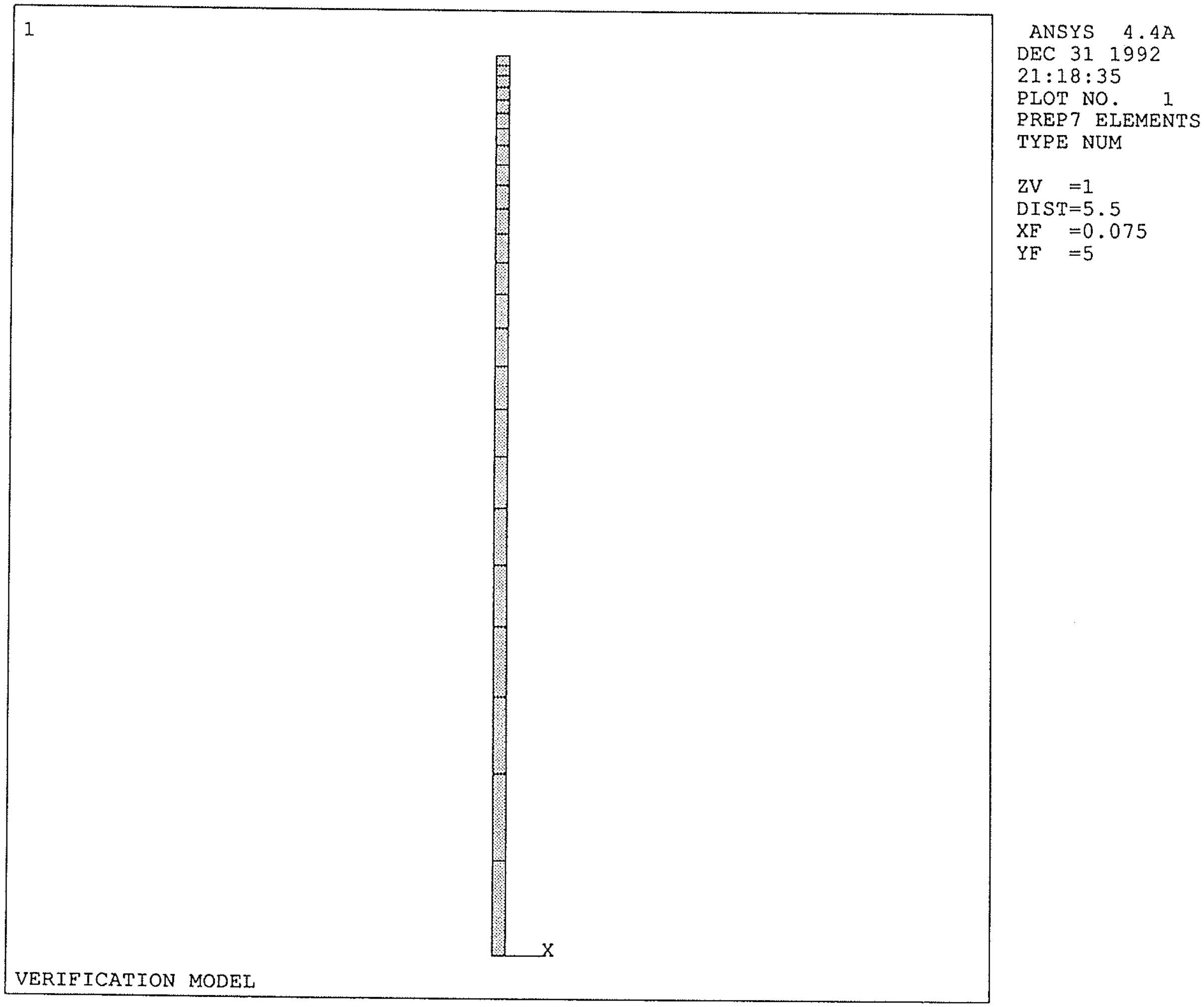

FIGURE B.1 - Finite Element Model for Software Verification Problems

The two side surfaces of the model are left unloaded for all of these problems (i.e., no boundary conditions are assigned) and therefore are treated as adiabatic surfaces. The model can then be loaded to behave one-dimensionally and results can be compared to analytical solutions that are one-dimensional in their derivation.

The width of the model was arbitrarily set, while the height was checked to ensure that the model could be considered as a semi-infinite solid, since some of the verification problems utilize analytical solutions that were derived for semi-infinite solids. Kreith[122] suggests that a plate of thickness L can be considered to be semi-infinite if

$$Fo = \frac{\alpha t}{L^2} < 1.0 \tag{B.1}$$

where α is the material thermal diffusivity, and t is time. For the material properties shown in Table B.1 and an arbitrary height of the model of 10 distance units, it is be calculated that the finite element model can be considered to be semi-infinite to a time of t = 28 000 time units. This is more than adequate for the transient problems used as part of this verification series.

The mesh pattern has element sizes decreasing approaching the top surface of the model to better respond to boundary conditions applied at that location. Figure B.2 shows the enlarged nodal pattern and node numbers for elements near the top surface of the model. The nodes along the left side of the model, their y-coordinates as defined by the above program code, and their depths below the top surface of the model are listed in Table B.2. It is these nodal locations that are used for computing analytical solutions for the different problems considered, so that a direct comparison between analytical and finite element results can be made.

Several of the analytical solutions require evaluation of the Gauss error function, erf(x). The strict definition of the function is:

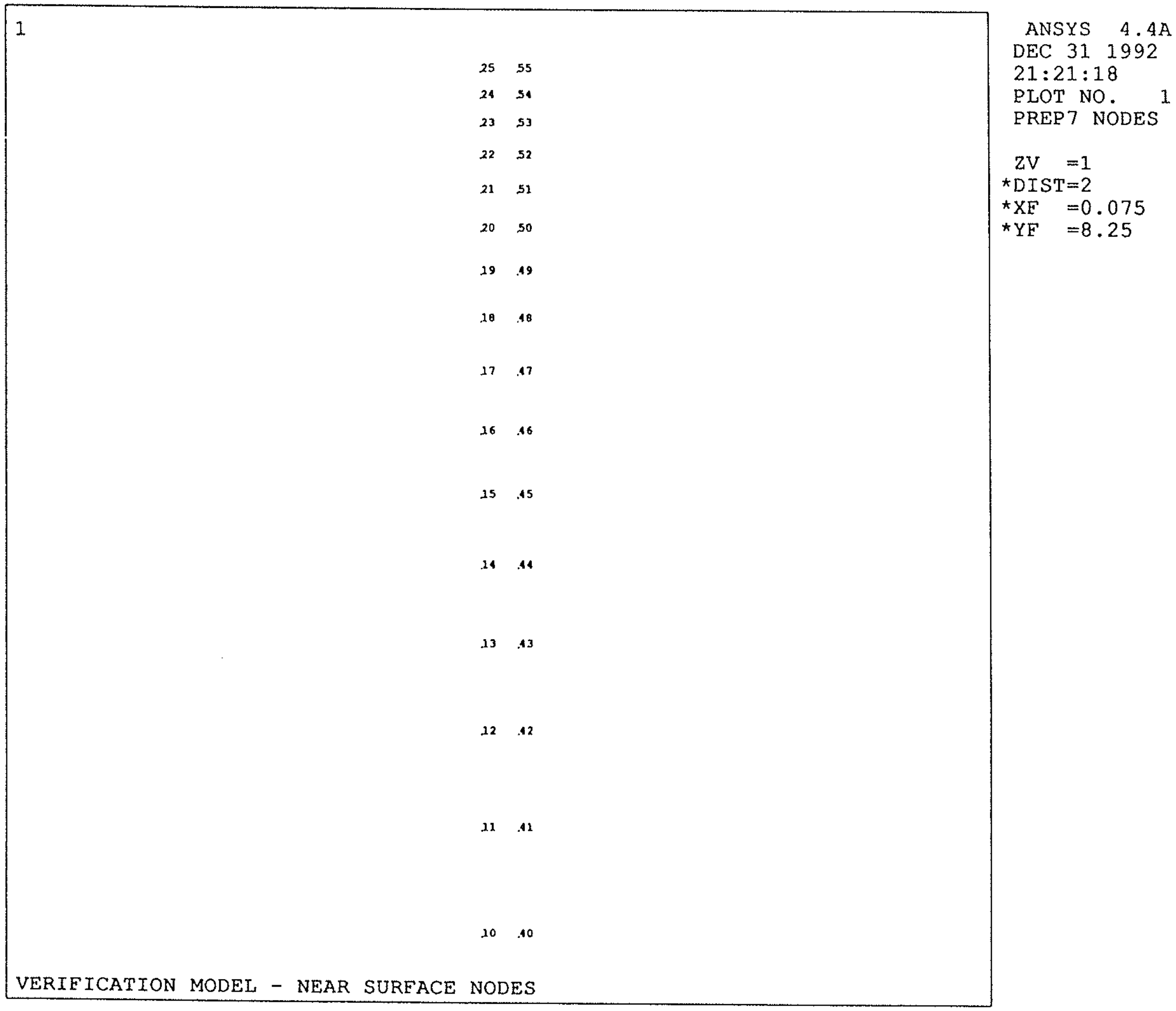

FIGURE B.2 - Verification Model Node Pattern and Numbering for Near Surface Elements

Node	Y-Coordinate	Depth (x)	Node	Y-Coordinate	Depth (x)
1	0.0000	10.0000	14	8.0027	1.9973
2	1.0474	8.9526	15	8.2877	1.7123
3	1.9950	8.0050	16	8.5456	1.4544
4	2.8524	7.1476	17	8.7789	1.2211
5	3.6281	6.3719	18	8.9900	1.0100
6	4.3298	5.6702	19	9.1810	0.8190
7	4.9648	5.0352	20	9.3538	0.6462
8	5.5392	4.4608	21	9.5101	0.4899
9	6.0589	3.9411	22	9.6515	0.3485
10	6.5291	3.4709	23	9.7795	0.2205
11	6.9545	3.0455	24	9.8953	0.1047
12	7.3394	2.6606	25	10.0000	0.0000
13	7.6876	2.3124			

TABLE B.2 - Nodal Locations for Software Verification Problem Model

$$erf\,(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-\eta^2} \partial\eta \; . \tag{B.2}$$

For this work, the function is calculated by the rational approximation[123]

$$erf(x) = 1 - (\, a_1 t + a_2 t^2 + a_3 t^3 + a_4 t^4 + a_5 t^5 \,)\, e^{-x^2} + \epsilon(x) \tag{B.3}$$

where

$$t = \frac{1}{1 + px} \, ,$$

$$|\epsilon(x)| \leq 1.5\times10^{-7} \, ,$$

and

$$
\begin{aligned}
p &= 0.3275911 \\
a_1 &= 0.254829592 \\
a_2 &= -0.284496736 \\
a_3 &= 1.421413741 \\
a_4 &= -1.453152027 \\
a_5 &= 1.061405429 \ .
\end{aligned}
$$

B.2 Steady State Problems

B.2.1 Conduction

The first problem solved to begin the software verification process is the simple situation of steady state conduction in a solid. For this problem, the general heat conduction equation (Equation 5 in Chapter 2) reduces to

$$\frac{\partial^2 T}{\partial x^2} = 0 \tag{B.4}$$

and the analytical solution is a straight line distribution of temperatures between the two specified temperatures in the solid. The boundary conditions applied for this problem are a temperature of 5 temperature units at the bottom of the solid and 80 at the top.

The finite element form of the problem is defined with the same specified temperatures assigned to the pairs of nodes at the top and bottom of the model. The code used to define the model, apply the boundary conditions, and submit this problem for solution is shown below.

```
$ansys44a
/prep7
/title,THERMAL VERIFICATION RUN 1 - STATIC CONDUCTION
kan,-1  $et,1,55  $type,1
mp,kxx,1,5  $mp,dens,1,700 $mp,c,1,2
mat,1 $n,1  $n,25,,10    $fill,,,,,,,,0.1 $ngen,2,30,1,30,1,0.15
e,1,31,32,2 $egen,24,1,1
c*****************************************************************
tref,5  $tunif,5 $nt,1,temp,5,,31,30  $nt,25,temp,80,,55,30
afwrite $finish
/input,27 $finish
/eof
```

The analytical and finite element solutions are compared in Table B.3.

Node	Analytical Solution	Finite Element Solution	Node	Analytical Solution	Finite Element Solution
1	5.0000	5.0000	14	65.0202	65.0202
2	12.8555	12.8555	15	67.1578	67.1580
3	19.9625	19.9627	16	69.0920	69.0921
4	26.3930	26.3928	17	70.8418	70.8419
5	32.2108	32.2104	18	72.4250	72.4251
6	37.4735	37.4738	19	73.8575	73.8574
7	42.2360	42.2357	20	75.1535	75.1533
8	46.5440	46.5440	21	76.3258	76.3257
9	50.4418	50.4419	22	77.3862	77.3865
10	53.9682	53.9684	23	78.3462	78.3462
11	57.1588	57.1590	24	79.2148	79.2144
12	60.0455	60.0457	25	80.0000	80.0000
13	62.6570	62.6573			

TABLE B.3 - Analytical and Finite Element Solutions for Steady State Conduction Problem

It is clear that the solutions for this problem are the same for the analytical and finite element procedures.

B.2.2 Conduction with Convection

The second problem solved is that of steady state conduction in a solid with the top surface convective to a fluid at a known temperature. The boundary conditions for this problem are a specified temperature of 5 at the bottom of the solid and the convection to a fluid with a temperature of 80 at the top surface. The convection coefficient h_c is 15.

The analytical solution of this problem is calculated through setting the rate of heat flow in the solid by conduction equal to the rate of heat loss from the surface of the solid by convection. The conduction heat flow rate is given by Equation 1 and the convection heat loss rate by Equation 2 (Chapter 2).

The finite element form of the problem is defined with a nodal temperature boundary condition applied to the bottom two nodes of the model, and the convection on the top surface. The code for this problem is:

```
$ansys44a
/prep7
/title,THERMAL VERIFICATION RUN 2 - STATIC CONDUCTION WITH CONVECTION
kan,-1  $et,1,55  $type,1
mp,kxx,1,5  $mp,dens,1,700 $mp,c,1,2
mat,1 $n,1  $n,25,,10    $fill,,,,,,,,0.1 $ngen,2,30,1,30,1,0.15
e,1,31,32,2 $egen,24,1,1
c*****************************************************************
tref,5  $tunif,5 $nt,1,temp,5,,31,30  $cv,25,55,15,80
afwrite $finish
/input,27 $finish
/eof
```

The two forms of the solution are compared in Table B.4, and again, the results are the same for both solution procedures of the problem.

B.2.3 Conduction with Internal Heat Generation

The steady state, one-dimensional problem of a solid of finite thickness with specified surface temperatures and a uniform internal heat generation rate was examined next. Heat generation is assumed to occur uniformly at all locations in the solid, and the thermal conductivity is taken to be constant. The surface temperatures are taken to be 5 and 80

Node	Analytical Solution	Finite Element Solution	Node	Analytical Solution	Finite Element Solution
1	5.0000	5.0000	14	63.0841	63.0841
2	12.6021	12.6021	15	65.1527	65.1529
3	19.4798	19.4801	16	67.0245	67.0246
4	25.7029	25.7028	17	68.7178	68.7180
5	31.3330	31.3327	18	70.2500	70.2501
6	36.4260	36.4262	19	71.6363	71.6362
7	41.0348	41.0346	20	72.8905	72.8903
8	45.2039	45.2039	21	74.0249	74.0249
9	48.9759	48.9760	22	75.0512	75.0514
10	52.3886	52.3888	23	75.9802	75.9802
11	55.4762	55.4765	24	76.8207	76.8204
12	58.2698	58.2700	25	77.5806	77.5806
13	60.7971	60.7974			

TABLE B.4 - Analytical and Finite Element Solutions for Steady State Conduction with Convection Problem

temperature units, and the rate of internal heat generation is taken to be 40 heat units per unit volume per unit time.

The analytical solution is derived by simplifying the general heat conduction equation for one dimension into

$$\frac{\partial^2 T}{\partial x^2} + \frac{q}{k_c} = 0 . \tag{B.5}$$

The general solution of the temperature distribution within the solid is given as[124]

$$T = \frac{qL^2}{2k_c}\left[\frac{x}{L} - \left(\frac{x}{L}\right)^2\right] + (T_2 - T_1)\,\frac{x}{L} + T_1 \tag{B.6}$$

where T is the temperature at a depth x from the surface, L is the thickness of the solid, q is the rate of internal heat generation, k_c the material conductivity value, and T_1 and T_2 the surface temperatures of the solid.

The finite element form of the problem consists of the specified nodal temperature boundary conditions at the surfaces of the solid, and the internal heat generation rate boundary condition for the elements of the solid. The program code for this problem looks like:

```
$ansys44a
/prep7
/title,THERMAL VERIFICATION RUN 3 - STATIC CONDUCTION WITH INTERNAL HEAT
kan,-1  $et,1,55  $type,1
mp,kxx,1,5  $mp,dens,1,700 $mp,c,1,2
mat,1 $n,1  $n,25,,10    $fill,,,,,,,,0.1 $ngen,2,30,1,30,1,0.15
e,1,31,32,2 $egen,24,1,1
c*****************************************************************
tref,5 $tunif,5 $ktemp,-1 $nt,1,temp,5,,31,30 $nt,25,temp,80,,55,30
esel,mat,1 $qe,all,40 $eall
afwrite $finish
/input,27 $finish
/eof
```

The two solution methods are compared in Table B.5. Again, the analytical and finite element solutions are the same. The next step in the verification process was to examine similar transient problems.

B.3 Transient Problems

B.3.1 Conduction

The first transient problem solved is the response of a semi-infinite solid to a step-change in surface temperature. The solid begins at a uniform temperature of 5 at time zero, and is then subjected to a forced change in surface temperature to 80 temperature units for all time greater than zero.

The general conduction equation simplifies to:

Node	Analytical Solution	Finite Element Solution	Node	Analytical Solution	Finite Element Solution
1	5.0000	5.0000	14	128.9554	128.9555
2	50.3633	50.3635	15	123.9219	123.9213
3	83.8424	83.8434	16	118.8069	118.8067
4	107.9443	107.9438	17	113.7214	113.7209
5	124.6823	124.6815	18	108.7446	108.7444
6	135.6768	135.6773	19	103.9344	103.9348
7	142.2310	142.2308	20	99.3312	99.3319
8	145.3810	145.3811	21	94.9617	94.9618
9	145.9567	145.9566	22	90.8404	90.8395
10	144.6157	144.6155	23	86.9718	86.9721
11	141.8785	141.8781	24	83.3589	83.3602
12	138.1543	138.1540	25	80.0000	80.0000
13	133.7642	133.7636			

TABLE B.5 - Analytical and Finite Element Solutions for Steady State Conduction with Internal Heat Generation Problem

$$\frac{\partial^2 T}{\partial x^2} = \frac{1}{\alpha}\frac{\partial T}{\partial t} \qquad \text{(B.7)}$$

where α is the thermal diffusivity of the material. The analytical solution is given as[125]

$$\frac{T(x,t) - T_s}{T_o - T_s} = erf\left(\frac{x}{2\sqrt{\alpha t}}\right) \qquad \text{(B.8)}$$

where $T(x,t)$ is the temperature at a depth of x at time t, T_o is the initial temperature of the solid and T_s the surface temperature for time greater than zero.

The finite element form of the problem is shown below.

```
$ansys44a
/prep7
/title,THERMAL VERIFICATION RUN 4 - TRANSIENT CONDUCTION
```

```
kan,-1  $et,1,55  $type,1
mp,kxx,1,5  $mp,dens,1,700 $mp,c,1,2
mat,1 $n,1  $n,25,,10    $fill,,,,,,,,0.1 $ngen,2,30,1,30,1,0.15
e,1,31,32,2 $egen,24,1,1
c*******************************************************************
kbc,1 $tref,5 $tunif,5 $nt,1,temp,5,,31,30
time,0   $iter,1,,1    $nt,25,temp,5,,55,30   $lwrite
time,300 $iter,600,,1  $nt,25,temp,80,,55,30  $lwrite
afwrite $finish
/input,27 $finish
/eof
```

The two sets of results are plotted together for comparison on Figure B.3, where it can be seen that the solutions are the same.

B.3.2 Conduction with Convection

The second transient problem in the series is calculation of the response of a semi-infinite solid to a step-change in overlying fluid temperature. At time zero, the solid and fluid both have temperatures of 5 temperature units. For all time greater than zero, the fluid temperature is held at 80 as a boundary condition. The convection coefficient h_c at the surface is 15.

The solution of the general heat conduction equation for this case yields the equation[126]

$$\frac{T(x,t) - T_o}{T_a - T_o} = 1 - erf(\xi) - \left[\exp\left(\frac{h_c\,x}{k_c} + \frac{h_c^2 \alpha t}{k_c^2}\right)\right]\left[1 - erf\left(\xi + \frac{h_c\sqrt{\alpha t}}{k_c}\right)\right] \qquad \text{(B.9)}$$

where

$$\xi = \sqrt{\frac{x^2}{4\alpha t}}\ .$$

The code that defines and solves the finite element form of this problem is:

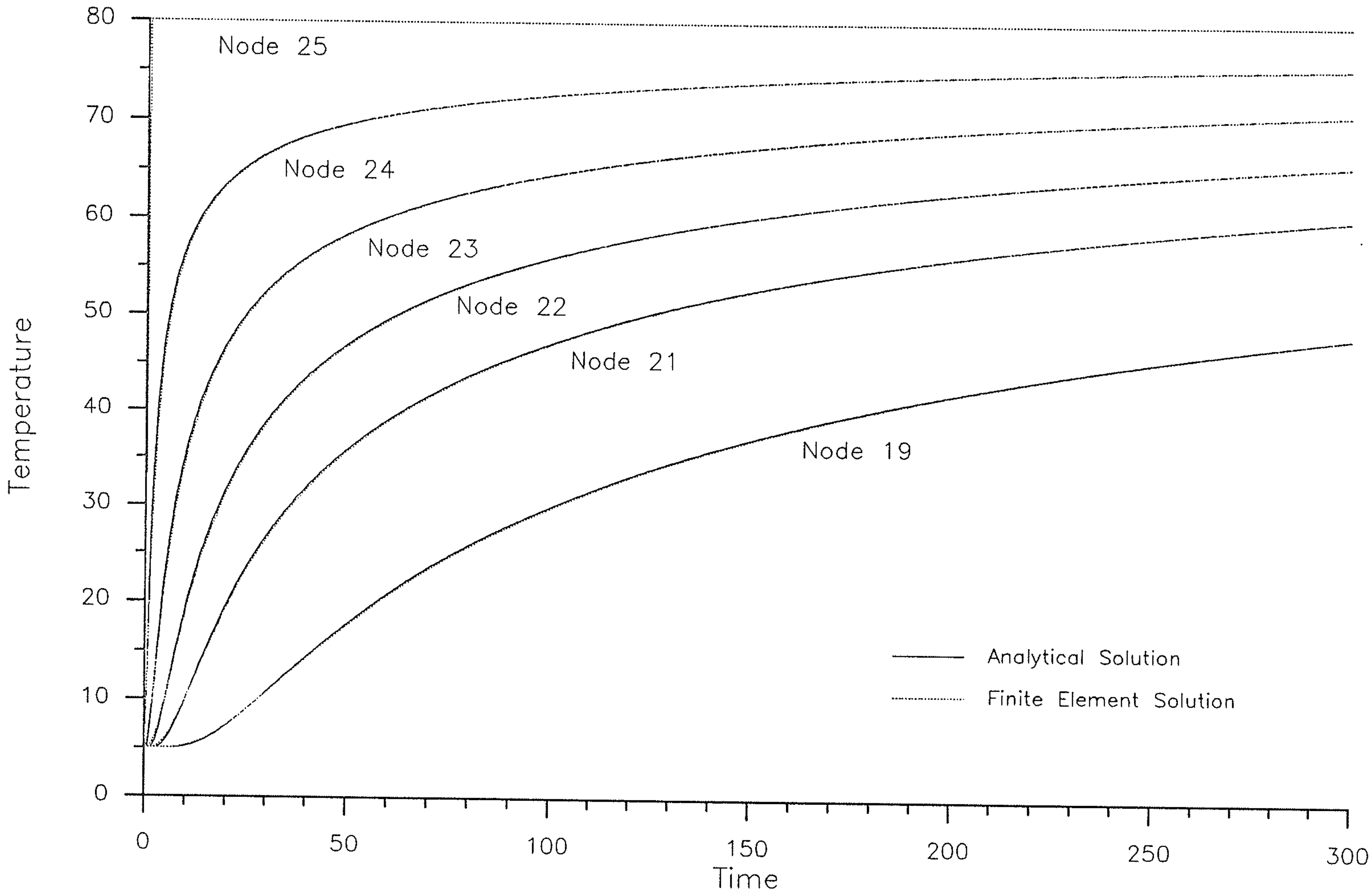

FIGURE B.3 - Finite Element and Analytical Solutions for Transient Conduction Verification Problem

```
$ansys44a
/prep7
/title,THERMAL VERIFICATION RUN 5 - TRANSIENT CONDUCTION WITH CONVECTION
kan,-1  $et,1,55  $type,1
mp,kxx,1,5  $mp,dens,1,700 $mp,c,1,2
mat,1 $n,1  $n,25,,10    $fill,,,,,,,,0.1 $ngen,2,30,1,30,1,0.15
e,1,31,32,2 $egen,24,1,1
c*****************************************************************
kbc,1 $tref,5 $tunif,5 $nt,1,temp,5,,31,30
time,0   $iter,1,,1    $cv,25,55,15,5    $lwrite
time,300 $iter,600,,1  $cv,25,55,15,80   $lwrite
afwrite $finish
/input,27 $finish
/eof
```

The two forms of the solution are plotted together on Figure B.4, where again the solutions are the same.

B.3.3 Conduction with Internal Heat Generation

The final problem solved in the software verification process is that of the transient response of a semi-infinite solid with internal heat generation. When one dimension is considered, the general heat conduction equation becomes

$$\frac{\partial^2 T}{\partial x^2} - \frac{1}{\alpha}\frac{\partial T}{\partial t} = -\frac{q}{k_c} \,. \tag{B.10}$$

One form of analytical solution[127] derived for a semi-infinite solid with an initial temperature distribution equal to $a + bx$, internal heat produced at a uniform unit rate of q_0 for all time greater zero, and a surface temperature equal to zero degrees for all time greater than zero is:

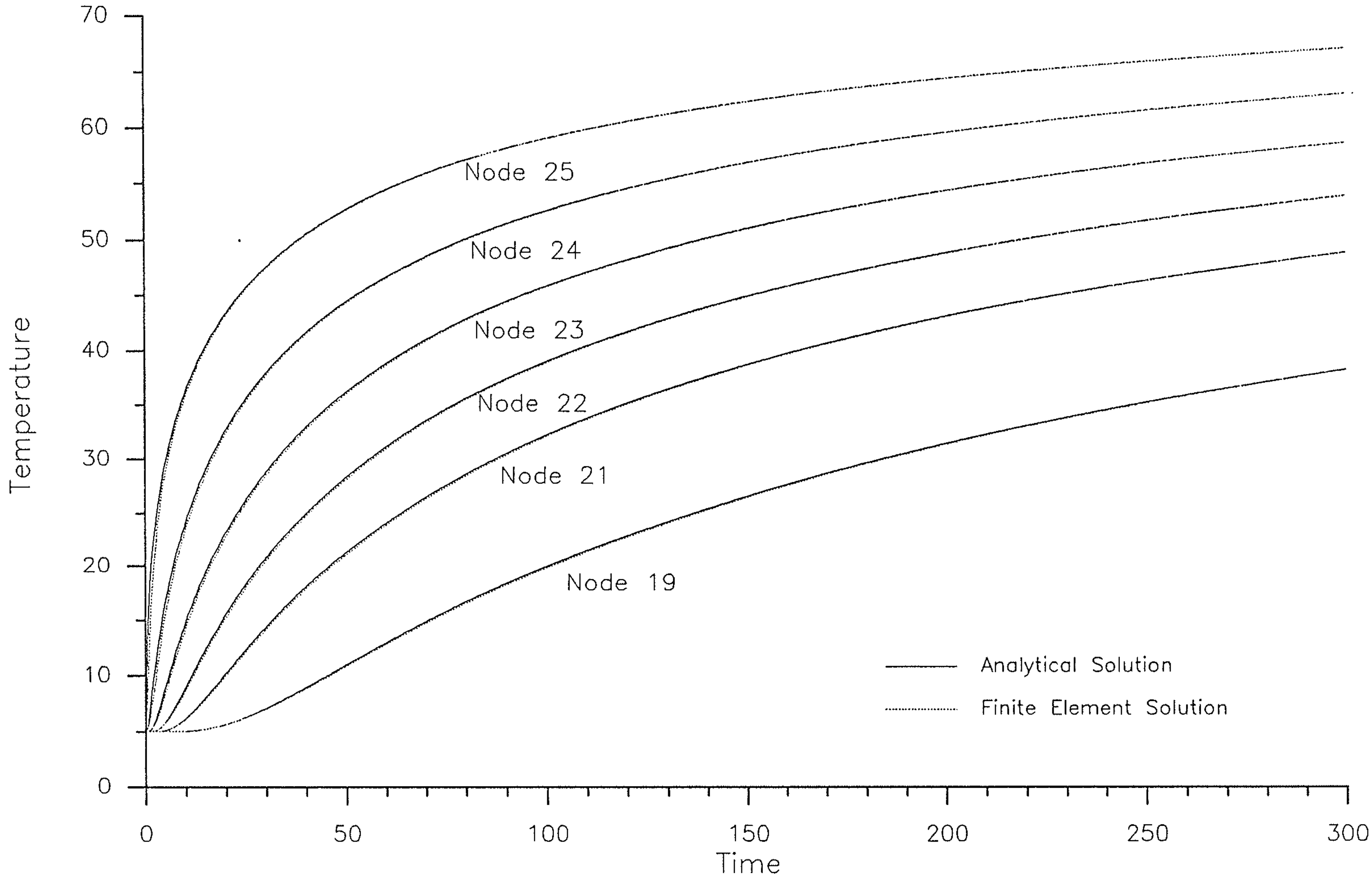

FIGURE B.4 - Finite Element and Analytical Solutions for Transient Conduction with Convection Verification Problem

$$T(x,t) = \left(a + \frac{\alpha t q_0}{k_c} + \frac{q_0 x^2}{2k_c} \right) erf \frac{x}{2\sqrt{\alpha t}} + \frac{q_0 x}{k_c} \left(\frac{\alpha t}{\pi} \right)^{\frac{1}{2}} e^{\frac{-x^2}{4\alpha t}} + bx - \frac{q_0 x^2}{2k_c} . \qquad \text{(B.11)}$$

For this problem, the solid has a temperature distribution at time zero given by $a = 5$ and $b = 1.5$, giving a surface temperature of 5 temperature units and a temperature of 20 at a depth of 10. As required by the form of solution for this problem, for time greater than zero, the surface temperature equals zero. The uniform internal heat generation rate is 40 heat units per unit volume per unit time.

In finite element form, the problem looks like:

```
$ansys44a
/prep7
/title,THERMAL VERIFICATION RUN 6 - TRANSIENT CONDUCTION WITH INTERNAL HEAT
kan,-1  $et,1,55  $type,1
mp,kxx,1,5  $mp,dens,1,700 $mp,c,1,2
mat,1 $n,1  $n,25,,10    $fill,,,,,,,,0.1 $ngen,2,30,1,30,1,0.15
e,1,31,32,2 $egen,24,1,1
c****************************************************************
kbc,1 $tref,5 $tunif,5
time,0  $iter,1,,1 $nt,25,temp,5,,55,30 $nt,1,temp,20,,31,30  $lwrite
time,300 $iter,600,,1 $nt,25,temp,0,,55,30
         esel,mat,1 $qe,all,40 $eall $lwrite
afwrite $finish
/input,27 $finish
/eof
```

The analytical and finite element solutions are plotted together for selected nodal locations in Figure B.5. These solutions are also the same for both approaches to this problem.

It is clear from the comparisons of analytical solutions to the solutions obtained through the finite element program that the finite element process provides acceptable results. It is thus reasonable to rely on the numerical procedures of the package to solve an analysis of an incrementally constructed mass concrete dam.

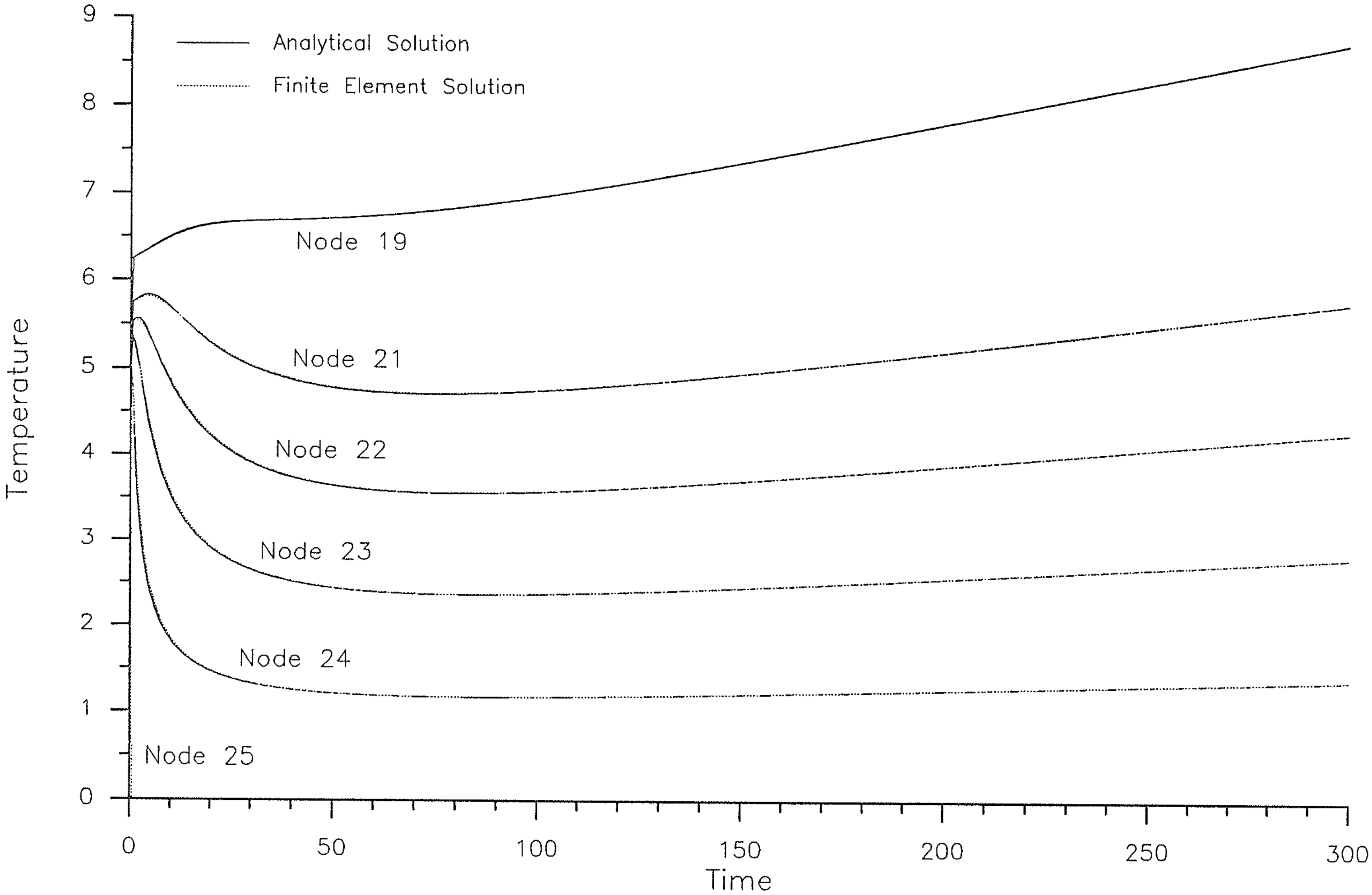

FIGURE B.5 - Finite Element and Analytical Solutions for Transient Conduction with Internal Heat Generation Verification Problem

APPENDIX C

CASE STUDY PROJECT CONSTRUCTION SPECIFICATION REQUIREMENTS

C CASE STUDY PROJECT CONSTRUCTION SPECIFICATION REQUIREMENTS

The construction specifications for the project included detailed requirements for concrete production and placement in all structures of the generating station[128]. This covered materials and storage, concrete composition, testing, batching and mixing, conveying, placing, compaction, surface preparation, requirements for winter and summer concreting, finishing, curing, embedded parts, and so on. Those portions of the specification for concrete work that provide background information for this thesis are briefly outlined below.

C.1 Concrete Materials

The materials specified to be used in the manufacture of concrete for the structures consisted of the following. All concrete mixes were to utilize Type 10 Normal Portland cement and two chemical admixtures. The first admixture was an air-entraining agent conforming to CSA Standard CAN3-A266.1-M78 to improve workability and enhance the freeze-thaw durability of in-place concrete for severe service conditions. The second was a water reducing chemical admixture of Type WR (set retarding water reducing admixture) or SR (set retarding strength increasing admixture) as specified in CSA Standard CAN3-A266.2-M78. The specification called for the water for processing of aggregates, and batching and curing of concrete to meet the requirements of Clause 4 of CSA Standard CAN3-A23.1-M77.

In general, fine and coarse aggregates had to meet the requirements of Clause 5 of CSA Standard CAN3-A23.1-M77. Fine aggregate had to be a natural sand from an approved local source, and was tested in accordance with CSA Standard CAN3-A23.2-M77 at different stages of production. The coarse aggregate was specified to be sound granitic rock from the excavations for the structures or an approved local quarry. Several poorer quality rock types present at the project site were not allowed to be used as coarse aggregate. Routine control tests and analyses were carried out at different stages of processing operations, and all coarse aggregate was to be washed upon entering the batch plant and re-screened to ensure it met the specified gradations. Concrete material storage (aggregates and water) was specified to be such that the materials could be heated during cold weather and cooled during hot weather. Aggregates were to be stored to maintain uniformity and avoid contamination.

C.2 Placing Procedures

The procedures which were allowed for placing concrete were generally based on principals required to achieve an acceptable degree of quality of the work, and to have some control of the thermal behaviour of the in-place concrete. This section describes the requirements as they relate to temperature control in the concrete, and aspects of the placing operations that have an influence on the developed modelling algorithm.

C.2.1 Lift Thicknesses

The horizontal lifts of concrete in the structures typically did not exceed 3 m in thickness, but shallower lifts were required to be placed for generally non-reinforced concrete in a number of particular situations. When a new block of a structure was started off the foundation bedrock, a minimum of two 0.75 m thick lifts were required until at least two-thirds of the surface area of the foundation was covered. Following this, there was required to be one lift not more that 1.5 m thick before the standard 3 m lift thickness could be adopted. There was a maximum time interval specified between the shallow lifts of 14 days. This pattern of initial lifts was intended to reduce or avoid problems with restraint offered by the foundation bedrock when thick lifts are placed[129]. Thick lifts would produce warm concrete for later cooling and cracking. This requirement had a direct effect on the lift divisions and placing schedule of NT2. Similar procedures have been reported for other projects[130].

For the same general reason, shallow lifts were also necessary when placing fresh concrete on concrete that was between 15 and 30 days old. In this situation, the first two lifts had to be not more than 1.5 m thick, and the time interval between them not more than 14 days. Placing fresh concrete on concrete that was more than 30 days old required the first two lifts to be 0.75 m thick, followed by one lift not greater than 1.5 m thick. These lifts had to be placed within a time interval not greater than 14 days.

The general time intervals between successive lifts of concrete in the structures was specified to be not less than 3 days after 0.75 m thick lifts, 5 days after 1.5 m lifts, and 7 days after lifts of greater thickness. These requirements also had a direct effect on the construction of NT2.

C.2.2 Concrete Placing

A number of rules governed the actual placing operations used to complete a lift as well. During placement, concrete was to be deposited in horizontal layers of thickness generally not greater than 0.5 m, and placing was to be carried out such that the exposed area of fresh concrete would be at a practical minimum at all times. Also, depending on prevailing weather conditions at the time of placement, each layer of concrete within a lift was specified to be covered within 45 minutes to an hour. As much as possible, each lift was to be placed in one continuous operation until the work was completed.

When more than one type of concrete was used in the same lift, the different concretes were specified to be placed as close to simultaneously as possible, so the different mixes would merge together in a plastic state and form a uniform, consistent material. All of this had application in work on the large volume lifts of NT2.

C.2.3 Placing Temperatures

The concrete was specified to be at a temperature between 5°C and 15°C at the time of placing. The lower bound of this temperature range was to avoid potential problems with freezing of the concrete, and the upper bound to help control the peak temperatures reached in the concrete after placement.

For periods of hot weather, several methods were suggested in the specification for keeping the placing temperature below 15°C. They included the cooling of coarse aggregate with refrigerated water, cooling of batching water, substituting flaked or crushed ice for a portion of the mixing water, minimizing mixing and conveying time for the concretes, and keeping fresh concrete from exposure to hot and/or dry weather conditions.

For concrete placement in cold weather, provisions had to be taken to protect the concrete from any possibility of damage due to freezing. Surfaces against which new concrete was to be placed had to have a temperature of at least 5°C prior to the start of placing. New concrete surfaces after placing were to be maintained at a temperature between 5°C and 25°C for at least 3 days after placement, and then for an additional 4 days at a temperature above freezing. After this, the air temperature surrounding the concrete was allowed to fall to the point where the concrete's surface temperature equalled ambient air temperature, but at a rate not greater than 10°C every 24 hours.

In all cases, lifts had to be approved by Manitoba Hydro before permission to begin placing operations would be granted.

C.2.4 Concrete Curing

Part of concrete placement at the project site is the curing process, and the specifications called for concrete surfaces to be kept continuously moist by water curing for at least 7 days after placement. Therefore, all horizontal construction joints were required to be kept moist until either the next lift of concrete was placed, or until curing was discontinued because placement of the next lift took place after more than 7 days. In this case, curing had to resume at least 24 hours before placement of the next lift in order to improve the bond between lifts.

APPENDIX D

CONSTRUCTION DATA FOR CASE STUDY STRUCTURE

D CONSTRUCTION DATA FOR CASE STUDY STRUCTURE

D.1 Concrete Materials

The local materials used in producing concrete for the project structures included fine aggregate of natural sand comprised primarily of limestone, quartz and granitics, with small traces of several other minerals present as well[131]. The coarse aggregate was more than 90 percent by mass granodiorite, and the remainder made up of minor traces of other rock types[132]. Nelson River water was generally used for the batching of concrete.

A sample of the cement used for the project was tested for heat of hydration by Ontario Hydro in a conduction calorimeter[133]. The results of the test are listed in Table D.1 and shown in Figure D.1.

Time (days)	Heat of Hydration (J/g)	Time (days)	Heat of Hydration (J/g)	Time (days)	Heat of Hydration (J/g)
0.00	0	2.50	268	5.00	329
0.25	23	2.75	277	5.25	332
0.50	90	3.00	286	5.50	335
0.75	147	3.25	294	5.75	338
1.00	187	3.50	301	6.00	340
1.25	209	3.75	307	6.25	342
1.50	224	4.00	313	6.50	344
1.75	236	4.25	317	6.75	346
2.00	247	4.50	322	7.00	348
2.25	257	4.75	326		

TABLE D.1 - Heat of Hydration Data for Case Study Structure Type 10 Cement

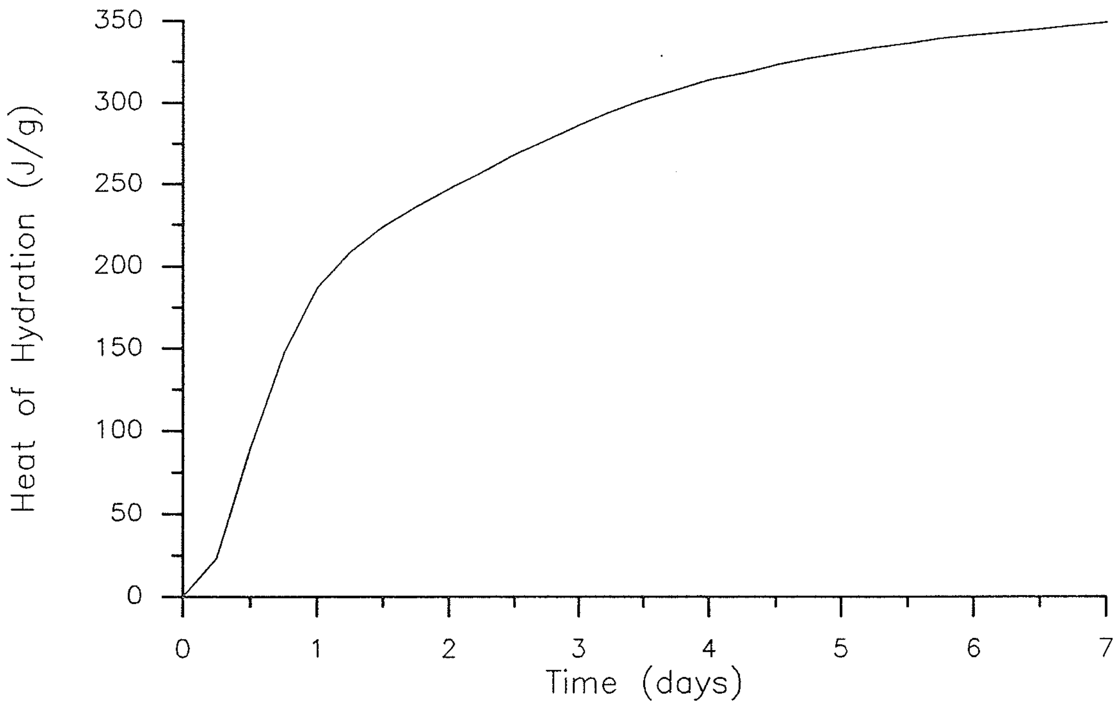

FIGURE D.1 - Heat of Hydration for Type 10 Cement Used for Case Study Project

D.2 Concrete Testing

Throughout the construction process a laboratory program of tests was carried out on a continuous basis to determine properties of fresh and hardened concrete in accordance with CSA Standard CAN3-A23.2-M77[134]. Properties routinely tested for included slump, air content, wet-density, and temperature of fresh concrete. Cylinders were frequently cast for strength testing, and some advanced tests were carried out off-site. Using the results of the testing program, mix designs were revised and adjusted both from time to time to improve the economy of the mixes, and on a daily basis to improve placing characteristics of the mixes.

D.3 Placing Procedures

D.3.1 Lift Thicknesses

The lift pattern used in construction of NT2 was determined based on the specification criteria outlined in Section C.2.1. Several preliminary "mud slab" pours were necessary to cover the foundation bedrock before the standard lift thicknesses could be adopted. At two points during construction of the structure it was necessary to break regular lifts into more than one shallower lift due to the time intervals between lifts. The first instance was the result of a delay in the placement of lift NT2-8, while the second was the resumption of work after suspending operations for the winter season following lift NT2-9. Table D.2 shows the lift-by-lift construction schedule, including placement dates and times, concrete volumes, and the average placing temperatures.

D.3.2 Placing Operations

The placing temperature of the concrete typically varied to a degree during each lift depending on the weather, the particular mixes in use, equipment capabilities for batching and placing, time that mixes spent waiting in trucks, number of placing operations ongoing at once, and so on. The temperature of the concrete arriving at a pour would be checked periodically by a placing inspector so that the batch plant could be advised to adjust the mixes to keep temperatures within specification limits. In some extreme cases when there was a limitation on the capability of the batch plant to produce cool mixes once a lift was started (for example, because of equipment problems), priority for temperature control was given to higher strength mixes in use on site at the time, as they have a higher expected temperature rise after placement.

Lift	Volume (m^3)	Date, Time Started	Date, Time Ended	Average Placing Temperature (°C)
NT2-1c	25.0	860605, 03:00	860605, 03:35	--
NT2-1b	55.0	860609, 23:20	860610, 00:35	--
NT2-1a	203.0	860612, 00:55	860612, 04:10	--
NT2-1	813.0	860616, 11:05	860617, 01:40	10
NT2-2	1 546.0	860624, 21:40	860625, 22:18	14
NT2-3a/b	1 685.0	860707, 05:30	860708, 11:20	9
NT2-4	852.0	860728, 21:15	860729, 13:15	12
NT2-5	1 644.0	860805, 10:55	860806, 08:15	12
NT2-6	1 483.5	860813, 04:55	860814, 03:30	13
NT2-7	1 365.0	860820, 11:55	860821, 07:25	11
NT2-8a	606.0	861004, 01:40	861004, 11:00	12
NT2-8b	562.0	861008, 12:20	861009, 04:50	11
NT2-9	985.0	861023, 13:15	861024, 08:45	9
NT2-10-1	240.0	870417, 09:20	870417, 14:15	12
NT2-10-2	221.0	870422, 08:05	870422, 12:15	13
NT2-10-3	437.0	870429, 13:10	870429, 18:50	11
NT2-11	825.0	870512, 14:20	870512, 23:50	11
NT2-12	750.0	870521, 11:25	870521, 21:30	10
NT2-13	664.0	870529, 07:20	870529, 17:55	10
NT2-14	606.0	870603, 17:00	870604, 05:35	7
NT2-15	360.0	870617, 12:20	870618, 01:35	12
NT2-16a/b	10.0	870620, 15:30	870620, 17:30	--

TABLE D.2 - Lift Statistics for Construction of the Case Study Structure

D.4 Earthfill Placement

Materials making up the north dam were placed against the north transition as concrete construction progressed. The final extent of earthfill placement around the structure is shown as part of Figure 5. Progress on earthfill placement was recorded at the project site in the form of a series of dates and the corresponding elevations reached at a variety of locations along the axis of the north dam, including the immediate area of the north transition[135]. The data points for the area of the north transition are shown in Table D.3. This information is plotted together with the concrete placing information from Table D.2 in Figure D.2, giving a graphical representation of progress made in construction of the structure.

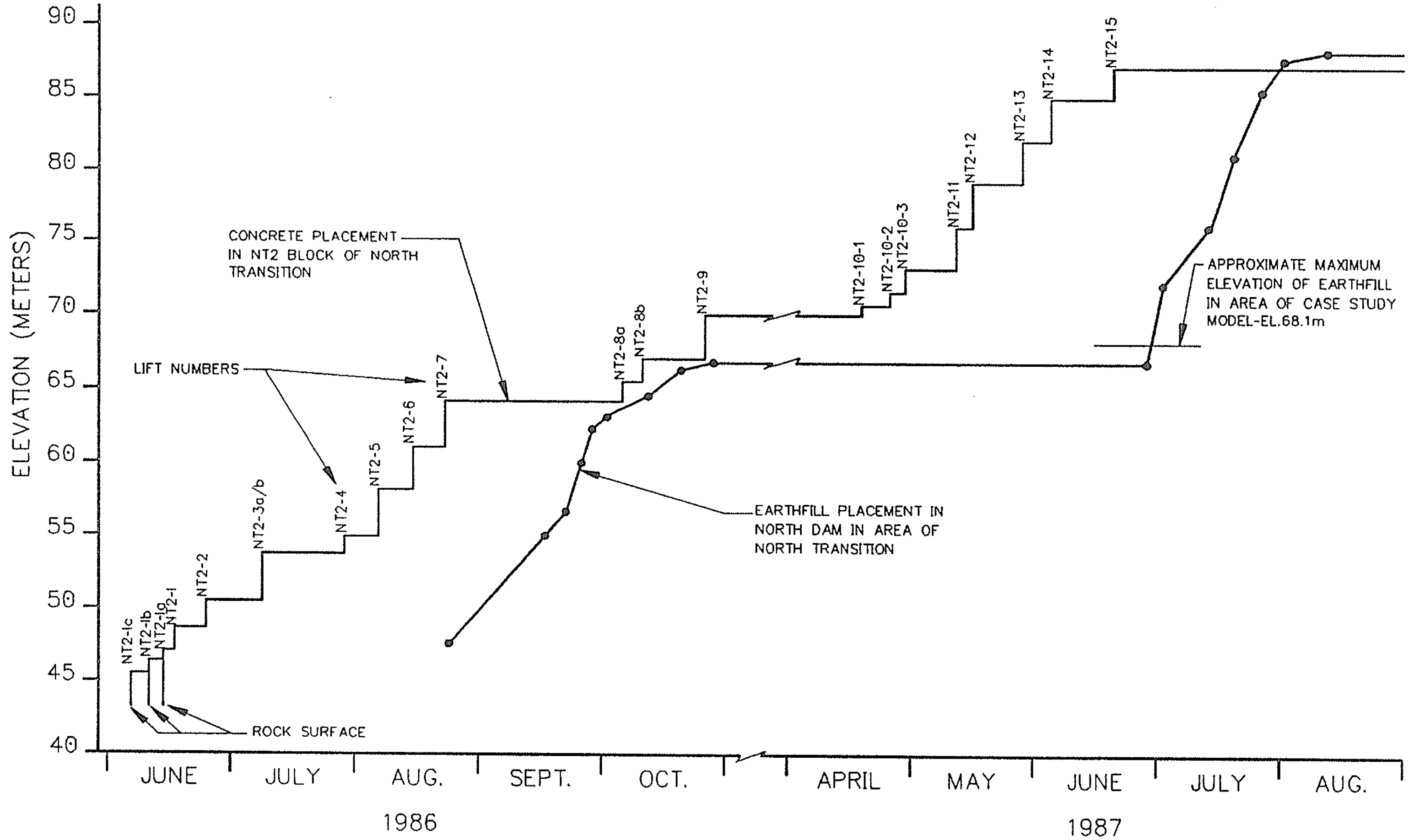

FIGURE D.2 - Construction Progress of Case Study Structure

Date	Elevation Reached at North Transition	Comment
860821	47.7	Start of earthfill placement adjacent to north transition
860915	55.0	
860918	56.6	
860924	60.0	
860927	62.1	
861003	63.1	
861010	64.5	
861018	66.2	
861025	66.7	End of earthfill placement for 1986; resumed 870629
870704	72.0	
870713	76.1	
870718	81.2	
870725	85.3	
870801	87.5	
870812	88.0	North dam complete at north transition

TABLE D.3 - Earthfill Placement Progress in the Area of the North Transition

The earthfill elevations reached are assumed to be the same on the upstream and downstream sides of the structure, as the information about earthfill height versus time did not identify if there were any differences.

APPENDIX E

CASE STUDY MEMORY MANAGEMENT AND POST-DATA FILE HANDLING

E CASE STUDY MEMORY MANAGEMENT AND POST-DATA FILE HANDLING

The size and complexity of executing an incremental thermal analysis of a mass concrete dam makes it necessary to have control of memory requirements and post-data information during an analysis. The following paragraphs describe the controls included for execution of the case study.

E.1 Memory Management

The case study analysis includes several provisions to keep computer memory requirements to a reasonable level. This is important because of the size of the finite element model (19 separate segments) and the length of time covered in the construction process (two years).

E.1.1 Suppression of file04.dat

The first provision is the suppression of an output file normally generated by the finite element program during execution of a transient thermal analysis. The program usually creates file04.dat to contain cumulative temperature results within an analysis. The generation of this file is suppressed as the first command of the analysis. No information is lost by doing this, as the same data written to file04.dat can be retrieved from another output file generated by the program, file12.dat. File12.dat is the primary post-data file for examining the results of any analysis using the finite element program.

used in the case study are typical of what is required as part of any modelling done using the developed algorithm.

Solution of each series of load steps in an analysis generates the primary post-data file file12.dat. As a sequence of load step series is required to completely analyze the thermal behaviour of a dam, it is necessary to preserve the contents of each file12.dat generated from a load step series so that results do not get overwritten during execution of the following series of load steps. One way to do this would be to rename the file from each series of load steps to a unique file name before beginning execution of the next series of load steps. Examination of results of an analysis would then have to be done from a variety of post-data results files.

A different sequence of operations is followed to accumulate post-data results from all load step series into a single file of complete analysis results for the case study. This is a preferred arrangement as it is the most convenient means of command execution to create listings and plots of analysis results spanning several different series of load steps.

The particular command sequence utilized accommodates certain peculiarities of the way ANSYS executes the file copy commands used to compile the results in a single file. The following are the steps carried out.

i) For each series of load steps in the analysis, the program writes solution results to the default post-data file, file12.dat. After execution of the first series of load steps, the contents of file12.dat are copied to an unused available non-overwritten file, file35.dat.

```
.
.   (Commands of the first series of load steps)
.
/aux1
copy,12,35
finish
.
.   (Commands of the second series of load steps)
.
```

This avoids the contents of the post-data file being overwritten by execution of the second series of load steps.

ii) The second series of load steps are executed, with solution results again written to file12.dat. Immediately after finishing this series of load steps and before starting the next, two copy operations are executed. The first copies the contents of the first non-overwritten file, file35.dat, to a second unused non-overwritten file, file36.dat. The next copy operation then appends the contents of file12.dat from the just-completed series of load steps to the end of the contents of the second non-overwritten file, file36.dat. File35.dat can then be deleted, as file36.dat contains a cumulative listing of all results obtained to the end of the just-completed series of load steps. Execution of the third series of load steps can then proceed writing solution results to file12.dat without overwriting any previously obtained results to that point in the analysis.

```
.
.   (Commands of the second series of load steps)
.
/aux1
copy,35,36 $copy,12,36
finish
/delete,file35,dat
.
.   (Commands of the third series of load steps)
.
```

A single copy operation to append the results of the just-completed series of load steps to the end of the first non-overwritten file cannot be used as the program will only append data to a target file beginning with the second copy operation.

iii) At the end of execution of the next series of load steps, this pattern of copying files is repeated, but using file35.dat as the target file for the two copy operations. File36.dat can then be deleted after the copying is complete.

```
.
.   (Commands of the previous series of load steps)
.
/aux1
copy,36,35 $copy,12,35
finish
/delete,file36,dat
.
.   (Commands of the next series of load steps)
.
```

This pattern of post-data file handling is repeated after each series of load steps involved in the analysis, alternating between target files for the copying operations. By the end of execution of the complete analysis, a cumulative listing of all results exists on a single file that is used for convenient post-processing operations.

APPENDIX F

CASE STUDY ANALYSIS COMMAND FILE LISTING

F CASE STUDY ANALYSIS COMMAND FILE LISTING

```
 * ~~~~~~~~~~~~~~~   CASE STUDY INCREMENTAL THERMAL ANALYSIS   ~~~~~~~~~~~~~~~
 *
 *                         Version Name = NT921222.mod
 *                     Date = 12-22-1992   Time = 22:26:53
 *
 * ~~~~~~~~~~~~~  MODEL DEFINITION COMMANDS - - Revision 921209  ~~~~~~~~~~~~~
/fdele,4,1           * Delete file04.dat (nodal temperatures) - do not save
/fdele,12,-1         * Save file12.dat (post-data) as external
/fdele,16,-1         * Save file16.dat (pre-processing) as external
/fdele,35,-1         * Save file35.dat (post-data copy file) as external
/fdele,36,-1         * Save file36.dat (post-data copy file) as external
/prep7
/title,CASE STUDY MODEL DEFINITION COMMANDS
kan,-1  $et,1,55  $kbc,0  $tref,5  $tunif,5  $ktemp,-1  $csys,0  $type,1
 * ~~~~~  MATERIAL PROPERTIES  ~~~~~
bk=55.2  $bc=0.22  $bd=2650   * Bedrock property parameters (k, Cp, dens)
ck=62.4  $cc=0.225            * Concrete property parameters (k, Cp)
mp,kxx,1,bk  $mp,c,1,bc  $mp,dens,1,bd     * Bedrock
mp,kxx,2,ck  $mp,c,2,cc  $mp,dens,2,2319   * Lift 1 - Class E
mp,kxx,3,ck  $mp,c,3,cc  $mp,dens,3,2319   * Lift 2 - Class E
mp,kxx,4,ck  $mp,c,4,cc  $mp,dens,4,2324   *          Class D
mp,kxx,5,ck  $mp,c,5,cc  $mp,dens,5,2298   *          Class C
mp,kxx,6,ck  $mp,c,6,cc  $mp,dens,6,2319   * Lift 3A/B - Class E
mp,kxx,7,ck  $mp,c,7,cc  $mp,dens,7,2324   *             Class D
mp,kxx,8,ck  $mp,c,8,cc  $mp,dens,8,2262   * Lift 4 - Class E
mp,kxx,9,ck  $mp,c,9,cc  $mp,dens,9,2284   *          Class D
mp,kxx,10,ck $mp,c,10,cc $mp,dens,10,2262  * Lift 5 - Class E
mp,kxx,11,ck $mp,c,11,cc $mp,dens,11,2284  *          Class D
mp,kxx,12,ck $mp,c,12,cc $mp,dens,12,2276  * Lift 6 - Class E
mp,kxx,13,ck $mp,c,13,cc $mp,dens,13,2285  *          Class D
mp,kxx,14,ck $mp,c,14,cc $mp,dens,14,2276  * Lift 7 - Class E
mp,kxx,15,ck $mp,c,15,cc $mp,dens,15,2285  *          Class D
mp,kxx,16,ck $mp,c,16,cc $mp,dens,16,2276  * Lift 8A - Class E
mp,kxx,17,ck $mp,c,17,cc $mp,dens,17,2285  *           Class D
mp,kxx,18,ck $mp,c,18,cc $mp,dens,18,2276  * Lift 8B - Class E
mp,kxx,19,ck $mp,c,19,cc $mp,dens,19,2285  *           Class D
mp,kxx,20,ck $mp,c,20,cc $mp,dens,20,2276  * Lift 9 - Class E
mp,kxx,21,ck $mp,c,21,cc $mp,dens,21,2285  *          Class D
mp,kxx,22,ck $mp,c,22,cc $mp,dens,22,2291  *          Class B
mp,kxx,23,ck $mp,c,23,cc $mp,dens,23,2258  * Lift 10-1 - Class E
mp,kxx,24,ck $mp,c,24,cc $mp,dens,24,2285  *              Class D
mp,kxx,25,ck $mp,c,25,cc $mp,dens,25,2303  *              Class B
mp,kxx,26,ck $mp,c,26,cc $mp,dens,26,2258  * Lift 10-2 - Class E
mp,kxx,27,ck $mp,c,27,cc $mp,dens,27,2285  *              Class D
mp,kxx,28,ck $mp,c,28,cc $mp,dens,28,2303  *              Class B
mp,kxx,29,ck $mp,c,29,cc $mp,dens,29,2258  * Lift 10-3 - Class E
mp,kxx,30,ck $mp,c,30,cc $mp,dens,30,2285  *              Class D
mp,kxx,31,ck $mp,c,31,cc $mp,dens,31,2303  *              Class B
mp,kxx,32,ck $mp,c,32,cc $mp,dens,32,2258  * Lift 11 - Class E
mp,kxx,33,ck $mp,c,33,cc $mp,dens,33,2285  *           Class D
mp,kxx,34,ck $mp,c,34,cc $mp,dens,34,2303  *           Class B
mp,kxx,35,ck $mp,c,35,cc $mp,dens,35,2258  * Lift 12 - Class E
mp,kxx,36,ck $mp,c,36,cc $mp,dens,36,2285  *           Class D
mp,kxx,37,ck $mp,c,37,cc $mp,dens,37,2303  *           Class B
```

```
mp,kxx,38,ck $mp,c,38,cc $mp,dens,38,2264  * Lift 13 - Class E
mp,kxx,39,ck $mp,c,39,cc $mp,dens,39,2317  *          Class B
mp,kxx,40,ck $mp,c,40,cc $mp,dens,40,2317  * Lift 14 - Class B
mp,kxx,41,ck $mp,c,41,cc $mp,dens,41,2305  * Lift 15 - Class B
mp,kxx,42,ck $mp,c,42,cc $mp,dens,42,2331  *          Class A
 * ~~~~~~ GEOMETRY ~~~~~~
 * ~~~ LIFT 15 ~~~
k,1,-3.5,87 $k,3,-1.5,87 $kfill $kgen,2,1,3,1,5.8 $kgen,3,1,6,1,,-1
l,1,7 $l,2,8 $l,3,9 $l,4,10 $l,5,11 $l,6,12 $l,13,7 $l,14,8 $l,15,9 $l,16,10
l,17,11 $l,18,12 $l,1,2 $l,2,3 $l,5,4 $l,6,5 $l,7,8 $l,8,9 $l,11,10 $l,12,11
l,13,14 $l,14,15 $l,17,16 $l,18,17 $l,3,4 $l,9,10 $l,15,16
lssel,,1,6,1 $lsasel,,13,21,4 $lsasel,,16,24,4 $ldvs,all,,3,2 $lsall
lssel,,7,12,1 $ldvs,all,,2,3 $lsall $lssel,,25,27,1 $ldvs,all,,2 $lsall
lssel,,14,22,4 $lsasel,,15,23,4 $ldvs,all,,1 $lsall $elsize,99,,2
mat,42 $a,1,2,8,7 $amesh,1 $a,2,3,9,8 $amesh,2 $a,3,4,10,9 $amesh,3
   a,4,5,11,10 $amesh,4 $a,5,6,12,11 $amesh,5
mat,41 $a,7,8,14,13 $amesh,6 $a,8,9,15,14 $amesh,7 $a,9,10,16,15 $amesh,8
   a,10,11,17,16 $amesh,9 $a,11,12,18,17 $amesh,10
 * ~~~ LIFTS 14 TO 11 ~~~
k,19,-3.5,85 $k,37,-3.65,82 $kfill,,,2 $kgen,3,19,37,6,1,,,1
k,22,2.3,85  $k,40,3.26,82  $kfill,,,2 $kgen,3,22,40,6,1,,,1
l,19,25 $l,20,26 $l,21,27 $l,25,31 $l,26,32 $l,27,33 $l,37,31 $l,38,32 $l,39,33
l,19,20 $l,25,26 $l,31,32 $l,37,38 $l,20,21 $l,26,27 $l,32,33 $l,38,39
lssel,,28,30,1 $lsasel,,37,40,1 $ldvs,all,,3,2 $lsall $lssel,,34,36,1
ldvs,all,,2,3 $lsall $lssel,,31,33,1 $lsasel,,41,44,1 $ldvs,all,,1 $lsall
lgen,4,28,44,1,-0.15,-3,,24          * Generates U/S lines for lifts 13 to 11
l,22,28 $l,23,29 $l,24,30 $l,28,34 $l,29,35 $l,30,36 $l,40,34 $l,41,35 $l,42,36
l,22,23 $l,28,29 $l,34,35 $l,40,41 $l,24,23 $l,30,29 $l,36,35 $l,42,41
lssel,,96,98,1 $lsasel,,109,112,1 $ldvs,all,,3,2 $lsall $lssel,,102,104,1
ldvs,all,,2,3 $lsall $lssel,,99,101,1 $lsasel,,105,108,1 $ldvs,all,,1 $lsall
lgen,4,96,112,1,0.96,-3,,24          * Generates D/S lines for lifts 13 to 11
l,21,22 $l,27,28 $l,33,34 $l,39,40 $l,45,46 $l,51,52  $l,57,58   $l,63,64
l,69,70 $l,75,76 $l,81,82 $l,87,88 $l,93,94 $l,99,100 $l,105,106 $l,111,112
lssel,,164,165,1 $ldvs,all,,2 $lsall $lssel,,166,169,1 $ldvs,all,,3 $lsall
lssel,,170,173,1 $ldvs,all,,4 $lsall $lssel,,174,177,1 $ldvs,all,,5 $lsall
lssel,,178,179,1 $ldvs,all,,6 $lsall
mat,40 $a,19,20,26,25 $amesh,11 $a,20,21,27,26 $amesh,12 $a,21,22,28,27
   amesh,13 $a,22,23,29,28 $amesh,14 $a,23,24,30,29 $amesh,15 $a,25,26,32,31
   amesh,16 $a,26,27,33,32 $amesh,17 $elsize,1 $a,27,28,34,33 $amesh,18
   elsize,99,,2 $a,28,29,35,34 $amesh,19 $a,29,30,36,35 $amesh,20
   a,31,32,38,37 $amesh,21 $a,32,33,39,38 $amesh,22 $a,33,34,40,39 $amesh,23
   a,34,35,41,40 $amesh,24 $a,35,36,42,41 $amesh,25
mat,39 $a,43,44,50,49 $amesh,26 $a,44,45,51,50 $amesh,27 $a,49,50,56,55
   amesh,28 $a,50,51,57,56 $amesh,29 $a,55,56,62,61 $amesh,30 $a,56,57,63,62
   amesh,31 $a,46,47,53,52 $amesh,32 $a,47,48,54,53 $amesh,33 $a,52,53,59,58
   amesh,34 $a,53,54,60,59 $amesh,35 $a,58,59,65,64 $amesh,36 $a,59,60,66,65
   amesh,37
mat,38 $a,45,46,52,51 $amesh,38 $elsize,1 $a,51,52,58,57 $amesh,39
   elsize,99,,2 $a,57,58,64,63 $amesh,40 $mat,36 $a,67,68,74,73 $amesh,41
   a,68,69,75,74 $amesh,42 $a,73,74,80,79 $amesh,43 $a,74,75,81,80 $amesh,44
   a,79,80,86,85 $amesh,45 $a,80,81,87,86 $amesh,46
mat,35 $a,69,70,76,75 $amesh,47 $elsize,1 $a,75,76,82,81 $amesh,48
   elsize,99,,2 $a,81,82,88,87 $amesh,49
mat,37 $a,70,71,77,76 $amesh,50 $a,71,72,78,77 $amesh,51 $a,76,77,83,82
   amesh,52 $a,77,78,84,83 $amesh,53 $a,82,83,89,88 $amesh,54 $a,83,84,90,89
   amesh,55
mat,33 $a,91,92,98,97 $amesh,56 $a,92,93,99,98 $amesh,57 $a,97,98,104,103
   amesh,58 $a,98,99,105,104 $amesh,59 $a,103,104,110,109 $amesh,60
   a,104,105,111,110 $amesh,61
mat,32 $a,93,94,100,99 $amesh,62 $elsize,1 $a,99,100,106,105 $amesh,63
   elsize,99,,2 $a,105,106,112,111 $amesh,64
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mat,34 $a,94,95,101,100 $amesh,65 $a,95,96,102,101 $amesh,66 $a,100,101,107,106
   amesh,67 $a,101,102,108,107 $amesh,68 $a,106,107,113,112 $amesh,69
   a,107,108,114,113 $amesh,70
 * ~~~  LIFT 10-3  ~~~
k,115,-4.1,73 $k,121,-4.15,72 $k,127,-4.175,71.5 $kgen,3,115,127,6,1,,,1
k,118,6.14,73 $k,124,6.46,72  $k,130,6.62,71.5   $kgen,3,118,130,6,1,,,1
l,115,121 $l,116,122 $l,117,123 $l,115,116 $l,121,122 $l,127,128 $l,116,117
l,122,123 $l,128,129 $l,127,121 $l,128,122 $l,129,123 $l,118,124 $l,119,125
l,120,126 $l,118,119 $l,124,125 $l,130,131 $l,120,119 $l,126,125 $l,132,131
l,130,124 $l,131,125 $l,132,126 $l,117,118 $l,123,124 $l,129,130
lssel,,180,185,1 $lsasel,,192,194,1 $lsasel,,198,200,1 $ldvs,all,,3,2 $lsall
lssel,,186,188,1 $lsasel,,195,197,1 $ldvs,all,,1 $lsall $lssel,,189,191,1
lsasel,,201,203,1 $ldvs,all,,2,2 $lsall $lssel,,204,206,1 $ldvs,all,,6 $lsall
mat,30 $a,115,116,122,121 $amesh,71 $a,116,117,123,122 $amesh,72
   a,121,122,128,127 $amesh,73 $a,122,123,129,128 $amesh,74
mat,29 $a,117,118,124,123 $amesh,75 $a,123,124,130,129 $amesh,76
mat,31 $a,118,119,125,124 $amesh,77 $a,119,120,126,125 $amesh,78
   a,124,125,131,130 $amesh,79 $a,125,126,132,131 $amesh,80
 * ~~~  LIFTS 10-2 & 10-1  ~~~
k,133,-4.175,71.5 $k,139,-4.2125,70.75 $kgen,3,133,139,6,1,,,1
k,136,6.62,71.5   $k,142,6.86,70.75    $kgen,3,136,142,6,1,,,1
l,133,139 $l,134,140 $l,135,141 $l,133,134 $l,139,140 $l,134,135 $l,140,141
lssel,,207,209,1 $ldvs,all,,3,-1.5 $lsall $ldvs,210,,3,2 $ldvs,211,,3,2
ldvs,212,,1 $ldvs,213,,1 $lgen,2,207,213,1,-0.0375,-0.75,,12    * Generate
l,136,142 $l,137,143 $l,138,144 $l,136,137 $l,142,143 $l,138,137 $l,144,143
lssel,,221,223,1 $ldvs,all,,3,-1.5 $lsall $ldvs,226,,3,2 $ldvs,227,,3,2
ldvs,224,,1 $ldvs,225,,1 $lgen,2,221,227,1,0.24,-0.75,,12       * Generate
l,135,136 $l,141,142 $l,147,148 $l,153,154 $lssel,,235,238,1 $ldvs,all,,6
lsall
mat,27 $a,133,134,140,139 $amesh,81 $a,134,135,141,140 $amesh,82
mat,26 $a,135,136,142,141 $amesh,83
mat,28 $a,136,137,143,142 $amesh,84 $a,137,138,144,143 $amesh,85
mat,24 $a,145,146,152,151 $amesh,86 $a,146,147,153,152 $amesh,87
mat,23 $a,147,148,154,153 $amesh,88
mat,25 $a,148,149,155,154 $amesh,89 $a,149,150,156,155 $amesh,90
 * ~~~  LIFT 9   ~~~
k,157,-4.25,70 $k,175,-4.4,67 $kfill,,,2 $kgen,3,157,175,6,1,,,1
k,160,7.1,70   $k,178,9.2,67  $kfill,,,2 $kgen,3,160,178,6,1,,,1
l,157,163 $l,158,164 $l,159,165 $l,157,158 $l,163,164 $l,169,170 $l,175,176
l,163,169 $l,164,170 $l,165,171 $l,158,159 $l,164,165 $l,170,171 $l,176,177
l,175,169 $l,176,170 $l,177,171 $l,160,166 $l,161,167 $l,162,168 $l,162,161
l,168,167 $l,174,173 $l,180,179 $l,166,172 $l,167,173 $l,168,174 $l,160,161
l,166,167 $l,172,173 $l,178,179 $l,178,172 $l,179,173 $l,180,174 $l,159,160
l,165,166 $l,171,172 $l,177,178
lssel,,239,245,1 $lsasel,,256,262,1 $ldvs,all,,3,2 $lsall $lssel,,246,252,1
lsasel,,263,269,1 $ldvs,all,,1 $lsall $lssel,,253,255,1 $lsasel,,270,272,1
ldvs,all,,2,3 $lsall $lssel,,273,274,1 $ldvs,all,,6 $lsall $lssel,,275,276,1
ldvs,all,,8 $lsall
mat,21 $a,157,158,164,163 $amesh,91 $a,158,159,165,164 $amesh,92
   a,163,164,170,169 $amesh,93 $a,164,165,171,170 $amesh,94 $a,169,170,176,175
   amesh,95 $a,170,171,177,176 $amesh,96
mat,20 $a,159,160,166,165 $amesh,97 $elsize,1 $a,165,166,172,171 $amesh,98
   elsize,99,,2 $a,171,172,178,177 $amesh,99
mat,22 $a,160,161,167,166 $amesh,100 $a,161,162,168,167 $amesh,101
   a,166,167,173,172 $amesh,102 $a,167,168,174,173 $amesh,103
   a,172,173,179,178 $amesh,104 $a,173,174,180,179 $amesh,105
 * ~~~  LIFTS 8b & 8a   ~~~
k,181,-4.4,67 $k,187,-4.45,66 $k,193,-4.475,65.5 $kgen,3,181,193,6,1,,,1
k,184,9.2,67  $k,190,9.9,66   $k,196,10.25,65.5  $kgen,3,184,196,6,1,,,1
l,181,187 $l,182,188 $l,183,189 $l,193,187 $l,194,188 $l,195,189
l,181,182 $l,187,188 $l,193,194 $l,182,183 $l,188,189 $l,194,195
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lssel,,277,279,1 $lsasel,,283,285,1 $ldvs,all,,3,2 $lsall $lssel,,286,288,1
ldvs,all,,1 $lsall $lssel,,280,282,1 $ldvs,all,,2,2 $lsall
lgen,2,277,288,1,-0.075,-1.5,,18          * Generates U/S lines of lift 8-A
l,184,190 $l,185,191 $l,186,192 $l,196,190 $l,197,191 $l,198,192
l,184,185 $l,190,191 $l,196,197 $l,186,185 $l,192,191 $l,198,197
lssel,,301,303,1 $lsasel,,310,312,1 $ldvs,all,,3,2 $lsall $lssel,,307,309,1
ldvs,all,,1 $lsall $lssel,,304,306,1 $ldvs,all,,2,2 $lsall
lgen,2,301,312,1,1.05,-1.5,,18             * Generates D/S lines of lift 8-A
l,183,184 $l,189,190 $l,195,196 $l,201,202 $l,207,208 $l,213,214
lssel,,325,330,1 $ldvs,all,,8 $lsall
mat,19 $a,181,182,188,187 $amesh,106 $a,182,183,189,188 $amesh,107
   a,187,188,194,193 $amesh,108 $a,188,189,195,194 $amesh,109
mat,18 $a,183,184,190,189 $amesh,110 $a,189,190,196,195 $amesh,111
mat,19 $a,184,185,191,190 $amesh,112 $a,185,186,192,191 $amesh,113
   a,190,191,197,196 $amesh,114 $a,191,192,198,197 $amesh,115
mat,17 $a,199,200,206,205 $amesh,116 $a,200,201,207,206 $amesh,117
   a,205,206,212,211 $amesh,118 $a,206,207,213,212 $amesh,119
mat,16 $a,201,202,208,207 $amesh,120 $a,207,208,214,213 $amesh,121
mat,17 $a,202,203,209,208 $amesh,122 $a,203,204,210,209 $amesh,123
   a,208,209,215,214 $amesh,124 $a,209,210,216,215 $amesh,125
 * ---  LIFTS 7 TO 5   ---
k,217,-4.55,64 $k,235,-4.7,61 $kfill,,,2 $kgen,3,217,235,6,1,,,1 $k,289,1.5,56
k,220,11.3,64  $k,238,13.4,61 $kfill,,,2 $kgen,3,220,238,6,1,,,1 $k,290,1.5,55
l,217,223 $l,218,224 $l,219,225 $l,223,229 $l,224,230 $l,225,231 $l,235,229
l,236,230 $l,237,231 $l,217,218 $l,223,224 $l,229,230 $l,235,236 $l,218,219
l,224,225 $l,230,231 $l,236,237
lssel,,331,333,1 $lsasel,,340,343,1 $ldvs,all,,3,2 $lsall $lssel,,334,336,1
lsasel,,344,347,1 $ldvs,all,,1 $lsall $lssel,,337,339,1 $ldvs,all,,2,3 $lsall
lgen,3,331,347,1,-0.15,-3,,24             * Generates U/S lines of lifts 6 & 5
l,220,226 $l,221,227 $l,222,228 $l,226,232 $l,227,233 $l,228,234 $l,238,232
l,239,233 $l,240,234 $l,220,221 $l,226,227 $l,232,233 $l,238,239 $l,222,221
l,228,227 $l,234,233 $l,240,239
lssel,,382,384,1 $lsasel,,395,398,1 $ldvs,all,,3,2 $lsall $lssel,,385,387,1
lsasel,,391,394,1 $ldvs,all,,1 $lsall $lssel,,388,390,1 $ldvs,all,,2,3 $lsall
lgen,3,382,398,1,2.1,-3,,24               * Generates D/S lines of lifts 6 & 5
l,219,220 $l,225,226 $l,231,232 $l,237,238 $l,243,244 $l,249,250 $l,255,256
l,261,262 $l,267,268 $l,273,274 $l,289,280 $l,290,286 $l,279,289 $l,285,290
l,290,289
lssel,,433,434,1 $ldvs,all,,8 $lsall $lssel,,435,438,1 $ldvs,all,,10 $lsall
lssel,,439,442,1 $ldvs,all,,12 $lsall $lssel,,443,444,1 $ldvs,all,,10 $lsall
lssel,,445,446,1 $ldvs,all,,3  $lsall $ldvs,447,,2,3
mat,15 $a,217,218,224,223 $amesh,126 $a,218,219,225,224 $amesh,127
   a,223,224,230,229 $amesh,128 $a,224,225,231,230 $amesh,129
   a,229,230,236,235 $amesh,130 $a,230,231,237,236 $amesh,131
mat,14 $a,219,220,226,225 $amesh,132 $elsize,1 $a,225,226,232,231 $amesh,133
   elsize,99,,2 $a,231,232,238,237 $amesh,134
mat,15 $a,220,221,227,226 $amesh,135 $a,221,222,228,227 $amesh,136
   a,226,227,233,232 $amesh,137 $a,227,228,234,233 $amesh,138
   a,232,233,239,238 $amesh,139 $a,233,234,240,239 $amesh,140
mat,13 $a,241,242,248,247 $amesh,141 $a,242,243,249,248 $amesh,142
   a,247,248,254,253 $amesh,143 $a,248,249,255,254 $amesh,144
   a,253,254,260,259 $amesh,145 $a,254,255,261,260 $amesh,146
mat,12 $a,243,244,250,249 $amesh,147 $elsize,1 $a,249,250,256,255 $amesh,148
   elsize,99,,2 $a,255,256,262,261 $amesh,149
mat,13 $a,244,245,251,250 $amesh,150 $a,245,246,252,251 $amesh,151
   a,250,251,257,256 $amesh,152 $a,251,252,258,257 $amesh,153
   a,256,257,263,262 $amesh,154 $a,257,258,264,263 $amesh,155
mat,11 $a,265,266,272,271 $amesh,156 $a,266,267,273,272 $amesh,157
   a,271,272,278,277 $amesh,158 $a,272,273,279,278 $amesh,159
   a,277,278,284,283 $amesh,160 $a,278,279,285,284 $amesh,161
mat,10 $a,267,268,274,273 $amesh,162 $elsize,1 $al,442,419,443,445,370
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   amesh,163 $elsize,99,,2 $a,289,280,286,290 $amesh,164
mat,11 $a,268,269,275,274 $amesh,165 $a,269,270,276,275 $amesh,166
   a,274,275,281,280 $amesh,167 $a,275,276,282,281 $amesh,168
   a,280,281,287,286 $amesh,169 $a,281,282,288,287 $amesh,170
mat,10 $a,279,289,290,285 $amesh,171
 * ~~~  LIFT 4   ~~~
k,291,-6.6,55 $k,301,-6.34,53.6 $k,296,-6.414,54 $kgen,2,291,301,5,1,,,1
k,293,17.6,55 $k,303,18.58,53.6 $k,298,18.3,54 $kgen,3,293,303,5,1,,,1
k,306,-5,55 $k,307,-4,55 $k,308,-3,55 $k,309,1.5,55 $kgen,2,307,309,1,,-1,,3
kgen,2,310,311,1,,-0.4,,3 $k,315,-2,53.6 $k,316,0.25,53.6 $k,317,1.5,53.6
l,291,296 $l,292,297 $l,307,310 $l,308,311 $l,309,312 $l,293,298 $l,294,299
l,295,300 $l,301,296 $l,302,297 $l,313,310 $l,314,311 $l,317,312 $l,303,298
l,304,299 $l,305,300 $l,291,292 $l,296,297 $l,301,302 $l,292,306 $l,306,307
l,297,310 $l,302,313 $l,307,308 $l,310,311 $l,313,314 $l,308,309 $l,311,312
l,315,314 $l,315,316 $l,316,317 $l,309,293 $l,312,298 $l,317,303 $l,293,294
l,298,299 $l,303,304 $l,295,294 $l,300,299 $l,305,304
lssel,,448,455,1 $ldvs,all,,3,2 $lsall $lssel,,456,463,1 $ldvs,all,,2,2 $lsall
lssel,,464,466,1 $ldvs,all,,2,3 $lsall $lssel,,485,487,1 $ldvs,all,,3,2 $lsall
ldvs,467,,1 $ldvs,468,,3,2 $lssel,,469,473,1 $ldvs,all,,1 $lsall $ldvs,474,,3
ldvs,475,,3 $ldvs,476,,2,2 $ldvs,477,,1 $ldvs,478,,2,2  $lssel,,479,481,1
ldvs,all,,10 $lsall $lssel,,482,484,1 $ldvs,all,,1 $lsall
mat,9 $a,291,292,297,296 $amesh,172 $elsize,2 $al,467,468,450,469,449
   amesh,173 $elsize,99,,2 $a,307,308,311,310 $amesh,174 $a,308,309,312,311
   amesh,175
mat,8 $a,309,293,298,312 $amesh,176
mat,9 $a,293,294,299,298 $amesh,177 $a,294,295,300,299 $amesh,178
   a,296,297,302,301 $amesh,179 $a,297,310,313,302 $amesh,180
   a,310,311,314,313 $amesh,181 $elsize,2 $al,475,460,478,477,476,459
   amesh,182 $elsize,99,,2
mat,8 $a,312,298,303,317 $amesh,183
mat,9 $a,298,299,304,303 $amesh,184 $a,299,300,305,304 $amesh,185
 * ~~~  LIFT 3a/b   ~~~
k,318,-6.34,53.6 $k,345,-5.79,50.6  $kfill,,,2 $kgen,2,318,345,9,1,,,1
k,320,-3,53.6    $k,347,-3,50.6     $kfill,,,2 $kgen,2,320,347,9,1,,,1
k,322,0.25,53.6  $k,349,0.25,50.6   $kfill,,,2 $kgen,2,322,349,9,1.25,,,1
k,324,18.58,53.6 $k,351,20.36,51.06 $k,326,20.58,53.6 $k,353,22.05,51.5
kfill,324,351,2  $kfill,326,353,2   $kfill,324,326,1  $kfill,333,335,1
kfill,342,344,1  $kfill,351,353,1   $k,354,-4,53.6    $k,355,-4,52.6
k,356,18.6,51.6  $k,357,18.6,50.6
l,318,327 $l,319,328 $l,354,355 $l,320,329 $l,321,330 $l,322,331 $l,323,332
l,324,333 $l,325,334 $l,326,335 $l,327,336 $l,328,337 $l,329,338 $l,330,339
l,331,340 $l,332,341 $l,333,342 $l,334,343 $l,335,344 $l,345,336 $l,346,337
l,347,338 $l,348,339 $l,349,340 $l,350,341 $l,357,356 $l,351,342 $l,352,343
l,353,344 $l,318,319 $l,327,328 $l,336,337 $l,345,346 $l,319,354 $l,328,355
l,337,338 $l,346,347 $l,354,320 $l,355,329 $l,321,320 $l,330,329 $l,339,338
l,348,347 $l,322,323 $l,331,332 $l,340,341 $l,349,350 $l,323,324 $l,332,333
l,341,356 $l,350,357 $l,356,342 $l,357,351 $l,324,325 $l,333,334 $l,342,343
l,351,352 $l,326,325 $l,335,334 $l,344,343 $l,353,352
lssel,,488,497,1 $ldvs,all,,3,2 $lsall $lssel,,498,506,1 $ldvs,all,,1 $lsall
lssel,,507,520,1 $ldvs,all,,2,3 $lsall $lssel,,521,526,1 $ldvs,all,,1 $lsall
lssel,,527,534,1 $ldvs,all,,2,2 $lsall $ldvs,535,,10 $ldvs,536,,10
ldvs,537,,10 $ldvs,538,,10 $ldvs,539,,1 $ldvs,540,,1 $lssel,,541,544,1
ldvs,all,,1 $lsall $lssel,,545,548,1 $ldvs,all,,3,2 $lsall
mat,6 $a,318,319,328,327 $amesh,186 $a,319,354,355,328 $amesh,187
   a,354,320,329,355 $amesh,188 $a,327,328,337,336 $amesh,189 $elsize,2
   al,522,526,500,523,499 $amesh,190 $elsize,99,,2 $a,336,337,346,345
   amesh,191 $a,337,338,347,346 $amesh,192
mat,7 $a,320,321,330,329 $amesh,193 $a,329,330,339,338 $amesh,194
   a,338,339,348,347 $amesh,195 $a,322,323,332,331 $amesh,196
   a,331,332,341,340 $amesh,197 $a,340,341,350,349 $amesh,198
mat,6 $a,323,324,333,332 $amesh,199 $elsize,2 $al,536,504,539,537,503
```

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   amesh,200 $elsize,99,,2 $a,341,356,357,350 $amesh,201 $a,356,342,351,357
   amesh,202
mat,7 $a,324,325,334,333 $amesh,203 $a,333,334,343,342 $amesh,204
   a,342,343,352,351 $amesh,205 $a,325,326,335,334 $amesh,206
   a,334,335,344,343 $amesh,207 $a,343,344,353,352 $amesh,208
 * ~~~  LIFT 2   ~~~
k,358,-5.79,50.6 $k,360,-5.609,49.6 $k,362,-5.41,48.5 $kgen,2,358,362,2,1,,,1
k,364,-3,50.6 $k,368,-3,49.6 $kgen,2,364,368,4,1,,,1 $kgen,2,365,369,4,2.25,,,1
kgen,2,366,370,4,1.25,,,1 $k,372,25.5,51.5 $k,374,24.5,50.5 $k,376,23.6,49.6
k,378,22.5,48.5 $kgen,2,372,378,2,1,,,1 $k,380,18.6,50.6 $k,381,20.36,51.06
k,383,22.05,51.5 $kfill,,,1 $k,384,18.6,49.6 $k,385,20.75,50.5
k,386,22.05,50.5 $k,387,18.6,48.5 $k,388,1.5,48.5
l,358,360 $l,359,361 $l,364,368 $l,365,369 $l,366,370 $l,367,371 $l,380,384
l,381,385 $l,383,386 $l,372,374 $l,373,375 $l,362,360 $l,363,361 $l,388,371
l,387,384 $l,378,376 $l,379,377 $l,358,359 $l,360,361 $l,362,363 $l,359,364
l,361,368 $l,365,364 $l,369,368 $l,366,367 $l,370,371 $l,365,366 $l,369,370
l,363,388 $l,367,380 $l,371,384 $l,388,387 $l,380,381 $l,384,385 $l,384,376
l,387,378 $l,382,381 $l,383,382 $l,385,386 $l,383,372 $l,386,374 $l,373,372
l,375,374 $l,377,376 $l,379,378 $l,374,376 $l,375,377
lssel,,549,559,1 $ldvs,all,,3,2 $lsall $lssel,,560,568,1 $ldvs,all,,2,3 $lsall
ldvs,569,,1 $ldvs,570,,1 $ldvs,571,,2,2 $ldvs,573,,2,2 $ldvs,572,,1
ldvs,574,,1 $ldvs,575,,1 $ldvs,576,,1 $ldvs,577,,3 $lssel,,578,580,1
ldvs,all,,10 $lsall $ldvs,581,,1 $ldvs,582,,1 $ldvs,583,,2 $ldvs,584,,2
ldvs,585,,1 $ldvs,586,,3,2 $ldvs,587,,1 $ldvs,588,,2 $ldvs,589,,2
lssel,,590,593,1 $ldvs,all,,2,3 $lsall
ldvs,594,,1 $ldvs,595,,1
mat,3 $a,358,359,361,360 $amesh,209 $a,359,364,368,361 $amesh,210
mat,5 $a,365,366,370,369 $amesh,211 $elsize,2
mat,4 $a,364,365,369,368 $amesh,212 $a,366,367,371,370 $amesh,213 $elsize,99,,2
mat,3 $a,360,361,363,362 $amesh,214 $elsize,2 $al,570,572,576,574,562,577,561
   amesh,215 $elsize,99,,2 $a,367,380,384,371 $amesh,216 $a,371,384,387,388
   amesh,217 $a,380,381,385,384 $amesh,218 $elsize,2 $al,582,587,589,594,583
   amesh,219 $elsize,99,,2 $a,384,376,378,387 $amesh,220 $a,374,375,377,376
   amesh,221 $a,376,377,379,378 $amesh,222 $elsize,2
mat,4 $al,585,586,557,587,556 $amesh,223 $elsize,99,,2 $a,383,372,374,386
   amesh,224 $a,372,373,375,374 $amesh,225
 * ~~~  LIFT  1   ~~~
k,389,-5.41,48.5 $k,391,-5.223,47.5 $k,393,-5.13,47 $kgen,2,389,393,2,1,,,1
k,395,1.5,48.5 $k,396,1.5,47.5 $k,397,1.5,47 $k,398,18.6,48.5
k,399,18.6,47.932 $k,400,18.6,47.648 $k,401,22.5,48.5 $k,402,23.5,48.5
k,406,23,48 $k,405,22,47.92 $kfill,401,405,1 $kfill,402,406,1
l,389,391 $l,390,392 $l,395,396 $l,398,399 $l,401,403 $l,402,404 $l,393,391
l,394,392 $l,397,396 $l,400,399 $l,405,403 $l,406,404 $l,389,390 $l,391,392
l,393,394 $l,390,395 $l,392,396 $l,394,397 $l,395,398 $l,396,399 $l,397,400
l,398,401 $l,399,403 $l,400,405 $l,402,401 $l,404,403 $l,406,405
lssel,,596,601,1 $ldvs,all,,3,2 $lsall $lssel,,602,610,1 $ldvs,all,,2,3 $lsall
lssel,,611,613,1 $ldvs,all,,3 $lsall $lssel,,614,616,1 $ldvs,all,,10 $lsall
lssel,,617,619,1 $ldvs,all,,2 $lsall $lssel,,620,622,1 $ldvs,all,,2,3 $lsall
mat,2 $a,389,390,392,391 $amesh,226 $a,390,395,396,392 $amesh,227
   a,395,398,399,396 $amesh,228 $a,398,401,403,399 $amesh,229
   a,401,402,404,403 $amesh,230 $a,391,392,394,393 $amesh,231
   a,392,396,397,394 $amesh,232 $a,396,399,400,397 $amesh,233
   a,399,403,405,400 $amesh,234 $a,403,404,406,405 $amesh,235
 * ~~~   BEDROCK   ~~~
k,407,-12,55 $k,408,-7.6,55 $k,409,-6.6,55 $k,410,-12,53.6 $k,411,-7.34,53.6
k,412,-6.414,54 $k,413,-6.34,53.6 $k,416,-5.79,50.6 $kfill,,,2
k,417,-5.609,49.6 $k,418,-5.41,48.5 $k,419,-5.223,47.5 $k,420,-5.13,47
k,421,-12,50 $k,422,-6.79,50.6 $k,423,-12,40 $k,424,-6.13,46 $k,425,-4.13,47
k,426,-4.13,46 $k,427,-4.13,40 $k,428,1.5,47 $k,429,1.5,46 $k,430,1.5,40
k,431,18.6,47.648 $k,432,18.6,46.6 $k,433,18.6,40 $k,434,22,47.92 $k,435,23,48
k,437,23.5,48.5 $kfill,,,1 $k,440,26.5,51.5 $k,438,24.6,49.6 $k,441,24,47
```

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k,442,35,40 $k,443,27.5,51.5 $k,444,35,49 $k,445,29,54 $k,446,30,54
k,447,35,54 $k,448,30,55 $k,449,31,55 $k,450,35,55 $k,439,25.5,50.5
l,409,408 $l,413,411 $l,416,422 $l,420,424 $l,425,426 $l,428,429 $l,431,432
l,435,441 $l,440,443 $l,445,446 $l,448,449 $l,448,445 $l,449,446 $l,450,447
l,408,407 $l,411,410 $l,422,421 $l,424,423 $l,426,427 $l,429,430 $l,432,433
l,441,442 $l,443,444 $l,446,447 $l,449,450 $l,407,410 $l,408,411 $l,409,412
l,413,412 $l,410,421 $l,411,422 $l,413,414 $l,414,415 $l,416,415 $l,421,423
l,422,424 $l,416,417 $l,418,417 $l,418,419 $l,420,419 $l,423,427 $l,424,426
l,420,425 $l,427,430 $l,426,429 $l,425,428 $l,428,431 $l,429,432 $l,430,433
l,431,434 $l,432,441 $l,433,442 $l,435,434 $l,435,436 $l,437,436 $l,437,438
l,438,439 $l,440,439 $l,443,441 $l,444,442 $l,445,440 $l,446,443 $l,447,444
lssel,,623,636,1 $ldvs,all,,2,3 $lsall $lssel,,637,647,1 $ldvs,all,,3,1.5
lsall $ldvs,648,,2,2 $ldvs,649,,2,2 $ldvs,650,,3,2 $ldvs,651,,2,2
ldvs,652,,2,1.5 $ldvs,653,,2,1.5 $ldvs,654,,3,2 $ldvs,655,,1 $ldvs,656,,2,3
ldvs,657,,2 $ldvs,658,,2 $ldvs,659,,3,2 $ldvs,660,,2,3 $ldvs,661,,3,2
ldvs,662,,2,3 $ldvs,663,,1 $ldvs,664,,1 $ldvs,665,,2,3 $ldvs,666,,1
ldvs,667,,3 $ldvs,668,,3 $ldvs,669,,10 $ldvs,670,,10 $ldvs,671,,2 $ldvs,672,,2
ldvs,673,,2 $ldvs,674,,2 $ldvs,675,,2,3 $ldvs,676,,2,3 $ldvs,677,,3,2
ldvs,678,,2,3 $ldvs,679,,1 $ldvs,680,,3,2 $ldvs,681,,2 $ldvs,682,,2
lssel,,683,685,1 $ldvs,all,,2,1.5 $lsall
mat,1 $a,407,408,411,410 $amesh,236 $elsize,2 $al,623,650,651,624,649
   amesh,237 $elsize,99,,2 $a,410,411,422,421 $amesh,238 $elsize,2
   al,624,654,655,656,625,653 $amesh,239 $elsize,99,,2 $a,421,422,424,423
   amesh,240 $elsize,2 $al,625,659,660,661,662,626,658 $amesh,241
   elsize,99,,2 $a,424,426,427,423 $amesh,242 $elsize,2 $a,420,425,426,424
   amesh,243 $elsize,99,,2 $a,425,428,429,426 $amesh,244 $elsize,2
   a,426,429,430,427 $amesh,245 $elsize,99,,2 $a,428,431,432,429
   amesh,246 $elsize,2 $a,429,432,433,430 $amesh,247 $al,672,675,630,673,629
   amesh,248 $al,676,677,678,679,680,631,681,630 $amesh,249 $elsize,99,,2
   a,432,441,442,433 $amesh,250 $a,441,443,444,442 $amesh,251
   a,445,446,443,440 $amesh,252 $a,446,447,444,443 $amesh,253
   a,448,449,446,445 $amesh,254 $a,449,450,447,446 $amesh,255
 * ~~~  INITIALIZE TEMPERATURES  ~~~
nt,1998,temp,2,,2025,27 $nt,2041,temp,2,,2078,37  * Constant 2C temperature
nt,2081,temp,2,,2142,61 $nt,2145,temp,2           * along bottom of model
nt,45,temp,12   $nt,123,temp,7        * Lifts 15 & 14 placing temperatures
nt,172,temp,10  $nt,259,temp,10       * Lifts 13 & 12 placing temperatures
nt,353,temp,11  $nt,449,temp,11       * Lifts 11 & 10-3 placing temperatures
nt,523,temp,13  $nt,583,temp,12       * Lifts 10-2 & 10-1 placing temperatures
nt,664,temp,9   $nt,770,temp,11       * Lifts 9 & 8B placing temperatures
nt,872,temp,12  $nt,979,temp,11       * Lifts 8A & 7 placing temperatures
nt,1104,temp,13 $nt,1243,temp,12      * Lifts 6 & 5 placing temperatures
nt,1478,temp,12                       * Lift 4 placing temperature
nt,1509,temp,9  $nt,1555,temp,9       * Lift 3A/B placing temperature (2 parts)
nt,1677,temp,14 $nt,1832,temp,10      * Lifts 2 & 1 placing temperatures
wsort,y
 *
 * ~~~~~~~~~~~~~~~~~~~~~~~  ANALYSIS COMMANDS  ~~~~~~~~~~~~~~~~~~~~~~~~~~
 *
/title,(NT921222.mod) CASE STUDY - Excavated Bedrock
lsse,,637 $lsas,,623 $lsas,,650 $lsas,,651 $lsas,,654 $lsas,,655 $lsas,,656
lsas,,659 $lsas,,660 $lsas,,661 $lsas,,662 $lsas,,665 $lsas,,668 $lsas,,669
lsas,,672 $lsas,,675 $lsas,,676 $lsas,,677 $lsas,,678 $lsas,,679 $lsas,,680
lsas,,683 $lsas,,634 $lsas,,633 $lsas,,647
iter,1 $podisp,-1 $postr,-1 $porf,-1
time,  0.0 $lcvsf,all, 272,  0.0        $lwrite * 851001 / #   1
iter,4 $podisp,-1 $postr,-1 $porf,-1
time,  7.0 $lcvsf,all, 421, -4.3        $lwrite * 851008 / #   2
time, 14.0 $lcvsf,all, 633, -5.3        $lwrite * 851015 / #   3
time, 21.0 $lcvsf,all, 421,  7.0        $lwrite * 851022 / #   4
time, 28.0 $lcvsf,all, 760,  0.3        $lwrite * 851029 / #   5
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 time, 35.0 $lcvsf,all, 399, -4.0            $lwrite * 851105 / #   6
 time, 42.0 $lcvsf,all, 272,-17.5            $lwrite * 851112 / #   7
 time, 49.0 $lcvsf,all, 315,-21.0            $lwrite * 851119 / #   8
 time, 56.0 $lcvsf,all, 399,-23.5            $lwrite * 851126 / #   9
 time, 63.0 $lcvsf,all, 399,-19.0            $lwrite * 851203 / #  10
 time, 70.0 $lcvsf,all, 357,-18.0            $lwrite * 851210 / #  11
 time, 77.0 $lcvsf,all, 569,-21.3            $lwrite * 851217 / #  12
 time, 84.0 $lcvsf,all, 612,-23.8            $lwrite * 851224 / #  13
 time, 91.0 $lcvsf,all, 240,-25.8            $lwrite * 851231 / #  14
 time, 98.0 $lcvsf,all, 548,-25.3            $lwrite * 860107 / #  15
 time,105.0 $lcvsf,all, 378,-16.0            $lwrite * 860114 / #  16
 time,112.0 $lcvsf,all, 590,-20.0            $lwrite * 860121 / #  17
 time,119.0 $lcvsf,all, 315,-20.3            $lwrite * 860128 / #  18
 time,126.0 $lcvsf,all, 378,-11.3            $lwrite * 860204 / #  19
 time,133.0 $lcvsf,all, 357,-20.8            $lwrite * 860211 / #  20
 time,140.0 $lcvsf,all, 315,-30.3            $lwrite * 860218 / #  21
 time,147.0 $lcvsf,all, 399,-18.8            $lwrite * 860225 / #  22
 time,154.0 $lcvsf,all, 336,-21.8            $lwrite * 860304 / #  23
 time,161.0 $lcvsf,all, 230,-25.0            $lwrite * 860311 / #  24
 time,168.0 $lcvsf,all, 442,-23.8            $lwrite * 860318 / #  25
 time,175.0 $lcvsf,all, 293,-15.0            $lwrite * 860325 / #  26
 time,182.0 $lcvsf,all, 399, -4.0            $lwrite * 860401 / #  27
 time,189.0 $lcvsf,all, 421, -3.0            $lwrite * 860408 / #  28
 time,196.0 $lcvsf,all, 230,-11.5            $lwrite * 860415 / #  29
 time,203.0 $lcvsf,all, 315,  3.8            $lwrite * 860422 / #  30
 time,207.0 $lcvsf,all, 421,  1.8            $lwrite * 860426 / #  31
 time,211.0 $lcvsf,all, 633, -7.3            $lwrite * 860430 / #  32
 time,215.0 $lcvsf,all, 548,  1.5            $lwrite * 860504 / #  33
 time,219.0 $lcvsf,all, 357, -2.0            $lwrite * 860508 / #  34
 time,223.0 $lcvsf,all, 336,  7.0            $lwrite * 860512 / #  35
 time,227.0 $lcvsf,all, 548,  0.8            $lwrite * 860516 / #  36
 time,231.0 $lcvsf,all, 315, 16.3            $lwrite * 860520 / #  37
 time,233.0 $lcvsf,all, 399, 17.5            $lwrite * 860522 / #  38
 time,235.0 $lcvsf,all, 187, 18.5            $lwrite * 860524 / #  39
 time,237.0 $lcvsf,all, 357, 12.5            $lwrite * 860526 / #  40
 time,239.0 $lcvsf,all, 399, 21.3            $lwrite * 860528 / #  41
 time,241.0 $lcvsf,all, 421,  2.3            $lwrite * 860530 / #  42
 time,243.0 $lcvsf,all, 399,  8.0            $lwrite * 860601 / #  43
 time,245.0 $lcvsf,all, 633,  8.0            $lwrite * 860603 / #  44
 time,247.0 $lcvsf,all, 272,  7.8            $lwrite * 860605 / #  45
 time,249.0 $lcvsf,all, 866,  3.3            $lwrite * 860607 / #  46
 time,251.0 $lcvsf,all, 527,  0.3            $lwrite * 860609 / #  47
 time,253.0 $lcvsf,all, 378,  9.8            $lwrite * 860611 / #  48
 time,254.0 $lcvsf,all, 654,  9.0            $lwrite * 860612 / #  49
 time,255.0 $lcvsf,all, 696,  5.0            $lwrite * 860613 / #  50
 time,256.0 $lcvsf,all, 654,  7.8            $lwrite * 860614 / #  51
 time,257.0 $lcvsf,all, 675,  7.5            $lwrite * 860615 / #  52
iter,4,,4
time,258.0 $lcvsf,all, 399,  5.8             $lwrite * 860616 / #  53
sbcdele,lcvsf,all $lsall $afwrite
finish
/input,27
finish
/aux1
copy,12,35
finish
/prep7
resume $krstrt, 53
/title,(NT921222.mod) CASE STUDY - Lift 1 Placed
ntdele,1832,temp $cp,  1,temp,1832,2008 $cp,  2,temp,1904,2111
cp,  3,temp,1838,2006 $cp,  4,temp,1840,2009 $cp,  5,temp,1841,2010
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cp,  6,temp,1906,2109 $cp,  7,temp,1907,2112 $cp,  8,temp,1908,2113
cp,  9,temp,1912,2028 $cp, 10,temp,1914,2004 $cp, 11,temp,1915,2029
cp, 12,temp,1916,2007 $cp, 13,temp,1918,2032 $cp, 14,temp,1920,2033
cp, 15,temp,1921,2034 $cp, 16,temp,1924,2048 $cp, 17,temp,1926,2049
cp, 18,temp,1927,2050 $cp, 19,temp,1928,2051 $cp, 20,temp,1929,2052
cp, 21,temp,1930,2053 $cp, 22,temp,1931,2054 $cp, 23,temp,1932,2055
cp, 24,temp,1933,2056 $cp, 25,temp,1934,2057 $cp, 26,temp,1944,2099
cp, 27,temp,1946,2100 $cp, 28,temp,1948,2101 $cp, 29,temp,1949,2110
cp, 30,temp,1950,2102
lsse,,637 $lsas,,623 $lsas,,650 $lsas,,651 $lsas,,654 $lsas,,655 $lsas,,656
lsas,,659 $lsas,,660 $lsas,,608 $lsas,,611 $lsas,,614 $lsas,,617 $lsas,,620
lsas,,678 $lsas,,679 $lsas,,680 $lsas,,683 $lsas,,634 $lsas,,633 $lsas,,647
iter,1,,1
time,258.1 $lcvsf,all, 399,  5.8
          esel,mat, 2 $qe,all, 7576 $eall $lwrite * 860616 / #  54
iter,4,,4
time,259.0 $lcvsf,all, 272, 11.8
          esel,mat, 2 $qe,all, 4183 $eall $lwrite * 860617 / #  55
podisp,-1 $postr,-1 $porf,-1
time,260.0 $lcvsf,all, 399, 16.5
          esel,mat, 2 $qe,all, 2162 $eall $lwrite * 860618 / #  56
iter,4,,4
time,261.0 $lcvsf,all, 357, 12.8
          esel,mat, 2 $qe,all, 1117 $eall $lwrite * 860619 / #  57
podisp,-1 $postr,-1 $porf,-1
time,262.0 $lcvsf,all, 399, 19.8
          esel,mat, 2 $qe,all,  578 $eall $lwrite * 860620 / #  58
iter,4,,4
time,263.0 $lcvsf,all, 399, 20.8
          esel,mat, 2 $qe,all,  298 $eall $lwrite * 860621 / #  59
podisp,-1 $postr,-1 $porf,-1
time,264.0 $lcvsf,all, 718, 16.0
          esel,mat, 2 $qe,all,  154 $eall $lwrite * 860622 / #  60
iter,4,,4
time,265.0 $lcvsf,all, 315,  7.8
          esel,mat, 2 $qe,all,   80 $eall $lwrite * 860623 / #  61
podisp,-1 $postr,-1 $porf,-1
time,266.0 $lcvsf,all, 378, 13.3
          esel,mat, 2 $qe,all,   41 $eall $lwrite * 860624 / #  62
iter,4,,4
time,267.0 $lcvsf,all, 315, 13.0
          esel,mat, 2 $qe,all,   21 $eall $lwrite * 860625 / #  63
sbcdele,lcvsf,all $lsall $afwrite
finish
/input,27
finish
/aux1
copy,35,36 $copy,12,36
finish
/delete,file35,dat
/prep7
resume $krstrt, 63
/title,(NT921222.mod) CASE STUDY - Lift 2 Placed
ntdele,1677,temp $cp, 31,temp,1677,1984 $cp, 32,temp,1683,2011
cp, 33,temp,1685,2013 $cp, 34,temp,1686,2014 $cp, 35,temp,1714,1833
cp, 36,temp,1717,1834 $cp, 37,temp,1718,2012 $cp, 38,temp,1720,1844
cp, 39,temp,1722,1845 $cp, 40,temp,1723,1846 $cp, 41,temp,1766,1856
cp, 42,temp,1768,1857 $cp, 43,temp,1769,1858 $cp, 44,temp,1770,1859
cp, 45,temp,1771,1860 $cp, 46,temp,1772,1861 $cp, 47,temp,1773,1862
cp, 48,temp,1774,1863 $cp, 49,temp,1775,1864 $cp, 50,temp,1776,1865
cp,  1,temp,1716 $cp, 51,temp,1797,1897 $cp, 52,temp,1799,2116
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cp, 53,temp,1801,2114 $cp, 54,temp,1804,2115 $cp,  2,temp,1803
cp, 55,temp,1826,2117 $cp, 56,temp,1828,2118 $cp, 57,temp,1829,2119
cp, 58,temp,1795,1896 $cp, 59,temp,1805,1905
lsse,,637 $lsas,,623 $lsas,,650 $lsas,,651 $lsas,,654 $lsas,,655 $lsas,,656
lsas,,566 $lsas,,569 $lsas,,571 $lsas,,575 $lsas,,573 $lsas,,578 $lsas,,581
lsas,,585 $lsas,,586 $lsas,,588 $lsas,,590 $lsas,,683 $lsas,,634 $lsas,,633
lsas,,647
iter,1,,1
time,267.1 $lcvsf,all, 315, 13.0
          esel,mat, 5 $qe,all,10350 $eall
          esel,mat, 4 $qe,all, 8982 $eall
          esel,mat, 3 $qe,all, 7576 $eall
          esel,mat, 2 $qe,all,   20 $eall $lwrite * 860625 / #  64
iter,4 $podisp,-1 $postr,-1 $porf,-1
time,268.0 $lcvsf,all, 378, 14.5
          esel,mat, 5 $qe,all, 5715 $eall
          esel,mat, 4 $qe,all, 5004 $eall
          esel,mat, 3 $qe,all, 4183 $eall
          esel,mat, 2 $qe,all,   11 $eall $lwrite * 860626 / #  65
iter,4,,4
time,269.0 $lcvsf,all, 484, 12.5
          esel,mat, 5 $qe,all, 2954 $eall
          esel,mat, 4 $qe,all, 2612 $eall
          esel,mat, 3 $qe,all, 2162 $eall
          esel,mat, 2 $qe,all,    6 $eall $lwrite * 860627 / #  66
podisp,-1 $postr,-1 $porf,-1
time,270.0 $lcvsf,all, 654,  6.3
          esel,mat, 5 $qe,all, 1527 $eall
          esel,mat, 4 $qe,all, 1364 $eall
          esel,mat, 3 $qe,all, 1117 $eall
          esel,mat, 2 $qe,all,    3 $eall $lwrite * 860628 / #  67
iter,4,,4
time,271.0 $lcvsf,all, 421, 12.8
          esel,mat, 5 $qe,all,  789 $eall
          esel,mat, 4 $qe,all,  712 $eall
          esel,mat, 3 $qe,all,  578 $eall
          esel,mat, 2 $qe,all,    2 $eall $lwrite * 860629 / #  68
podisp,-1 $postr,-1 $porf,-1
time,272.0 $lcvsf,all, 399, 10.3
          esel,mat, 5 $qe,all,  408 $eall
          esel,mat, 4 $qe,all,  372 $eall
          esel,mat, 3 $qe,all,  298 $eall
          esel,mat, 2 $qe,all,    1 $eall $lwrite * 860630 / #  69
iter,4,,4
time,273.0 $lcvsf,all, 506, 10.5
          esel,mat, 5 $qe,all,  211 $eall
          esel,mat, 4 $qe,all,  194 $eall
          esel,mat, 3 $qe,all,  154 $eall
          esel,mat, 2 $qedele,all   $eall $lwrite * 860701 / #  70
podisp,-1 $postr,-1 $porf,-1
time,274.0 $lcvsf,all, 336, 13.3
          esel,mat, 5 $qe,all,  109 $eall
          esel,mat, 4 $qe,all,  101 $eall
          esel,mat, 3 $qe,all,   80 $eall $lwrite * 860702 / #  71
iter,4,,4
time,275.0 $lcvsf,all, 421, 15.3
          esel,mat, 5 $qe,all,   56 $eall
          esel,mat, 4 $qe,all,   53 $eall
          esel,mat, 3 $qe,all,   41 $eall $lwrite * 860703 / #  72
podisp,-1 $postr,-1 $porf,-1
time,276.0 $lcvsf,all, 527, 10.3
```

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          esel,mat, 5 $qe,all,   29 $eall
          esel,mat, 4 $qe,all,   28 $eall
          esel,mat, 3 $qe,all,   21 $eall $lwrite * 860704 / #  73
iter,4,,4
time,277.0 $lcvsf,all, 569, 12.5
          esel,mat, 5 $qe,all,   15 $eall
          esel,mat, 4 $qe,all,   14 $eall
          esel,mat, 3 $qe,all,   11 $eall $lwrite * 860705 / #  74
podisp,-1 $postr,-1 $porf,-1
time,278.0 $lcvsf,all, 802, 11.5
          esel,mat, 5 $qe,all,    8 $eall
          esel,mat, 4 $qe,all,    8 $eall
          esel,mat, 3 $qe,all,    6 $eall $lwrite * 860706 / #  75
iter,4,,4
time,279.0 $lcvsf,all, 718,  9.5
          esel,mat, 5 $qe,all,    4 $eall
          esel,mat, 4 $qe,all,    4 $eall
          esel,mat, 3 $qe,all,    3 $eall $lwrite * 860707 / #  76
sbcdele,lcvsf,all $lsall $afwrite
finish
/input,27
finish
/aux1
copy,36,35 $copy,12,35
finish
/delete,file36,dat
/prep7
resume $krstrt, 76
/title,(NT921222.mod) CASE STUDY - Lift 3a/b Placed
ntdele,1555,temp $ntdele,1509,temp $cp, 60,temp,1509,1966 $cp, 61,temp,1515,1988
cp, 62,temp,1517,1989 $cp, 63,temp,1518,1990 $cp, 64,temp,1530,1986
cp, 65,temp,1533,1678 $cp, 66,temp,1536,1679 $cp, 67,temp,1537,1987
cp, 68,temp,1539,1689 $cp, 69,temp,1551,1693 $cp, 70,temp,1553,1701
cp, 71,temp,1570,1704 $cp, 72,temp,1572,1694 $cp, 73,temp,1573,1705
cp, 74,temp,1627,1726 $cp, 75,temp,1629,1727 $cp, 76,temp,1630,1728
cp, 77,temp,1631,1729 $cp, 78,temp,1632,1730 $cp, 79,temp,1633,1731
cp, 80,temp,1634,1732 $cp, 81,temp,1635,1733 $cp, 82,temp,1636,1734
cp, 83,temp,1637,1735 $cp, 84,temp,1647,1786 $cp, 85,temp,1654,1807
cp, 86,temp,1671,1808 $cp, 87,temp,1673,1811 $cp, 88,temp,1674,1812
cp, 31,temp,1535
lsse,,637 $lsas,,623 $lsas,,650 $lsas,,651 $lsas,,517 $lsas,,521 $lsas,,525
lsas,,527 $lsas,,492 $lsas,,501 $lsas,,510 $lsas,,575 $lsas,,511 $lsas,,502
lsas,,493 $lsas,,531 $lsas,,535 $lsas,,541 $lsas,,545 $lsas,,497 $lsas,,506
lsas,,516 $lsas,,588 $lsas,,590 $lsas,,683 $lsas,,634 $lsas,,633 $lsas,,647
iter,1,,1
time,279.1 $lcvsf,all, 718,  9.5
          esel,mat, 7 $qe,all, 8982 $eall
          esel,mat, 6 $qe,all, 7576 $eall
          esel,mat, 5 $qe,all,    4 $eall
          esel,mat, 4 $qe,all,    4 $eall
          esel,mat, 3 $qe,all,    3 $eall $lwrite * 860707 / #  77
iter,4 $podisp,-1 $postr,-1 $porf,-1
time,280.0 $lcvsf,all, 463, 11.0
          esel,mat, 7 $qe,all, 5004 $eall
          esel,mat, 6 $qe,all, 4183 $eall
          esel,mat, 5 $qe,all,    2 $eall
          esel,mat, 4 $qe,all,    2 $eall
          esel,mat, 3 $qe,all,    2 $eall $lwrite * 860708 / #  78
iter,4,,4
time,281.0 $lcvsf,all, 230, 12.0
          esel,mat, 7 $qe,all, 2612 $eall
```

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          esel,mat, 6 $qe,all, 2162 $eall
          esel,mat, 5 $qe,all,    1 $eall
          esel,mat, 4 $qe,all,    1 $eall
          esel,mat, 3 $qe,all,    1 $eall $lwrite * 860709 / #  79
podisp,-1 $postr,-1 $porf,-1
time,282.0 $lcvsf,all, 315, 14.3
          esel,mat, 7 $qe,all, 1364 $eall
          esel,mat, 6 $qe,all, 1117 $eall
          esel,mat, 5 $qe,all,    1 $eall
          esel,mat, 4 $qe,all,    1 $eall
          esel,mat, 3 $qedele,all   $eall $lwrite * 860710 / #  80
iter,4,,4
time,283.0 $lcvsf,all, 399, 18.3
          esel,mat, 7 $qe,all,  712 $eall
          esel,mat, 6 $qe,all,  578 $eall
          esel,mat, 5 $qedele,all   $eall
          esel,mat, 4 $qedele,all   $eall $lwrite * 860711 / #  81
podisp,-1 $postr,-1 $porf,-1
time,284.0 $lcvsf,all, 421, 18.8
          esel,mat, 7 $qe,all,  372 $eall
          esel,mat, 6 $qe,all,  298 $eall $lwrite * 860712 / #  82
iter,4,,4
time,285.0 $lcvsf,all, 357, 18.5
          esel,mat, 7 $qe,all,  194 $eall
          esel,mat, 6 $qe,all,  154 $eall $lwrite * 860713 / #  83
podisp,-1 $postr,-1 $porf,-1
time,286.0 $lcvsf,all, 315, 19.8
          esel,mat, 7 $qe,all,  101 $eall
          esel,mat, 6 $qe,all,   80 $eall $lwrite * 860714 / #  84
iter,4,,4
time,287.0 $lcvsf,all, 293, 18.8
          esel,mat, 7 $qe,all,   53 $eall
          esel,mat, 6 $qe,all,   41 $eall $lwrite * 860715 / #  85
podisp,-1 $postr,-1 $porf,-1
time,288.0 $lcvsf,all, 569, 13.5
          esel,mat, 7 $qe,all,   28 $eall
          esel,mat, 6 $qe,all,   21 $eall $lwrite * 860716 / #  86
iter,4,,4
time,289.0 $lcvsf,all, 399, 12.5
          esel,mat, 7 $qe,all,   14 $eall
          esel,mat, 6 $qe,all,   11 $eall $lwrite * 860717 / #  87
podisp,-1 $postr,-1 $porf,-1
time,290.0 $lcvsf,all, 378, 13.0
          esel,mat, 7 $qe,all,    8 $eall
          esel,mat, 6 $qe,all,    6 $eall $lwrite * 860718 / #  88
iter,4,,4
time,291.0 $lcvsf,all, 590, 10.3
          esel,mat, 7 $qe,all,    4 $eall
          esel,mat, 6 $qe,all,    3 $eall $lwrite * 860719 / #  89
podisp,-1 $postr,-1 $porf,-1
time,292.0 $lcvsf,all, 484, 13.3
          esel,mat, 7 $qe,all,    2 $eall
          esel,mat, 6 $qe,all,    2 $eall $lwrite * 860720 / #  90
iter,4,,4
time,293.0 $lcvsf,all, 739, 11.0
          esel,mat, 7 $qe,all,    1 $eall
          esel,mat, 6 $qe,all,    1 $eall $lwrite * 860721 / #  91
podisp,-1 $postr,-1 $porf,-1
time,294.0 $lcvsf,all, 357, 15.8
          esel,mat, 7 $qe,all,    1 $eall
          esel,mat, 6 $qedele,all   $eall $lwrite * 860722 / #  92
```

```
iter,4,,4
time,295.0 $lcvsf,all, 527, 15.0
           esel,mat, 7 $qedele,all   $eall $lwrite * 860723 / #  93
podisp,-1 $postr,-1 $porf,-1
time,296.0 $lcvsf,all, 654,  6.5          $lwrite * 860724 / #  94
iter,4,,4
time,297.0 $lcvsf,all, 378, 12.3          $lwrite * 860725 / #  95
podisp,-1 $postr,-1 $porf,-1
time,298.0 $lcvsf,all, 336, 12.3          $lwrite * 860726 / #  96
iter,4,,4
time,299.0 $lcvsf,all, 357, 14.5          $lwrite * 860727 / #  97
podisp,-1 $postr,-1 $porf,-1
time,300.0 $lcvsf,all, 315, 10.3          $lwrite * 860728 / #  98
iter,4,,4
time,301.0 $lcvsf,all, 293, 13.0          $lwrite * 860729 / #  99
sbcdele,lcvsf,all $lsall $afwrite
finish
/input,27
finish
/aux1
copy,35,36 $copy,12,36
finish
/delete,file35,dat
/prep7
resume $krstrt, 99
/title,(NT921222.mod) CASE STUDY - Lift 4 Placed
ntdele,1478,temp $cp, 89,temp,1368,1964 $cp, 90,temp,1374,1968
cp, 91,temp,1376,1970 $cp, 92,temp,1377,1971 $cp, 93,temp,1464,1510
cp, 94,temp,1467,1511 $cp, 95,temp,1468,1969 $cp, 96,temp,1470,1521
cp, 97,temp,1472,1525 $cp, 98,temp,1474,1556 $cp, 99,temp,1476,1555
cp,100,temp,1477,1557 $cp,101,temp,1478,1541 $cp,102,temp,1479,1542
cp,103,temp,1481,1576 $cp,104,temp,1483,1577 $cp,105,temp,1484,1578
cp,106,temp,1485,1579 $cp,107,temp,1486,1580 $cp,108,temp,1487,1581
cp,109,temp,1488,1582 $cp,110,temp,1489,1583 $cp,111,temp,1490,1584
cp,112,temp,1491,1585 $cp,113,temp,1501,1649 $cp,114,temp,1503,1656
cp,115,temp,1505,1657 $cp,116,temp,1506,1658 $cp, 60,temp,1466
lsse,,637 $lsas,,623 $lsas,,464 $lsas,,467 $lsas,,468 $lsas,,471 $lsas,,474
lsas,,479 $lsas,,482 $lsas,,485 $lsas,,455 $lsas,,463 $lsas,,497 $lsas,,506
lsas,,516 $lsas,,588 $lsas,,590 $lsas,,683 $lsas,,634 $lsas,,633 $lsas,,647
iter,1,,1
time,301.1 $lcvsf,all, 293, 13.0
          esel,mat, 9 $qe,all, 8733 $eall
          esel,mat, 8 $qe,all, 7578 $eall $lwrite * 860729 / # 100
iter,4 $podisp,-1 $postr,-1 $porf,-1
time,302.0 $lcvsf,all, 378,  9.3
          esel,mat, 9 $qe,all, 4865 $eall
          esel,mat, 8 $qe,all, 4184 $eall $lwrite * 860730 / # 101
iter,4,,4
time,303.0 $lcvsf,all, 240, 10.8
          esel,mat, 9 $qe,all, 2540 $eall
          esel,mat, 8 $qe,all, 2163 $eall $lwrite * 860731 / # 102
podisp,-1 $postr,-1 $porf,-1
time,304.0 $lcvsf,all, 484, 13.8
          esel,mat, 9 $qe,all, 1326 $eall
          esel,mat, 8 $qe,all, 1118 $eall $lwrite * 860801 / # 103
iter,4,,4
time,305.0 $lcvsf,all, 399, 17.0
          esel,mat, 9 $qe,all,  692 $eall
          esel,mat, 8 $qe,all,  578 $eall $lwrite * 860802 / # 104
podisp,-1 $postr,-1 $porf,-1
time,306.0 $lcvsf,all, 293, 14.3
```

```
          esel,mat, 9 $qe,all,  361 $eall
          esel,mat, 8 $qe,all,  299 $eall $lwrite * 860803 / # 105
iter,4,,4
time,307.0 $lcvsf,all, 336, 14.0
          esel,mat, 9 $qe,all,  189 $eall
          esel,mat, 8 $qe,all,  154 $eall $lwrite * 860804 / # 106
time,308.0 $lcvsf,all, 293, 15.8
          esel,mat, 9 $qe,all,   98 $eall
          esel,mat, 8 $qe,all,   80 $eall $lwrite * 860805 / # 107
sbcdele,lcvsf,all $lsall $afwrite
finish
/input,27
finish
/aux1
copy,36,35 $copy,12,35
finish
/delete,file36,dat
/prep7
resume $krstrt,107
/title,(NT921222.mod) CASE STUDY - Lift 5 Placed
ntdele,1243,temp $cp,117,temp,1243,1381 $cp,118,temp,1245,1380
cp,119,temp,1246,1382 $cp,120,temp,1247,1383 $cp,121,temp,1251,1392
cp,122,temp,1314,1408 $cp,123,temp,1316,1396 $cp,124,temp,1317,1409
cp,125,temp,1318,1410 $cp,126,temp,1319,1411 $cp,127,temp,1320,1412
cp,128,temp,1321,1413 $cp,129,temp,1322,1414 $cp,130,temp,1323,1415
cp,131,temp,1324,1416 $cp,132,temp,1325,1417 $cp,133,temp,1356,1448
cp,134,temp,1358,1452 $cp,135,temp,1360,1453 $cp,136,temp,1361,1454
cp,137,temp,1364,1397 $cp,138,temp,1365,1398
lsse,,637 $lsas,,623 $lsas,,464 $lsas,,467 $lsas,,371 $lsas,,368 $lsas,,365
lsas,,374 $lsas,,378 $lsas,,441 $lsas,,425 $lsas,,429 $lsas,,418 $lsas,,421
lsas,,424 $lsas,,455 $lsas,,463 $lsas,,497 $lsas,,506 $lsas,,516 $lsas,,588
lsas,,590 $lsas,,683 $lsas,,634 $lsas,,633 $lsas,,647
iter,1,,1
time,308.1 $lcvsf,all, 293, 15.8
          esel,mat,11 $qe,all, 8733 $eall
          esel,mat,10 $qe,all, 7578 $eall
          esel,mat, 9 $qe,all,   92 $eall
          esel,mat, 8 $qe,all,   75 $eall $lwrite * 860805 / # 108
iter,4,,4
time,309.0 $lcvsf,all, 378, 18.3
          esel,mat,11 $qe,all, 4865 $eall
          esel,mat,10 $qe,all, 4184 $eall
          esel,mat, 9 $qe,all,   51 $eall
          esel,mat, 8 $qe,all,   41 $eall $lwrite * 860806 / # 109
podisp,-1 $postr,-1 $porf,-1
time,310.0 $lcvsf,all, 421, 17.0
          esel,mat,11 $qe,all, 2540 $eall
          esel,mat,10 $qe,all, 2163 $eall
          esel,mat, 9 $qe,all,   27 $eall
          esel,mat, 8 $qe,all,   21 $eall $lwrite * 860807 / # 110
iter,4,,4
time,311.0 $lcvsf,all, 612, 11.5
          esel,mat,11 $qe,all, 1326 $eall
          esel,mat,10 $qe,all, 1118 $eall
          esel,mat, 9 $qe,all,   14 $eall
          esel,mat, 8 $qe,all,   11 $eall $lwrite * 860808 / # 111
podisp,-1 $postr,-1 $porf,-1
time,312.0 $lcvsf,all, 675,  8.8
          esel,mat,11 $qe,all,  692 $eall
          esel,mat,10 $qe,all,  578 $eall
          esel,mat, 9 $qe,all,    7 $eall
```

```
          esel,mat, 8 $qe,all,    6 $eall $lwrite * 860809 / # 112
iter,4,,4
time,313.0 $lcvsf,all, 590,  9.5
          esel,mat,11 $qe,all,  361 $eall
          esel,mat,10 $qe,all,  299 $eall
          esel,mat, 9 $qe,all,    4 $eall
          esel,mat, 8 $qe,all,    3 $eall $lwrite * 860810 / # 113
podisp,-1 $postr,-1 $porf,-1
time,314.0 $lcvsf,all, 357, 12.0
          esel,mat,11 $qe,all,  189 $eall
          esel,mat,10 $qe,all,  154 $eall
          esel,mat, 9 $qe,all,    2 $eall
          esel,mat, 8 $qe,all,    2 $eall $lwrite * 860811 / # 114
iter,4,,4
time,315.0 $lcvsf,all, 506, 20.0
          esel,mat,11 $qe,all,   98 $eall
          esel,mat,10 $qe,all,   80 $eall
          esel,mat, 9 $qe,all,    1 $eall
          esel,mat, 8 $qe,all,    1 $eall $lwrite * 860812 / # 115
time,316.0 $lcvsf,all, 442,  8.3
          esel,mat,11 $qe,all,   51 $eall
          esel,mat,10 $qe,all,   41 $eall
          esel,mat, 9 $qe,all,    1 $eall
          esel,mat, 8 $qedele,all   $eall $lwrite * 860813 / # 116
sbcdele,lcvsf,all $lsall $afwrite
finish
/input,27
finish
/aux1
copy,35,36 $copy,12,36
finish
/delete,file35,dat
/prep7
resume $krstrt,116
/title,(NT921222.mod) CASE STUDY - Lift 6 Placed
ntdele,1104,temp $cp,139,temp,1104,1219 $cp,140,temp,1106,1218
cp,141,temp,1107,1220 $cp,142,temp,1108,1221 $cp,143,temp,1112,1234
cp,144,temp,1166,1253 $cp,145,temp,1168,1254 $cp,146,temp,1169,1255
cp,147,temp,1170,1256 $cp,148,temp,1171,1257 $cp,149,temp,1172,1258
cp,150,temp,1173,1259 $cp,151,temp,1174,1260 $cp,152,temp,1175,1261
cp,153,temp,1176,1262 $cp,154,temp,1177,1263 $cp,155,temp,1178,1264
cp,156,temp,1210,1336 $cp,157,temp,1212,1340 $cp,158,temp,1214,1341
cp,159,temp,1215,1342
lsse,,637 $lsas,,623 $lsas,,464 $lsas,,467 $lsas,,371 $lsas,,368 $lsas,,365
lsas,,354 $lsas,,351 $lsas,,348 $lsas,,357 $lsas,,361 $lsas,,437 $lsas,,408
lsas,,412 $lsas,,401 $lsas,,404 $lsas,,407 $lsas,,418 $lsas,,421 $lsas,,424
lsas,,455 $lsas,,463 $lsas,,497 $lsas,,506 $lsas,,516 $lsas,,588 $lsas,,590
lsas,,683 $lsas,,634 $lsas,,633 $lsas,,647
iter,1,,1
time,316.1 $lcvsf,all, 442,  8.3
          esel,mat,13 $qe,all, 8987 $eall
          esel,mat,12 $qe,all, 7847 $eall
          esel,mat,11 $qe,all,   48 $eall
          esel,mat,10 $qe,all,   39 $eall
          esel,mat, 9 $qedele,all   $eall $lwrite * 860813 / # 117
iter,4,,4
time,317.0 $lcvsf,all, 251,  9.0
          esel,mat,13 $qe,all, 5007 $eall
          esel,mat,12 $qe,all, 4332 $eall
          esel,mat,11 $qe,all,   27 $eall
          esel,mat,10 $qe,all,   21 $eall $lwrite * 860814 / # 118
```

```
podisp,-1 $postr,-1 $porf,-1
time,318.0 $lcvsf,all, 357, 14.5
          esel,mat,13 $qe,all, 2614 $eall
          esel,mat,12 $qe,all, 2239 $eall
          esel,mat,11 $qe,all,   14 $eall
          esel,mat,10 $qe,all,   11 $eall $lwrite * 860815 / # 119
iter,4,,4
time,319.0 $lcvsf,all, 654, 11.8
          esel,mat,13 $qe,all, 1365 $eall
          esel,mat,12 $qe,all, 1157 $eall
          esel,mat,11 $qe,all,    7 $eall
          esel,mat,10 $qe,all,    6 $eall $lwrite * 860816 / # 120
podisp,-1 $postr,-1 $porf,-1
time,320.0 $lcvsf,all, 675, 10.3
          esel,mat,13 $qe,all,  712 $eall
          esel,mat,12 $qe,all,  598 $eall
          esel,mat,11 $qe,all,    4 $eall
          esel,mat,10 $qe,all,    3 $eall $lwrite * 860817 / # 121
iter,4,,4
time,321.0 $lcvsf,all, 421, 11.8
          esel,mat,13 $qe,all,  372 $eall
          esel,mat,12 $qe,all,  309 $eall
          esel,mat,11 $qe,all,    2 $eall
          esel,mat,10 $qe,all,    2 $eall $lwrite * 860818 / # 122
podisp,-1 $postr,-1 $porf,-1
time,322.0 $lcvsf,all, 590, 16.8
          esel,mat,13 $qe,all,  194 $eall
          esel,mat,12 $qe,all,  160 $eall
          esel,mat,11 $qe,all,    1 $eall
          esel,mat,10 $qe,all,    1 $eall $lwrite * 860819 / # 123
iter,4,,4
time,323.0 $lcvsf,all, 802,  9.5
          esel,mat,13 $qe,all,  101 $eall
          esel,mat,12 $qe,all,   83 $eall
          esel,mat,11 $qe,all,    1 $eall
          esel,mat,10 $qedele,all   $eall $lwrite * 860820 / # 124
sbcdele,lcvsf,all $lsall $afwrite
finish
/input,27
finish
/aux1
copy,36,35 $copy,12,35
finish
/delete,file36,dat
/prep7
resume $krstrt,124
/title,(NT921222.mod) CASE STUDY - Lift 7 Placed
ntdele, 979,temp $cp,160,temp, 979,1080 $cp,161,temp, 981,1079
cp,162,temp, 982,1081 $cp,163,temp, 983,1082 $cp,164,temp, 987,1095
cp,165,temp,1031,1114 $cp,166,temp,1033,1115 $cp,167,temp,1034,1116
cp,168,temp,1035,1117 $cp,169,temp,1036,1118 $cp,170,temp,1037,1119
cp,171,temp,1038,1120 $cp,172,temp,1039,1121 $cp,173,temp,1040,1122
cp,174,temp,1041,1123 $cp,175,temp,1071,1190 $cp,176,temp,1073,1194
cp,177,temp,1075,1195 $cp,178,temp,1076,1196
lsse,,637 $lsas,,623 $lsas,,464 $lsas,,467 $lsas,,371 $lsas,,368 $lsas,,365
lsas,,354 $lsas,,351 $lsas,,348 $lsas,,337 $lsas,,334 $lsas,,331 $lsas,,340
lsas,,344 $lsas,,433 $lsas,,391 $lsas,,395 $lsas,,384 $lsas,,387 $lsas,,390
lsas,,401 $lsas,,404 $lsas,,407 $lsas,,418 $lsas,,421 $lsas,,424 $lsas,,455
lsas,,634 $lsas,,633 $lsas,,647
iter,1,,1
time,323.1 $lcvsf,all, 802,  9.5
```

```
          esel,mat,15 $qe,all, 8987 $eall
          esel,mat,14 $qe,all, 7847 $eall
          esel,mat,13 $qe,all,   95 $eall
          esel,mat,12 $qe,all,   77 $eall
          esel,mat,11 $qedele,all   $eall $lwrite * 860820 / # 125
iter,4 $podisp,-1 $postr,-1 $porf,-1
time,324.0 $lcvsf,all, 527, 11.3
          esel,mat,15 $qe,all, 5007 $eall
          esel,mat,14 $qe,all, 4332 $eall
          esel,mat,13 $qe,all,   53 $eall
          esel,mat,12 $qe,all,   43 $eall $lwrite * 860821 / # 126
iter,4,,4
time,325.0 $lcvsf,all, 378, 10.5
          esel,mat,15 $qe,all, 2614 $eall
          esel,mat,14 $qe,all, 2239 $eall
          esel,mat,13 $qe,all,   28 $eall
          esel,mat,12 $qe,all,   22 $eall $lwrite * 860822 / # 127
podisp,-1 $postr,-1 $porf,-1
time,326.0 $lcvsf,all, 421, 14.5
          esel,mat,15 $qe,all, 1365 $eall
          esel,mat,14 $qe,all, 1157 $eall
          esel,mat,13 $qe,all,   14 $eall
          esel,mat,12 $qe,all,   11 $eall $lwrite * 860823 / # 128
iter,4,,4
time,327.0 $lcvsf,all, 633, 17.8
          esel,mat,15 $qe,all,  712 $eall
          esel,mat,14 $qe,all,  598 $eall
          esel,mat,13 $qe,all,    8 $eall
          esel,mat,12 $qe,all,    6 $eall $lwrite * 860824 / # 129
podisp,-1 $postr,-1 $porf,-1
time,328.0 $lcvsf,all, 612,  8.3
          esel,mat,15 $qe,all,  372 $eall
          esel,mat,14 $qe,all,  309 $eall
          esel,mat,13 $qe,all,    4 $eall
          esel,mat,12 $qe,all,    3 $eall $lwrite * 860825 / # 130
iter,4,,4
time,329.0 $lcvsf,all, 442,  8.8
          esel,mat,15 $qe,all,  194 $eall
          esel,mat,14 $qe,all,  160 $eall
          esel,mat,13 $qe,all,    2 $eall
          esel,mat,12 $qe,all,    2 $eall $lwrite * 860826 / # 131
podisp,-1 $postr,-1 $porf,-1
time,330.0 $lcvsf,all, 612,  8.5
          esel,mat,15 $qe,all,  101 $eall
          esel,mat,14 $qe,all,   83 $eall
          esel,mat,13 $qe,all,    1 $eall
          esel,mat,12 $qe,all,    1 $eall $lwrite * 860827 / # 132
iter,4,,4
time,331.0 $lcvsf,all, 315, 13.5
          esel,mat,15 $qe,all,   53 $eall
          esel,mat,14 $qe,all,   43 $eall
          esel,mat,13 $qe,all,    1 $eall
          esel,mat,12 $qedele,all   $eall $lwrite * 860828 / # 133
podisp,-1 $postr,-1 $porf,-1
time,332.0 $lcvsf,all, 463, 13.3
          esel,mat,15 $qe,all,   28 $eall
          esel,mat,14 $qe,all,   22 $eall
          esel,mat,13 $qedele,all   $eall $lwrite * 860829 / # 134
iter,4,,4
time,333.0 $lcvsf,all, 378, 13.8
          esel,mat,15 $qe,all,   14 $eall
```

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          esel,mat,14 $qe,all,   11 $eall $lwrite * 860830 / # 135
podisp,-1 $postr,-1 $porf,-1
time,334.0 $lcvsf,all, 240, 10.0
          esel,mat,15 $qe,all,    8 $eall
          esel,mat,14 $qe,all,    6 $eall $lwrite * 860831 / # 136
iter,4,,4
time,335.0 $lcvsf,all, 378,  5.8
          esel,mat,15 $qe,all,    4 $eall
          esel,mat,14 $qe,all,    3 $eall $lwrite * 860901 / # 137
podisp,-1 $postr,-1 $porf,-1
time,336.0 $lcvsf,all, 240,  9.8
          esel,mat,15 $qe,all,    2 $eall
          esel,mat,14 $qe,all,    2 $eall $lwrite * 860902 / # 138
iter,4,,4
time,337.0 $lcvsf,all, 336, 10.0
          esel,mat,15 $qe,all,    1 $eall
          esel,mat,14 $qe,all,    1 $eall $lwrite * 860903 / # 139
podisp,-1 $postr,-1 $porf,-1
time,338.0 $lcvsf,all, 802,  4.3
          esel,mat,15 $qe,all,    1 $eall
          esel,mat,14 $qedele,all   $eall $lwrite * 860904 / # 140
iter,4,,4
time,339.0 $lcvsf,all, 675,  3.8
          esel,mat,15 $qedele,all   $eall $lwrite * 860905 / # 141
podisp,-1 $postr,-1 $porf,-1
time,340.0 $lcvsf,all, 463,  6.0         $lwrite * 860906 / # 142
iter,4,,4
time,341.0 $lcvsf,all, 240,  5.0         $lwrite * 860907 / # 143
podisp,-1 $postr,-1 $porf,-1
time,342.0 $lcvsf,all, 240,  0.3         $lwrite * 860908 / # 144
iter,4,,4
time,343.0 $lcvsf,all, 336,  2.8         $lwrite * 860909 / # 145
podisp,-1 $postr,-1 $porf,-1
time,344.0 $lcvsf,all, 293,  3.0         $lwrite * 860910 / # 146
iter,4,,4
time,345.0 $lcvsf,all, 357,  3.0         $lwrite * 860911 / # 147
podisp,-1 $postr,-1 $porf,-1
time,346.0 $lcvsf,all, 633,  3.0         $lwrite * 860912 / # 148
iter,4,,4
time,347.0 $lcvsf,all, 421,  2.8         $lwrite * 860913 / # 149
podisp,-1 $postr,-1 $porf,-1
time,348.0 $lcvsf,all, 399,  1.5         $lwrite * 860914 / # 150
iter,4,,4
time,349.0 $lcvsf,all, 399,  5.5         $lwrite * 860915 / # 151
podisp,-1 $postr,-1 $porf,-1
time,350.0 $lcvsf,all, 315,  6.8         $lwrite * 860916 / # 152
iter,4,,4
time,351.0 $lcvsf,all, 378,  7.0         $lwrite * 860917 / # 153
podisp,-1 $postr,-1 $porf,-1
time,352.0 $lcvsf,all, 463,  3.3         $lwrite * 860918 / # 154
iter,4,,4
time,353.0 $lcvsf,all, 463,  7.8         $lwrite * 860919 / # 155
podisp,-1 $postr,-1 $porf,-1
time,354.0 $lcvsf,all, 315,  7.0         $lwrite * 860920 / # 156
iter,4,,4
time,355.0 $lcvsf,all, 272, 10.8         $lwrite * 860921 / # 157
podisp,-1 $postr,-1 $porf,-1
time,356.0 $lcvsf,all, 293,  8.5         $lwrite * 860922 / # 158
iter,4,,4
time,357.0 $lcvsf,all, 421,  6.5         $lwrite * 860923 / # 159
podisp,-1 $postr,-1 $porf,-1
```

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time,358.0 $lcvsf,all, 399,  6.8          $lwrite * 860924 / # 160
iter,4,,4
time,359.0 $lcvsf,all, 569,  4.3          $lwrite * 860925 / # 161
podisp,-1 $postr,-1 $porf,-1
time,360.0 $lcvsf,all, 548,  4.8          $lwrite * 860926 / # 162
iter,4,,4
time,361.0 $lcvsf,all, 463,  3.8          $lwrite * 860927 / # 163
podisp,-1 $postr,-1 $porf,-1
time,362.0 $lcvsf,all, 293,  3.5          $lwrite * 860928 / # 164
iter,4,,4
time,363.0 $lcvsf,all, 251,  3.3          $lwrite * 860929 / # 165
podisp,-1 $postr,-1 $porf,-1
time,364.0 $lcvsf,all, 399,  8.3          $lwrite * 860930 / # 166
iter,4,,4
time,365.0 $lcvsf,all, 378, -1.3          $lwrite * 861001 / # 167
podisp,-1 $postr,-1 $porf,-1
time,366.0 $lcvsf,all, 527, -2.3          $lwrite * 861002 / # 168
iter,4,,4
time,367.0 $lcvsf,all, 357, -3.0          $lwrite * 861003 / # 169
time,368.0 $lcvsf,all, 463, -0.5          $lwrite * 861004 / # 170
sbcdele,lcvsf,all $lsall $afwrite
finish
/input,27
finish
/aux1
copy,35,36 $copy,12,36
finish
/delete,file35,dat
/prep7
resume $krstrt,170
/title,(NT921222.mod) CASE STUDY - Lift 8a Placed
ntdele, 872,temp $cp,179,temp, 872, 955 $cp,180,temp, 874, 954
cp,181,temp, 875, 956 $cp,182,temp, 876, 957 $cp,183,temp, 880, 970
cp,184,temp, 914, 989 $cp,185,temp, 916, 990 $cp,186,temp, 917, 991
cp,187,temp, 918, 992 $cp,188,temp, 919, 993 $cp,189,temp, 920, 994
cp,190,temp, 921, 995 $cp,191,temp, 922, 996 $cp,192,temp, 946,1051
cp,193,temp, 948,1055 $cp,194,temp, 950,1056 $cp,195,temp, 951,1057
lsse,,331 $lsas,,292 $lsas,,289 $lsas,,295 $lsas,,298 $lsas,,328 $lsas,,319
lsas,,322 $lsas,,315 $lsas,,318 $lsas,,384
iter,1,,1
time,368.1 $lcvsf,all, 463, -0.5
          esel,mat,17 $qe,all, 8987 $eall
          esel,mat,16 $qe,all, 7847 $eall $lwrite * 861004 / # 171
iter,4,,4
time,369.0 $lcvsf,all, 442, -0.8
          esel,mat,17 $qe,all, 5007 $eall
          esel,mat,16 $qe,all, 4332 $eall $lwrite * 861005 / # 172
podisp,-1 $postr,-1 $porf,-1
time,370.0 $lcvsf,all, 506,  0.8
          esel,mat,17 $qe,all, 2614 $eall
          esel,mat,16 $qe,all, 2239 $eall $lwrite * 861006 / # 173
iter,4,,4
time,371.0 $lcvsf,all, 696, -0.3
          esel,mat,17 $qe,all, 1365 $eall
          esel,mat,16 $qe,all, 1157 $eall $lwrite * 861007 / # 174
time,372.0 $lcvsf,all, 802, -3.8
          esel,mat,17 $qe,all,  712 $eall
          esel,mat,16 $qe,all,  598 $eall $lwrite * 861008 / # 175
sbcdele,lcvsf,all $lsall $afwrite
finish
/input,27
```

```
finish
/aux1
copy,36,35 $copy,12,35
finish
/delete,file36,dat
/prep7
resume $krstrt,175
/title,(NT921222.mod) CASE STUDY - Lift 8b Placed
ntdele, 770,temp $cp,196,temp, 770, 853 $cp,197,temp, 772, 852
cp,198,temp, 773, 854 $cp,199,temp, 774, 855 $cp,200,temp, 778, 868
cp,201,temp, 812, 882 $cp,202,temp, 814, 883 $cp,203,temp, 815, 884
cp,204,temp, 816, 885 $cp,205,temp, 817, 886 $cp,206,temp, 818, 887
cp,207,temp, 819, 888 $cp,208,temp, 820, 889 $cp,209,temp, 844, 930
cp,210,temp, 846, 934 $cp,211,temp, 848, 935 $cp,212,temp, 849, 936
lsse,,280 $lsas,,277 $lsas,,283 $lsas,,286 $lsas,,325 $lsas,,307 $lsas,,310
lsas,,303 $lsas,,306
iter,1,,1
time,372.1 $lcvsf,all, 802, -3.8
          esel,mat,19 $qe,all, 8987 $eall
          esel,mat,18 $qe,all, 7847 $eall
          esel,mat,17 $qe,all,  668 $eall
          esel,mat,16 $qe,all,  560 $eall $lwrite * 861008 / # 176
iter,4,,4
time,373.0 $lcvsf,all, 506, -3.0
          esel,mat,19 $qe,all, 5007 $eall
          esel,mat,18 $qe,all, 4332 $eall
          esel,mat,17 $qe,all,  372 $eall
          esel,mat,16 $qe,all,  309 $eall $lwrite * 861009 / # 177
podisp,-1 $postr,-1 $porf,-1
time,374.0 $lcvsf,all, 612,  3.3
          esel,mat,19 $qe,all, 2614 $eall
          esel,mat,18 $qe,all, 2239 $eall
          esel,mat,17 $qe,all,  194 $eall
          esel,mat,16 $qe,all,  160 $eall $lwrite * 861010 / # 178
iter,4,,4
time,375.0 $lcvsf,all, 590, -5.8
          esel,mat,19 $qe,all, 1365 $eall
          esel,mat,18 $qe,all, 1157 $eall
          esel,mat,17 $qe,all,  101 $eall
          esel,mat,16 $qe,all,   83 $eall $lwrite * 861011 / # 179
podisp,-1 $postr,-1 $porf,-1
time,376.0 $lcvsf,all, 612,  1.5
          esel,mat,19 $qe,all,  712 $eall
          esel,mat,18 $qe,all,  598 $eall
          esel,mat,17 $qe,all,   53 $eall
          esel,mat,16 $qe,all,   43 $eall $lwrite * 861012 / # 180
iter,4,,4
time,377.0 $lcvsf,all, 569,  0.3
          esel,mat,19 $qe,all,  372 $eall
          esel,mat,18 $qe,all,  309 $eall
          esel,mat,17 $qe,all,   28 $eall
          esel,mat,16 $qe,all,   22 $eall $lwrite * 861013 / # 181
podisp,-1 $postr,-1 $porf,-1
time,378.0 $lcvsf,all, 442, -2.0
          esel,mat,19 $qe,all,  194 $eall
          esel,mat,18 $qe,all,  160 $eall
          esel,mat,17 $qe,all,   14 $eall
          esel,mat,16 $qe,all,   11 $eall $lwrite * 861014 / # 182
iter,4,,4
time,379.0 $lcvsf,all, 548,  0.8
          esel,mat,19 $qe,all,  101 $eall
```

```
          esel,mat,18 $qe,all,   83 $eall
          esel,mat,17 $qe,all,    8 $eall
          esel,mat,16 $qe,all,    6 $eall $lwrite * 861015 / # 183
podisp,-1 $postr,-1 $porf,-1
time,380.0 $lcvsf,all, 336,  0.0
          esel,mat,19 $qe,all,   53 $eall
          esel,mat,18 $qe,all,   43 $eall
          esel,mat,17 $qe,all,    4 $eall
          esel,mat,16 $qe,all,    3 $eall $lwrite * 861016 / # 184
iter,4,,4
time,381.0 $lcvsf,all, 272,  8.0
          esel,mat,19 $qe,all,   28 $eall
          esel,mat,18 $qe,all,   22 $eall
          esel,mat,17 $qe,all,    2 $eall
          esel,mat,16 $qe,all,    2 $eall $lwrite * 861017 / # 185
podisp,-1 $postr,-1 $porf,-1
time,382.0 $lcvsf,all, 336,  3.8
          esel,mat,19 $qe,all,   14 $eall
          esel,mat,18 $qe,all,   11 $eall
          esel,mat,17 $qe,all,    1 $eall
          esel,mat,16 $qe,all,    1 $eall $lwrite * 861018 / # 186
iter,4,,4
time,383.0 $lcvsf,all, 378,  2.5
          esel,mat,19 $qe,all,    8 $eall
          esel,mat,18 $qe,all,    6 $eall
          esel,mat,17 $qe,all,    1 $eall
          esel,mat,16 $qedele,all   $eall $lwrite * 861019 / # 187
podisp,-1 $postr,-1 $porf,-1
time,384.0 $lcvsf,all, 421,  3.0
          esel,mat,19 $qe,all,    4 $eall
          esel,mat,18 $qe,all,    3 $eall
          esel,mat,17 $qedele,all   $eall $lwrite * 861020 / # 188
iter,4,,4
time,385.0 $lcvsf,all, 399,  1.5
          esel,mat,19 $qe,all,    2 $eall
          esel,mat,18 $qe,all,    2 $eall $lwrite * 861021 / # 189
podisp,-1 $postr,-1 $porf,-1
time,386.0 $lcvsf,all, 357,  0.8
          esel,mat,19 $qe,all,    1 $eall
          esel,mat,18 $qe,all,    1 $eall $lwrite * 861022 / # 190
iter,4,,4
time,387.0 $lcvsf,all, 315,  1.0
          esel,mat,19 $qe,all,    1 $eall
          esel,mat,18 $qedele,all   $eall $lwrite * 861023 / # 191
sbcdele,lcvsf,all $lsall $afwrite
finish
/input,27
finish
/aux1
copy,35,36 $copy,12,36
finish
/delete,file35,dat
/prep7
resume $krstrt,191
/title,(NT921222.mod) CASE STUDY - Lift 9 Placed
ntdele, 664,temp $cp,213,temp, 664, 751 $cp,214,temp, 666, 750
cp,215,temp, 667, 752 $cp,216,temp, 668, 753 $cp,217,temp, 672, 766
cp,218,temp, 706, 780 $cp,219,temp, 708, 781 $cp,220,temp, 709, 782
cp,221,temp, 710, 783 $cp,222,temp, 711, 784 $cp,223,temp, 712, 785
cp,224,temp, 713, 786 $cp,225,temp, 714, 787 $cp,226,temp, 742, 828
cp,227,temp, 744, 832 $cp,228,temp, 746, 833 $cp,229,temp, 747, 834
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lsse,,277 $lsas,,253 $lsas,,246 $lsas,,239 $lsas,,242 $lsas,,249 $lsas,,273
lsas,,266 $lsas,,259 $lsas,,258 $lsas,,265 $lsas,,272 $lsas,,303
iter,1,,1
time,387.1 $lcvsf,all, 315,  1.0
          esel,mat,22 $qe,all,11879 $eall
          esel,mat,21 $qe,all, 8987 $eall
          esel,mat,20 $qe,all, 7847 $eall
          esel,mat,19 $qe,all,    1 $eall $lwrite * 861023 / # 192
iter,4 $podisp,-1 $postr,-1 $porf,-1
time,388.0 $lcvsf,all, 506,  6.3
          esel,mat,22 $qe,all, 6559 $eall
          esel,mat,21 $qe,all, 5007 $eall
          esel,mat,20 $qe,all, 4332 $eall
          esel,mat,19 $qedele,all   $eall $lwrite * 861024 / # 193
iter,4,,4
time,389.0 $lcvsf,all, 463, -1.0
          esel,mat,22 $qe,all, 3390 $eall
          esel,mat,21 $qe,all, 2614 $eall
          esel,mat,20 $qe,all, 2239 $eall $lwrite * 861025 / # 194
podisp,-1 $postr,-1 $porf,-1
time,390.0 $lcvsf,all, 357, -1.0
          esel,mat,22 $qe,all, 1752 $eall
          esel,mat,21 $qe,all, 1365 $eall
          esel,mat,20 $qe,all, 1157 $eall $lwrite * 861026 / # 195
iter,4,,4
time,391.0 $lcvsf,all, 357, -1.3
          esel,mat,22 $qe,all,  906 $eall
          esel,mat,21 $qe,all,  712 $eall
          esel,mat,20 $qe,all,  598 $eall $lwrite * 861027 / # 196
podisp,-1 $postr,-1 $porf,-1
time,392.0 $lcvsf,all, 760, -9.5
          esel,mat,22 $qe,all,  468 $eall
          esel,mat,21 $qe,all,  372 $eall
          esel,mat,20 $qe,all,  309 $eall $lwrite * 861028 / # 197
iter,4,,4
time,393.0 $lcvsf,all, 760,-10.0
          esel,mat,22 $qe,all,  242 $eall
          esel,mat,21 $qe,all,  194 $eall
          esel,mat,20 $qe,all,  160 $eall $lwrite * 861029 / # 198
podisp,-1 $postr,-1 $porf,-1
time,394.0 $lcvsf,all, 484, -5.5
          esel,mat,22 $qe,all,  125 $eall
          esel,mat,21 $qe,all,  101 $eall
          esel,mat,20 $qe,all,   83 $eall $lwrite * 861030 / # 199
iter,4,,4
time,395.0 $lcvsf,all, 240,-14.0
          esel,mat,22 $qe,all,   65 $eall
          esel,mat,21 $qe,all,   53 $eall
          esel,mat,20 $qe,all,   43 $eall $lwrite * 861031 / # 200
podisp,-1 $postr,-1 $porf,-1
time,396.0 $lcvsf,all, 908,-16.8
          esel,mat,22 $qe,all,   33 $eall
          esel,mat,21 $qe,all,   28 $eall
          esel,mat,20 $qe,all,   22 $eall $lwrite * 861101 / # 201
iter,4,,4
time,397.0 $lcvsf,all, 612,-16.8
          esel,mat,22 $qe,all,   17 $eall
          esel,mat,21 $qe,all,   14 $eall
          esel,mat,20 $qe,all,   11 $eall $lwrite * 861102 / # 202
podisp,-1 $postr,-1 $porf,-1
time,398.0 $lcvsf,all, 463,-20.8
```

```
            esel,mat,22 $qe,all,    9 $eall
            esel,mat,21 $qe,all,    8 $eall
            esel,mat,20 $qe,all,    6 $eall $lwrite * 861103 / # 203
iter,4,,4
time,399.0 $lcvsf,all, 315,-14.0
            esel,mat,22 $qe,all,    5 $eall
            esel,mat,21 $qe,all,    4 $eall
            esel,mat,20 $qe,all,    3 $eall $lwrite * 861104 / # 204
time,400.0 $lcvsf,all, 293, -6.3
            esel,mat,22 $qe,all,    2 $eall
            esel,mat,21 $qe,all,    2 $eall
            esel,mat,20 $qe,all,    2 $eall $lwrite * 861105 / # 205
time,401.0 $lcvsf,all, 527,-18.5
            esel,mat,22 $qe,all,    1 $eall
            esel,mat,21 $qe,all,    1 $eall
            esel,mat,20 $qe,all,    1 $eall $lwrite * 861106 / # 206
time,402.0 $lcvsf,all, 272,-20.0
            esel,mat,22 $qe,all,    1 $eall
            esel,mat,21 $qe,all,    1 $eall
            esel,mat,20 $qedele,all   $eall $lwrite * 861107 / # 207
podisp,-1 $postr,-1 $porf,-1
time,403.0 $lcvsf,all, 612,-21.0
            esel,mat,22 $qedele,all   $eall
            esel,mat,21 $qedele,all   $eall $lwrite * 861108 / # 208
time,404.0 $lcvsf,all, 548,-21.5        $lwrite * 861109 / # 209
time,405.0 $lcvsf,all, 357,-21.8        $lwrite * 861110 / # 210
time,406.0 $lcvsf,all, 421,-21.8        $lwrite * 861111 / # 211
time,407.0 $lcvsf,all, 548,-23.8        $lwrite * 861112 / # 212
time,408.0 $lcvsf,all, 357,-21.5        $lwrite * 861113 / # 213
iter,4,,4
time,409.0 $lcvsf,all, 421,-24.0        $lwrite * 861114 / # 214
podisp,-1 $postr,-1 $porf,-1
time,410.0 $lcvsf,all, 230,-24.5        $lwrite * 861115 / # 215
time,411.0 $lcvsf,all, 293,-25.8        $lwrite * 861116 / # 216
time,412.0 $lcvsf,all, 463,-24.3        $lwrite * 861117 / # 217
time,413.0 $lcvsf,all, 463,-21.3        $lwrite * 861118 / # 218
time,414.0 $lcvsf,all, 209,-26.0        $lwrite * 861119 / # 219
time,415.0 $lcvsf,all, 209,-25.3        $lwrite * 861120 / # 220
iter,4,,4
time,416.0 $lcvsf,all, 251,-17.8        $lwrite * 861121 / # 221
podisp,-1 $postr,-1 $porf,-1
time,417.0 $lcvsf,all, 251,-13.8        $lwrite * 861122 / # 222
time,418.0 $lcvsf,all, 293,-18.8        $lwrite * 861123 / # 223
time,419.0 $lcvsf,all, 378, -9.3        $lwrite * 861124 / # 224
iter,4,,4
time,420.0 $lcvsf,all, 378, -9.3        $lwrite * 861125 / # 225
podisp,-1 $postr,-1 $porf,-1
time,421.0 $lcvsf,all, 357,-15.3        $lwrite * 861126 / # 226
time,422.0 $lcvsf,all, 463,-18.3        $lwrite * 861127 / # 227
iter,4,,4
time,423.0 $lcvsf,all, 251,-17.8        $lwrite * 861128 / # 228
podisp,-1 $postr,-1 $porf,-1
time,424.0 $lcvsf,all, 357,-16.5        $lwrite * 861129 / # 229
time,425.0 $lcvsf,all, 590,-12.5        $lwrite * 861130 / # 230
iter,4,,4
time,426.0 $lcvsf,all, 506, -7.0        $lwrite * 861201 / # 231
podisp,-1 $postr,-1 $porf,-1
time,427.0 $lcvsf,all, 739, -7.8        $lwrite * 861202 / # 232
time,428.0 $lcvsf,all, 696,-12.3        $lwrite * 861203 / # 233
time,429.0 $lcvsf,all, 293,-17.0        $lwrite * 861204 / # 234
iter,4,,4
```

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time,430.0 $lcvsf,all, 272,-26.3          $lwrite * 861205 / # 235
podisp,-1 $postr,-1 $porf,-1
time,431.0 $lcvsf,all, 399,-30.5          $lwrite * 861206 / # 236
time,432.0 $lcvsf,all, 293,-31.8          $lwrite * 861207 / # 237
time,433.0 $lcvsf,all, 378,-32.0          $lwrite * 861208 / # 238
time,434.0 $lcvsf,all, 272,-27.3          $lwrite * 861209 / # 239
time,435.0 $lcvsf,all, 272,-26.0          $lwrite * 861210 / # 240
time,436.0 $lcvsf,all, 315,-23.0          $lwrite * 861211 / # 241
iter,4,,4
time,437.0 $lcvsf,all, 506,-22.0          $lwrite * 861212 / # 242
podisp,-1 $postr,-1 $porf,-1
time,438.0 $lcvsf,all, 654,-17.8          $lwrite * 861213 / # 243
time,439.0 $lcvsf,all, 336, -9.5          $lwrite * 861214 / # 244
iter,4,,4
time,440.0 $lcvsf,all, 421,-10.8          $lwrite * 861215 / # 245
podisp,-1 $postr,-1 $porf,-1
time,441.0 $lcvsf,all, 506,-10.3          $lwrite * 861216 / # 246
time,442.0 $lcvsf,all, 463,-12.5          $lwrite * 861217 / # 247
time,443.0 $lcvsf,all, 548,-16.8          $lwrite * 861218 / # 248
iter,4,,4
time,444.0 $lcvsf,all, 357,-22.0          $lwrite * 861219 / # 249
podisp,-1 $postr,-1 $porf,-1
time,445.0 $lcvsf,all, 230,-16.8          $lwrite * 861220 / # 250
time,446.0 $lcvsf,all, 187,-13.0          $lwrite * 861221 / # 251
time,447.0 $lcvsf,all, 590, -8.5          $lwrite * 861222 / # 252
time,448.0 $lcvsf,all, 251,-17.5          $lwrite * 861223 / # 253
time,449.0 $lcvsf,all, 506,-13.0          $lwrite * 861224 / # 254
time,450.0 $lcvsf,all, 272,-25.5          $lwrite * 861225 / # 255
time,451.0 $lcvsf,all, 548,-14.5          $lwrite * 861226 / # 256
time,452.0 $lcvsf,all, 442, -7.0          $lwrite * 861227 / # 257
time,453.0 $lcvsf,all, 293,-10.0          $lwrite * 861228 / # 258
time,454.0 $lcvsf,all, 421,-10.5          $lwrite * 861229 / # 259
time,455.0 $lcvsf,all, 527,-13.5          $lwrite * 861230 / # 260
time,456.0 $lcvsf,all, 240,-23.0          $lwrite * 861231 / # 261
time,457.0 $lcvsf,all, 336,-22.0          $lwrite * 870101 / # 262
iter,4,,4
time,458.0 $lcvsf,all, 421,-10.5          $lwrite * 870102 / # 263
podisp,-1 $postr,-1 $porf,-1
time,459.0 $lcvsf,all, 251,-17.5          $lwrite * 870103 / # 264
iter,4,,4
time,460.0 $lcvsf,all, 442,-16.5          $lwrite * 870104 / # 265
podisp,-1 $postr,-1 $porf,-1
time,461.0 $lcvsf,all, 463,-13.0          $lwrite * 870105 / # 266
time,462.0 $lcvsf,all, 357,-15.5          $lwrite * 870106 / # 267
time,463.0 $lcvsf,all, 442,-10.0          $lwrite * 870107 / # 268
time,464.0 $lcvsf,all, 336, -7.3          $lwrite * 870108 / # 269
iter,4,,4
time,465.0 $lcvsf,all, 357,-18.8          $lwrite * 870109 / # 270
podisp,-1 $postr,-1 $porf,-1
time,466.0 $lcvsf,all, 633, -9.5          $lwrite * 870110 / # 271
time,467.0 $lcvsf,all, 484, -3.0          $lwrite * 870111 / # 272
time,468.0 $lcvsf,all, 240, -8.5          $lwrite * 870112 / # 273
time,469.0 $lcvsf,all, 612,-14.3          $lwrite * 870113 / # 274
time,470.0 $lcvsf,all, 718,-26.3          $lwrite * 870114 / # 275
time,471.0 $lcvsf,all, 399,-26.8          $lwrite * 870115 / # 276
time,472.0 $lcvsf,all, 315,-26.8          $lwrite * 870116 / # 277
time,473.0 $lcvsf,all, 357,-22.0          $lwrite * 870117 / # 278
time,474.0 $lcvsf,all, 399,-31.3          $lwrite * 870118 / # 279
iter,4,,4
time,475.0 $lcvsf,all, 336,-27.5          $lwrite * 870119 / # 280
podisp,-1 $postr,-1 $porf,-1
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time,476.0 $lcvsf,all, 336,-21.8          $lwrite * 870120 / # 281
time,477.0 $lcvsf,all, 527,-31.0          $lwrite * 870121 / # 282
time,478.0 $lcvsf,all, 399,-35.8          $lwrite * 870122 / # 283
iter,4,,4
time,479.0 $lcvsf,all, 315,-36.5          $lwrite * 870123 / # 284
time,480.0 $lcvsf,all, 336,-30.8          $lwrite * 870124 / # 285
podisp,-1 $postr,-1 $porf,-1
time,481.0 $lcvsf,all, 484,-26.0          $lwrite * 870125 / # 286
time,482.0 $lcvsf,all, 336,-17.5          $lwrite * 870126 / # 287
time,483.0 $lcvsf,all, 421,-23.0          $lwrite * 870127 / # 288
time,484.0 $lcvsf,all, 230,-21.5          $lwrite * 870128 / # 289
time,485.0 $lcvsf,all, 399,-20.8          $lwrite * 870129 / # 290
iter,4,,4
time,486.0 $lcvsf,all, 230,-25.0          $lwrite * 870130 / # 291
podisp,-1 $postr,-1 $porf,-1
time,487.0 $lcvsf,all, 240,-18.3          $lwrite * 870131 / # 292
time,488.0 $lcvsf,all, 484,-22.0          $lwrite * 870201 / # 293
time,489.0 $lcvsf,all, 187,-29.8          $lwrite * 870202 / # 294
time,490.0 $lcvsf,all, 187,-25.5          $lwrite * 870203 / # 295
time,491.0 $lcvsf,all, 442,-19.0          $lwrite * 870204 / # 296
time,492.0 $lcvsf,all, 336,-10.5          $lwrite * 870205 / # 297
time,493.0 $lcvsf,all, 484,-16.5          $lwrite * 870206 / # 298
time,494.0 $lcvsf,all, 315,-25.3          $lwrite * 870207 / # 299
time,495.0 $lcvsf,all, 506,-15.0          $lwrite * 870208 / # 300
iter,4,,4
time,496.0 $lcvsf,all, 378,-12.0          $lwrite * 870209 / # 301
podisp,-1 $postr,-1 $porf,-1
time,497.0 $lcvsf,all, 272,-20.5          $lwrite * 870210 / # 302
time,498.0 $lcvsf,all, 484,-16.5          $lwrite * 870211 / # 303
time,499.0 $lcvsf,all, 240,-30.3          $lwrite * 870212 / # 304
iter,4,,4
time,500.0 $lcvsf,all, 187,-28.3          $lwrite * 870213 / # 305
podisp,-1 $postr,-1 $porf,-1
time,501.0 $lcvsf,all, 357,-25.0          $lwrite * 870214 / # 306
time,502.0 $lcvsf,all, 442,-17.3          $lwrite * 870215 / # 307
time,503.0 $lcvsf,all, 293,-11.0          $lwrite * 870216 / # 308
time,504.0 $lcvsf,all, 293,-14.5          $lwrite * 870217 / # 309
time,505.0 $lcvsf,all, 315,-14.3          $lwrite * 870218 / # 310
time,506.0 $lcvsf,all, 336,-11.8          $lwrite * 870219 / # 311
iter,4,,4
time,507.0 $lcvsf,all, 336, -9.8          $lwrite * 870220 / # 312
podisp,-1 $postr,-1 $porf,-1
time,508.0 $lcvsf,all, 442, -8.8          $lwrite * 870221 / # 313
time,509.0 $lcvsf,all, 484,-12.8          $lwrite * 870222 / # 314
time,510.0 $lcvsf,all, 421,-19.3          $lwrite * 870223 / # 315
time,511.0 $lcvsf,all, 293,-19.0          $lwrite * 870224 / # 316
time,512.0 $lcvsf,all, 230,-21.0          $lwrite * 870225 / # 317
time,513.0 $lcvsf,all, 357,-16.8          $lwrite * 870226 / # 318
iter,4,,4
time,514.0 $lcvsf,all, 336,-14.3          $lwrite * 870227 / # 319
podisp,-1 $postr,-1 $porf,-1
time,515.0 $lcvsf,all, 421,-19.8          $lwrite * 870228 / # 320
time,516.0 $lcvsf,all, 463,-14.0          $lwrite * 870301 / # 321
time,517.0 $lcvsf,all, 336, -9.8          $lwrite * 870302 / # 322
time,518.0 $lcvsf,all, 315,-16.5          $lwrite * 870303 / # 323
time,519.0 $lcvsf,all, 209, -5.0          $lwrite * 870304 / # 324
iter,4,,4
time,520.0 $lcvsf,all, 590, -5.8          $lwrite * 870305 / # 325
time,521.0 $lcvsf,all, 463,-21.0          $lwrite * 870306 / # 326
podisp,-1 $postr,-1 $porf,-1
time,522.0 $lcvsf,all, 240,-16.3          $lwrite * 870307 / # 327
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time,523.0 $lcvsf,all, 240,-21.3          $lwrite * 870308 / # 328
time,524.0 $lcvsf,all, 399,-18.0          $lwrite * 870309 / # 329
time,525.0 $lcvsf,all, 378,-14.3          $lwrite * 870310 / # 330
time,526.0 $lcvsf,all, 240,-21.8          $lwrite * 870311 / # 331
time,527.0 $lcvsf,all, 569,-16.0          $lwrite * 870312 / # 332
iter,4,,4
time,528.0 $lcvsf,all, 230,-18.0          $lwrite * 870313 / # 333
podisp,-1 $postr,-1 $porf,-1
time,529.0 $lcvsf,all, 251,-10.3          $lwrite * 870314 / # 334
time,530.0 $lcvsf,all, 463, -9.5          $lwrite * 870315 / # 335
time,531.0 $lcvsf,all, 240,  0.3          $lwrite * 870316 / # 336
time,532.0 $lcvsf,all, 336, -5.8          $lwrite * 870317 / # 337
time,533.0 $lcvsf,all, 378, -2.0          $lwrite * 870318 / # 338
time,534.0 $lcvsf,all, 315,  3.3          $lwrite * 870319 / # 339
iter,4,,4
time,535.0 $lcvsf,all, 336,  6.0          $lwrite * 870320 / # 340
podisp,-1 $postr,-1 $porf,-1
time,536.0 $lcvsf,all, 421,  3.3          $lwrite * 870321 / # 341
time,537.0 $lcvsf,all, 484, -5.3          $lwrite * 870322 / # 342
time,538.0 $lcvsf,all, 463, -9.8          $lwrite * 870323 / # 343
time,539.0 $lcvsf,all, 421, -8.8          $lwrite * 870324 / # 344
iter,4,,4
time,540.0 $lcvsf,all, 336,-14.5          $lwrite * 870325 / # 345
podisp,-1 $postr,-1 $porf,-1
time,541.0 $lcvsf,all, 654, -6.5          $lwrite * 870326 / # 346
iter,4,,4
time,542.0 $lcvsf,all, 696,-23.0          $lwrite * 870327 / # 347
podisp,-1 $postr,-1 $porf,-1
time,543.0 $lcvsf,all, 293,-19.5          $lwrite * 870328 / # 348
time,544.0 $lcvsf,all, 251,-16.8          $lwrite * 870329 / # 349
time,545.0 $lcvsf,all, 272,-13.8          $lwrite * 870330 / # 350
time,546.0 $lcvsf,all, 240,-11.5          $lwrite * 870331 / # 351
time,547.0 $lcvsf,all, 315,-13.5          $lwrite * 870401 / # 352
time,548.0 $lcvsf,all, 272, -6.3          $lwrite * 870402 / # 353
iter,4,,4
time,549.0 $lcvsf,all, 675, -2.3          $lwrite * 870403 / # 354
podisp,-1 $postr,-1 $porf,-1
time,550.0 $lcvsf,all, 357,-15.3          $lwrite * 870404 / # 355
time,551.0 $lcvsf,all, 421, -5.8          $lwrite * 870405 / # 356
time,552.0 $lcvsf,all, 357, -7.5          $lwrite * 870406 / # 357
time,553.0 $lcvsf,all, 463,  3.8          $lwrite * 870407 / # 358
time,554.0 $lcvsf,all, 506, -5.3          $lwrite * 870408 / # 359
time,555.0 $lcvsf,all, 718,-11.3          $lwrite * 870409 / # 360
iter,4,,4
time,556.0 $lcvsf,all, 696,-12.5          $lwrite * 870410 / # 361
podisp,-1 $postr,-1 $porf,-1
time,557.0 $lcvsf,all, 442, -9.5          $lwrite * 870411 / # 362
time,558.0 $lcvsf,all, 506,  0.0          $lwrite * 870412 / # 363
time,559.0 $lcvsf,all, 590, -1.0          $lwrite * 870413 / # 364
iter,4,,4
time,560.0 $lcvsf,all, 506, -1.3          $lwrite * 870414 / # 365
podisp,-1 $postr,-1 $porf,-1
time,561.0 $lcvsf,all, 463,  9.0          $lwrite * 870415 / # 366
time,562.0 $lcvsf,all, 251,  7.0          $lwrite * 870416 / # 367
iter,4,,4
time,563.0 $lcvsf,all, 336,  8.3          $lwrite * 870417 / # 368
sbcdele,lcvsf,all $lsall $afwrite
finish
/input,27
finish
/aux1
```

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copy,36,35 $copy,12,35
finish
/delete,file36,dat
/prep7
resume $krstrt,368
/title,(NT921222.mod) CASE STUDY - Lift 10-1 Placed
ntdele, 583,temp $cp,230,temp, 583, 640 $cp,231,temp, 586, 639
cp,232,temp, 587, 641 $cp,233,temp, 588, 642 $cp,234,temp, 596, 655
cp,235,temp, 605, 674 $cp,236,temp, 608, 675 $cp,237,temp, 609, 676
cp,238,temp, 610, 677 $cp,239,temp, 611, 678 $cp,240,temp, 612, 679
cp,241,temp, 624, 722 $cp,242,temp, 630, 726 $cp,243,temp, 633, 727
cp,244,temp, 634, 728
lsse,,277 $lsas,,253 $lsas,,246 $lsas,,239 $lsas,,214 $lsas,,217 $lsas,,219
lsas,,237 $lsas,,231 $lsas,,233 $lsas,,230 $lsas,,258 $lsas,,265 $lsas,,272
lsas,,303
iter,1,,1
time,563.1 $lcvsf,all, 336,  8.3
          esel,mat,25 $qe,all,12646 $eall
          esel,mat,24 $qe,all, 9238 $eall
          esel,mat,23 $qe,all, 7847 $eall $lwrite * 870417 / # 369
iter,4 $podisp,-1 $postr,-1 $porf,-1
time,564.0 $lcvsf,all, 336,  7.0
          esel,mat,25 $qe,all, 6982 $eall
          esel,mat,24 $qe,all, 5147 $eall
          esel,mat,23 $qe,all, 4333 $eall $lwrite * 870418 / # 370
iter,4,,4
time,565.0 $lcvsf,all, 675,  6.8
          esel,mat,25 $qe,all, 3609 $eall
          esel,mat,24 $qe,all, 2687 $eall
          esel,mat,23 $qe,all, 2239 $eall $lwrite * 870419 / # 371
podisp,-1 $postr,-1 $porf,-1
time,566.0 $lcvsf,all, 718,  2.5
          esel,mat,25 $qe,all, 1865 $eall
          esel,mat,24 $qe,all, 1403 $eall
          esel,mat,23 $qe,all, 1157 $eall $lwrite * 870420 / # 372
iter,4,,4
time,567.0 $lcvsf,all, 548,  1.0
          esel,mat,25 $qe,all,  964 $eall
          esel,mat,24 $qe,all,  732 $eall
          esel,mat,23 $qe,all,  598 $eall $lwrite * 870421 / # 373
time,568.0 $lcvsf,all, 527,  4.5
          esel,mat,25 $qe,all,  498 $eall
          esel,mat,24 $qe,all,  382 $eall
          esel,mat,23 $qe,all,  309 $eall $lwrite * 870422 / # 374
sbcdele,lcvsf,all $lsall $afwrite
finish
/input,27
finish
/aux1
copy,35,36 $copy,12,36
finish
/delete,file35,dat
/prep7
resume $krstrt,374
/title,(NT921222.mod) CASE STUDY - Lift 10-2 Placed
ntdele, 523,temp $cp,245,temp, 523, 580 $cp,246,temp, 526, 579
cp,247,temp, 527, 581 $cp,248,temp, 528, 582 $cp,249,temp, 536, 595
cp,250,temp, 545, 599 $cp,251,temp, 548, 600 $cp,252,temp, 549, 601
cp,253,temp, 550, 602 $cp,254,temp, 551, 603 $cp,255,temp, 552, 604
cp,256,temp, 564, 623 $cp,257,temp, 570, 627 $cp,258,temp, 573, 628
cp,259,temp, 574, 629
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lsse,,277 $lsas,,253 $lsas,,246 $lsas,,239 $lsas,,214 $lsas,,207 $lsas,,210
lsas,,212 $lsas,,235 $lsas,,224 $lsas,,226 $lsas,,223 $lsas,,230 $lsas,,258
lsas,,265 $lsas,,272 $lsas,,303
iter,1,,1
time,568.1 $lcvsf,all, 527,  4.5
          esel,mat,28 $qe,all,12646 $eall
          esel,mat,27 $qe,all, 9238 $eall
          esel,mat,26 $qe,all, 7847 $eall
          esel,mat,25 $qe,all,  466 $eall
          esel,mat,24 $qe,all,  358 $eall
          esel,mat,23 $qe,all,  289 $eall $lwrite * 870422 / # 375
iter,4,,4
time,569.0 $lcvsf,all, 240,  0.8
          esel,mat,28 $qe,all, 6982 $eall
          esel,mat,27 $qe,all, 5147 $eall
          esel,mat,26 $qe,all, 4333 $eall
          esel,mat,25 $qe,all,  258 $eall
          esel,mat,24 $qe,all,  200 $eall
          esel,mat,23 $qe,all,  160 $eall $lwrite * 870423 / # 376
podisp,-1 $postr,-1 $porf,-1
time,570.0 $lcvsf,all, 378, -2.0
          esel,mat,28 $qe,all, 3609 $eall
          esel,mat,27 $qe,all, 2687 $eall
          esel,mat,26 $qe,all, 2239 $eall
          esel,mat,25 $qe,all,  133 $eall
          esel,mat,24 $qe,all,  104 $eall
          esel,mat,23 $qe,all,   83 $eall $lwrite * 870424 / # 377
iter,4,,4
time,571.0 $lcvsf,all, 421,  3.3
          esel,mat,28 $qe,all, 1865 $eall
          esel,mat,27 $qe,all, 1403 $eall
          esel,mat,26 $qe,all, 1157 $eall
          esel,mat,25 $qe,all,   69 $eall
          esel,mat,24 $qe,all,   54 $eall
          esel,mat,23 $qe,all,   43 $eall $lwrite * 870425 / # 378
podisp,-1 $postr,-1 $porf,-1
time,572.0 $lcvsf,all, 272,  3.0
          esel,mat,28 $qe,all,  964 $eall
          esel,mat,27 $qe,all,  732 $eall
          esel,mat,26 $qe,all,  598 $eall
          esel,mat,25 $qe,all,   36 $eall
          esel,mat,24 $qe,all,   28 $eall
          esel,mat,23 $qe,all,   22 $eall $lwrite * 870426 / # 379
iter,4,,4
time,573.0 $lcvsf,all, 378,  2.3
          esel,mat,28 $qe,all,  498 $eall
          esel,mat,27 $qe,all,  382 $eall
          esel,mat,26 $qe,all,  309 $eall
          esel,mat,25 $qe,all,   18 $eall
          esel,mat,24 $qe,all,   15 $eall
          esel,mat,23 $qe,all,   11 $eall $lwrite * 870427 / # 380
podisp,-1 $postr,-1 $porf,-1
time,574.0 $lcvsf,all, 866,  8.3
          esel,mat,28 $qe,all,  258 $eall
          esel,mat,27 $qe,all,  200 $eall
          esel,mat,26 $qe,all,  160 $eall
          esel,mat,25 $qe,all,    9 $eall
          esel,mat,24 $qe,all,    8 $eall
          esel,mat,23 $qe,all,    6 $eall $lwrite * 870428 / # 381
iter,4,,4
time,575.0 $lcvsf,all, 506,  2.8
```

```
          esel,mat,28 $qe,all,  133 $eall
          esel,mat,27 $qe,all,  104 $eall
          esel,mat,26 $qe,all,   83 $eall
          esel,mat,25 $qe,all,    5 $eall
          esel,mat,24 $qe,all,    4 $eall
          esel,mat,23 $qe,all,    3 $eall $lwrite * 870429 / # 382
sbcdele,lcvsf,all $lsall $afwrite
finish
/input,27
finish
/aux1
copy,36,35 $copy,12,35
finish
/delete,file36,dat
/prep7
resume $krstrt,382
/title,(NT921222.mod) CASE STUDY - Lift 10-3 Placed
ntdele, 449,temp $cp,260,temp, 449, 520 $cp,261,temp, 451, 519
cp,262,temp, 452, 521 $cp,263,temp, 453, 522 $cp,264,temp, 457, 535
cp,265,temp, 483, 539 $cp,266,temp, 485, 540 $cp,267,temp, 486, 541
cp,268,temp, 487, 542 $cp,269,temp, 488, 543 $cp,270,temp, 489, 544
cp,271,temp, 511, 563 $cp,272,temp, 513, 567 $cp,273,temp, 515, 568
cp,274,temp, 516, 569
lsse,,277 $lsas,,253 $lsas,,246 $lsas,,239 $lsas,,214 $lsas,,207 $lsas,,189
lsas,,180 $lsas,,183 $lsas,,186 $lsas,,204 $lsas,,195 $lsas,,198 $lsas,,194
lsas,,203 $lsas,,223 $lsas,,230 $lsas,,258 $lsas,,265 $lsas,,272 $lsas,,303
iter,1,,1
time,575.1 $lcvsf,all, 506,  2.8
          esel,mat,31 $qe,all,12646 $eall
          esel,mat,30 $qe,all, 9238 $eall
          esel,mat,29 $qe,all, 7847 $eall
          esel,mat,28 $qe,all,  125 $eall
          esel,mat,27 $qe,all,   98 $eall
          esel,mat,26 $qe,all,   77 $eall
          esel,mat,25 $qe,all,    5 $eall
          esel,mat,24 $qe,all,    4 $eall
          esel,mat,23 $qe,all,    3 $eall $lwrite * 870429 / # 383
iter,4 $podisp,-1 $postr,-1 $porf,-1
time,576.0 $lcvsf,all, 484, -1.0
          esel,mat,31 $qe,all, 6982 $eall
          esel,mat,30 $qe,all, 5147 $eall
          esel,mat,29 $qe,all, 4333 $eall
          esel,mat,28 $qe,all,   69 $eall
          esel,mat,27 $qe,all,   54 $eall
          esel,mat,26 $qe,all,   43 $eall
          esel,mat,25 $qe,all,    3 $eall
          esel,mat,24 $qe,all,    2 $eall
          esel,mat,23 $qe,all,    2 $eall $lwrite * 870430 / # 384
iter,4,,4
time,577.0 $lcvsf,all, 336, -5.8
          esel,mat,31 $qe,all, 3609 $eall
          esel,mat,30 $qe,all, 2687 $eall
          esel,mat,29 $qe,all, 2239 $eall
          esel,mat,28 $qe,all,   36 $eall
          esel,mat,27 $qe,all,   28 $eall
          esel,mat,26 $qe,all,   22 $eall
          esel,mat,25 $qe,all,    1 $eall
          esel,mat,24 $qe,all,    1 $eall
          esel,mat,23 $qe,all,    1 $eall $lwrite * 870501 / # 385
podisp,-1 $postr,-1 $porf,-1
time,578.0 $lcvsf,all, 378,  2.0
```

```
          esel,mat,31 $qe,all, 1865 $eall
          esel,mat,30 $qe,all, 1403 $eall
          esel,mat,29 $qe,all, 1157 $eall
          esel,mat,28 $qe,all,   18 $eall
          esel,mat,27 $qe,all,   15 $eall
          esel,mat,26 $qe,all,   11 $eall
          esel,mat,25 $qe,all,    1 $eall
          esel,mat,24 $qe,all,    1 $eall
          esel,mat,23 $qedele,all   $eall $lwrite * 870502 / # 386
iter,4,,4
time,579.0 $lcvsf,all, 612, 10.5
          esel,mat,31 $qe,all,  964 $eall
          esel,mat,30 $qe,all,  732 $eall
          esel,mat,29 $qe,all,  598 $eall
          esel,mat,28 $qe,all,    9 $eall
          esel,mat,27 $qe,all,    8 $eall
          esel,mat,26 $qe,all,    6 $eall
          esel,mat,25 $qedele,all   $eall
          esel,mat,24 $qedele,all   $eall $lwrite * 870503 / # 387
podisp,-1 $postr,-1 $porf,-1
time,580.0 $lcvsf,all, 590, 16.3
          esel,mat,31 $qe,all,  498 $eall
          esel,mat,30 $qe,all,  382 $eall
          esel,mat,29 $qe,all,  309 $eall
          esel,mat,28 $qe,all,    5 $eall
          esel,mat,27 $qe,all,    4 $eall
          esel,mat,26 $qe,all,    3 $eall $lwrite * 870504 / # 388
iter,4,,4
time,581.0 $lcvsf,all, 484,  9.8
          esel,mat,31 $qe,all,  258 $eall
          esel,mat,30 $qe,all,  200 $eall
          esel,mat,29 $qe,all,  160 $eall
          esel,mat,28 $qe,all,    3 $eall
          esel,mat,27 $qe,all,    2 $eall
          esel,mat,26 $qe,all,    2 $eall $lwrite * 870505 / # 389
podisp,-1 $postr,-1 $porf,-1
time,582.0 $lcvsf,all, 399,  3.5
          esel,mat,31 $qe,all,  133 $eall
          esel,mat,30 $qe,all,  104 $eall
          esel,mat,29 $qe,all,   83 $eall
          esel,mat,28 $qe,all,    1 $eall
          esel,mat,27 $qe,all,    1 $eall
          esel,mat,26 $qe,all,    1 $eall $lwrite * 870506 / # 390
iter,4,,4
time,583.0 $lcvsf,all, 378,  2.0
          esel,mat,31 $qe,all,   69 $eall
          esel,mat,30 $qe,all,   54 $eall
          esel,mat,29 $qe,all,   43 $eall
          esel,mat,28 $qe,all,    1 $eall
          esel,mat,27 $qe,all,    1 $eall
          esel,mat,26 $qedele,all   $eall $lwrite * 870507 / # 391
podisp,-1 $postr,-1 $porf,-1
time,584.0 $lcvsf,all, 654,  5.0
          esel,mat,31 $qe,all,   36 $eall
          esel,mat,30 $qe,all,   28 $eall
          esel,mat,29 $qe,all,   22 $eall
          esel,mat,28 $qedele,all   $eall
          esel,mat,27 $qedele,all   $eall $lwrite * 870508 / # 392
iter,4,,4
time,585.0 $lcvsf,all, 484, -0.8
          esel,mat,31 $qe,all,   18 $eall
```

```
          esel,mat,30 $qe,all,   15 $eall
          esel,mat,29 $qe,all,   11 $eall $lwrite * 870509 / # 393
podisp,-1 $postr,-1 $porf,-1
time,586.0 $lcvsf,all, 251,  3.3
          esel,mat,31 $qe,all,    9 $eall
          esel,mat,30 $qe,all,    8 $eall
          esel,mat,29 $qe,all,    6 $eall $lwrite * 870510 / # 394
iter,4,,4
time,587.0 $lcvsf,all, 357,  6.5
          esel,mat,31 $qe,all,    5 $eall
          esel,mat,30 $qe,all,    4 $eall
          esel,mat,29 $qe,all,    3 $eall $lwrite * 870511 / # 395
time,588.0 $lcvsf,all, 421,  8.3
          esel,mat,31 $qe,all,    3 $eall
          esel,mat,30 $qe,all,    2 $eall
          esel,mat,29 $qe,all,    2 $eall $lwrite * 870512 / # 396
sbcdele,lcvsf,all $lsall $afwrite
finish
/input,27
finish
/aux1
copy,35,36 $copy,12,36
finish
/delete,file35,dat
/prep7
resume $krstrt,396
/title,(NT921222.mod) CASE STUDY - Lift 11 Placed
ntdele, 353,temp $cp,275,temp, 353, 430 $cp,276,temp, 355, 429
cp,277,temp, 356, 431 $cp,278,temp, 357, 432 $cp,279,temp, 361, 445
cp,280,temp, 389, 459 $cp,281,temp, 391, 460 $cp,282,temp, 392, 461
cp,283,temp, 393, 462 $cp,284,temp, 394, 463 $cp,285,temp, 395, 464
cp,286,temp, 421, 495 $cp,287,temp, 423, 499 $cp,288,temp, 425, 500
cp,289,temp, 426, 501
lsse,,277 $lsas,,253 $lsas,,246 $lsas,,239 $lsas,,214 $lsas,,207 $lsas,,189
lsas,,180 $lsas,, 85 $lsas,, 82 $lsas,, 79 $lsas,, 88 $lsas,, 92 $lsas,,176
lsas,,156 $lsas,,160 $lsas,,149 $lsas,,152 $lsas,,155 $lsas,,194 $lsas,,203
lsas,,223 $lsas,,230 $lsas,,258 $lsas,,265 $lsas,,272 $lsas,,303
iter,1,,1
time,588.1 $lcvsf,all, 421,  8.3
          esel,mat,34 $qe,all,12646 $eall
          esel,mat,33 $qe,all, 9238 $eall
          esel,mat,32 $qe,all, 7847 $eall
          esel,mat,31 $qe,all,    2 $eall
          esel,mat,30 $qe,all,    2 $eall
          esel,mat,29 $qe,all,    1 $eall $lwrite * 870512 / # 397
iter,4,,4
time,589.0 $lcvsf,all, 675, -2.8
          esel,mat,34 $qe,all, 6982 $eall
          esel,mat,33 $qe,all, 5147 $eall
          esel,mat,32 $qe,all, 4333 $eall
          esel,mat,31 $qe,all,    1 $eall
          esel,mat,30 $qe,all,    1 $eall
          esel,mat,29 $qe,all,    1 $eall $lwrite * 870513 / # 398
podisp,-1 $postr,-1 $porf,-1
time,590.0 $lcvsf,all, 357, -2.0
          esel,mat,34 $qe,all, 3609 $eall
          esel,mat,33 $qe,all, 2687 $eall
          esel,mat,32 $qe,all, 2239 $eall
          esel,mat,31 $qe,all,    1 $eall
          esel,mat,30 $qe,all,    1 $eall
          esel,mat,29 $qedele,all   $eall $lwrite * 870514 / # 399
```

```
iter,4,,4
time,591.0 $lcvsf,all, 421,  0.0
          esel,mat,34 $qe,all, 1865 $eall
          esel,mat,33 $qe,all, 1403 $eall
          esel,mat,32 $qe,all, 1157 $eall
          esel,mat,31 $qedele,all   $eall
          esel,mat,30 $qedele,all   $eall $lwrite * 870515 / # 400
podisp,-1 $postr,-1 $porf,-1
time,592.0 $lcvsf,all, 548, -2.5
          esel,mat,34 $qe,all,  964 $eall
          esel,mat,33 $qe,all,  732 $eall
          esel,mat,32 $qe,all,  598 $eall $lwrite * 870516 / # 401
iter,4,,4
time,593.0 $lcvsf,all, 251,  1.0
          esel,mat,34 $qe,all,  498 $eall
          esel,mat,33 $qe,all,  382 $eall
          esel,mat,32 $qe,all,  309 $eall $lwrite * 870517 / # 402
podisp,-1 $postr,-1 $porf,-1
time,594.0 $lcvsf,all, 590, 10.3
          esel,mat,34 $qe,all,  258 $eall
          esel,mat,33 $qe,all,  200 $eall
          esel,mat,32 $qe,all,  160 $eall $lwrite * 870518 / # 403
iter,4,,4
time,595.0 $lcvsf,all, 506,  1.3
          esel,mat,34 $qe,all,  133 $eall
          esel,mat,33 $qe,all,  104 $eall
          esel,mat,32 $qe,all,   83 $eall $lwrite * 870519 / # 404
podisp,-1 $postr,-1 $porf,-1
time,596.0 $lcvsf,all, 654, -2.3
          esel,mat,34 $qe,all,   69 $eall
          esel,mat,33 $qe,all,   54 $eall
          esel,mat,32 $qe,all,   43 $eall $lwrite * 870520 / # 405
iter,4,,4
time,597.0 $lcvsf,all, 336, -1.0
          esel,mat,34 $qe,all,   36 $eall
          esel,mat,33 $qe,all,   28 $eall
          esel,mat,32 $qe,all,   22 $eall $lwrite * 870521 / # 406
sbcdele,lcvsf,all $lsall $afwrite
finish
/input,27
finish
/aux1
copy,36,35 $copy,12,35
finish
/delete,file36,dat
/prep7
resume $krstrt,406
/title,(NT921222.mod) CASE STUDY - Lift 12 Placed
ntdele, 259,temp $cp,290,temp, 259, 329 $cp,291,temp, 261, 328
cp,292,temp, 262, 330 $cp,293,temp, 263, 331 $cp,294,temp, 267, 344
cp,295,temp, 290, 363 $cp,296,temp, 292, 364 $cp,297,temp, 293, 365
cp,298,temp, 294, 366 $cp,299,temp, 295, 367 $cp,300,temp, 320, 401
cp,301,temp, 322, 405 $cp,302,temp, 324, 406 $cp,303,temp, 325, 407
lsse,,277 $lsas,,253 $lsas,,246 $lsas,,239 $lsas,,214 $lsas,,207 $lsas,,189
lsas,,180 $lsas,, 85 $lsas,, 82 $lsas,, 79 $lsas,, 68 $lsas,, 65 $lsas,, 62
lsas,, 71 $lsas,, 75 $lsas,,172 $lsas,,139 $lsas,,143 $lsas,,132 $lsas,,135
lsas,,138 $lsas,,149 $lsas,,152 $lsas,,155 $lsas,,194 $lsas,,203 $lsas,,223
lsas,,230 $lsas,,258 $lsas,,265 $lsas,,272 $lsas,,303
iter,1,,1
time,597.1 $lcvsf,all, 336, -1.0
          esel,mat,37 $qe,all,12646 $eall
```

```
          esel,mat,36 $qe,all, 9238 $eall
          esel,mat,35 $qe,all, 7847 $eall
          esel,mat,34 $qe,all,   33 $eall
          esel,mat,33 $qe,all,   27 $eall
          esel,mat,32 $qe,all,   21 $eall $lwrite * 870521 / # 407
iter,4 $podisp,-1 $postr,-1 $porf,-1
time,598.0 $lcvsf,all, 590, 15.8
          esel,mat,37 $qe,all, 6982 $eall
          esel,mat,36 $qe,all, 5147 $eall
          esel,mat,35 $qe,all, 4333 $eall
          esel,mat,34 $qe,all,   18 $eall
          esel,mat,33 $qe,all,   15 $eall
          esel,mat,32 $qe,all,   11 $eall $lwrite * 870522 / # 408
iter,4,,4
time,599.0 $lcvsf,all, 357,  4.8
          esel,mat,37 $qe,all, 3609 $eall
          esel,mat,36 $qe,all, 2687 $eall
          esel,mat,35 $qe,all, 2239 $eall
          esel,mat,34 $qe,all,    9 $eall
          esel,mat,33 $qe,all,    8 $eall
          esel,mat,32 $qe,all,    6 $eall $lwrite * 870523 / # 409
podisp,-1 $postr,-1 $porf,-1
time,600.0 $lcvsf,all, 378,  4.3
          esel,mat,37 $qe,all, 1865 $eall
          esel,mat,36 $qe,all, 1403 $eall
          esel,mat,35 $qe,all, 1157 $eall
          esel,mat,34 $qe,all,    5 $eall
          esel,mat,33 $qe,all,    4 $eall
          esel,mat,32 $qe,all,    3 $eall $lwrite * 870524 / # 410
iter,4,,4
time,601.0 $lcvsf,all, 399, 12.0
          esel,mat,37 $qe,all,  964 $eall
          esel,mat,36 $qe,all,  732 $eall
          esel,mat,35 $qe,all,  598 $eall
          esel,mat,34 $qe,all,    3 $eall
          esel,mat,33 $qe,all,    2 $eall
          esel,mat,32 $qe,all,    2 $eall $lwrite * 870525 / # 411
podisp,-1 $postr,-1 $porf,-1
time,602.0 $lcvsf,all, 357, 16.0
          esel,mat,37 $qe,all,  498 $eall
          esel,mat,36 $qe,all,  382 $eall
          esel,mat,35 $qe,all,  309 $eall
          esel,mat,34 $qe,all,    1 $eall
          esel,mat,33 $qe,all,    1 $eall
          esel,mat,32 $qe,all,    1 $eall $lwrite * 870526 / # 412
iter,4,,4
time,603.0 $lcvsf,all, 463,  2.8
          esel,mat,37 $qe,all,  258 $eall
          esel,mat,36 $qe,all,  200 $eall
          esel,mat,35 $qe,all,  160 $eall
          esel,mat,34 $qe,all,    1 $eall
          esel,mat,33 $qe,all,    1 $eall
          esel,mat,32 $qedele,all   $eall $lwrite * 870527 / # 413
podisp,-1 $postr,-1 $porf,-1
time,604.0 $lcvsf,all, 569,  5.0
          esel,mat,37 $qe,all,  133 $eall
          esel,mat,36 $qe,all,  104 $eall
          esel,mat,35 $qe,all,   83 $eall
          esel,mat,34 $qedele,all   $eall
          esel,mat,33 $qedele,all   $eall $lwrite * 870528 / # 414
iter,4,,4
```

```
time,605.0 $lcvsf,all, 240,  4.0
          esel,mat,37 $qe,all,   69 $eall
          esel,mat,36 $qe,all,   54 $eall
          esel,mat,35 $qe,all,   43 $eall $lwrite * 870529 / # 415
sbcdele,lcvsf,all $lsall $afwrite
finish
/input,27
finish
/aux1
copy,35,36 $copy,12,36
finish
/delete,file35,dat
/prep7
resume $krstrt,415
/title,(NT921222.mod) CASE STUDY - Lift 13 Placed
ntdele, 172,temp $cp,304,temp, 172, 235 $cp,305,temp, 174, 234
cp,306,temp, 175, 236 $cp,307,temp, 176, 237 $cp,308,temp, 180, 250
cp,309,temp, 207, 300 $cp,310,temp, 209, 269 $cp,311,temp, 211, 304
cp,312,temp, 213, 305 $cp,313,temp, 214, 306 $cp,314,temp, 228, 270
cp,315,temp, 229, 271 $cp,316,temp, 230, 272
lsse,,277 $lsas,,253 $lsas,,246 $lsas,,239 $lsas,,214 $lsas,,207 $lsas,,189
lsas,,180 $lsas,, 85 $lsas,, 82 $lsas,, 79 $lsas,, 68 $lsas,, 65 $lsas,, 62
lsas,, 51 $lsas,, 48 $lsas,, 45 $lsas,, 54 $lsas,, 58 $lsas,,168 $lsas,,122
lsas,,126 $lsas,,115 $lsas,,118 $lsas,,121 $lsas,,132 $lsas,,135 $lsas,,138
lsas,,149 $lsas,,152 $lsas,,155 $lsas,,194 $lsas,,203 $lsas,,223 $lsas,,230
lsas,,258 $lsas,,265 $lsas,,272 $lsas,,303
iter,1,,1
time,605.1 $lcvsf,all, 240,  4.0
          esel,mat,39 $qe,all,12987 $eall
          esel,mat,38 $qe,all, 8089 $eall
          esel,mat,37 $qe,all,   64 $eall
          esel,mat,36 $qe,all,   51 $eall
          esel,mat,35 $qe,all,   40 $eall $lwrite * 870529 / # 416
iter,4 $podisp,-1 $postr,-1 $porf,-1
time,606.0 $lcvsf,all, 484,  4.0
          esel,mat,39 $qe,all, 7235 $eall
          esel,mat,38 $qe,all, 4466 $eall
          esel,mat,37 $qe,all,   36 $eall
          esel,mat,36 $qe,all,   28 $eall
          esel,mat,35 $qe,all,   22 $eall $lwrite * 870530 / # 417
iter,4,,4
time,607.0 $lcvsf,all, 240, 11.5
          esel,mat,39 $qe,all, 3777 $eall
          esel,mat,38 $qe,all, 2308 $eall
          esel,mat,37 $qe,all,   18 $eall
          esel,mat,36 $qe,all,   15 $eall
          esel,mat,35 $qe,all,   11 $eall $lwrite * 870531 / # 418
podisp,-1 $postr,-1 $porf,-1
time,608.0 $lcvsf,all, 569, 19.9
          esel,mat,39 $qe,all, 1972 $eall
          esel,mat,38 $qe,all, 1193 $eall
          esel,mat,37 $qe,all,    9 $eall
          esel,mat,36 $qe,all,    8 $eall
          esel,mat,35 $qe,all,    6 $eall $lwrite * 870601 / # 419
iter,4,,4
time,609.0 $lcvsf,all, 654, 13.8
          esel,mat,39 $qe,all, 1029 $eall
          esel,mat,38 $qe,all,  617 $eall
          esel,mat,37 $qe,all,    5 $eall
          esel,mat,36 $qe,all,    4 $eall
          esel,mat,35 $qe,all,    3 $eall $lwrite * 870602 / # 420
```

```
time,610.0 $lcvsf,all, 760,  0.4
          esel,mat,39 $qe,all,  537 $eall
          esel,mat,38 $qe,all,  319 $eall
          esel,mat,37 $qe,all,    3 $eall
          esel,mat,36 $qe,all,    2 $eall
          esel,mat,35 $qe,all,    2 $eall $lwrite * 870603 / # 421
sbcdele,lcvsf,all $lsall $afwrite
finish
/input,27
finish
/aux1
copy,36,35 $copy,12,35
finish
/delete,file36,dat
/prep7
resume $krstrt,421
/title,(NT921222.mod) CASE STUDY - Lift 14 Placed
ntdele, 123,temp $cp,317,temp, 123, 148 $cp,318,temp, 125, 147
cp,319,temp, 126, 149 $cp,320,temp, 127, 150 $cp,321,temp, 131, 163
cp,322,temp, 133, 182 $cp,323,temp, 135, 217 $cp,324,temp, 136, 218
cp,325,temp, 139, 183 $cp,326,temp, 141, 190 $cp,327,temp, 143, 191
cp,328,temp, 144, 192
lsse,,277 $lsas,,253 $lsas,,246 $lsas,,239 $lsas,,214 $lsas,,207 $lsas,,189
lsas,,180 $lsas,, 85 $lsas,, 82 $lsas,, 79 $lsas,, 68 $lsas,, 65 $lsas,, 62
lsas,, 51 $lsas,, 48 $lsas,, 45 $lsas,, 34 $lsas,, 31 $lsas,, 28 $lsas,, 37
lsas,, 41 $lsas,,164 $lsas,,105 $lsas,,109 $lsas,, 98 $lsas,,101 $lsas,,104
lsas,,115 $lsas,,118 $lsas,,121 $lsas,,132 $lsas,,135 $lsas,,138 $lsas,,149
lsas,,152 $lsas,,155 $lsas,,194 $lsas,,203 $lsas,,223 $lsas,,230 $lsas,,258
lsas,,265 $lsas,,272 $lsas,,303
iter,1,,1
time,610.1 $lcvsf,all, 760,  0.4
          esel,mat,40 $qe,all,12987 $eall
          esel,mat,39 $qe,all,  504 $eall
          esel,mat,38 $qe,all,  298 $eall
          esel,mat,37 $qe,all,    2 $eall
          esel,mat,36 $qe,all,    2 $eall
          esel,mat,35 $qe,all,    1 $eall $lwrite * 870603 / # 422
iter,4,,4
time,611.0 $lcvsf,all, 739,  4.9
          esel,mat,40 $qe,all, 7235 $eall
          esel,mat,39 $qe,all,  281 $eall
          esel,mat,38 $qe,all,  165 $eall
          esel,mat,37 $qe,all,    1 $eall
          esel,mat,36 $qe,all,    1 $eall
          esel,mat,35 $qe,all,    1 $eall $lwrite * 870604 / # 423
podisp,-1 $postr,-1 $porf,-1
time,612.0 $lcvsf,all, 506,  9.8
          esel,mat,40 $qe,all, 3777 $eall
          esel,mat,39 $qe,all,  146 $eall
          esel,mat,38 $qe,all,   85 $eall
          esel,mat,37 $qe,all,    1 $eall
          esel,mat,36 $qe,all,    1 $eall
          esel,mat,35 $qedele,all   $eall $lwrite * 870605 / # 424
iter,4,,4
time,613.0 $lcvsf,all, 399,  8.6
          esel,mat,40 $qe,all, 1972 $eall
          esel,mat,39 $qe,all,   76 $eall
          esel,mat,38 $qe,all,   44 $eall
          esel,mat,37 $qedele,all   $eall
          esel,mat,36 $qedele,all   $eall $lwrite * 870606 / # 425
podisp,-1 $postr,-1 $porf,-1
```

```
time,614.0 $lcvsf,all, 442,  8.6
          esel,mat,40 $qe,all, 1029 $eall
          esel,mat,39 $qe,all,   40 $eall
          esel,mat,38 $qe,all,   23 $eall $lwrite * 870607 / # 426
iter,4,,4
time,615.0 $lcvsf,all, 357, 11.1
          esel,mat,40 $qe,all,  537 $eall
          esel,mat,39 $qe,all,   21 $eall
          esel,mat,38 $qe,all,   12 $eall $lwrite * 870608 / # 427
podisp,-1 $postr,-1 $porf,-1
time,616.0 $lcvsf,all, 421, 14.3
          esel,mat,40 $qe,all,  281 $eall
          esel,mat,39 $qe,all,   11 $eall
          esel,mat,38 $qe,all,    6 $eall $lwrite * 870609 / # 428
iter,4,,4
time,617.0 $lcvsf,all, 399, 18.0
          esel,mat,40 $qe,all,  146 $eall
          esel,mat,39 $qe,all,    6 $eall
          esel,mat,38 $qe,all,    3 $eall $lwrite * 870610 / # 429
podisp,-1 $postr,-1 $porf,-1
time,618.0 $lcvsf,all, 378, 19.8
          esel,mat,40 $qe,all,   76 $eall
          esel,mat,39 $qe,all,    3 $eall
          esel,mat,38 $qe,all,    2 $eall $lwrite * 870611 / # 430
iter,4,,4
time,619.0 $lcvsf,all, 378, 14.9
          esel,mat,40 $qe,all,   40 $eall
          esel,mat,39 $qe,all,    2 $eall
          esel,mat,38 $qe,all,    1 $eall $lwrite * 870612 / # 431
podisp,-1 $postr,-1 $porf,-1
time,620.0 $lcvsf,all, 675, 21.1
          esel,mat,40 $qe,all,   21 $eall
          esel,mat,39 $qe,all,    1 $eall
          esel,mat,38 $qedele,all   $eall $lwrite * 870613 / # 432
iter,4,,4
time,621.0 $lcvsf,all, 633, 19.0
          esel,mat,40 $qe,all,   11 $eall
          esel,mat,39 $qedele,all   $eall $lwrite * 870614 / # 433
podisp,-1 $postr,-1 $porf,-1
time,622.0 $lcvsf,all, 484, 18.1
          esel,mat,40 $qe,all,    6 $eall $lwrite * 870615 / # 434
iter,4,,4
time,623.0 $lcvsf,all, 442, 14.8
          esel,mat,40 $qe,all,    3 $eall $lwrite * 870616 / # 435
time,624.0 $lcvsf,all, 527, 20.4
          esel,mat,40 $qe,all,    2 $eall $lwrite * 870617 / # 436
sbcdele,lcvsf,all $lsall $afwrite
finish
/input,27
finish
/aux1
copy,35,36 $copy,12,36
finish
/delete,file35,dat
/prep7
resume $krstrt,436
/title,(NT921222.mod) CASE STUDY - Lift 15 Placed
ntdele,  45,temp $cp,329,temp,  45,  68 $cp,330,temp,  47,  67
cp,331,temp,  48,  69 $cp,332,temp,  49,  70 $cp,333,temp,  53,  83
cp,334,temp,  55,  87 $cp,335,temp,  57,  88 $cp,336,temp,  59,  95
cp,337,temp,  61,  99 $cp,338,temp,  63, 100 $cp,339,temp,  64, 101
```

```
lsse,,246 $lsas,,239 $lsas,,214 $lsas,,207 $lsas,,189 $lsas,,180 $lsas,, 85
lsas,, 82 $lsas,, 79 $lsas,, 68 $lsas,, 65 $lsas,, 62 $lsas,, 51 $lsas,, 48
lsas,, 45 $lsas,, 34 $lsas,, 31 $lsas,, 28 $lsas,,  7 $lsas,,  1 $lsas,, 13
lsas,, 14 $lsas,, 25 $lsas,, 15 $lsas,, 16 $lsas,,  6 $lsas,, 12 $lsas,, 98
lsas,,101 $lsas,,104 $lsas,,115 $lsas,,118 $lsas,,121 $lsas,,132 $lsas,,135
lsas,,138 $lsas,,149 $lsas,,152 $lsas,,155 $lsas,,194 $lsas,,203 $lsas,,223
lsas,,230 $lsas,,258 $lsas,,265
iter,1,,1
time,624.1 $lcvsf,all, 527, 20.4
          esel,mat,42 $qe,all,15554 $eall
          esel,mat,41 $qe,all,12822 $eall
          esel,mat,40 $qe,all,     1 $eall $lwrite * 870617 / # 437
iter,4,,4
time,625.0 $lcvsf,all, 675, 15.3
          esel,mat,42 $qe,all, 8588 $eall
          esel,mat,41 $qe,all, 7111 $eall
          esel,mat,40 $qe,all,     1 $eall $lwrite * 870618 / # 438
podisp,-1 $postr,-1 $porf,-1
time,626.0 $lcvsf,all, 506, 15.7
          esel,mat,42 $qe,all, 4439 $eall
          esel,mat,41 $qe,all, 3694 $eall
          esel,mat,40 $qedele,all   $eall $lwrite * 870619 / # 439
iter,4,,4
time,627.0 $lcvsf,all, 442, 16.8
          esel,mat,42 $qe,all, 2294 $eall
          esel,mat,41 $qe,all, 1919 $eall $lwrite * 870620 / # 440
podisp,-1 $postr,-1 $porf,-1
time,628.0 $lcvsf,all, 506, 11.5
          esel,mat,42 $qe,all, 1186 $eall
          esel,mat,41 $qe,all,  997 $eall $lwrite * 870621 / # 441
iter,4,,4
time,629.0 $lcvsf,all, 484, 13.9
          esel,mat,42 $qe,all,  613 $eall
          esel,mat,41 $qe,all,  518 $eall $lwrite * 870622 / # 442
podisp,-1 $postr,-1 $porf,-1
time,630.0 $lcvsf,all, 590, 14.6
          esel,mat,42 $qe,all,  317 $eall
          esel,mat,41 $qe,all,  269 $eall $lwrite * 870623 / # 443
iter,4,,4
time,631.0 $lcvsf,all, 421, 18.3
          esel,mat,42 $qe,all,  164 $eall
          esel,mat,41 $qe,all,  140 $eall $lwrite * 870624 / # 444
podisp,-1 $postr,-1 $porf,-1
time,632.0 $lcvsf,all, 548, 10.4
          esel,mat,42 $qe,all,   85 $eall
          esel,mat,41 $qe,all,   73 $eall $lwrite * 870625 / # 445
iter,4,,4
time,633.0 $lcvsf,all, 569,  9.5
          esel,mat,42 $qe,all,   44 $eall
          esel,mat,41 $qe,all,   38 $eall $lwrite * 870626 / # 446
podisp,-1 $postr,-1 $porf,-1
time,634.0 $lcvsf,all, 654,  9.9
          esel,mat,42 $qe,all,   23 $eall
          esel,mat,41 $qe,all,   20 $eall $lwrite * 870627 / # 447
time,635.0 $lcvsf,all, 718, 11.6
          esel,mat,42 $qe,all,   12 $eall
          esel,mat,41 $qe,all,   10 $eall $lwrite * 870628 / # 448
time,636.0 $lcvsf,all, 612, 12.4
          esel,mat,42 $qe,all,    6 $eall
          esel,mat,41 $qe,all,    5 $eall $lwrite * 870629 / # 449
time,637.0 $lcvsf,all, 442, 13.1
```

```
           esel,mat,42 $qe,all,    3 $eall
           esel,mat,41 $qe,all,    3 $eall $lwrite * 870630 / # 450
time,638.0 $lcvsf,all, 315, 14.0
           esel,mat,42 $qe,all,    2 $eall
           esel,mat,41 $qe,all,    1 $eall $lwrite * 870701 / # 451
time,639.0 $lcvsf,all, 315, 12.4
           esel,mat,42 $qe,all,    1 $eall
           esel,mat,41 $qe,all,    1 $eall $lwrite * 870702 / # 452
iter,4,,4
time,640.0 $lcvsf,all, 548, 18.9
           esel,mat,42 $qedele,all   $eall
           esel,mat,41 $qedele,all   $eall $lwrite * 870703 / # 453
podisp,-1 $postr,-1 $porf,-1
time,641.0 $lcvsf,all, 378, 16.6         $lwrite * 870704 / # 454
time,642.0 $lcvsf,all, 357, 12.5         $lwrite * 870705 / # 455
time,643.0 $lcvsf,all, 272, 12.6         $lwrite * 870706 / # 456
time,644.0 $lcvsf,all, 612, 11.4         $lwrite * 870707 / # 457
time,645.0 $lcvsf,all, 506, 13.8         $lwrite * 870708 / # 458
time,646.0 $lcvsf,all, 506, 15.0         $lwrite * 870709 / # 459
time,647.0 $lcvsf,all, 548, 10.4         $lwrite * 870710 / # 460
time,648.0 $lcvsf,all, 336,  9.6         $lwrite * 870711 / # 461
time,649.0 $lcvsf,all, 315, 11.5         $lwrite * 870712 / # 462
time,650.0 $lcvsf,all, 293, 14.8         $lwrite * 870713 / # 463
time,651.0 $lcvsf,all, 315, 15.6         $lwrite * 870714 / # 464
time,652.0 $lcvsf,all, 442, 17.3         $lwrite * 870715 / # 465
time,653.0 $lcvsf,all, 527, 17.5         $lwrite * 870716 / # 466
iter,4,,4
time,654.0 $lcvsf,all, 506, 12.1         $lwrite * 870717 / # 467
podisp,-1 $postr,-1 $porf,-1
time,655.0 $lcvsf,all, 272, 15.3         $lwrite * 870718 / # 468
time,656.0 $lcvsf,all, 357, 17.0         $lwrite * 870719 / # 469
time,657.0 $lcvsf,all, 336, 16.0         $lwrite * 870720 / # 470
time,658.0 $lcvsf,all, 548, 15.3         $lwrite * 870721 / # 471
time,659.0 $lcvsf,all, 463, 18.8         $lwrite * 870722 / # 472
iter,4,,4
time,660.0 $lcvsf,all, 675, 13.1         $lwrite * 870723 / # 473
time,661.0 $lcvsf,all, 569, 15.8         $lwrite * 870724 / # 474
podisp,-1 $postr,-1 $porf,-1
time,662.0 $lcvsf,all, 421, 15.6         $lwrite * 870725 / # 475
time,663.0 $lcvsf,all, 336, 14.8         $lwrite * 870726 / # 476
time,664.0 $lcvsf,all, 399, 14.1         $lwrite * 870727 / # 477
time,665.0 $lcvsf,all, 357, 20.5         $lwrite * 870728 / # 478
time,666.0 $lcvsf,all, 463, 15.5         $lwrite * 870729 / # 479
time,667.0 $lcvsf,all, 357, 16.5         $lwrite * 870730 / # 480
iter,4,,4
time,668.0 $lcvsf,all, 240, 23.3         $lwrite * 870731 / # 481
podisp,-1 $postr,-1 $porf,-1
time,669.0 $lcvsf,all, 506, 23.5         $lwrite * 870801 / # 482
time,670.0 $lcvsf,all, 760,  6.8         $lwrite * 870802 / # 483
time,671.0 $lcvsf,all, 421, 10.0         $lwrite * 870803 / # 484
time,672.0 $lcvsf,all, 463, 15.6         $lwrite * 870804 / # 485
time,673.0 $lcvsf,all, 399, 17.6         $lwrite * 870805 / # 486
time,674.0 $lcvsf,all, 421, 17.0         $lwrite * 870806 / # 487
iter,4,,4
time,675.0 $lcvsf,all, 421, 15.0         $lwrite * 870807 / # 488
podisp,-1 $postr,-1 $porf,-1
time,676.0 $lcvsf,all, 463, 14.6         $lwrite * 870808 / # 489
time,677.0 $lcvsf,all, 548, 12.9         $lwrite * 870809 / # 490
time,678.0 $lcvsf,all, 315, 13.0         $lwrite * 870810 / # 491
time,679.0 $lcvsf,all, 590, 11.2         $lwrite * 870811 / # 492
iter,4,,4
```

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time,680.0 $lcvsf,all, 612, 13.8          $lwrite * 870812 / # 493
podisp,-1 $postr,-1 $porf,-1
time,681.0 $lcvsf,all, 612, 11.9          $lwrite * 870813 / # 494
time,682.0 $lcvsf,all, 484, 12.9          $lwrite * 870814 / # 495
time,683.0 $lcvsf,all, 421, 13.4          $lwrite * 870815 / # 496
iter,4,,4
time,684.0 $lcvsf,all, 251, 12.5          $lwrite * 870816 / # 497
podisp,-1 $postr,-1 $porf,-1
time,685.0 $lcvsf,all, 399, 12.5          $lwrite * 870817 / # 498
time,686.0 $lcvsf,all, 506,  9.9          $lwrite * 870818 / # 499
time,687.0 $lcvsf,all, 527,  9.8          $lwrite * 870819 / # 500
time,688.0 $lcvsf,all, 463,  9.9          $lwrite * 870820 / # 501
time,689.0 $lcvsf,all, 569,  9.3          $lwrite * 870821 / # 502
time,690.0 $lcvsf,all, 739,  8.7          $lwrite * 870822 / # 503
time,691.0 $lcvsf,all, 463, 10.0          $lwrite * 870823 / # 504
time,692.0 $lcvsf,all, 527, 10.2          $lwrite * 870824 / # 505
time,693.0 $lcvsf,all, 378,  9.1          $lwrite * 870825 / # 506
time,694.0 $lcvsf,all, 612, 14.3          $lwrite * 870826 / # 507
time,695.0 $lcvsf,all, 357, 10.3          $lwrite * 870827 / # 508
iter,4,,4
time,696.0 $lcvsf,all, 421, 14.0          $lwrite * 870828 / # 509
podisp,-1 $postr,-1 $porf,-1
time,697.0 $lcvsf,all, 548, 12.0          $lwrite * 870829 / # 510
time,698.0 $lcvsf,all, 930,  4.5          $lwrite * 870830 / # 511
time,699.0 $lcvsf,all, 240,  7.2          $lwrite * 870831 / # 512
iter,4,,4
time,700.0 $lcvsf,all, 633,  5.5          $lwrite * 870901 / # 513
podisp,-1 $postr,-1 $porf,-1
time,701.0 $lcvsf,all, 442,  5.8          $lwrite * 870902 / # 514
time,702.0 $lcvsf,all, 527, 10.3          $lwrite * 870903 / # 515
iter,4,,4
time,703.0 $lcvsf,all, 696,  7.5          $lwrite * 870904 / # 516
podisp,-1 $postr,-1 $porf,-1
time,704.0 $lcvsf,all, 336,  7.3          $lwrite * 870905 / # 517
time,705.0 $lcvsf,all, 421, 12.3          $lwrite * 870906 / # 518
time,706.0 $lcvsf,all, 293, 13.2          $lwrite * 870907 / # 519
time,707.0 $lcvsf,all, 315, 13.0          $lwrite * 870908 / # 520
time,708.0 $lcvsf,all, 484, 11.8          $lwrite * 870909 / # 521
time,709.0 $lcvsf,all, 675,  8.1          $lwrite * 870910 / # 522
time,710.0 $lcvsf,all, 378,  7.5          $lwrite * 870911 / # 523
time,711.0 $lcvsf,all, 378,  8.0          $lwrite * 870912 / # 524
iter,4,,4
time,712.0 $lcvsf,all, 421,  9.3          $lwrite * 870913 / # 525
podisp,-1 $postr,-1 $porf,-1
time,713.0 $lcvsf,all, 548, 13.8          $lwrite * 870914 / # 526
time,714.0 $lcvsf,all, 569,  7.8          $lwrite * 870915 / # 527
time,715.0 $lcvsf,all, 293,  8.1          $lwrite * 870916 / # 528
time,716.0 $lcvsf,all, 293, 14.0          $lwrite * 870917 / # 529
time,717.0 $lcvsf,all, 421, 11.6          $lwrite * 870918 / # 530
time,718.0 $lcvsf,all, 251, 11.5          $lwrite * 870919 / # 531
iter,4,,4
time,719.0 $lcvsf,all, 272, 10.5          $lwrite * 870920 / # 532
time,720.0 $lcvsf,all, 590, 14.0          $lwrite * 870921 / # 533
podisp,-1 $postr,-1 $porf,-1
time,721.0 $lcvsf,all, 527, 13.9          $lwrite * 870922 / # 534
time,722.0 $lcvsf,all, 718,  8.3          $lwrite * 870923 / # 535
time,723.0 $lcvsf,all, 696,  7.9          $lwrite * 870924 / # 536
iter,4,,4
time,724.0 $lcvsf,all, 506,  7.7          $lwrite * 870925 / # 537
time,725.0 $lcvsf,all, 399,  3.8          $lwrite * 870926 / # 538
sbcdele,lcvsf,all $lsall $afwrite
```

```
finish
/input,27
finish
/aux1
copy,36,35 $copy,12,35
finish
/delete,file36,dat
/get,12,file35,dat
 *
 * ~~~~~~~~~~~~~~~~~~~~~~  POST-PROCESSING COMMANDS  ~~~~~~~~~~~~~~~~~~~~~~~
 *
*create,outlines
lsall $lsse,,  7 $lsas,,  1 $lsas,, 13 $lsas,, 14 $lsas,, 25 $lsas,, 15
lsas,, 16 $lsas,,  6 $lsas,, 12 $lsas,, 34 $lsas,, 31 $lsas,, 28 $lsas,, 37
lsas,, 41 $lsas,,164 $lsas,,105 $lsas,,109 $lsas,, 98 $lsas,,101 $lsas,,104
lsas,, 51 $lsas,, 48 $lsas,, 45 $lsas,, 54 $lsas,, 58 $lsas,,168 $lsas,,122
lsas,,126 $lsas,,115 $lsas,,118 $lsas,,121 $lsas,, 68 $lsas,, 65 $lsas,, 62
lsas,, 71 $lsas,, 75 $lsas,,172 $lsas,,139 $lsas,,143 $lsas,,132 $lsas,,135
lsas,,138 $lsas,, 85 $lsas,, 82 $lsas,, 79 $lsas,, 88 $lsas,, 92 $lsas,,176
lsas,,156 $lsas,,160 $lsas,,149 $lsas,,152 $lsas,,155 $lsas,,189 $lsas,,180
lsas,,183 $lsas,,186 $lsas,,204 $lsas,,195 $lsas,,198 $lsas,,194 $lsas,,203
lsas,,207 $lsas,,210 $lsas,,212 $lsas,,235 $lsas,,224 $lsas,,226 $lsas,,223
lsas,,214 $lsas,,217 $lsas,,219 $lsas,,237 $lsas,,231 $lsas,,233 $lsas,,230
lsas,,253 $lsas,,246 $lsas,,239 $lsas,,242 $lsas,,249 $lsas,,273 $lsas,,266
lsas,,259 $lsas,,258 $lsas,,265 $lsas,,272 $lsas,,280 $lsas,,277 $lsas,,283
lsas,,286 $lsas,,325 $lsas,,307 $lsas,,310 $lsas,,303 $lsas,,306 $lsas,,292
lsas,,289 $lsas,,295 $lsas,,298 $lsas,,328 $lsas,,319 $lsas,,322 $lsas,,315
lsas,,318 $lsas,,337 $lsas,,334 $lsas,,331 $lsas,,340 $lsas,,344 $lsas,,433
lsas,,391 $lsas,,395 $lsas,,384 $lsas,,387 $lsas,,390 $lsas,,354 $lsas,,351
lsas,,348 $lsas,,357 $lsas,,361 $lsas,,437 $lsas,,408 $lsas,,412 $lsas,,401
lsas,,404 $lsas,,407 $lsas,,371 $lsas,,368 $lsas,,365 $lsas,,374 $lsas,,378
lsas,,441 $lsas,,425 $lsas,,429 $lsas,,418 $lsas,,421 $lsas,,424 $lsas,,464
lsas,,467 $lsas,,468 $lsas,,471 $lsas,,474 $lsas,,479 $lsas,,482 $lsas,,485
lsas,,455 $lsas,,463 $lsas,,477 $lsas,,517 $lsas,,521 $lsas,,525 $lsas,,527
lsas,,492 $lsas,,501 $lsas,,510 $lsas,,511 $lsas,,502 $lsas,,493 $lsas,,531
lsas,,535 $lsas,,541 $lsas,,545 $lsas,,497 $lsas,,506 $lsas,,516 $lsas,,566
lsas,,569 $lsas,,571 $lsas,,575 $lsas,,573 $lsas,,578 $lsas,,581 $lsas,,585
lsas,,586 $lsas,,588 $lsas,,590 $lsas,,608 $lsas,,611 $lsas,,614 $lsas,,617
lsas,,620 $lsas,,637 $lsas,,623 $lsas,,650 $lsas,,651 $lsas,,654 $lsas,,655
lsas,,656 $lsas,,659 $lsas,,660 $lsas,,661 $lsas,,662 $lsas,,665 $lsas,,668
lsas,,669 $lsas,,672 $lsas,,675 $lsas,,676 $lsas,,677 $lsas,,678 $lsas,,679
lsas,,680 $lsas,,683 $lsas,,634 $lsas,,633 $lsas,,647
*end
/show,plots,f33
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,258.0
/title,(NT921222.mod) CASE STUDY - Lift 1 Placed, 860616
esel,mat,1, 2,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,259.0
/title,(NT921222.mod) CASE STUDY - Lift 1 Placed, 860617
esel,mat,1, 2,1 $plnstr,temp
finish
/prep7
resume $/noerase
```

```
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,261.0
/title,(NT921222.mod) CASE STUDY - Lift 1 Placed, 860619
esel,mat,1, 2,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,263.0
/title,(NT921222.mod) CASE STUDY - Lift 1 Placed, 860621
esel,mat,1, 2,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,267.0
/title,(NT921222.mod) CASE STUDY - Lift 2 Placed, 860625
esel,mat,1, 5,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,269.0
/title,(NT921222.mod) CASE STUDY - Lift 2 Placed, 860627
esel,mat,1, 5,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,271.0
/title,(NT921222.mod) CASE STUDY - Lift 2 Placed, 860629
esel,mat,1, 5,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,273.0
/title,(NT921222.mod) CASE STUDY - Lift 2 Placed, 860701
esel,mat,1, 5,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
```

```
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,279.0
/title,(NT921222.mod) CASE STUDY - Lift 3a/b Placed, 860707
esel,mat,1, 7,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,281.0
/title,(NT921222.mod) CASE STUDY - Lift 3a/b Placed, 860709
esel,mat,1, 7,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,283.0
/title,(NT921222.mod) CASE STUDY - Lift 3a/b Placed, 860711
esel,mat,1, 7,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,285.0
/title,(NT921222.mod) CASE STUDY - Lift 3a/b Placed, 860713
esel,mat,1, 7,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,293.0
/title,(NT921222.mod) CASE STUDY - Lift 3a/b Placed, 860721
esel,mat,1, 7,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,301.0
/title,(NT921222.mod) CASE STUDY - Lift 4 Placed, 860729
esel,mat,1, 9,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
```

```
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,303.0
/title,(NT921222.mod) CASE STUDY - Lift 4 Placed, 860731
esel,mat,1, 9,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,305.0
/title,(NT921222.mod) CASE STUDY - Lift 4 Placed, 860802
esel,mat,1, 9,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,307.0
/title,(NT921222.mod) CASE STUDY - Lift 4 Placed, 860804
esel,mat,1, 9,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,308.0
/title,(NT921222.mod) CASE STUDY - Lift 5 Placed, 860805
esel,mat,1,11,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,309.0
/title,(NT921222.mod) CASE STUDY - Lift 5 Placed, 860806
esel,mat,1,11,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,311.0
/title,(NT921222.mod) CASE STUDY - Lift 5 Placed, 860808
esel,mat,1,11,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
```

```
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,313.0
/title,(NT921222.mod) CASE STUDY - Lift 5 Placed, 860810
esel,mat,1,11,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,316.0
/title,(NT921222.mod) CASE STUDY - Lift 6 Placed, 860813
esel,mat,1,13,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,317.0
/title,(NT921222.mod) CASE STUDY - Lift 6 Placed, 860814
esel,mat,1,13,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,319.0
/title,(NT921222.mod) CASE STUDY - Lift 6 Placed, 860816
esel,mat,1,13,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,321.0
/title,(NT921222.mod) CASE STUDY - Lift 6 Placed, 860818
esel,mat,1,13,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,323.0
/title,(NT921222.mod) CASE STUDY - Lift 7 Placed, 860820
esel,mat,1,15,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
```

```
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,325.0
/title,(NT921222.mod) CASE STUDY - Lift 7 Placed, 860822
esel,mat,1,15,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,327.0
/title,(NT921222.mod) CASE STUDY - Lift 7 Placed, 860824
esel,mat,1,15,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,329.0
/title,(NT921222.mod) CASE STUDY - Lift 7 Placed, 860826
esel,mat,1,15,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,335.0
/title,(NT921222.mod) CASE STUDY - Lift 7 Placed, 860901
esel,mat,1,15,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,343.0
/title,(NT921222.mod) CASE STUDY - Lift 7 Placed, 860909
esel,mat,1,15,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,351.0
/title,(NT921222.mod) CASE STUDY - Lift 7 Placed, 860917
esel,mat,1,15,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,359.0
```

```
/title,(NT921222.mod) CASE STUDY - Lift 7 Placed, 860925
esel,mat,1,15,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,365.0
/title,(NT921222.mod) CASE STUDY - Lift 7 Placed, 861001
esel,mat,1,15,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,368.0
/title,(NT921222.mod) CASE STUDY - Lift 8a Placed, 861004
esel,mat,1,17,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,369.0
/title,(NT921222.mod) CASE STUDY - Lift 8a Placed, 861005
esel,mat,1,17,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,371.0
/title,(NT921222.mod) CASE STUDY - Lift 8a Placed, 861007
esel,mat,1,17,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,372.0
/title,(NT921222.mod) CASE STUDY - Lift 8b Placed, 861008
esel,mat,1,19,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,373.0
/title,(NT921222.mod) CASE STUDY - Lift 8b Placed, 861009
```

```
esel,mat,1,19,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,375.0
/title,(NT921222.mod) CASE STUDY - Lift 8b Placed, 861011
esel,mat,1,19,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,377.0
/title,(NT921222.mod) CASE STUDY - Lift 8b Placed, 861013
esel,mat,1,19,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,385.0
/title,(NT921222.mod) CASE STUDY - Lift 8b Placed, 861021
esel,mat,1,19,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,387.0
/title,(NT921222.mod) CASE STUDY - Lift 9 Placed, 861023
esel,mat,1,22,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,389.0
/title,(NT921222.mod) CASE STUDY - Lift 9 Placed, 861025
esel,mat,1,22,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,391.0
/title,(NT921222.mod) CASE STUDY - Lift 9 Placed, 861027
esel,mat,1,22,1 $plnstr,temp
```

```
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,393.0
/title,(NT921222.mod) CASE STUDY - Lift 9 Placed, 861029
esel,mat,1,22,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,397.0
/title,(NT921222.mod) CASE STUDY - Lift 9 Placed, 861102
esel,mat,1,22,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,409.0
/title,(NT921222.mod) CASE STUDY - Lift 9 Placed, 861114
esel,mat,1,22,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,416.0
/title,(NT921222.mod) CASE STUDY - Lift 9 Placed, 861121
esel,mat,1,22,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,423.0
/title,(NT921222.mod) CASE STUDY - Lift 9 Placed, 861128
esel,mat,1,22,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,426.0
/title,(NT921222.mod) CASE STUDY - Lift 9 Placed, 861201
esel,mat,1,22,1 $plnstr,temp
finish
```

```
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,437.0
/title,(NT921222.mod) CASE STUDY - Lift 9 Placed, 861212
esel,mat,1,22,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,444.0
/title,(NT921222.mod) CASE STUDY - Lift 9 Placed, 861219
esel,mat,1,22,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,458.0
/title,(NT921222.mod) CASE STUDY - Lift 9 Placed, 870102
esel,mat,1,22,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,465.0
/title,(NT921222.mod) CASE STUDY - Lift 9 Placed, 870109
esel,mat,1,22,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,475.0
/title,(NT921222.mod) CASE STUDY - Lift 9 Placed, 870119
esel,mat,1,22,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,486.0
/title,(NT921222.mod) CASE STUDY - Lift 9 Placed, 870130
esel,mat,1,22,1 $plnstr,temp
finish
/prep7
```

```
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,496.0
/title,(NT921222.mod) CASE STUDY - Lift 9 Placed, 870209
esel,mat,1,22,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,507.0
/title,(NT921222.mod) CASE STUDY - Lift 9 Placed, 870220
esel,mat,1,22,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,514.0
/title,(NT921222.mod) CASE STUDY - Lift 9 Placed, 870227
esel,mat,1,22,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,520.0
/title,(NT921222.mod) CASE STUDY - Lift 9 Placed, 870305
esel,mat,1,22,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,528.0
/title,(NT921222.mod) CASE STUDY - Lift 9 Placed, 870313
esel,mat,1,22,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,535.0
/title,(NT921222.mod) CASE STUDY - Lift 9 Placed, 870320
esel,mat,1,22,1 $plnstr,temp
finish
/prep7
resume $/noerase
```

```
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,542.0
/title,(NT921222.mod) CASE STUDY - Lift 9 Placed, 870327
esel,mat,1,22,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,549.0
/title,(NT921222.mod) CASE STUDY - Lift 9 Placed, 870403
esel,mat,1,22,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,556.0
/title,(NT921222.mod) CASE STUDY - Lift 9 Placed, 870410
esel,mat,1,22,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,563.0
/title,(NT921222.mod) CASE STUDY - Lift 10-1 Placed, 870417
esel,mat,1,25,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,565.0
/title,(NT921222.mod) CASE STUDY - Lift 10-1 Placed, 870419
esel,mat,1,25,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,567.0
/title,(NT921222.mod) CASE STUDY - Lift 10-1 Placed, 870421
esel,mat,1,25,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
```

```
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,568.0
/title,(NT921222.mod) CASE STUDY - Lift 10-1 Placed, 870422
esel,mat,1,25,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,568.0
/title,(NT921222.mod) CASE STUDY - Lift 10-2 Placed, 870422
esel,mat,1,28,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,569.0
/title,(NT921222.mod) CASE STUDY - Lift 10-2 Placed, 870423
esel,mat,1,28,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,571.0
/title,(NT921222.mod) CASE STUDY - Lift 10-2 Placed, 870425
esel,mat,1,28,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,573.0
/title,(NT921222.mod) CASE STUDY - Lift 10-2 Placed, 870427
esel,mat,1,28,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,575.0
/title,(NT921222.mod) CASE STUDY - Lift 10-3 Placed, 870429
esel,mat,1,31,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
```

```
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,577.0
/title,(NT921222.mod) CASE STUDY - Lift 10-3 Placed, 870501
esel,mat,1,31,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,579.0
/title,(NT921222.mod) CASE STUDY - Lift 10-3 Placed, 870503
esel,mat,1,31,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,581.0
/title,(NT921222.mod) CASE STUDY - Lift 10-3 Placed, 870505
esel,mat,1,31,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,588.0
/title,(NT921222.mod) CASE STUDY - Lift 11 Placed, 870512
esel,mat,1,34,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,589.0
/title,(NT921222.mod) CASE STUDY - Lift 11 Placed, 870513
esel,mat,1,34,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,591.0
/title,(NT921222.mod) CASE STUDY - Lift 11 Placed, 870515
esel,mat,1,34,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
```

```
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,593.0
/title,(NT921222.mod) CASE STUDY - Lift 11 Placed, 870517
esel,mat,1,34,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,597.0
/title,(NT921222.mod) CASE STUDY - Lift 12 Placed, 870521
esel,mat,1,37,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,599.0
/title,(NT921222.mod) CASE STUDY - Lift 12 Placed, 870523
esel,mat,1,37,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,601.0
/title,(NT921222.mod) CASE STUDY - Lift 12 Placed, 870525
esel,mat,1,37,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,603.0
/title,(NT921222.mod) CASE STUDY - Lift 12 Placed, 870527
esel,mat,1,37,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,605.0
/title,(NT921222.mod) CASE STUDY - Lift 13 Placed, 870529
esel,mat,1,39,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
```

```
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,607.0
/title,(NT921222.mod) CASE STUDY - Lift 13 Placed, 870531
esel,mat,1,39,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,609.0
/title,(NT921222.mod) CASE STUDY - Lift 13 Placed, 870602
esel,mat,1,39,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,610.0
/title,(NT921222.mod) CASE STUDY - Lift 13 Placed, 870603
esel,mat,1,39,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,610.0
/title,(NT921222.mod) CASE STUDY - Lift 14 Placed, 870603
esel,mat,1,40,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,611.0
/title,(NT921222.mod) CASE STUDY - Lift 14 Placed, 870604
esel,mat,1,40,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,613.0
/title,(NT921222.mod) CASE STUDY - Lift 14 Placed, 870606
esel,mat,1,40,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,615.0
```

```
/title,(NT921222.mod) CASE STUDY - Lift 14 Placed, 870608
esel,mat,1,40,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,623.0
/title,(NT921222.mod) CASE STUDY - Lift 14 Placed, 870616
esel,mat,1,40,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,624.0
/title,(NT921222.mod) CASE STUDY - Lift 15 Placed, 870617
esel,mat,1,42,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,625.0
/title,(NT921222.mod) CASE STUDY - Lift 15 Placed, 870618
esel,mat,1,42,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,627.0
/title,(NT921222.mod) CASE STUDY - Lift 15 Placed, 870620
esel,mat,1,42,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,629.0
/title,(NT921222.mod) CASE STUDY - Lift 15 Placed, 870622
esel,mat,1,42,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,640.0
/title,(NT921222.mod) CASE STUDY - Lift 15 Placed, 870703
```

```
esel,mat,1,42,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,654.0
/title,(NT921222.mod) CASE STUDY - Lift 15 Placed, 870717
esel,mat,1,42,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,661.0
/title,(NT921222.mod) CASE STUDY - Lift 15 Placed, 870724
esel,mat,1,42,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,668.0
/title,(NT921222.mod) CASE STUDY - Lift 15 Placed, 870731
esel,mat,1,42,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,675.0
/title,(NT921222.mod) CASE STUDY - Lift 15 Placed, 870807
esel,mat,1,42,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,684.0
/title,(NT921222.mod) CASE STUDY - Lift 15 Placed, 870816
esel,mat,1,42,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,696.0
/title,(NT921222.mod) CASE STUDY - Lift 15 Placed, 870828
esel,mat,1,42,1 $plnstr,temp
```

```
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,700.0
/title,(NT921222.mod) CASE STUDY - Lift 15 Placed, 870901
esel,mat,1,42,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,712.0
/title,(NT921222.mod) CASE STUDY - Lift 15 Placed, 870913
esel,mat,1,42,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,719.0
/title,(NT921222.mod) CASE STUDY - Lift 15 Placed, 870920
esel,mat,1,42,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,725.0
/title,(NT921222.mod) CASE STUDY - Lift 15 Placed, 870926
esel,mat,1,42,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
 * Create a handful of color plots ~~~~~~~~~~~
/show,colplots,f33
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,319.0
/title,(NT921222.mod) CASE STUDY - Lift 6 Placed, 860816
esel,mat,1,13,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,327.0
/title,(NT921222.mod) CASE STUDY - Lift 7 Placed, 860824
```

```
esel,mat,1,15,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,391.0
/title,(NT921222.mod) CASE STUDY - Lift 9 Placed, 861027
esel,mat,1,22,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,591.0
/title,(NT921222.mod) CASE STUDY - Lift 11 Placed, 870515
esel,mat,1,34,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,601.0
/title,(NT921222.mod) CASE STUDY - Lift 12 Placed, 870525
esel,mat,1,37,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,609.0
/title,(NT921222.mod) CASE STUDY - Lift 13 Placed, 870602
esel,mat,1,39,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post1
/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,627.0
/title,(NT921222.mod) CASE STUDY - Lift 15 Placed, 870620
esel,mat,1,42,1 $plnstr,temp
finish
/prep7
resume $/noerase
*use,outlines
/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff
finish
/post26
lines,200
time, 253 , 725  $disp,2,1888,temp,NODE $disp,3,1904,temp,NODE
disp,4,1910,temp,NODE
```

```
/out,trash,dat $prvar, 2 , 3 , 4
/title,(NT921222.mod) CASE STUDY - Lift 1 Internal Temperatures
/out,NT921222,001 $prvar, 2 , 3 , 4  $/out,6
time, 262 , 725  $disp,2,1740,temp,NODE $disp,3,1808,temp,NODE
disp,4,1826,temp,NODE $disp,5,1830,temp,NODE
/out,trash,dat $prvar, 2 , 3 , 4 , 5
/title,(NT921222.mod) CASE STUDY - Lift 2 Internal Temperatures
/out,NT921222,002 $prvar, 2 , 3 , 4 , 5  $/out,6
time, 274 , 725  $disp,2,1590,temp,NODE $disp,3,1619,temp,NODE
disp,4,1656,temp,NODE $disp,5,1665,temp,NODE
/out,trash,dat $prvar, 2 , 3 , 4 , 5
/title,(NT921222.mod) CASE STUDY - Lift 3a/b Internal Temperatures
/out,NT921222,3ab $prvar, 2 , 3 , 4 , 5  $/out,6
time, 296 , 725  $disp,2,1440,temp,NODE $disp,3,1422,temp,NODE
disp,4,1452,temp,NODE $disp,5,1461,temp,NODE
/out,trash,dat $prvar, 2 , 3 , 4 , 5
/title,(NT921222.mod) CASE STUDY - Lift 4 Internal Temperatures
/out,NT921222,004 $prvar, 2 , 3 , 4 , 5  $/out,6
time, 303 , 725  $disp,2,1272,temp,NODE $disp,3,1304,temp,NODE
disp,4,1218,temp,NODE $disp,5,1230,temp,NODE
/out,trash,dat $prvar, 2 , 3 , 4 , 5
/title,(NT921222.mod) CASE STUDY - Lift 5 Internal Temperatures
/out,NT921222,005 $prvar, 2 , 3 , 4 , 5  $/out,6
time, 311 , 725  $disp,2,1132,temp,NODE $disp,3,1161,temp,NODE
disp,4,1079,temp,NODE $disp,5,1091,temp,NODE
/out,trash,dat $prvar, 2 , 3 , 4 , 5
/title,(NT921222.mod) CASE STUDY - Lift 6 Internal Temperatures
/out,NT921222,006 $prvar, 2 , 3 , 4 , 5  $/out,6
time, 318 , 725  $disp,2,1003,temp,NODE $disp,3,1025,temp,NODE
disp,4, 954,temp,NODE $disp,5, 966,temp,NODE
/out,trash,dat $prvar, 2 , 3 , 4 , 5
/title,(NT921222.mod) CASE STUDY - Lift 7 Internal Temperatures
/out,NT921222,007 $prvar, 2 , 3 , 4 , 5  $/out,6
time, 363 , 725  $disp,2, 910,temp,NODE $disp,3, 896,temp,NODE
disp,4, 852,temp,NODE $disp,5, 864,temp,NODE
/out,trash,dat $prvar, 2 , 3 , 4 , 5
/title,(NT921222.mod) CASE STUDY - Lift 8a Internal Temperatures
/out,NT921222,08a $prvar, 2 , 3 , 4 , 5  $/out,6
time, 367 , 725  $disp,2, 805,temp,NODE $disp,3, 791,temp,NODE
disp,4, 750,temp,NODE $disp,5, 762,temp,NODE
/out,trash,dat $prvar, 2 , 3 , 4 , 5
/title,(NT921222.mod) CASE STUDY - Lift 8b Internal Temperatures
/out,NT921222,08b $prvar, 2 , 3 , 4 , 5  $/out,6
time, 382 , 725  $disp,2, 699,temp,NODE $disp,3, 723,temp,NODE
disp,4, 738,temp,NODE $disp,5, 639,temp,NODE $disp,6, 651,temp,NODE
/out,trash,dat $prvar, 2 , 3 , 4 , 5 , 6
/title,(NT921222.mod) CASE STUDY - Lift 9 Internal Temperatures
/out,NT921222,009 $prvar, 2 , 3 , 4 , 5 , 6  $/out,6
time, 558 , 725  $disp,2, 613,temp,NODE $disp,3, 618,temp,NODE
disp,4, 579,temp,NODE $disp,5, 591,temp,NODE
/out,trash,dat $prvar, 2 , 3 , 4 , 5
/title,(NT921222.mod) CASE STUDY - Lift 10-1 Internal Temperatures
/out,NT921222,101 $prvar, 2 , 3 , 4 , 5  $/out,6
time, 563 , 725  $disp,2, 556,temp,NODE $disp,3, 561,temp,NODE
disp,4, 519,temp,NODE $disp,5, 531,temp,NODE
/out,trash,dat $prvar, 2 , 3 , 4 , 5
/title,(NT921222.mod) CASE STUDY - Lift 10-2 Internal Temperatures
/out,NT921222,102 $prvar, 2 , 3 , 4 , 5  $/out,6
time, 570 , 725  $disp,2, 479,temp,NODE $disp,3, 469,temp,NODE
disp,4, 429,temp,NODE $disp,5, 441,temp,NODE
/out,trash,dat $prvar, 2 , 3 , 4 , 5
```

```
/title,(NT921222.mod) CASE STUDY - Lift 10-3 Internal Temperatures
/out,NT921222,103 $prvar, 2 , 3 , 4 , 5  $/out,6
time, 583 , 725  $disp,2, 371,temp,NODE $disp,3, 384,temp,NODE
disp,4, 328,temp,NODE $disp,5, 340,temp,NODE
/out,trash,dat $prvar, 2 , 3 , 4 , 5
/title,(NT921222.mod) CASE STUDY - Lift 11 Internal Temperatures
/out,NT921222,011 $prvar, 2 , 3 , 4 , 5  $/out,6
time, 592 , 725  $disp,2, 276,temp,NODE $disp,3, 286,temp,NODE
disp,4, 234,temp,NODE $disp,5, 246,temp,NODE
/out,trash,dat $prvar, 2 , 3 , 4 , 5
/title,(NT921222.mod) CASE STUDY - Lift 12 Internal Temperatures
/out,NT921222,012 $prvar, 2 , 3 , 4 , 5  $/out,6
time, 600 , 725  $disp,2, 219,temp,NODE $disp,3, 225,temp,NODE
disp,4, 147,temp,NODE $disp,5, 159,temp,NODE
/out,trash,dat $prvar, 2 , 3 , 4 , 5
/title,(NT921222.mod) CASE STUDY - Lift 13 Internal Temperatures
/out,NT921222,013 $prvar, 2 , 3 , 4 , 5  $/out,6
time, 605 , 725  $disp,2,  92,temp,NODE $disp,3, 117,temp,NODE
disp,4,  67,temp,NODE $disp,5,  79,temp,NODE
/out,trash,dat $prvar, 2 , 3 , 4 , 5
/title,(NT921222.mod) CASE STUDY - Lift 14 Internal Temperatures
/out,NT921222,014 $prvar, 2 , 3 , 4 , 5  $/out,6
time, 619 , 725  $disp,2,  26,temp,NODE $disp,3,  58,temp,NODE
disp,4,   1,temp,NODE $disp,5,  13,temp,NODE
/out,trash,dat $prvar, 2 , 3 , 4 , 5
/title,(NT921222.mod) CASE STUDY - Lift 15 Internal Temperatures
/out,NT921222,015 $prvar, 2 , 3 , 4 , 5  $/out,6
finish
/delete,trash,dat
/eof
```

APPENDIX G

GENERATION OF CASE STUDY ANALYSIS PROGRAM CODE

G GENERATION OF CASE STUDY ANALYSIS PROGRAM CODE

The steps of the analysis algorithm shown in Figure 2 form the basis for a pattern of finite element commands that define and execute an incremental analysis of a mass concrete dam. For the case study, a computer program in QuickBASIC® (QB) was written to generate an ASCII file of ANSYS commands that executes the analysis and post-processes the results. The benefits of this approach are that modifications to details of the model loading could be made conveniently and efficiently, command syntaxes could be corrected uniformly throughout the analysis file, and the ultimate size of the command file was unimportant. The following paragraphs are a very brief description of the process involved.

G.1 Finite Element Model Definition Commands

Commands for the finite element model were defined "by hand" in a separate file as the first step of the procedure. This allowed the mesh to be refined and proper node, line and material property data set numbers to be determined for use in the rest of the analysis command specifications. After the mesh was finalized, nodal temperature commands for the isothermal plane in the foundation and the placing temperature boundary conditions for the concrete lifts were added to the end of the file.

The QB program begins execution by initializing a series of variables and carrying out some preliminary input and output file openings. Following this, the finite element model and nodal temperature specification commands are copied over to an output file that ultimately becomes the file of commands that carries out the case study.

G.2 Analysis Commands

The commands that define the thermal loading on the dam and submit the model for solution follow a consistent pattern beginning with the loading on the foundation portion of the model. A series of load steps is defined for each period of time that the geometry of the model remains constant. Between each load step series, commands to add a new lift of concrete to the model are specified. The general process of defining each series of load steps is:

1. A unique analysis title for the current series of load steps is issued for reference purposes.

2. Beginning with the first series of load steps on the model with concrete in place, delete the nodal temperature boundary condition on the new concrete lift, and specify the coupling commands to add the lift to the active portion of the model.

3. Issue commands to flag the set of line numbers that make up the exposed surface of the dam for this series of load steps.

4. Open an input file containing weather data. Each record of the file contains data for one day, with a chronological date number (days since the start of the analysis, 851001), a date label, the low, high and median temperatures for that day, and the value of wind speed. Read through the file until the date one day before that of the first load step for this series is encountered.

5. Issue commands for the load steps making up this series. Begin on either the first day of the analysis (for the foundation loading series) or the day a new lift of concrete is placed, and end with the day the next lift of concrete is placed or the last day of the analysis. For each load step:
    a. Read a record from the weather data file.
    b. Calculate the convection coefficient for this day according to the wind data. If the data is listed as missing, adopt a default value.
    c. Determine how many iterations to solve this load step for, and whether this date is one that the solution of model temperatures should be recorded on.
    d. Write the appropriate iteration and post-data control commands for this load step.
    e. Issue the command to apply the convective boundary condition on the set of selected lines for this load step series. Utilize the chronologic value of time for this load step, the calculated value of h_c and the median temperature for the day.
    f. Starting with the first series of load steps on the model with concrete in place, calculate internal heat generation rates and issue the necessary commands. For each concrete type in the model:

i) If the concrete has been placed at this time in the analysis and it is still generating heat according to the heat generation rate equation for that concrete, calculate the rate for this load step.

ii) If the rate is greater than a limiting value below which it is considered to be zero, issue commands to select the elements of the concrete, assign the rate, and then un-select the elements. Otherwise, select the elements, delete the internal heat rate for subsequent load steps, and un-select the elements. Flag the concrete as no longer generating any heat.

iii) Issue commands to end this load step. Add a comment to identify the date and load step number for reference purposes.

g. For the series of load steps on the foundation, skip ahead a few days in the weather data file according to a pre-determined pattern of time intervals between load steps. This is a means of reducing the total number of load steps to be executed in this portion of the analysis.

6. After all load steps for this series are defined, close the weather data file and issue a command to delete the convective boundary condition so that definition of the next series of load steps can begin without any remnant convective boundary conditions on the model.

7. Issue commands that end this series of load steps and submit the analysis for solution over the time period covered by these load steps.

8. Issue file handling commands to accumulate the post-data results files from each load step series on a single file for later post-processing.

G.3 Post-processing Commands

Concurrent with writing analysis commands for each load step of the case study, post-processing commands to create thermal contour plots are written to a separate temporary file. Additional commands to create temperature listings for certain nodes are added to this file, and then the file contents are appended to the analysis commands to create the final executed form of the case study analysis file. The general steps to this portion of the code generation are as follows.

1. During the preliminary input and output file openings, open a temporary file for post-processing commands and write some comments as headings for this part of the code.

2. An ANSYS macro of model line selection commands is written to the file to be used as part of the thermal contour plotting process.

3. While writing commands for each load step of the analysis, check to see if a thermal contour plot should be created for the date of the load step. Contour plots are created generally on the day a lift is placed, on or about the third, fifth and seventh days after placement of a lift, and then approximately every week after that if a new lift has not yet been added to the model.

4. If a plot is to be created for this day, write a series of commands to the post-processing file:
   a. Issue commands to call the finite element program post-processor and retrieve the temperature distribution for this particular point in time in the analysis.
   b. Specify a title for the plot that reflects the date and most recent lift of concrete placed in the model.
   c. Issue a command for the algorithm to plot thermal contours for those segments of the model that are active at that point in time in the analysis.
   d. Exit the post-processor and enter the finite element program's pre-processor.
   e. Utilize the previously defined line selection macro to create an overlay on the contour plot that outlines the different lifts of the dam.
   f. Exit the pre-processor.

5. After all commands for contour plots are written to the post-processing file, issue commands that create listings of nodal temperatures through time for particular nodes in the model. Nodes for these listings are selected as being those reasonably near to the locations of the thermocouple wires embedded in each lift of concrete. The steps are as follows:
   a. Enter the finite element program's time-history post-processor.
   b. For each lift of concrete in the model:
      i) Issue a command to designate a time frame beginning just prior to the placing time for the lift and ending at the end time of the analysis.
      ii) Specify the node numbers to be listed for this concrete lift and send a dummy listing to a trash file. This is done so that the title for the listing can be revised from that defined during execution of the analysis.
      iii) Specify a revised title and send the temperature listing to a file for later reference.
   c. Write commands to exit the time-history post-processor and the ANSYS program.
6. Append the temporary file of post-processing commands to the file of analysis commands.

This final form of the file then defines the finite element model, specifies the sets of series of load steps and submits them for solution, and post-processes the analysis results.

G.4 QB Program Listing

The code for the QB program that generates the file of ANSYS commands to carry out the case study is shown below.

```
'
'
'                   ANSYS  THERMAL  ANALYSIS  FILE  GENERATION  PROGRAM
'
'
'
'
'
'              REVISION:  December 22, 1992
'
' Initialize assorted variables and define output format strings:

CLEAR : dt$ = DATE$
version$ = "NT" + MID$(dt$, 9, 2) + MID$(dt$, 1, 2) + MID$(dt$, 4, 2) + ".mod"
input.dir$ = "c:\terry\input\": node.input.dir$ = "c:\terry\input\nodes\"
line.input.dir$ = "c:\terry\input\lines\": output.dir$ = "c:\terry\output\"
no.runs = 19: no.materials = 42: Cp = .225: minimum.Q = .51
loadstep = 0: node.set.no = 0: a$ = "*": c$ = ",": d$ = "-": p$ = "#": s$ = "/"
krstrt$ = " $krstrt,###": tytle$ = "/title,(&) CASE STUDY - &"
ntdele$ = "ntdele,####&temp"
cpl$ = "cp,###&temp,####&####": cpmod$ = "cp,###&temp,####"
lssel$ = "lsse,,###": lsasel$ = "lsas,,###": DIM iter$(44)
iter$(10) = "iter,1": iter$(11) = "iter,1,,1": iter$(40) = "iter,4"
iter$(44) = "iter,4,,4": suppress$ = "podisp,-1 $postr,-1 $porf,-1"
lcvsf$ = "time,###.# $lcvsf,all,####&###.#          "
qe$ = "           esel,mat,## $qe,all,##### $eall"
qedele$ = "           esel,mat,## $qedele,all   $eall"
lwrite$ = " $lwrite & ###### & &####"
set$ = "/gline,1,-1 $/contour,,,-10,5,55 $set,,,,,###.#"
plnstr$ = "esel,mat,1&##&1 $plnstr,temp"
disp$ = "disp&#&####&temp,NODE": post26.out$ = "/out,&&&"
get$ = "/get,12,file##&dat": xrange$ = "xrange,###&### $plvar"

' ---------------------------------------------------------------------------
' Dimension and initialize data arrays (arrays identified at DATA listings):

CLS : LOCATE 13, 25: PRINT "Dimensioning and reading arrays. . ."
DIM title$(no.runs), nt.node(no.runs), coupled.nodes$(no.runs)
DIM loaded.lines$(no.runs), start.time(no.runs), end.time(no.runs)
DIM max.active.mat(no.runs), active$(no.materials), Q.data(no.materials, 5)
DIM post.nodes(no.runs, 10), post26.ext$(no.runs), time AS DOUBLE

'   "title$()" - partial titles for use in various places:
FOR i = 1 TO no.runs: READ title$(i): NEXT i
DATA "Excavated Bedrock","Lift 1","Lift 2","Lift 3a/b","Lift 4","Lift 5"
DATA "Lift 6","Lift 7","Lift 8a","Lift 8b","Lift 9","Lift 10-1","Lift 10-2"
DATA "Lift 10-3","Lift 11","Lift 12","Lift 13","Lift 14","Lift 15"

'   "nt.node()" - node numbers that initialized each lift to the placing
'   temperature; note that nt.node(1) is the second node initializing lift
'   3a/b; each nt is deleted immediately prior to the loading of its run:
FOR i = 1 TO no.runs: READ nt.node(i): NEXT i
DATA 1555,1832,1677,1509,1478,1243,1104,979,872,770,664,583,523,449,353,259
DATA 172,123,45
'   "coupled.nodes$()" - file names of node pair lists for coupling, and
'   "loaded.lines$()" - file names of convective line lists for loading:
FOR i = 1 TO no.runs
```

```
   READ coupled.nodes$(i): loaded.lines$(i) = coupled.nodes$(i)
NEXT i
DATA "Bedrock","Lift001","Lift002","Lift3ab","Lift004","Lift005","Lift006"
DATA "Lift007","Lift08a","Lift08b","Lift009","Lift101","Lift102","Lift103"
DATA "Lift011","Lift012","Lift013","Lift014","Lift015"

'    "start.time()" - start times for each run (days since 851001):
FOR i = 1 TO no.runs: READ start.time(i): NEXT i
DATA 0,258,267,279,301,308,316,323,368,372,387,563,568,575,588,597,605,610,624

'    "end.time()" - end times for each run (days since 851001):
FOR i = 1 TO no.runs: READ end.time(i): NEXT i
DATA 258,267,279,301,308,316,323,368,372,387,563,568,575,588,597,605,610,624,725

'    "max.active.mat()" - the maximum active material number for each run:
FOR i = 1 TO no.runs: READ max.active.mat(i): NEXT i
DATA 1,2,5,7,9,11,13,15,17,19,22,25,28,31,34,37,39,40,42

'    "active$()" - indicator of whether a concrete is still generating heat:
FOR i = 1 TO no.materials: active$(i) = "yep": NEXT i

'    "Q.data()" - parameters for calculation of internal heat generated
'    by each concrete at any age (mat #, density, K, alfa, active time):
FOR i = 1 TO no.materials: FOR j = 1 TO 5: READ Q.data(i, j): NEXT j, i
DATA  1,    0,   0,     0,   0,  2,2319,23.5,0.660,258,  3,2319,23.5,0.660,267
DATA  4,2324,28.2,0.650,267,  5,2298,32.4,0.660,267,  6,2319,23.5,0.660,279
DATA  7,2324,28.2,0.650,279,  8,2262,24.1,0.660,301,  9,2284,27.9,0.650,301
DATA 10,2262,24.1,0.660,308, 11,2284,27.9,0.650,308, 12,2276,24.8,0.660,316
DATA 13,2285,28.7,0.650,316, 14,2276,24.8,0.660,323, 15,2285,28.7,0.650,323
DATA 16,2276,24.8,0.660,368, 17,2285,28.7,0.650,368, 18,2276,24.8,0.660,372
DATA 19,2285,28.7,0.650,372, 20,2276,24.8,0.660,387, 21,2285,28.7,0.650,387
DATA 22,2291,37.3,0.660,387, 23,2258,25.0,0.660,563, 24,2285,29.5,0.650,563
DATA 25,2303,39.5,0.660,563, 26,2258,25.0,0.660,568, 27,2285,29.5,0.650,568
DATA 28,2303,39.5,0.660,568, 29,2258,25.0,0.660,575, 30,2285,29.5,0.650,575
DATA 31,2303,39.5,0.660,575, 32,2258,25.0,0.660,588, 33,2285,29.5,0.650,588
DATA 34,2303,39.5,0.660,588, 35,2258,25.0,0.660,597, 36,2285,29.5,0.650,597
DATA 37,2303,39.5,0.660,597, 38,2264,25.7,0.660,605, 39,2317,40.9,0.650,605
DATA 40,2317,40.9,0.650,610, 41,2305,40.3,0.655,624, 42,2331,48.0,0.660,624

'    "Post.nodes()" - node numbers for post26 temperature plots and listings
'    (run number, no. of nodes for post-processing this runn, node numbers):
FOR i = 1 TO no.runs: READ runn, n
   post.nodes(runn, 1) = n: FOR j = 2 TO n + 1: READ post.nodes(runn, j)
NEXT j, i
DATA 1,0,  2,3,1888,1904,1910,  3,4,1740,1808,1826,1830
DATA 4,4,1590,1619,1656,1665,   5,4,1440,1422,1452,1461
DATA 6,4,1272,1304,1218,1230,   7,4,1132,1161,1079,1091
DATA 8,4,1003,1025,954,966,     9,4,910,896,852,864
DATA 10,4,805,791,750,762,      11,5,699,723,738,639,651
DATA 12,4,613,618,579,591,      13,4,556,561,519,531
DATA 14,4,479,469,429,441,      15,4,371,384,328,340
DATA 16,4,276,286,234,246,      17,4,219,225,147,159
DATA 18,4,92,117,67,79,         19,4,26,58,1,13

'  "post26.ext$()" - file extensions for names of output files containing
'  temperature listings from post26:
FOR i = 2 TO no.runs: READ post26.ext$(i): NEXT i
DATA "001","002","3ab","004","005","006","007","08a","08b","009","101"
DATA "102","103","011","012","013","014","015"

' ---------------------------------------------------------------------------
'  Preliminary file openings and initializations:

CLS : LOCATE 13, 18: PRINT "Preliminary file openings and initializations"

   ' Open the file of dates to write file12 on and read the first one:
OPEN input.dir$ + "f12dates.dat" FOR INPUT AS #3: INPUT #3, ref.date

   ' Open the file of dates that color plots are going to be created on:
```

```
OPEN input.dir$ + "colplots.dat" FOR INPUT AS #8: INPUT #8, color.date

   '  Open a file to temporarily list commands for post1 and post26 plots,
   '  beginning with a macro to outline lifts for thermal contour plots:
OPEN output.dir$ + "temp.dat" FOR OUTPUT AS #4
PRINT #4, " *"
PRINT #4, " * ~~~~~~~~~~~~~~~~~~~~~~   POST-PROCESSING COMMANDS   ~~~~~~~~~~~~~~~~~~~~~~~~~"
PRINT #4, " *": PRINT #4, "*create,outlines"
OPEN line.input.dir$ + "postline.dat" FOR INPUT AS #7: PRINT #4, "lsall $";
INPUT #7, line.no: PRINT #4, USING lssel$; line.no; : counter = 1
WHILE NOT EOF(7)
   INPUT #7, line.no: counter = counter + 1
   IF counter MOD 7 = 0 THEN PRINT #4,  ELSE PRINT #4, " $";
   PRINT #4, USING lsasel$; line.no;
WEND
CLOSE #7: PRINT #4, : PRINT #4, "*end": PRINT #4, "/show,plots,f33"

   '  Open a file for commands to create color plots (separate from
   '  the file for black and white plots):
OPEN output.dir$ + "temp2.dat" FOR OUTPUT AS #9
PRINT #9, " * Create a handful of color plots ~~~~~~~~~~~"
PRINT #9, "/show,colplots,f33"

   '  Open file for commands that define the model, carry out the incremental
   '  thermal analysis, and do the post-processing.  The filename reflects
   '  the date this program was run.  Print a header as a comment.
OPEN output.dir$ + version$ FOR OUTPUT AS #1
PRINT #1, " * ~~~~~~~~~~~~~~~   CASE STUDY INCREMENTAL THERMAL ANALYSIS   ~~~~~~~~~~~~~~~"
PRINT #1, " *": PRINT #1, " *                              Version Name = "; version$
PRINT #1, " *                    Date = "; DATE$; "   Time = "; TIME$: PRINT #1, " *"

   '  Open the file of commands that define the geometry of the model and
   '  copy them over into the master command file:
OPEN input.dir$ + "nt2.mod" FOR INPUT AS #6: LINE INPUT #6, x$
DO: PRINT #1, x$: LINE INPUT #6, x$: LOOP UNTIL x$ = "finish": CLOSE #6
PRINT #1, " *"
PRINT #1, " * ~~~~~~~~~~~~~~~~~~~~~~~~~   ANALYSIS COMMANDS   ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~"
PRINT #1, " *"

' ------------------------------------------------------------------------------------------
'  Loop through each of the thermal runs writing the analysis and
'  post-processing commands:

FOR runn = 1 TO no.runs

   SOUND 1500, 5: CLS : LOCATE 13, 25: PRINT "Writing commands for run "; runn
   IF runn = 1 THEN
      PRINT #1, USING tytle$; version$; title$(runn)
   ELSE
      PRINT #1, "/prep7": PRINT #1, "resume"; : PRINT #1, USING krstrt$; loadstep
      t$ = title$(runn) + " Placed": PRINT #1, USING tytle$; version$; t$
   END IF

   '  For second and subsequent runs, delete nt boundary condition for the
   '  new lift, and couple bottom nodes of the new lift to the model:

   IF runn > 1 THEN
      IF runn = 4 THEN PRINT #1, USING ntdele$; nt.node(1); c$; : PRINT #1, " $";
      PRINT #1, USING ntdele$; nt.node(runn); c$; : counter = 0

      OPEN node.input.dir$ + coupled.nodes$(runn) + ".nds" FOR INPUT AS #2
      WHILE NOT EOF(2)
         INPUT #2, node1, node2: counter = counter + 1
         IF counter MOD 3 = 0 THEN PRINT #1,  ELSE PRINT #1, " $";
         IF runn = 3 AND node1 = 1803 THEN
            PRINT #1, USING cpmod$; nset1904; c$; 1803; : GOTO next.pair:
         ELSEIF runn = 3 AND node1 = 1716 THEN
            PRINT #1, USING cpmod$; nset1832; c$; 1716; : GOTO next.pair:
         ELSEIF runn = 4 AND node1 = 1535 THEN
```

```
            PRINT #1, USING cpmod$; nset1677; c$; 1535; : GOTO next.pair:
         ELSEIF runn = 5 AND node1 = 1466 THEN
            PRINT #1, USING cpmod$; nset1509; c$; 1466; : GOTO next.pair:
         END IF
         node.set.no = node.set.no + 1
         PRINT #1, USING cpl$; node.set.no; c$; node1; c$; node2;
         IF node1 = 1904 THEN nset1904 = node.set.no
         IF node1 = 1832 THEN nset1832 = node.set.no
         IF node1 = 1677 THEN nset1677 = node.set.no
         IF node1 = 1509 THEN nset1509 = node.set.no
next.pair:
      WEND
      PRINT #1, : CLOSE #2
   END IF

   '  Write convective line selection commands:

   OPEN line.input.dir$ + loaded.lines$(runn) + ".lns" FOR INPUT AS #2
   INPUT #2, line.no: PRINT #1, USING lssel$; line.no; : counter = 0
   WHILE NOT EOF(2)
      INPUT #2, line.no: counter = counter + 1
      IF counter MOD 7 = 0 THEN PRINT #1,  ELSE PRINT #1, " $";
      PRINT #1, USING lsasel$; line.no;
   WEND
   PRINT #1, : CLOSE #2

   '  Open weather data file and find the start of data for current run:

   OPEN input.dir$ + "weather.dat" FOR INPUT AS #2: time = 0
   WHILE time < (start.time(runn) - 1)
      INPUT #2, time, date, lo, high, median, wind
   WEND

   '  Write load steps for this run beginning with convective load, but
   '  only write file12 when required and suppress it otherwise:

   last.it.str.no = 99: plot.no = 0
   WHILE time < end.time(runn)

      INPUT #2, time, date, lo, hi, median, wind
      loadstep = loadstep + 1: plot$ = "no"
      IF time = 0 THEN median = 0                ' Special case at time = 0

      '  Calculate Hc according to daily average wind speed, or
      '  adopt a default value if data is missing:

      IF wind <> -999 THEN
         H = 20.633 * (6 + 3.7 * (wind * 1000 / 60 / 60))
      ELSE
         H = 240
      END IF

      '  Determine which iter command to use for this load step:

      SELECT CASE time
         CASE start.time(runn)
            IF date = ref.date THEN
               IF NOT EOF(3) THEN INPUT #3, ref.date ELSE ref.date = 999999: CLOSE #3
            END IF
            IF runn = 1 THEN it.str.no = 10 ELSE it.str.no = 11: time = time + .1
         CASE start.time(runn) + 1 TO end.time(runn) - 1
            IF date = ref.date THEN
               it.str.no = 44
               IF NOT EOF(3) THEN INPUT #3, ref.date ELSE ref.date = 999999: CLOSE #3
            ELSEIF (runn = 11 OR runn = 19) AND time MOD 20 = 0 THEN it.str.no = 44
            ELSE it.str.no = 40
            END IF
         CASE ELSE
            IF date = ref.date THEN
```

```
         IF NOT EOF(3) THEN INPUT #3, ref.date ELSE ref.date = 999999: CLOSE #3
      END IF
      it.str.no = 44
END SELECT

' Decide whether to write the file12 suppress commands or not:

IF it.str.no <> last.it.str.no THEN
   last.it.str.no = it.str.no
   SELECT CASE it.str.no
      CASE 10: PRINT #1, iter$(10); " $"; suppress$
      CASE 40
         SELECT CASE runn
            CASE 1: PRINT #1, iter$(40); " $"; suppress$
            CASE ELSE
               IF time = start.time(runn) + 1 THEN
                  PRINT #1, iter$(40); " $"; suppress$
               ELSE PRINT #1, suppress$
               END IF
         END SELECT
      CASE ELSE: PRINT #1, iter$(it.str.no)
   END SELECT
END IF

PRINT #1, USING lcvsf$; time; H; c$; median;

' If applicable, calculate and write internal heat generation loading:

IF runn > 1 THEN
   FOR mat.no = max.active.mat(runn) TO 2 STEP -1
      IF active$(mat.no) = "yep" THEN
         Q = Q.data(mat.no, 4) * Q.data(mat.no, 3) * Cp * Q.data(mat.no, 2)
         Q = Q * EXP(-Q.data(mat.no, 4) * (time - Q.data(mat.no, 5)))
         IF Q >= minimum.Q THEN
            PRINT #1, : PRINT #1, USING qe$; mat.no; Q;
         ELSE
            PRINT #1, : PRINT #1, USING qedele$; mat.no;
            active$(mat.no) = "nope"
         END IF
      END IF
   NEXT mat.no
END IF

PRINT #1, USING lwrite$; a$; date; s$; p$; loadstep

' Decide whether or not to generate a thermal contour plot:

IF runn > 1 THEN
   IF time = (start.time(runn) + .1) THEN
      plot.no = 1: plot$ = "yep": plot.time = time - .1: plot.date = date
   ELSEIF time >= (start.time(runn) + 1) AND time < (start.time(runn) + 3) THEN
      IF plot.no = 1 AND it.str.no = 44 THEN
         plot.no = 2: plot$ = "yep": plot.time = time: plot.date = date
      END IF
   ELSEIF time >= (start.time(runn) + 3) AND time < (start.time(runn) + 5) THEN
      IF plot.no = 2 AND it.str.no = 44 THEN
         plot.no = 3: plot$ = "yep": plot.time = time: plot.date = date
      END IF
   ELSEIF time >= (start.time(runn) + 5) AND time < (start.time(runn) + 7) THEN
      IF plot.no = 3 AND it.str.no = 44 THEN
         plot.no = 4: plot$ = "yep": plot.time = time: plot.date = date
      END IF
   ELSEIF time >= (start.time(runn) + 7) AND time < end.time(runn) THEN
      IF plot.no <> 3 AND it.str.no = 44 AND date - plot.date >= 7 THEN
         plot$ = "yep": plot.time = time: plot.date = date
      END IF
   ELSEIF time = end.time(runn) AND runn = 19 THEN
      plot$ = "yep": plot.time = time: plot.date = date
   END IF
```

```
    END IF

    '  Write commands to generate post1 plots with line overlay from prep7:

    IF plot$ = "yep" THEN
       IF runn = 1 THEN
          t$ = title$(runn) + c$ + STR$(plot.date)
       ELSE
          t$ = title$(runn) + " Placed," + STR$(plot.date)
       END IF
       PRINT #4, "/post1": PRINT #4, USING set$; plot.time
       PRINT #4, USING tytle$; version$; t$
       PRINT #4, USING plnstr$; c$; max.active.mat(runn); c$
       PRINT #4, "finish": PRINT #4, "/prep7"
       PRINT #4, "resume $/noerase": PRINT #4, "*use,outlines"
       PRINT #4, "/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff"
       PRINT #4, "finish"
    END IF

    '  If a color plot is called for, print commands to send plot to
    '  a separate file that will get converted to color postscript:

    IF date >= color.date AND it.str.no = 44 THEN
       IF NOT EOF(8) THEN
          INPUT #8, color.date
       ELSE
          color.date = 999999: CLOSE #8
       END IF
       plot.time = time: plot.date = date
       IF runn = 1 THEN
          t$ = title$(runn) + c$ + STR$(plot.date)
       ELSE
          t$ = title$(runn) + " Placed," + STR$(plot.date)
       END IF
       PRINT #9, "/post1": PRINT #9, USING set$; plot.time
       PRINT #9, USING tytle$; version$; t$
       PRINT #9, USING plnstr$; c$; max.active.mat(runn); c$
       PRINT #9, "finish": PRINT #9, "/prep7"
       PRINT #9, "resume $/noerase": PRINT #9, "*use,outlines"
       PRINT #9, "/ploff,1,1,1,1 $lplot $/erase $lsall $/ploff"
       PRINT #9, "finish"
    END IF

    '  Skip ahead a few days at a time for the bedrock loading:

    IF runn = 1 THEN
       time.left = end.time(1) - time
       IF time.left >= 60 THEN
          FOR i = 1 TO 6: INPUT #2, time, date, lo, hi, median, wind: NEXT i
       ELSEIF time.left >= 28 THEN
          FOR i = 1 TO 3: INPUT #2, time, date, lo, hi, median, wind: NEXT i
       ELSEIF time.left >= 7 THEN
          INPUT #2, time, date, lo, hi, median, wind
       END IF
    END IF

WEND
CLOSE #2

'  Delete convective loading, print wrap-up and solution commands for
'  this run, and go into aux1 to append file12 to the bottom of
'  a cumulative post-data file (alternate between file35 and file36):

PRINT #1, "sbcdele,lcvsf,all $lsall $afwrite": PRINT #1, "finish"
PRINT #1, "/input,27": PRINT #1, "finish"

IF runn = 1 THEN
   PRINT #1, "/aux1": PRINT #1, "copy,12,35": PRINT #1, "finish"
ELSEIF runn MOD 2 = 0 THEN
```

```
      PRINT #1, "/aux1": PRINT #1, "copy,35,36 $copy,12,36"
      PRINT #1, "finish": PRINT #1, "/delete,file35,dat": last.file12.no = 36
   ELSE
      PRINT #1, "/aux1": PRINT #1, "copy,36,35 $copy,12,35"
      PRINT #1, "finish": PRINT #1, "/delete,file36,dat": last.file12.no = 35
   END IF

NEXT runn

' ----------------------------------------------------------------------
' Place color plot commands on bottom of temporary file:

CLOSE #9: OPEN output.dir$ + "temp2.dat" FOR INPUT AS #9
WHILE NOT EOF(9): LINE INPUT #9, x$: PRINT #4, x$: WEND: CLOSE #9
KILL output.dir$ + "temp2.dat"

' ----------------------------------------------------------------------
' Write commands for post26 post-processing to the temporary file:

PRINT #4, "/post26": PRINT #4, "lines,200"
'PRINT #4, "lines,200 $/graph,laby,TEMP $yrange,-15,55"

FOR runn = 2 TO no.runs

   PRINT #4, "time,"; start.time(runn) - 5; c$; end.time(no.runs);
   FOR i = 2 TO post.nodes(runn, 1) + 1
      IF i MOD 4 = 0 THEN PRINT #4,  ELSE PRINT #4, " $";
      PRINT #4, USING disp$; c$; i; c$; post.nodes(runn, i); c$;
   NEXT i
   PRINT #4, : PRINT #4, "/out,trash,dat $prvar";
   FOR i = 2 TO post.nodes(runn, 1) + 1: PRINT #4, c$; i; : NEXT i: PRINT #4,
   t$ = title$(runn) + " Internal Temperatures"
   PRINT #4, USING tytle$; version$; t$
   PRINT #4, USING post26.out$; MID$(version$, 1, 8); c$; post26.ext$(runn);
   PRINT #4, " $prvar";
   FOR i = 2 TO post.nodes(runn, 1) + 1: PRINT #4, c$; i; : NEXT i
   PRINT #4, " $/out,6"
   'PRINT #4, USING xrange$; start.time(runn) - 10; c$; start.time(runn) + 110;
   'FOR i = 2 TO post.nodes(runn, 1) + 1: PRINT #4, c$; i; : NEXT i: PRINT #4,

NEXT runn

PRINT #4, "finish": PRINT #4, "/delete,trash,dat": PRINT #4, "/eof": CLOSE #4

' ----------------------------------------------------------------------
' Tack the post-processing commands onto the end of the master
' file of commands to make one monster file for all purposes:

PRINT #1, USING get$; last.file12.no; c$
OPEN output.dir$ + "temp.dat" FOR INPUT AS #4

WHILE NOT EOF(4): LINE INPUT #4, x$: PRINT #1, x$: WEND: CLOSE #4
KILL output.dir$ + "temp.dat"

CLOSE : FOR i = 180 TO 1 STEP -1: SOUND 100 * i, .15: NEXT i

END
```

APPENDIX H

CASE STUDY ANALYSIS COMPARISONS TO IN SITU DATA

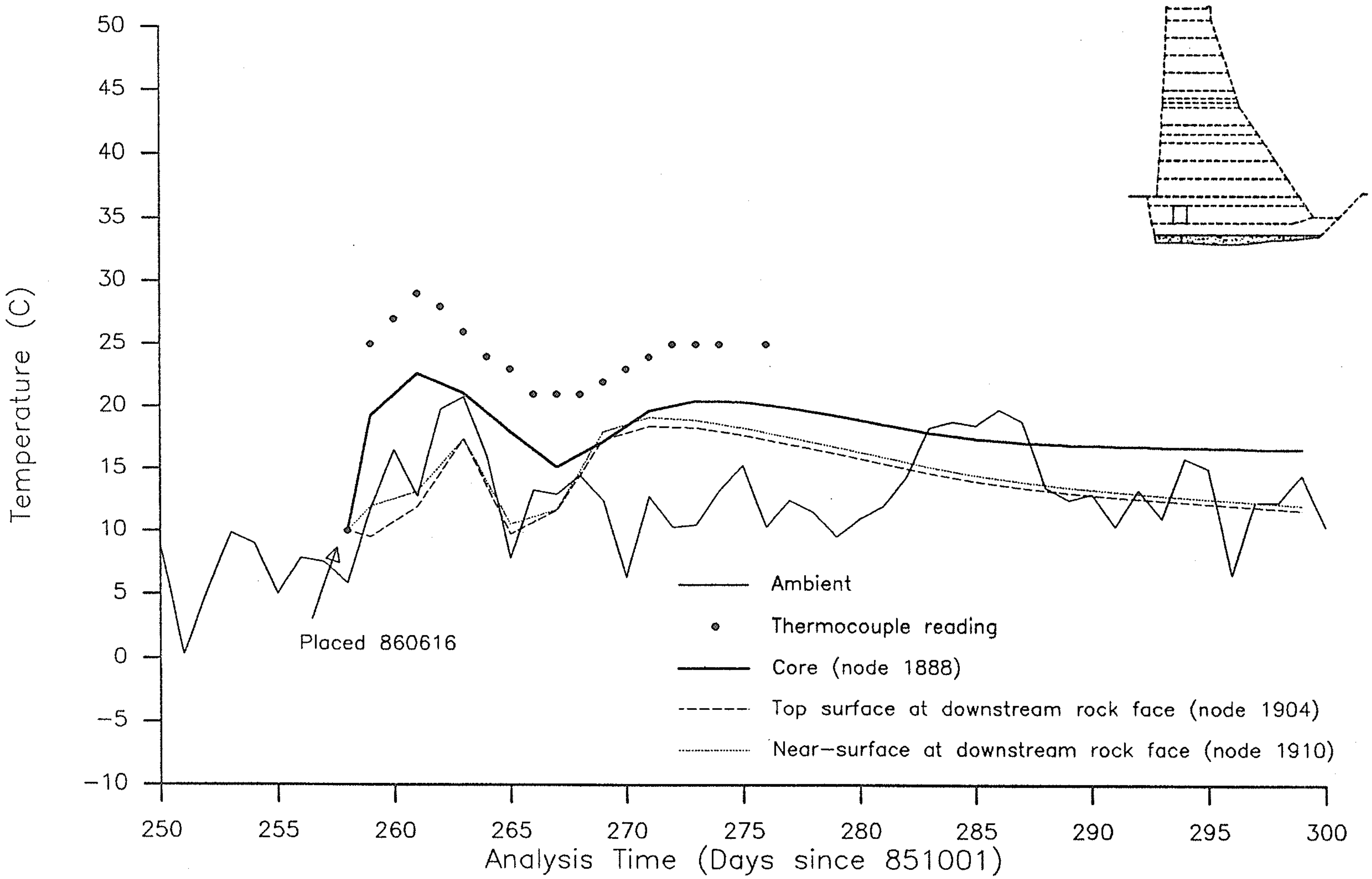

FIGURE H.1 - Comparison of Case Study Analysis Results to Measured In Situ Data for Lift NT2-1

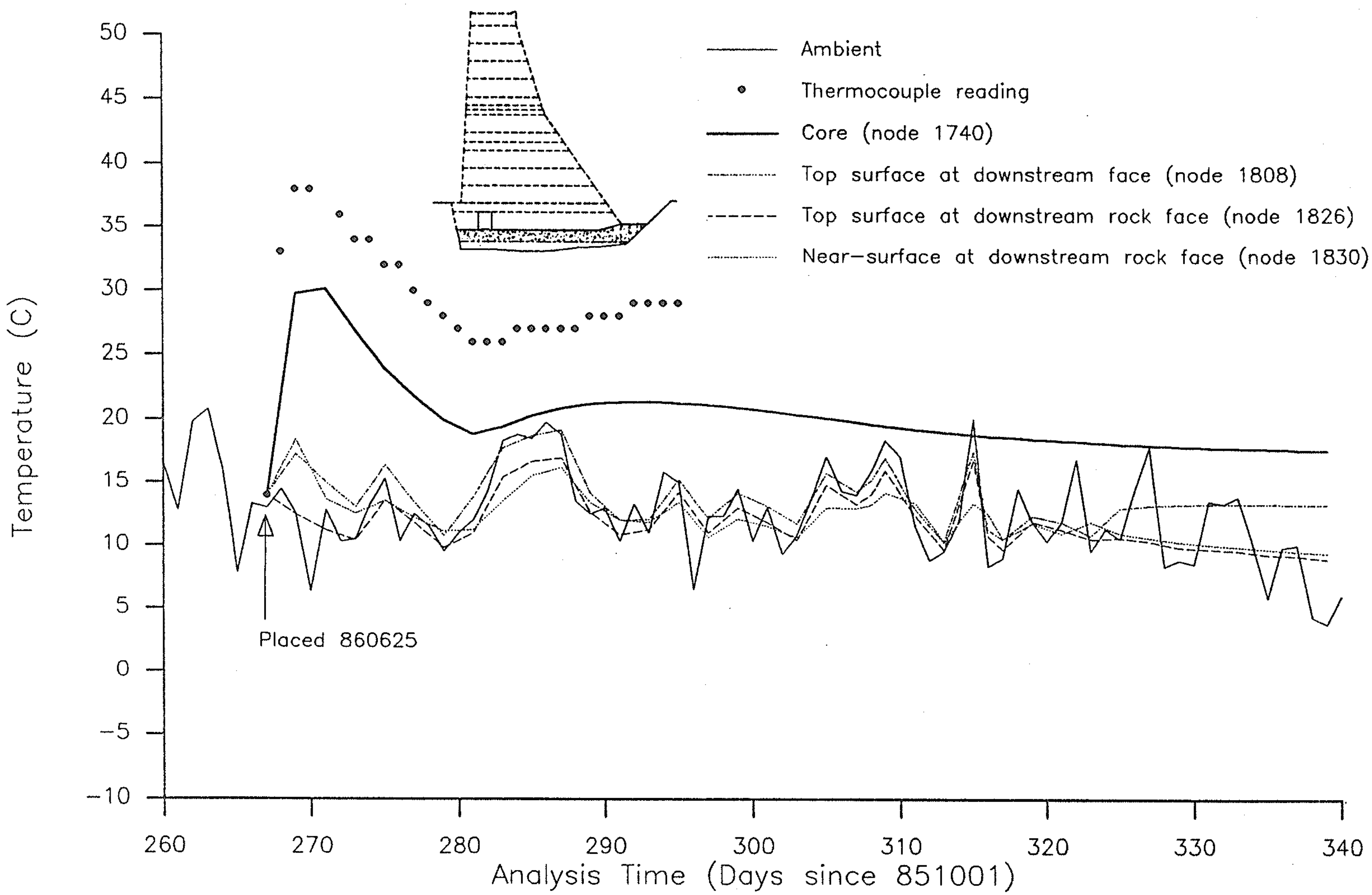

FIGURE H.2 - Comparison of Case Study Analysis Results to Measured In Situ Data for Lift NT2-2

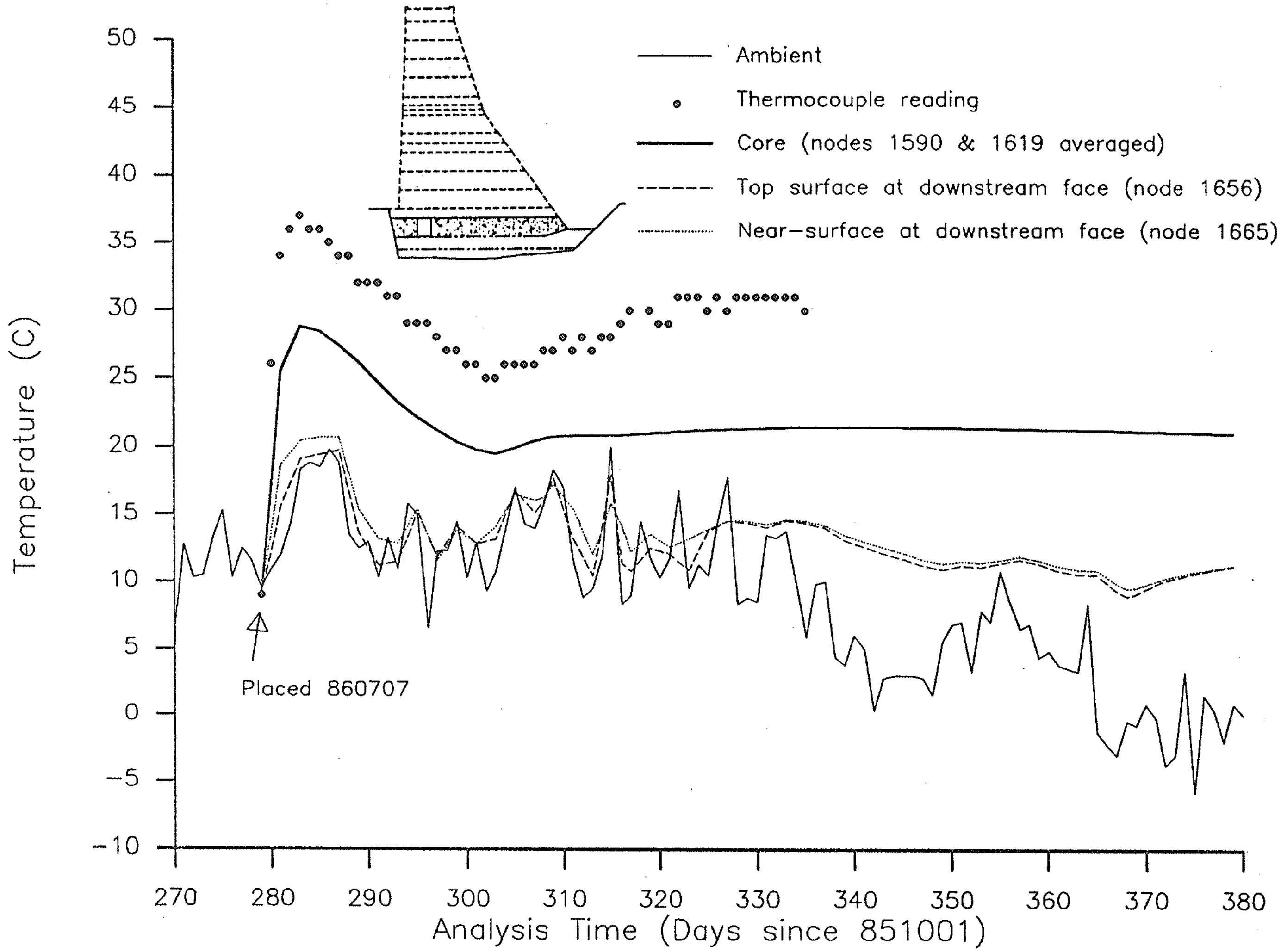

FIGURE H.3 - Comparison of Case Study Analysis Results to Measured In Situ Data for Lift NT2-3a/b

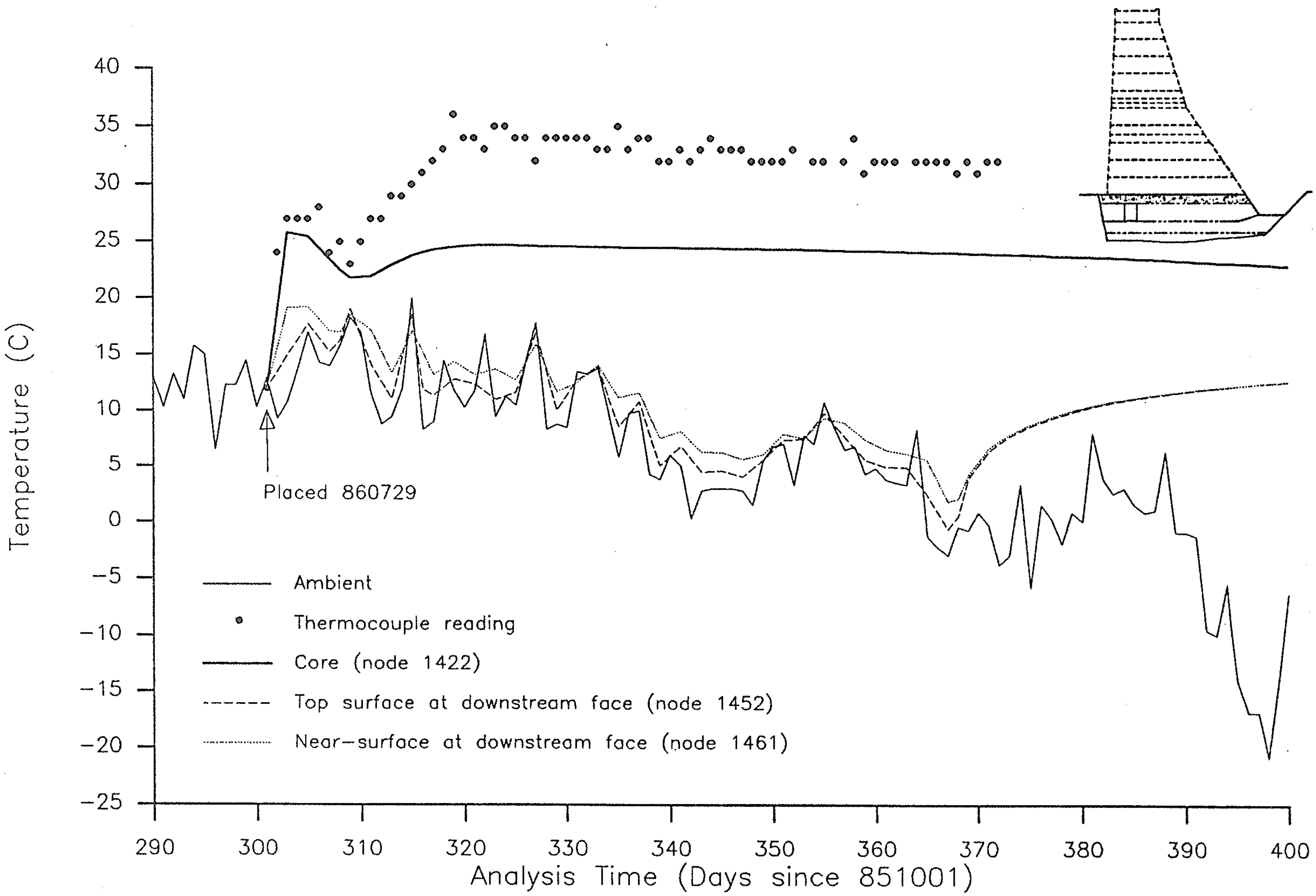

FIGURE H.4 - Comparison of Case Study Analysis Results to Measured In Situ Data for Lift NT2-4

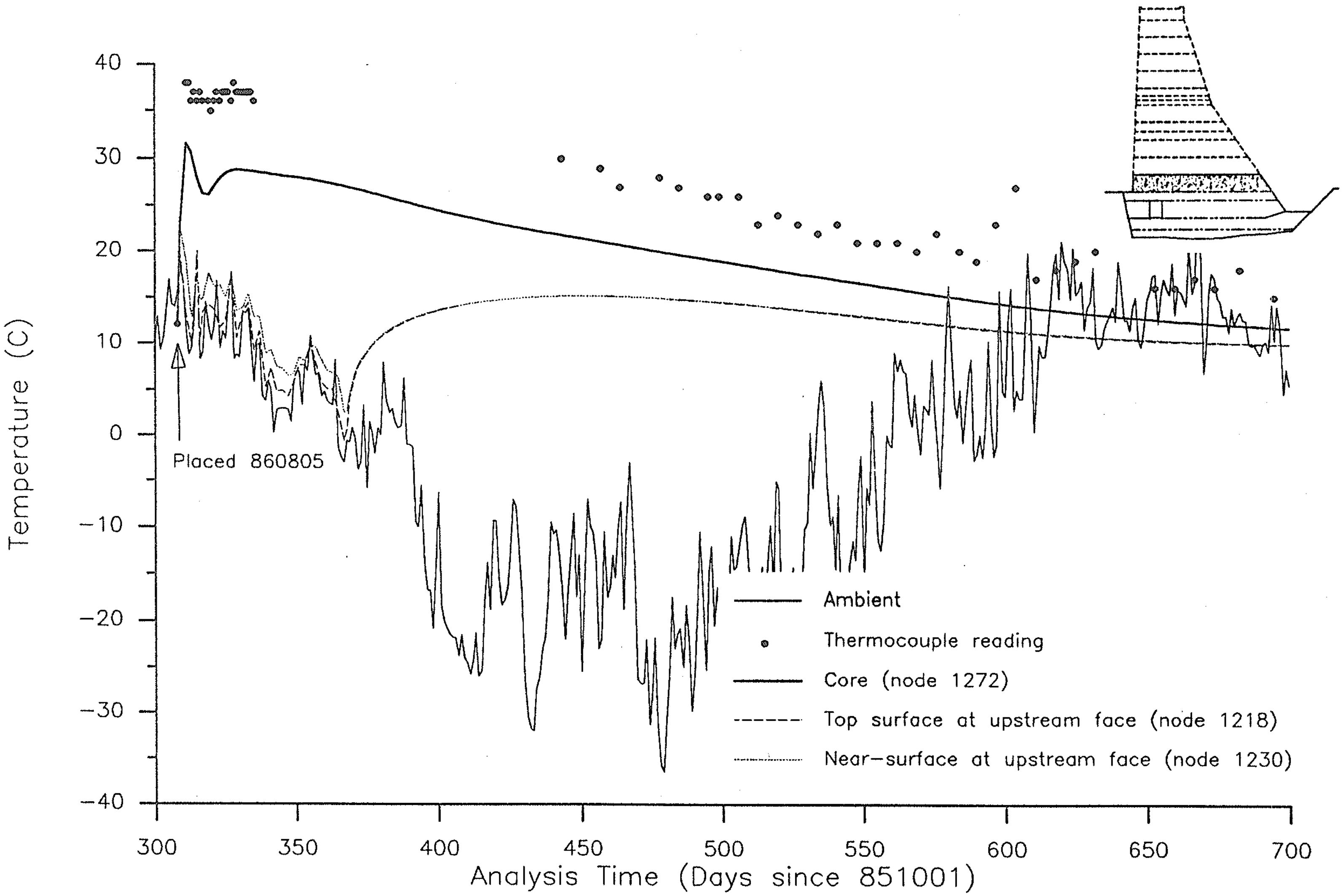

FIGURE H.5 - Comparison of Case Study Analysis Results to Measured In Situ Data for Lift NT2-5

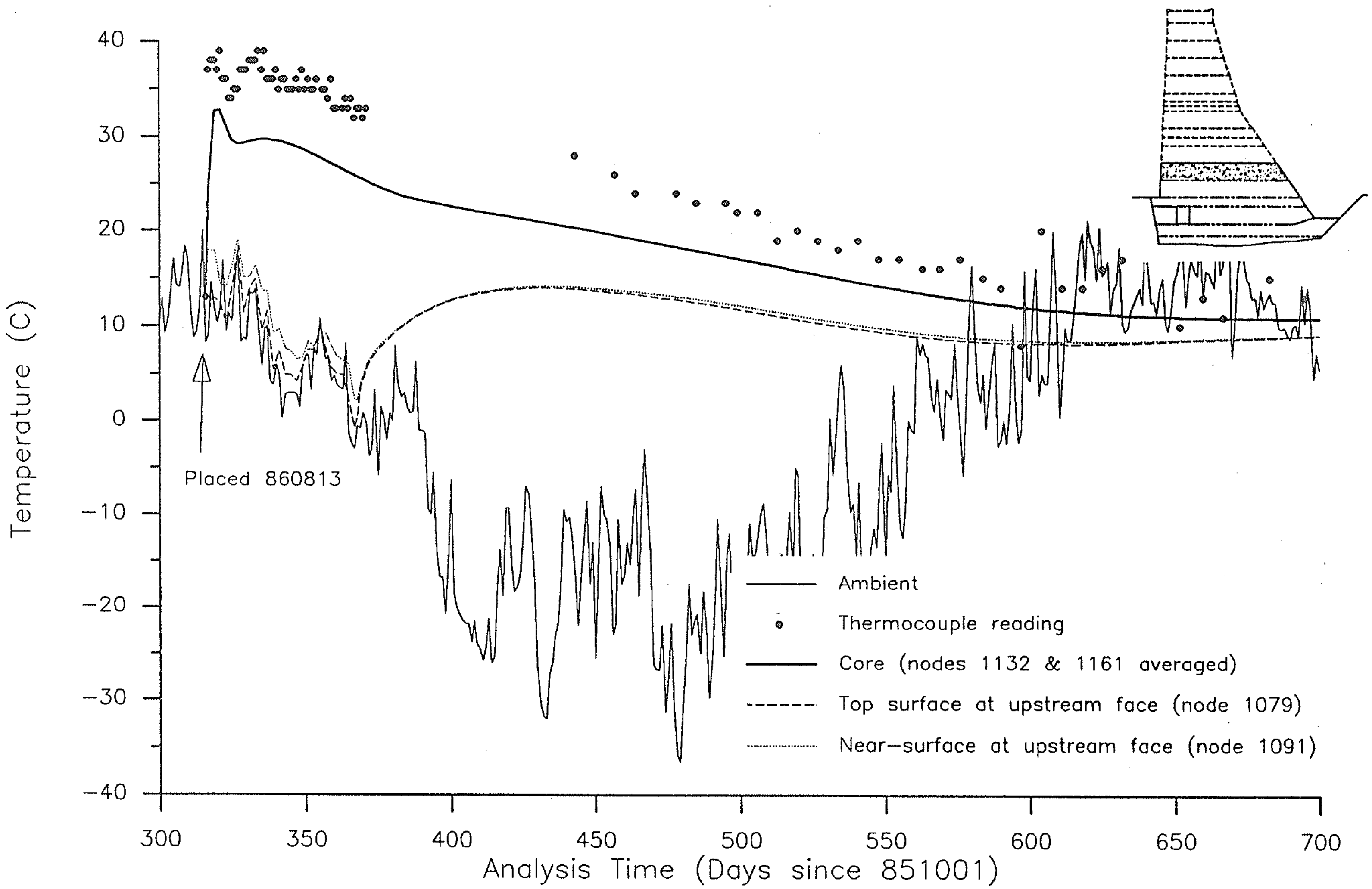

FIGURE H.6 - Comparison of Case Study Analysis Results to Measured In Situ Data for Lift NT2-6

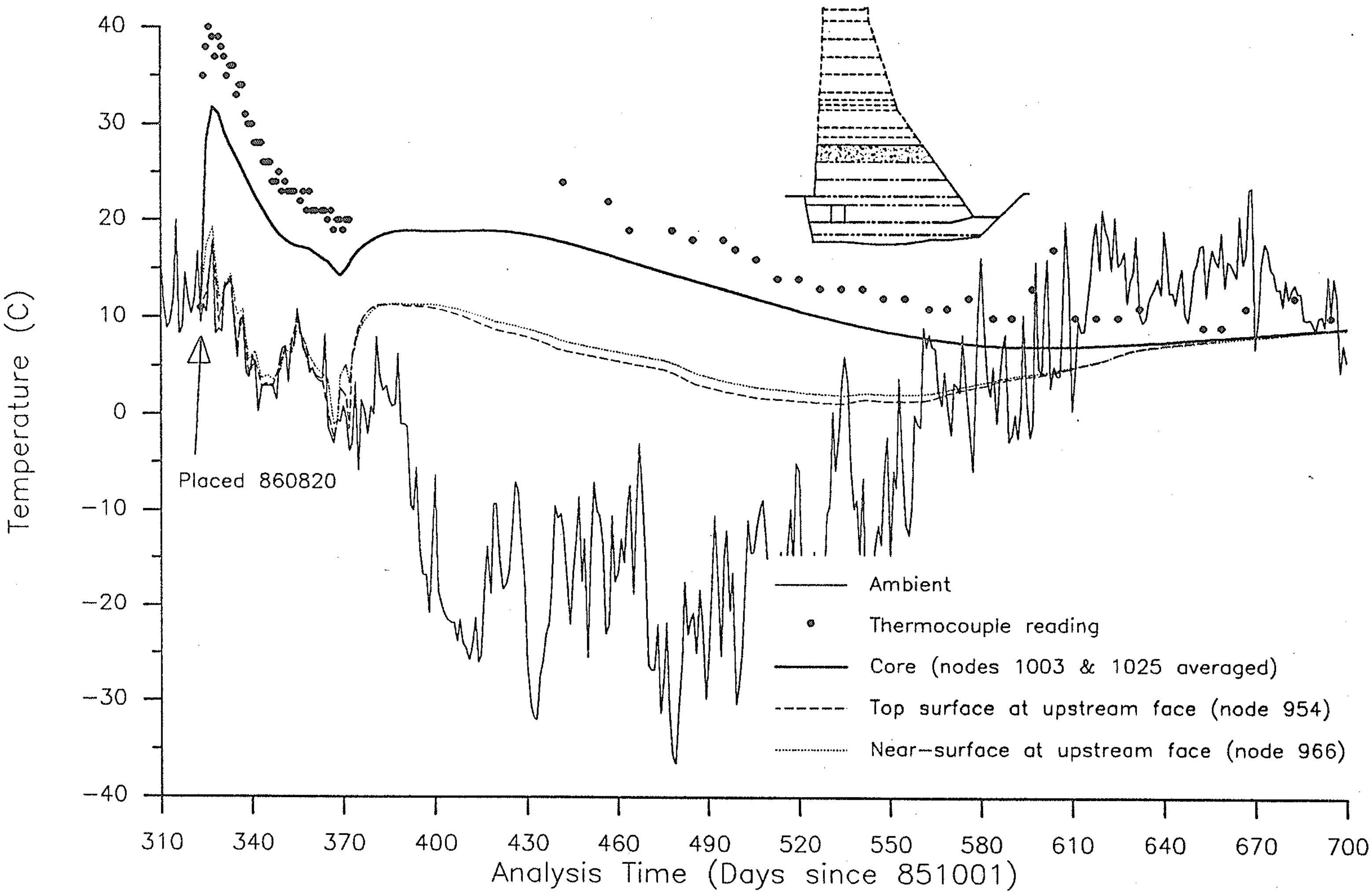

FIGURE H.7 - Comparison of Case Study Analysis Results to Measured In Situ Data for Lift NT2-7

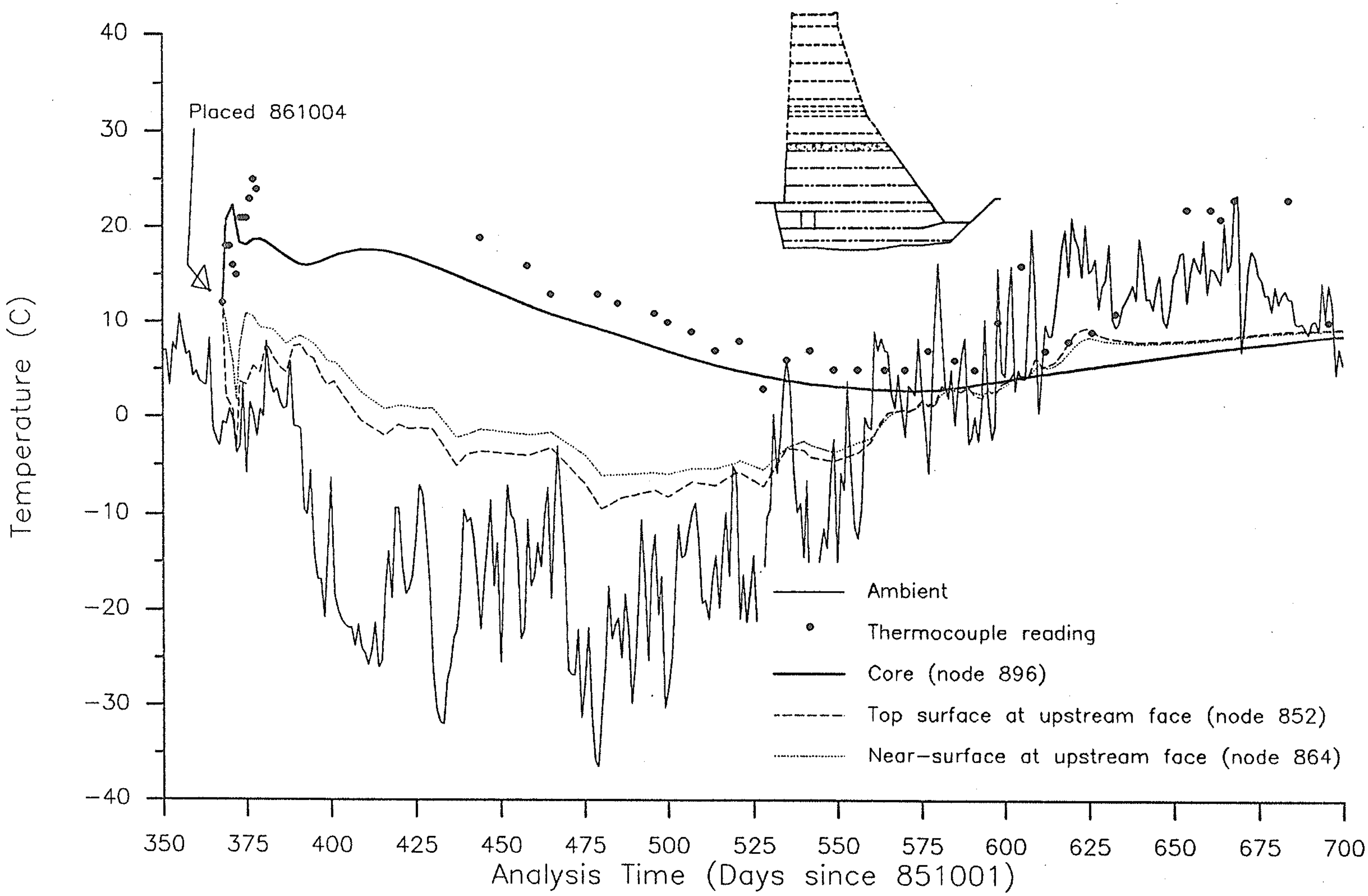

FIGURE H.8 - Comparison of Case Study Analysis Results to Measured In Situ Data for Lift NT2-8a

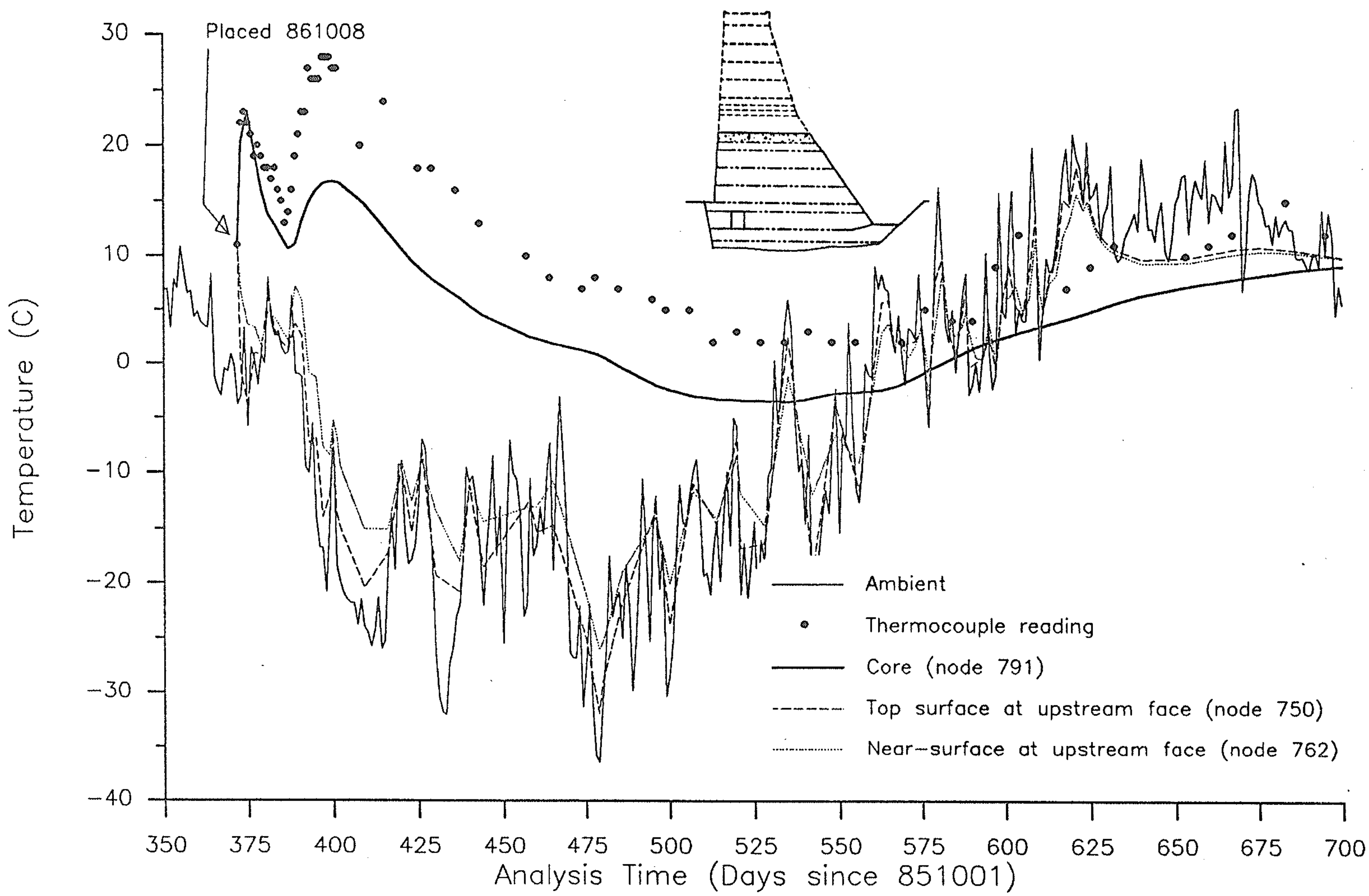

FIGURE H.9 - Comparison of Case Study Analysis Results to Measured In Situ Data for Lift NT2-8b

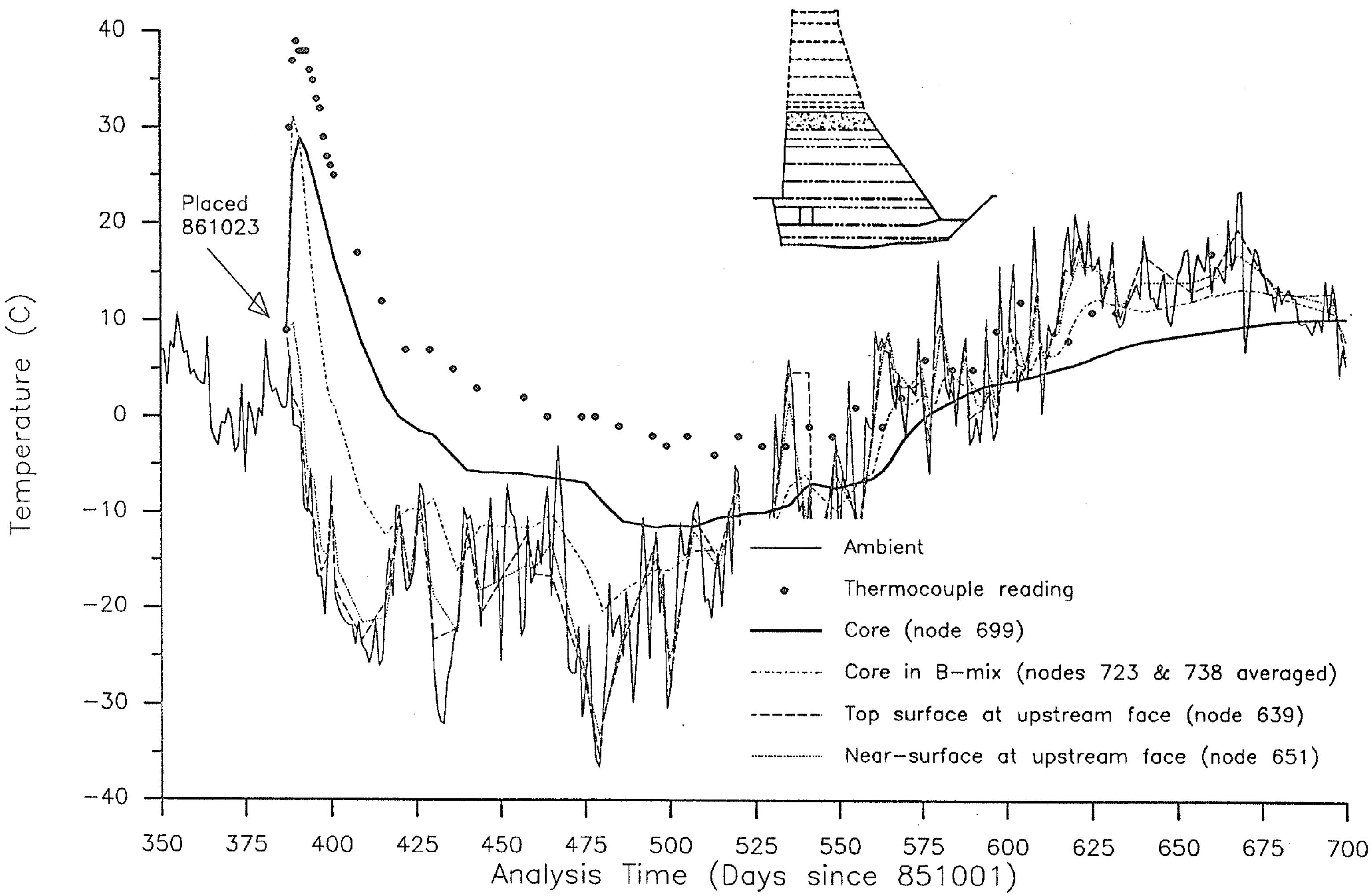

FIGURE H.10 - **Comparison of Case Study Analysis Results to Measured In Situ Data for Lift NT2-9**

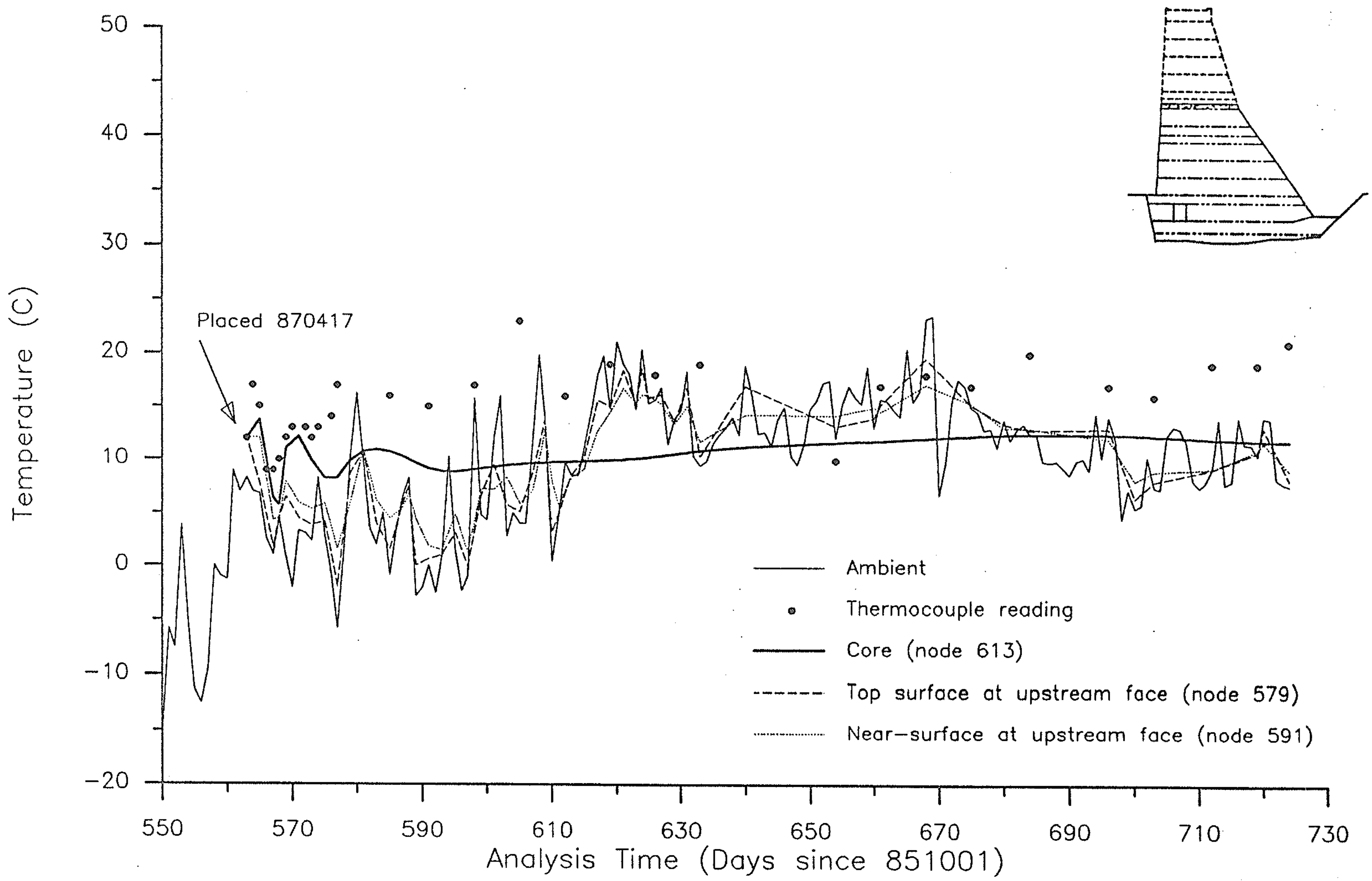

FIGURE H.11 - Comparison of Case Study Analysis Results to Measured In Situ Data for Lift NT2-10-1

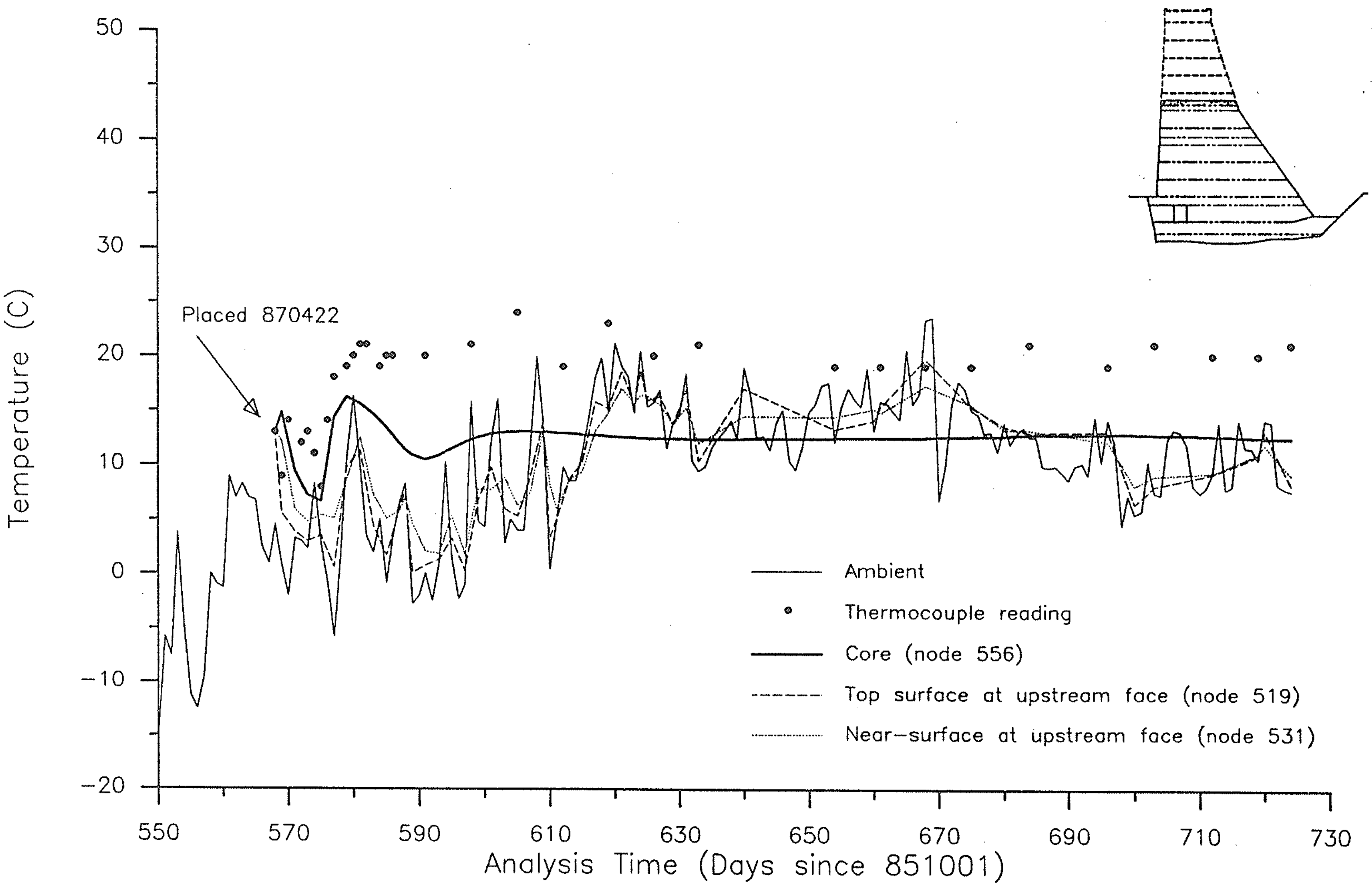

FIGURE H.12 - **Comparison of Case Study Analysis Results to Measured In Situ Data for Lift NT2-10-2**

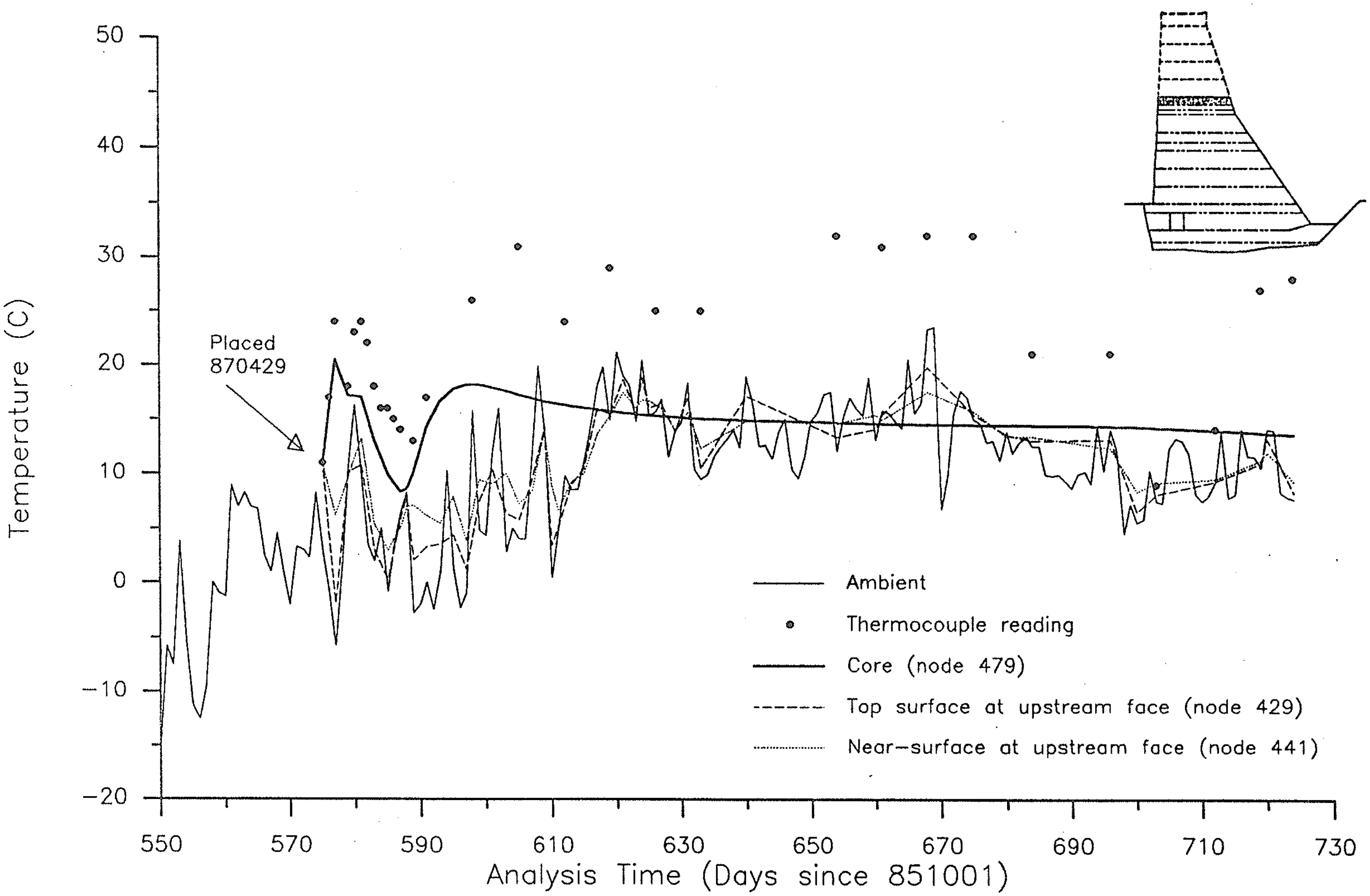

FIGURE H.13 - Comparison of Case Study Analysis Results to Measured In Situ Data for Lift NT2-10-3

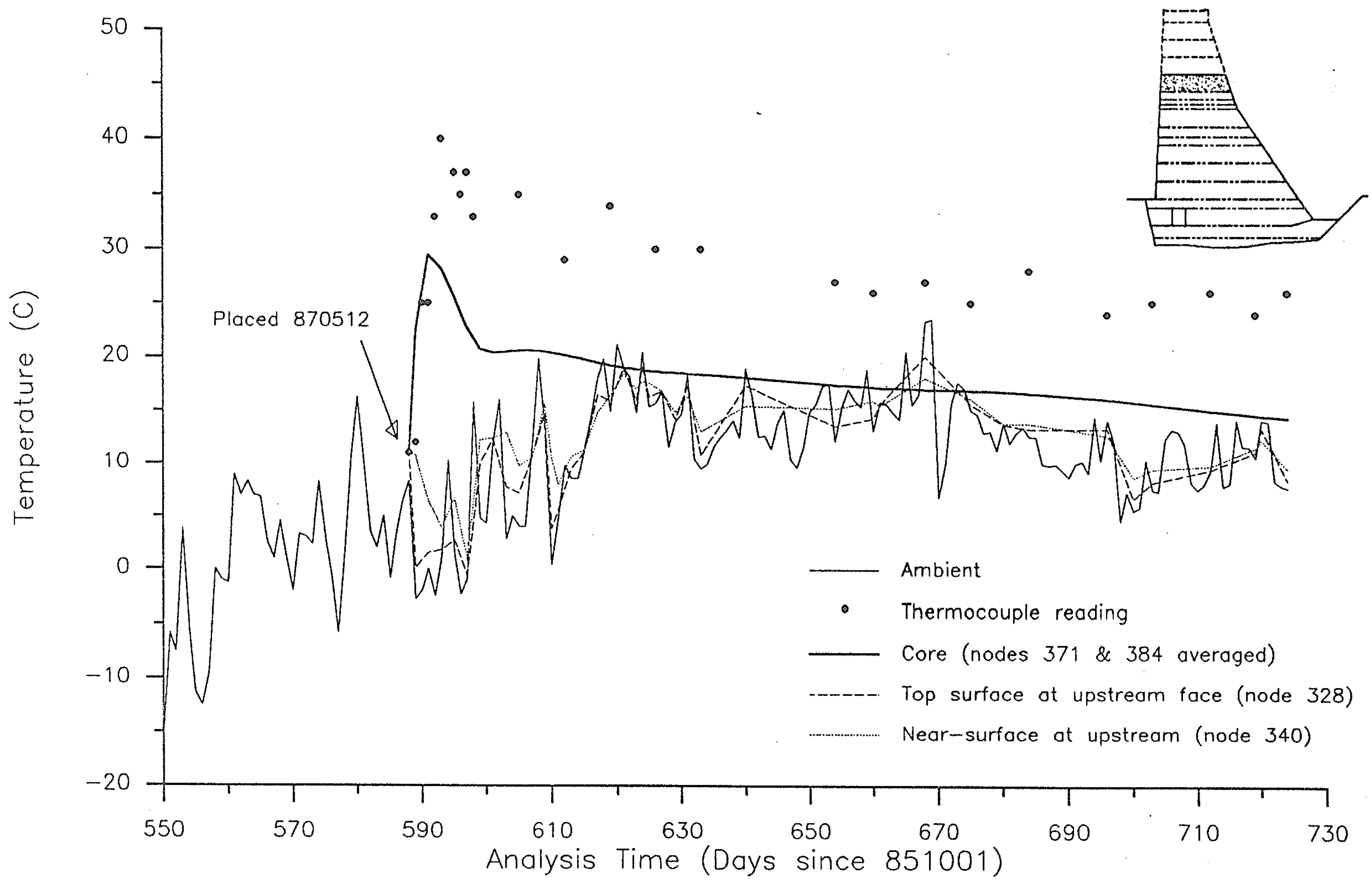

FIGURE H.14 - Comparison of Case Study Analysis Results to Measured In Situ Data for Lift NT2-11

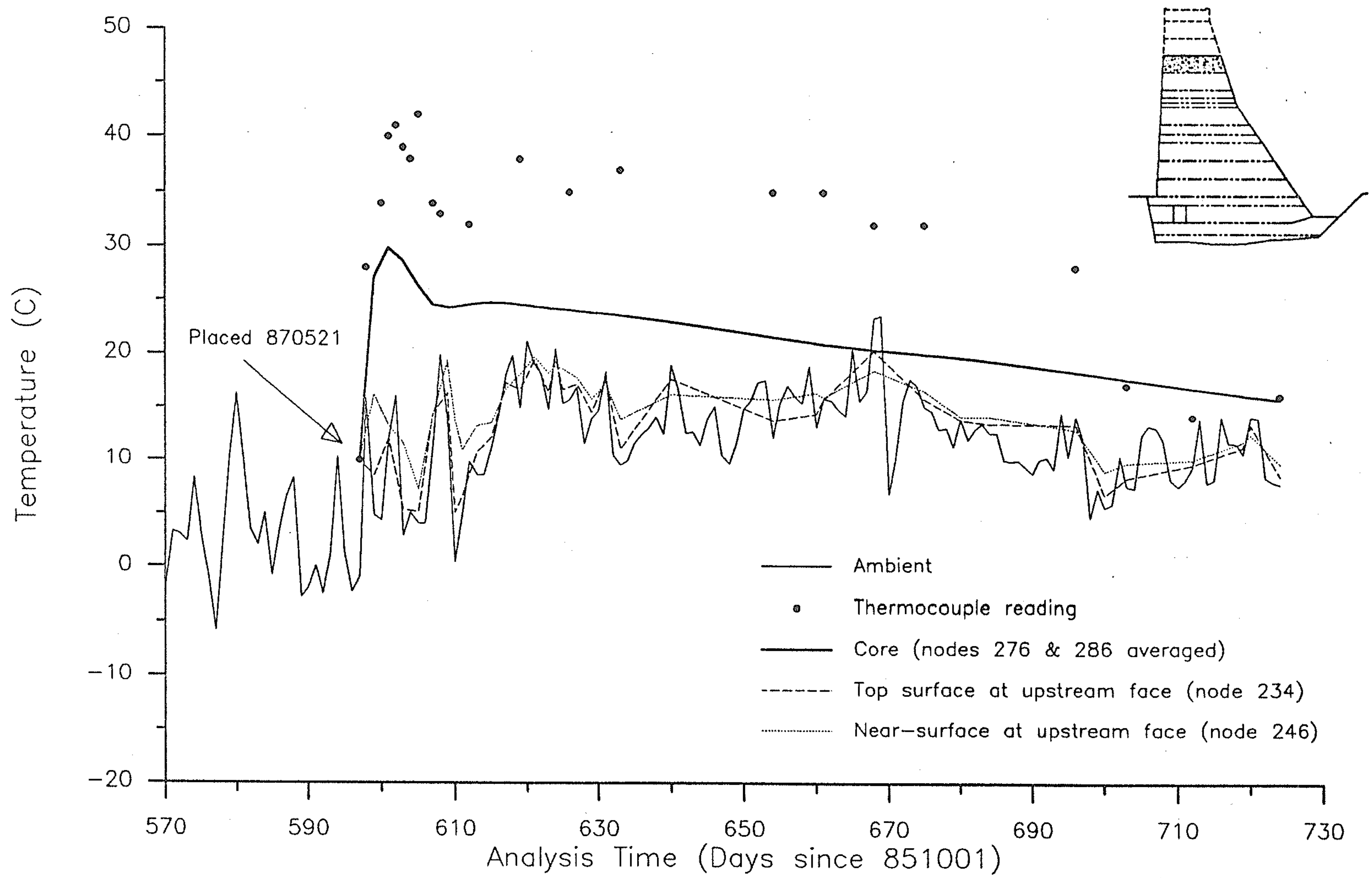

FIGURE H.15 - Comparison of Case Study Analysis Results to Measured In Situ Data for Lift NT2-12

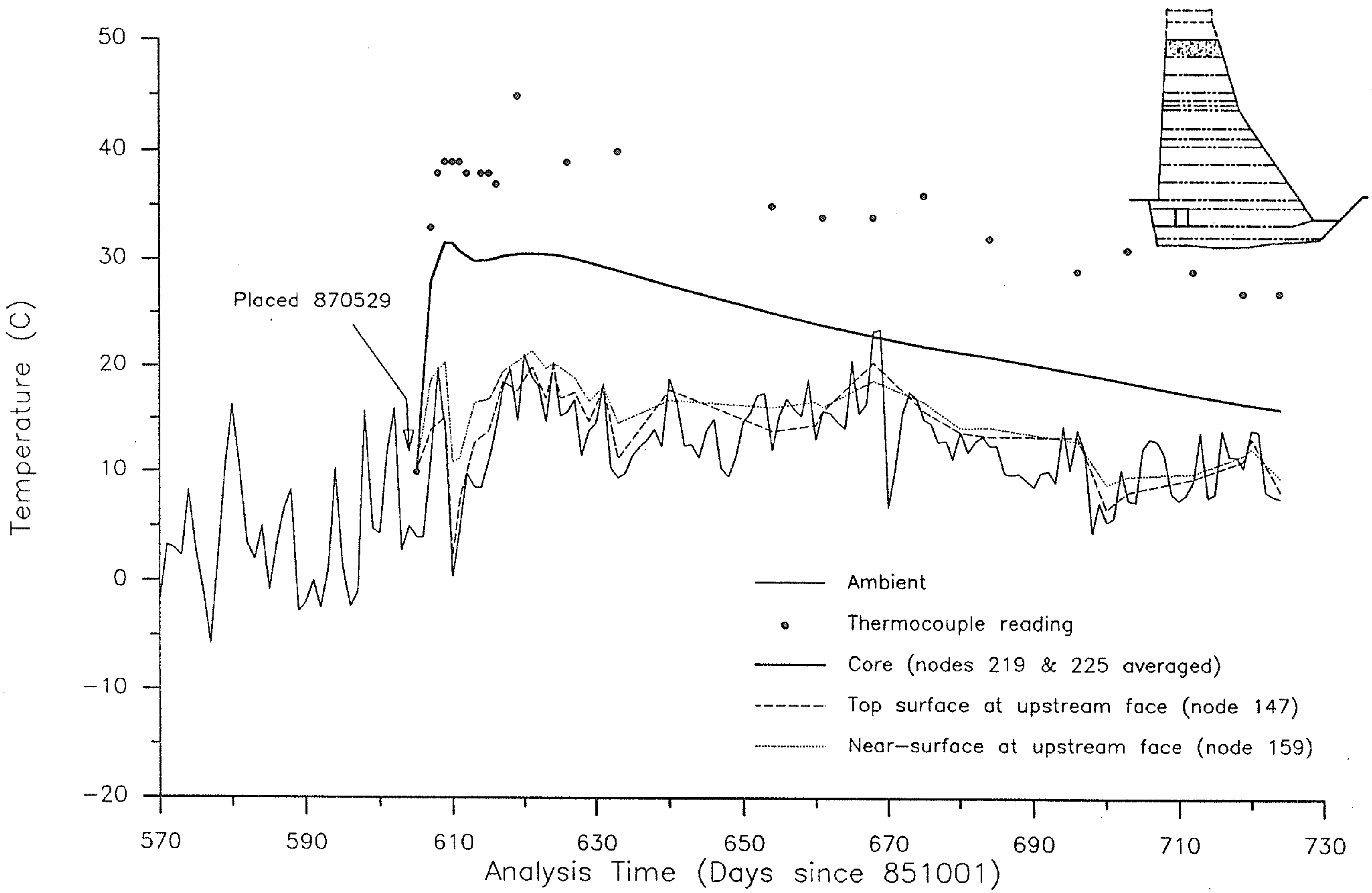

FIGURE H.16 - Comparison of Case Study Analysis Results to Measured In Situ Data for Lift NT2-13

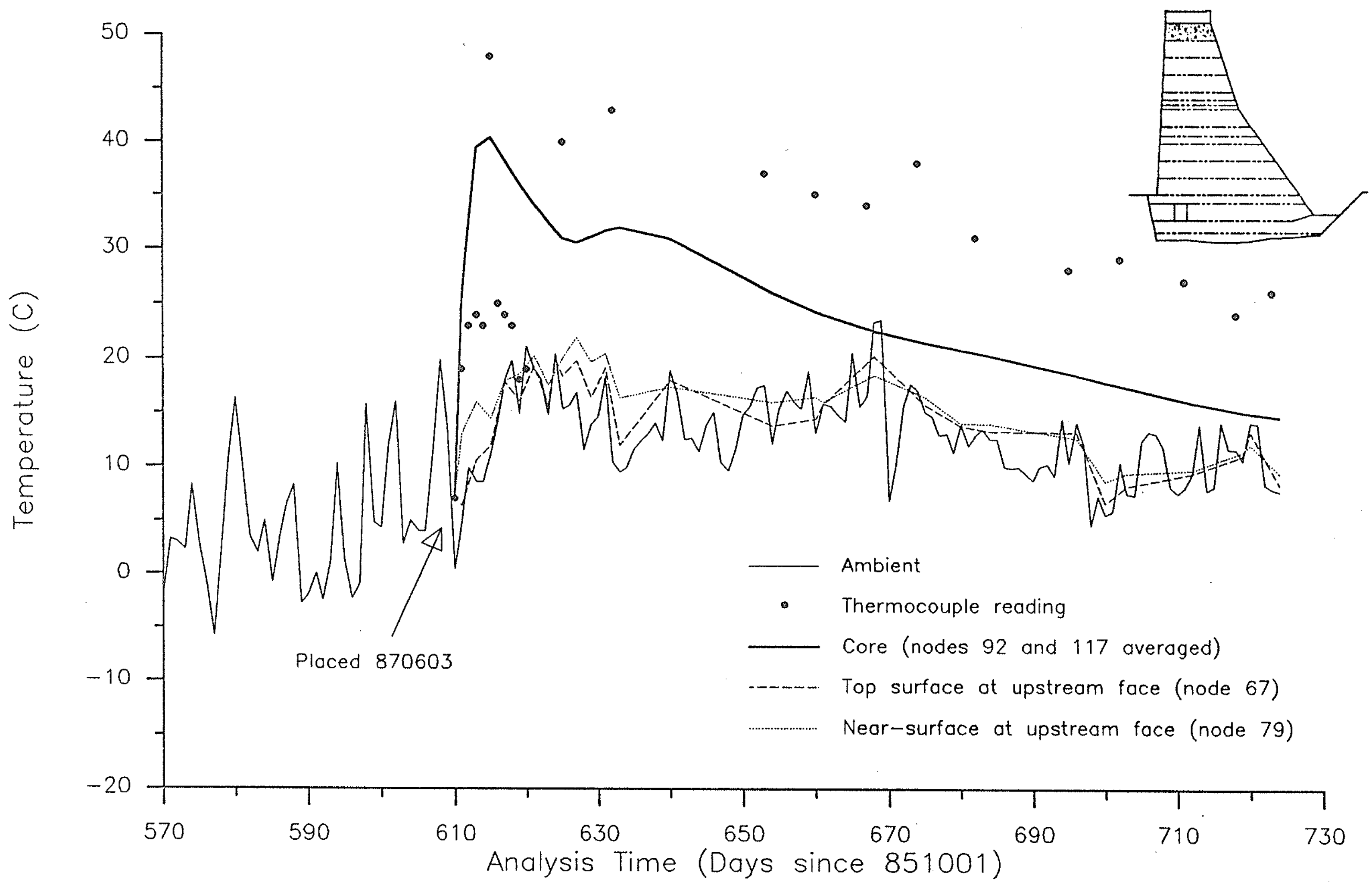

FIGURE H.17 - Comparison of Case Study Analysis Results to Measured In Situ Data for Lift NT2-14

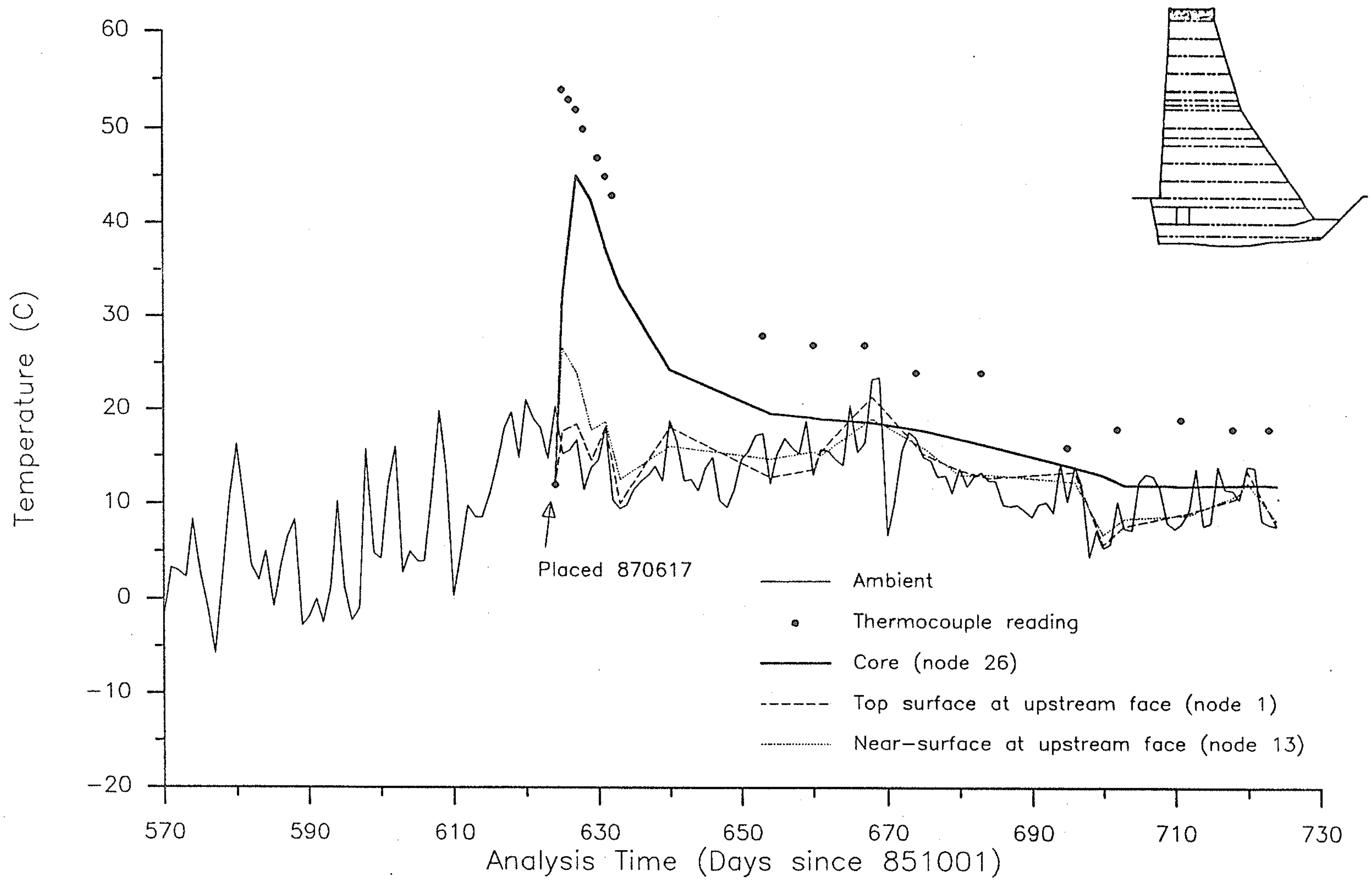

FIGURE H.18 - Comparison of Case Study Analysis Results to Measured In Situ Data for Lift NT2-15

APPENDIX I

CASE STUDY ANALYSIS THERMAL CONTOUR PLOTS

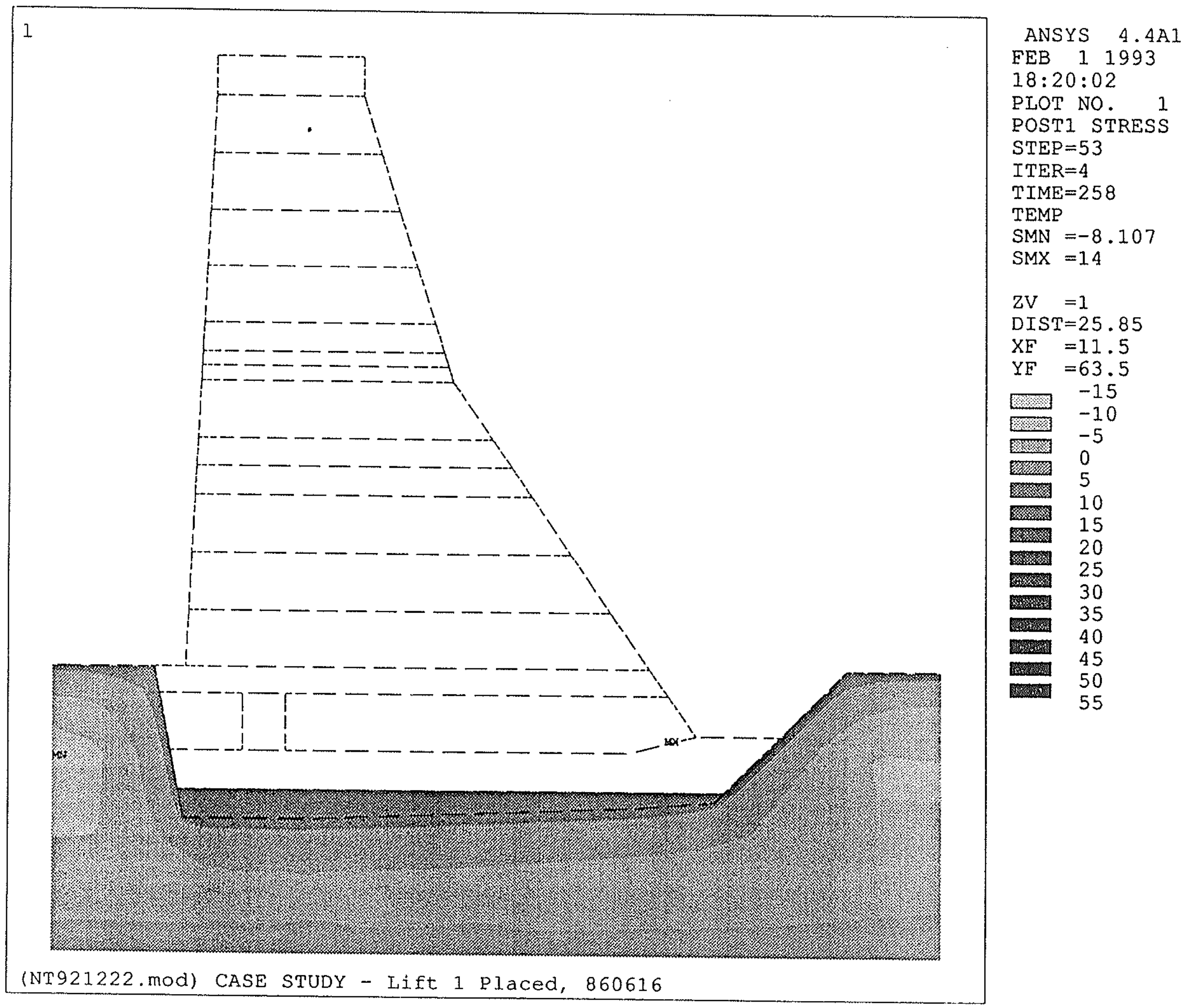

FIGURE I.1 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 860616 (Day of Placement of Lift NT2-1)

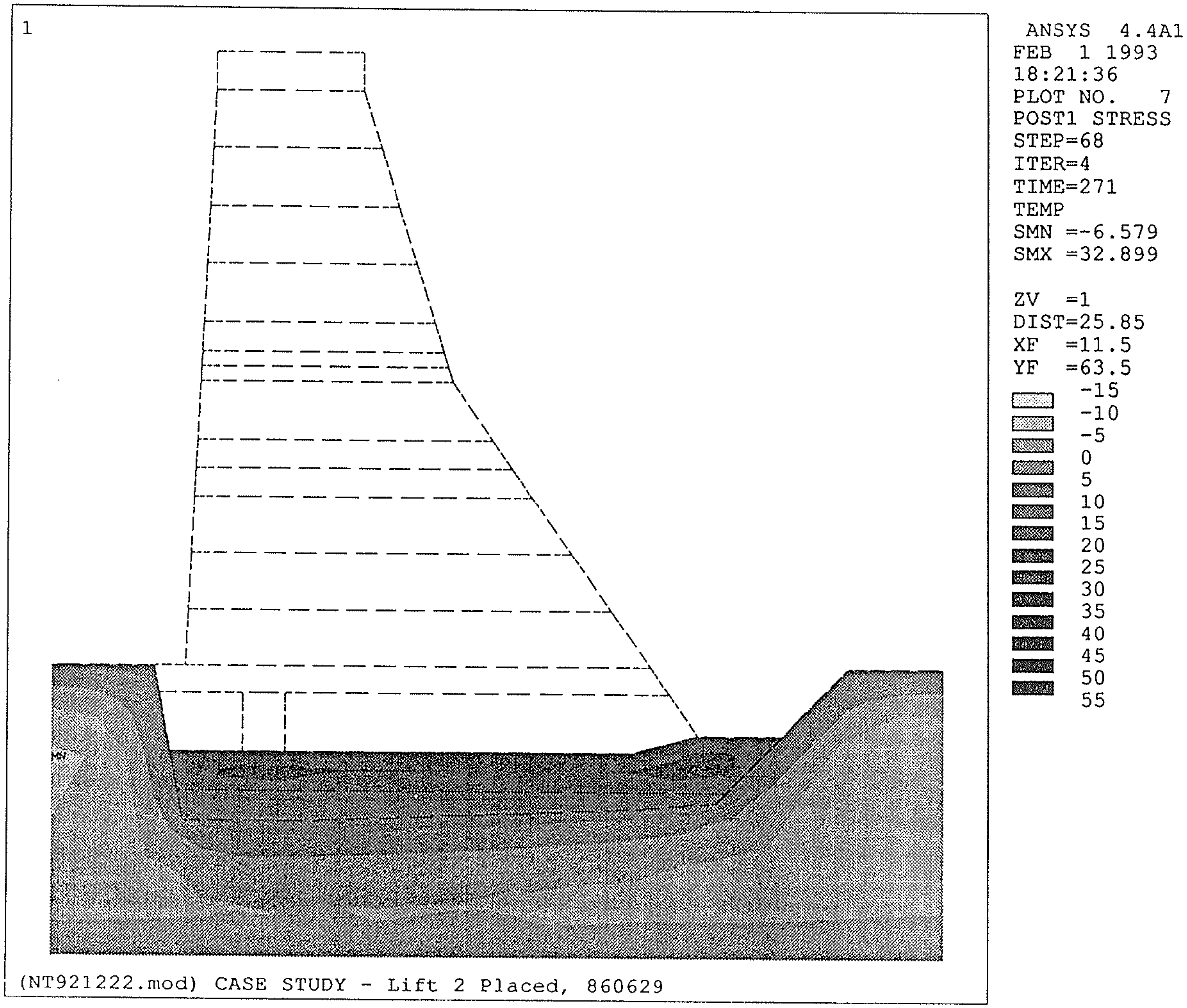

FIGURE I.2 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 860629 (4 Days after Placement of Lift NT2-2)

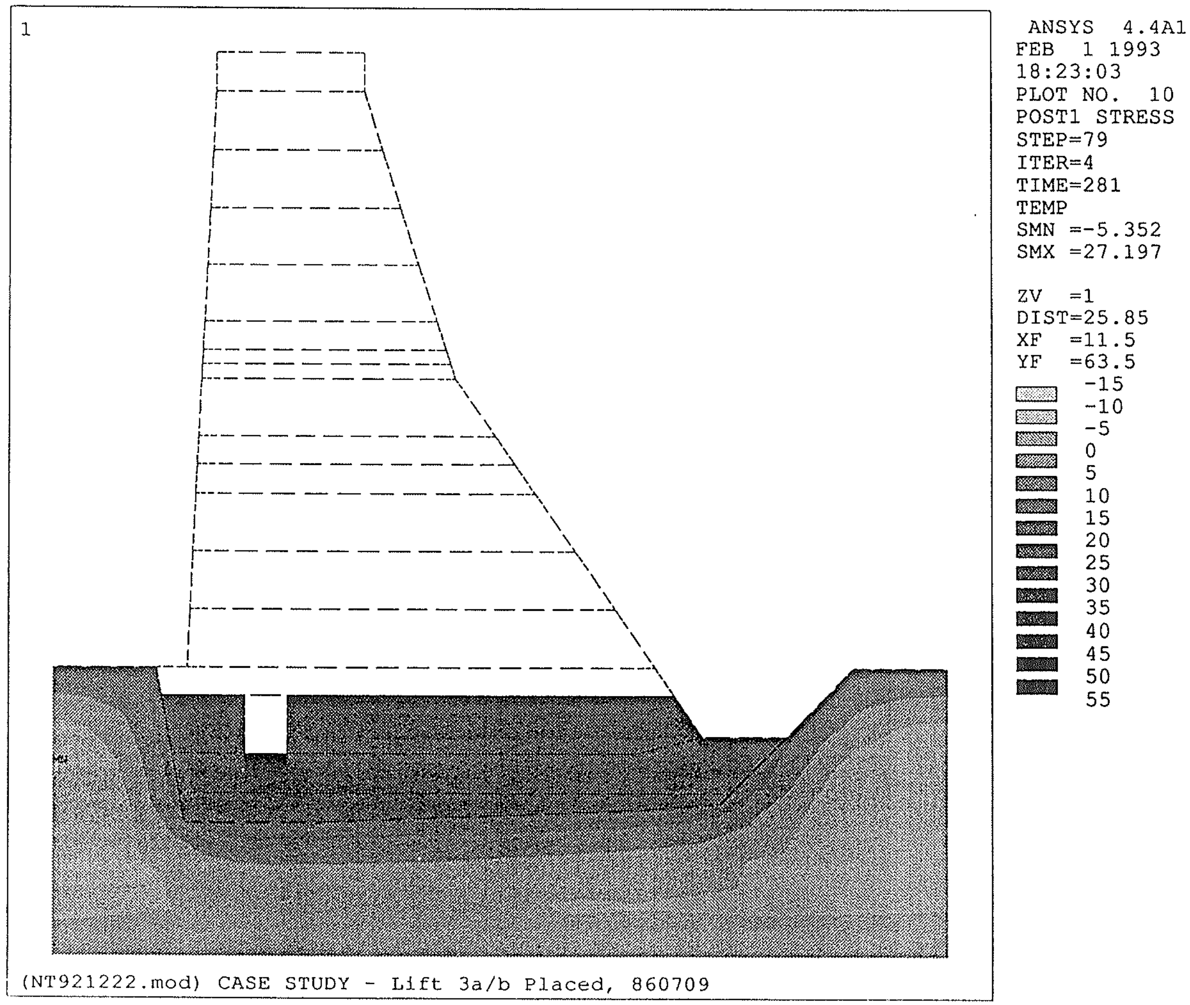

FIGURE I.3 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 860709 (2 Days after Placement of Lift NT2-3a/b)

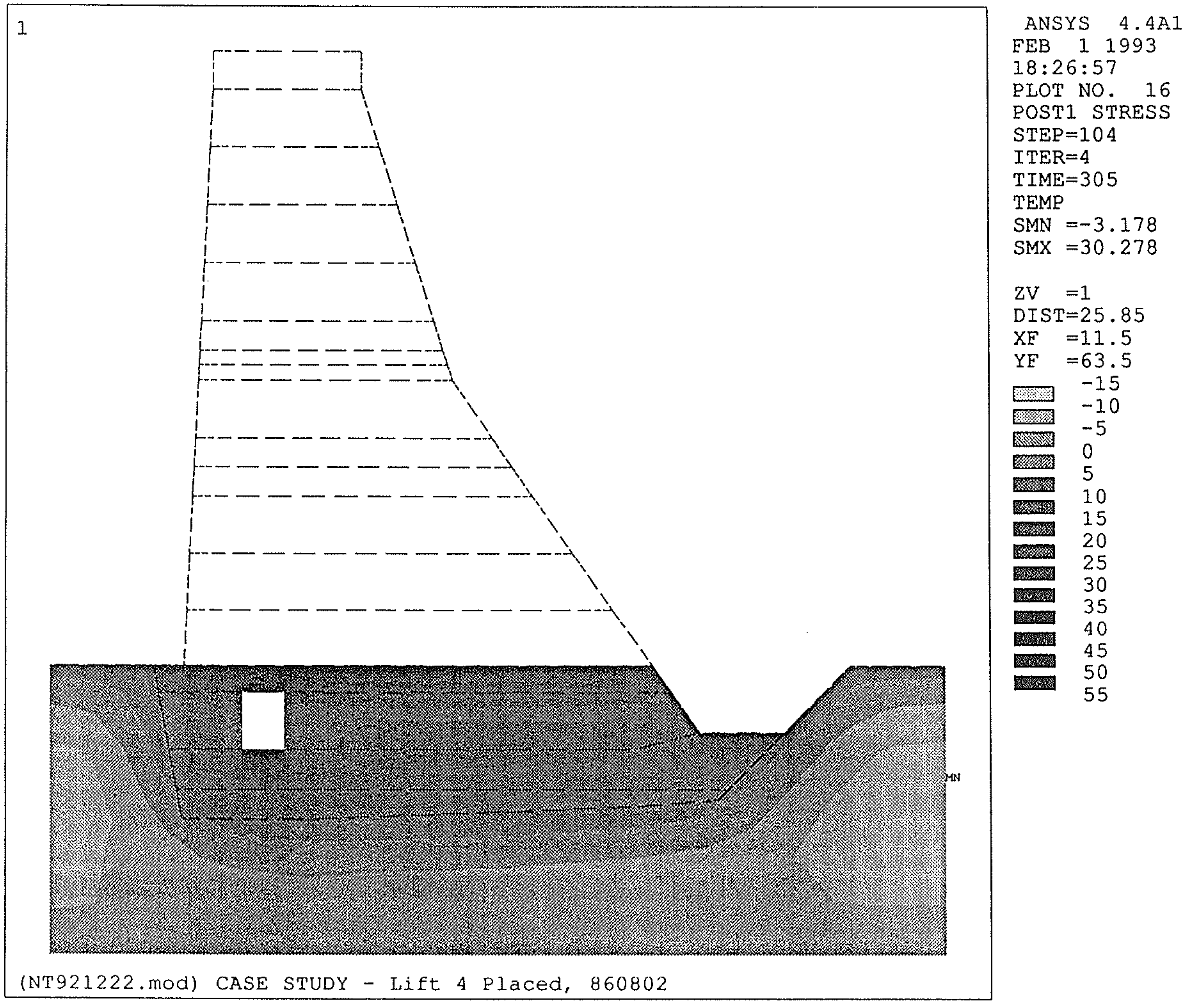

FIGURE I.4 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 860802 (4 Days after Placement of Lift NT2-4)

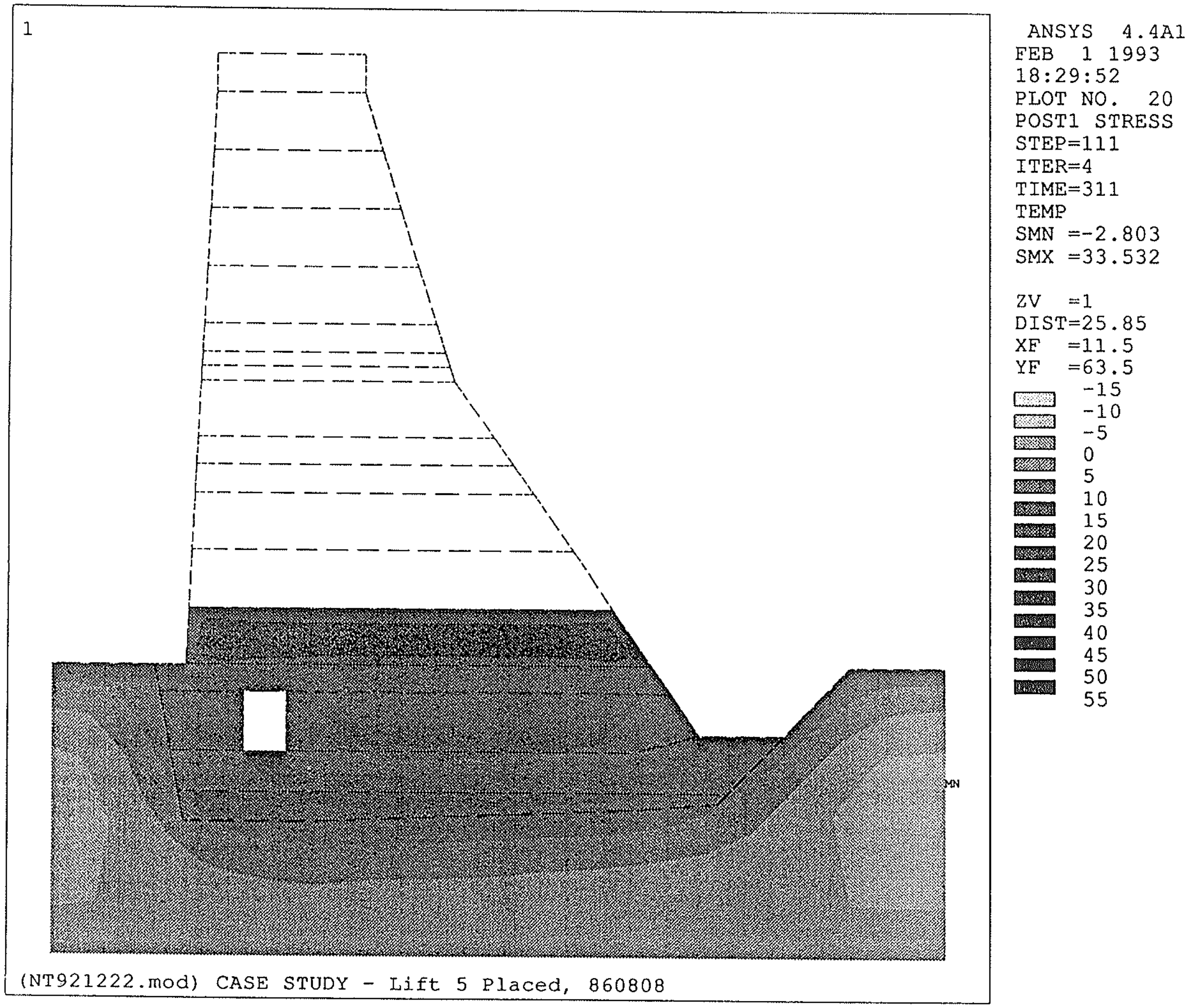

FIGURE I.5 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 860808 (3 Days after Placement of Lift NT2-5)

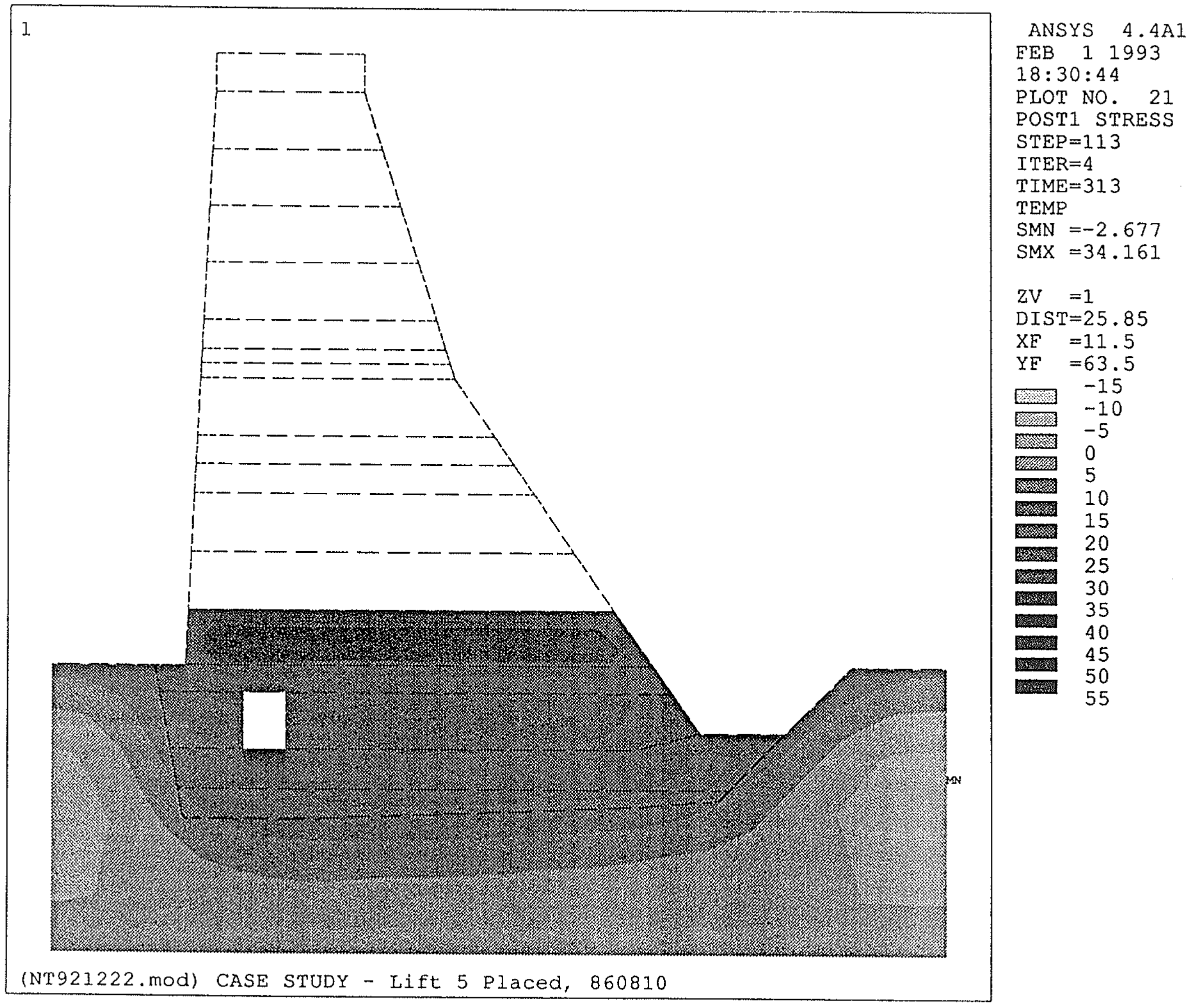

FIGURE I.6 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 860810 (5 Days after Placement of Lift NT2-5)

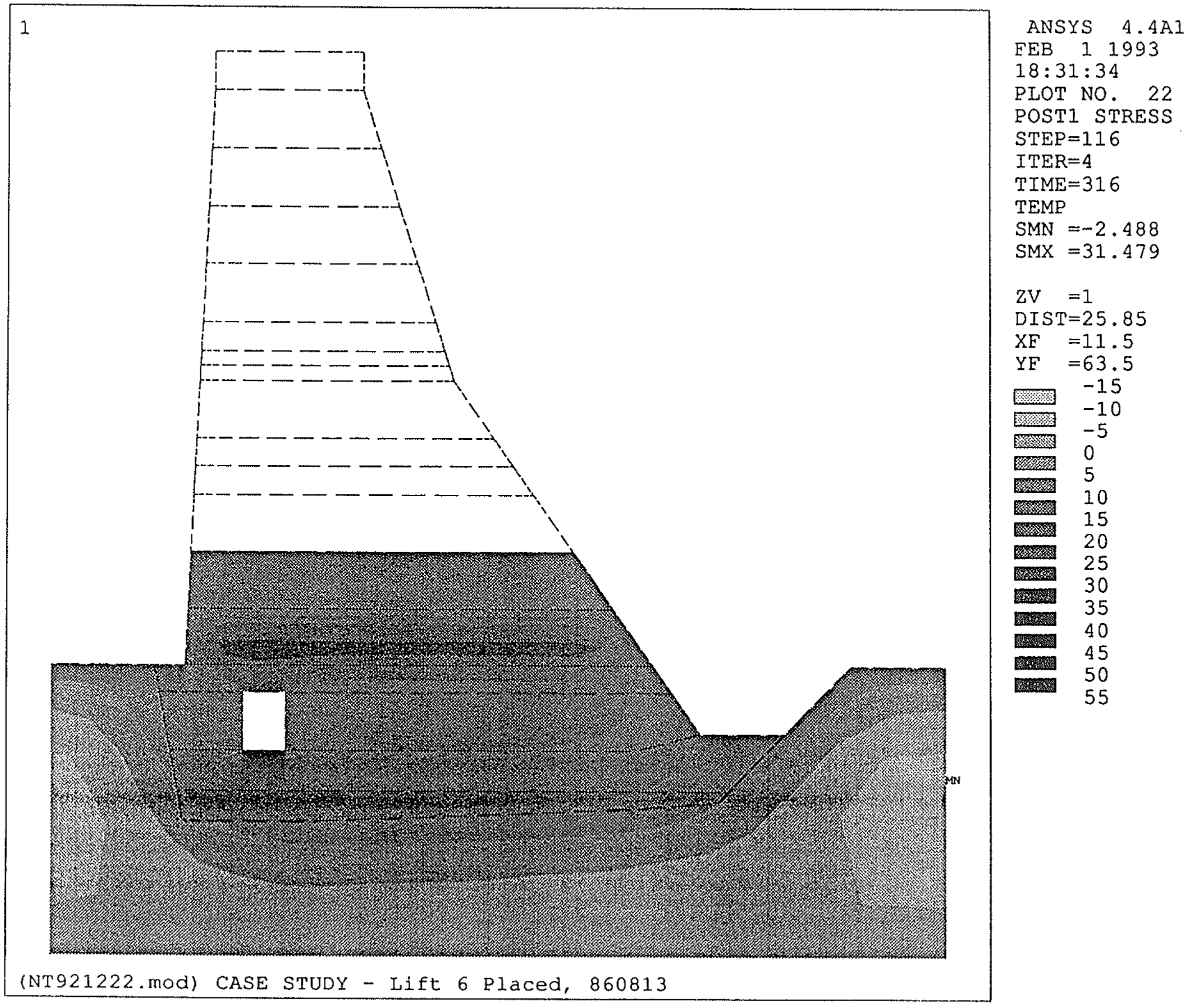

FIGURE I.7 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 860813 (Day of Placement of Lift NT2-6)

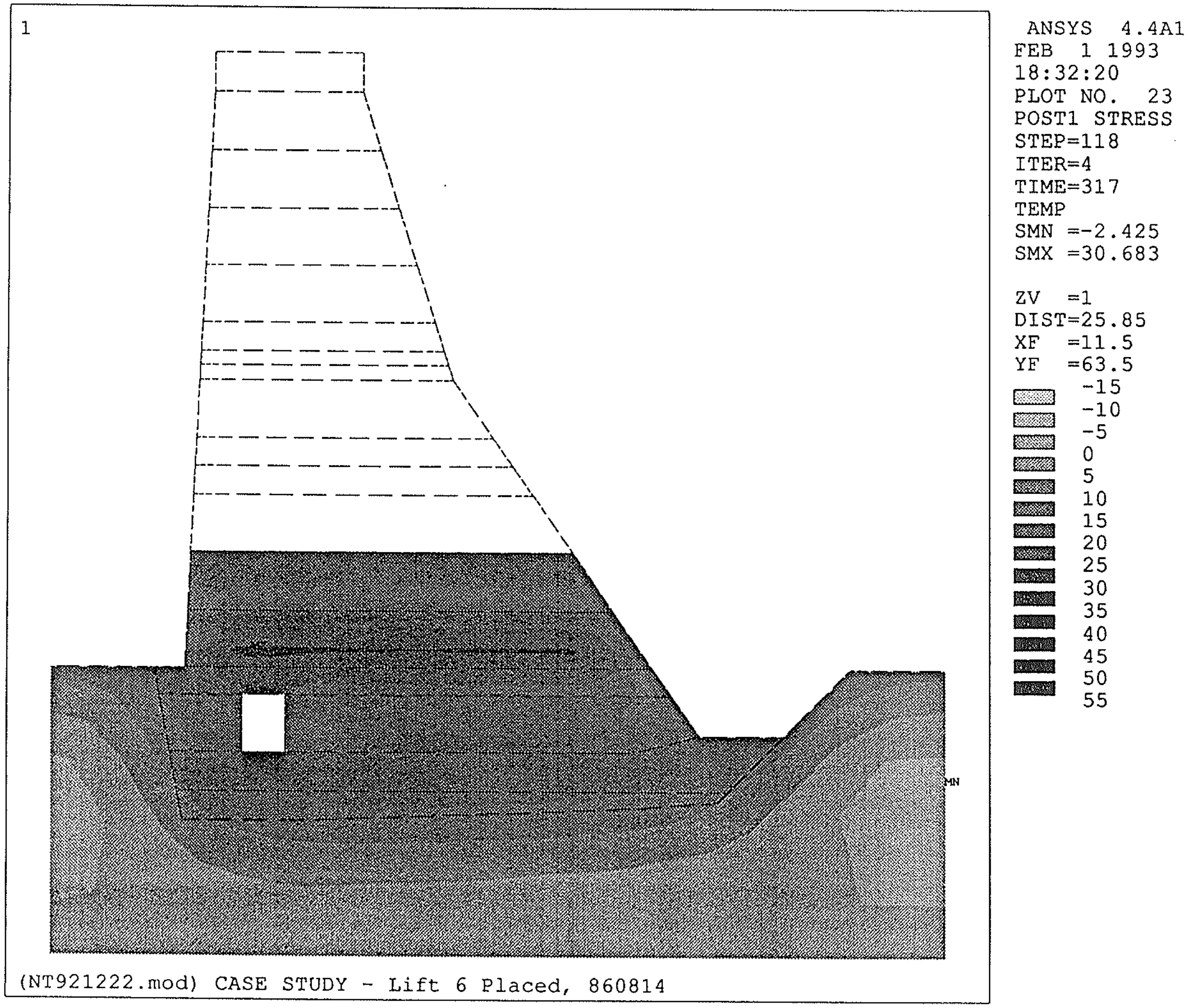

FIGURE I.8 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 860814 (1 Day after Placement of Lift NT2-6)

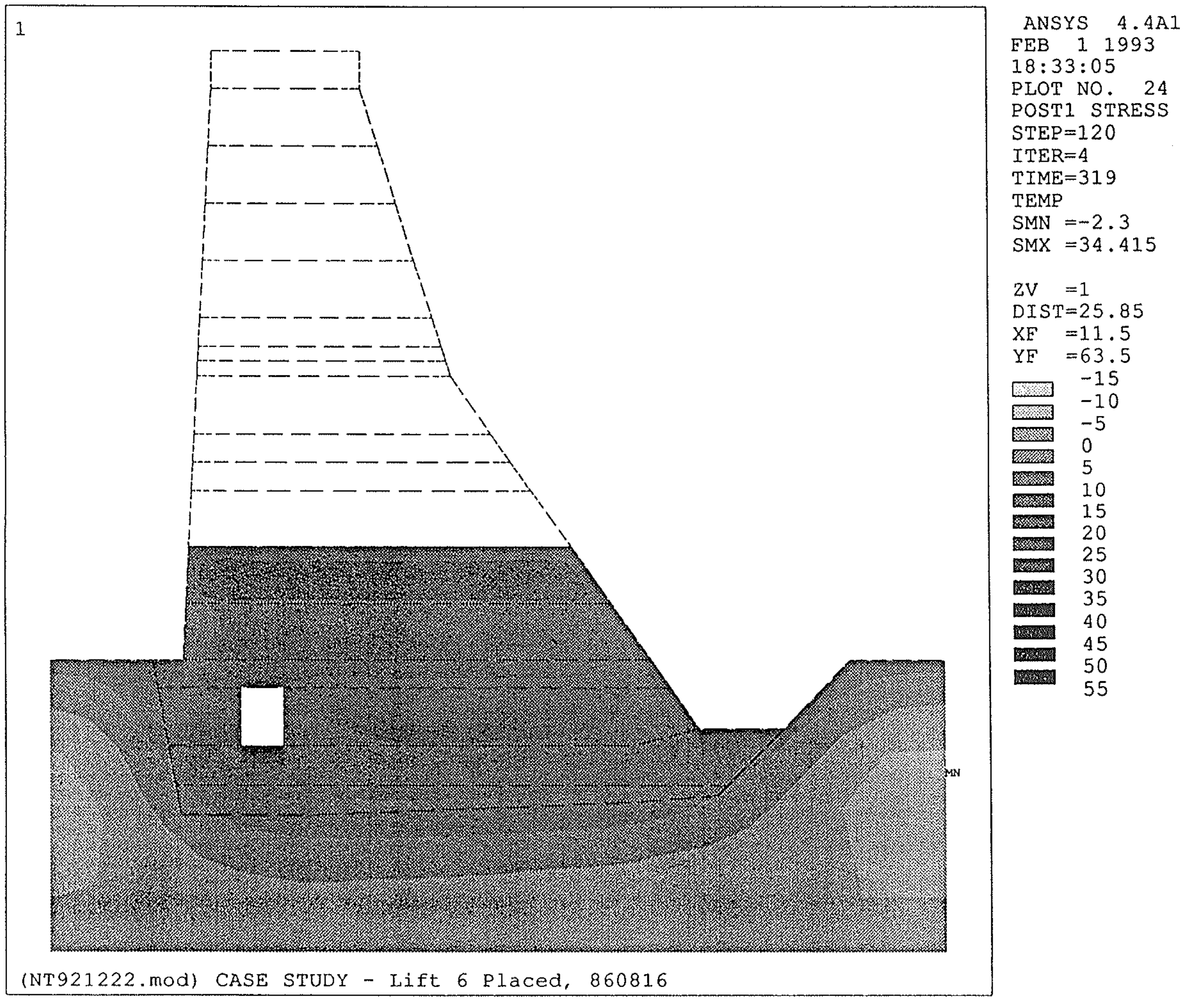

FIGURE I.9 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 860816 (3 Days after Placement of Lift NT2-6)

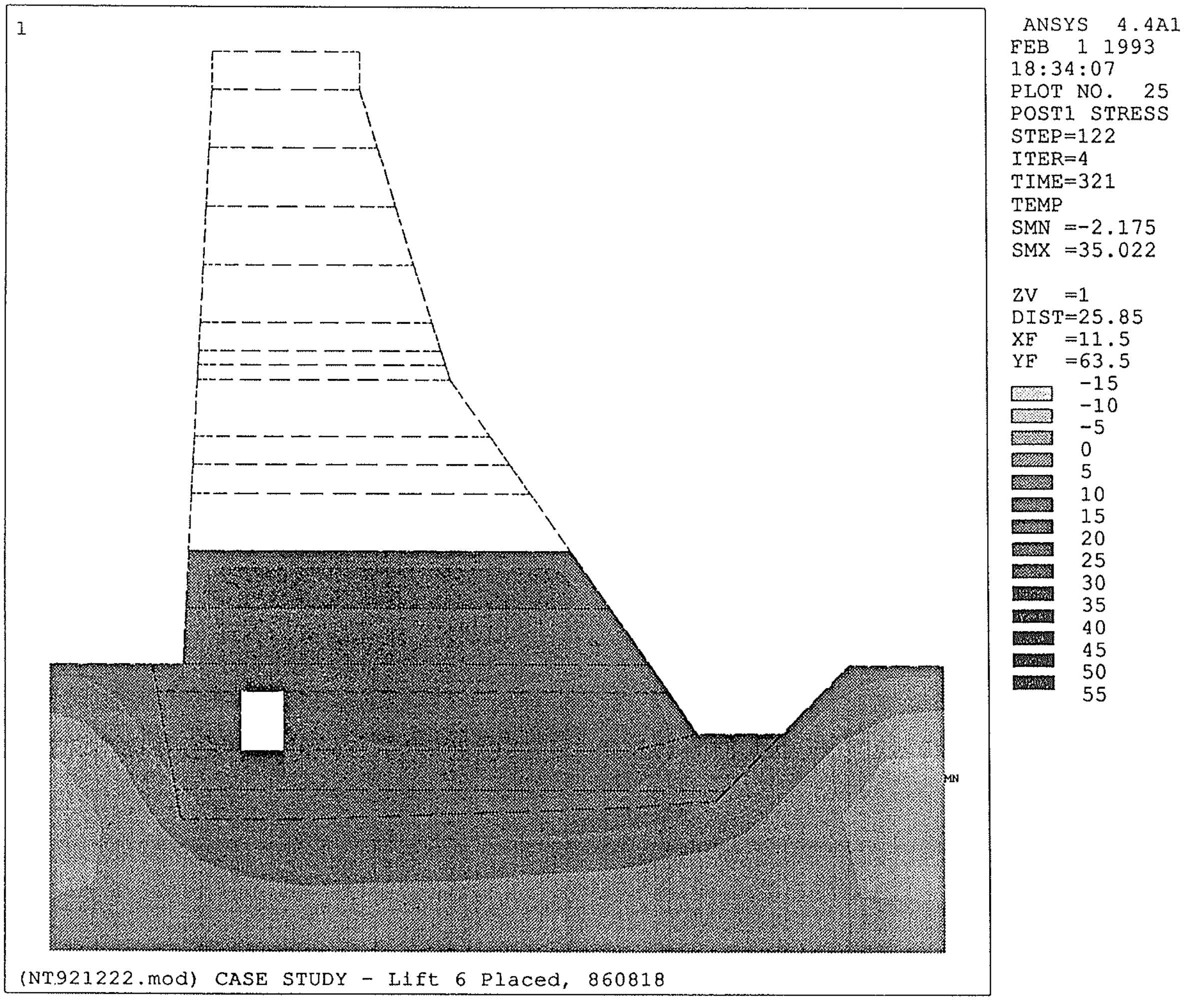

FIGURE I.10 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 860818 (5 Days after Placement of Lift NT2-6)

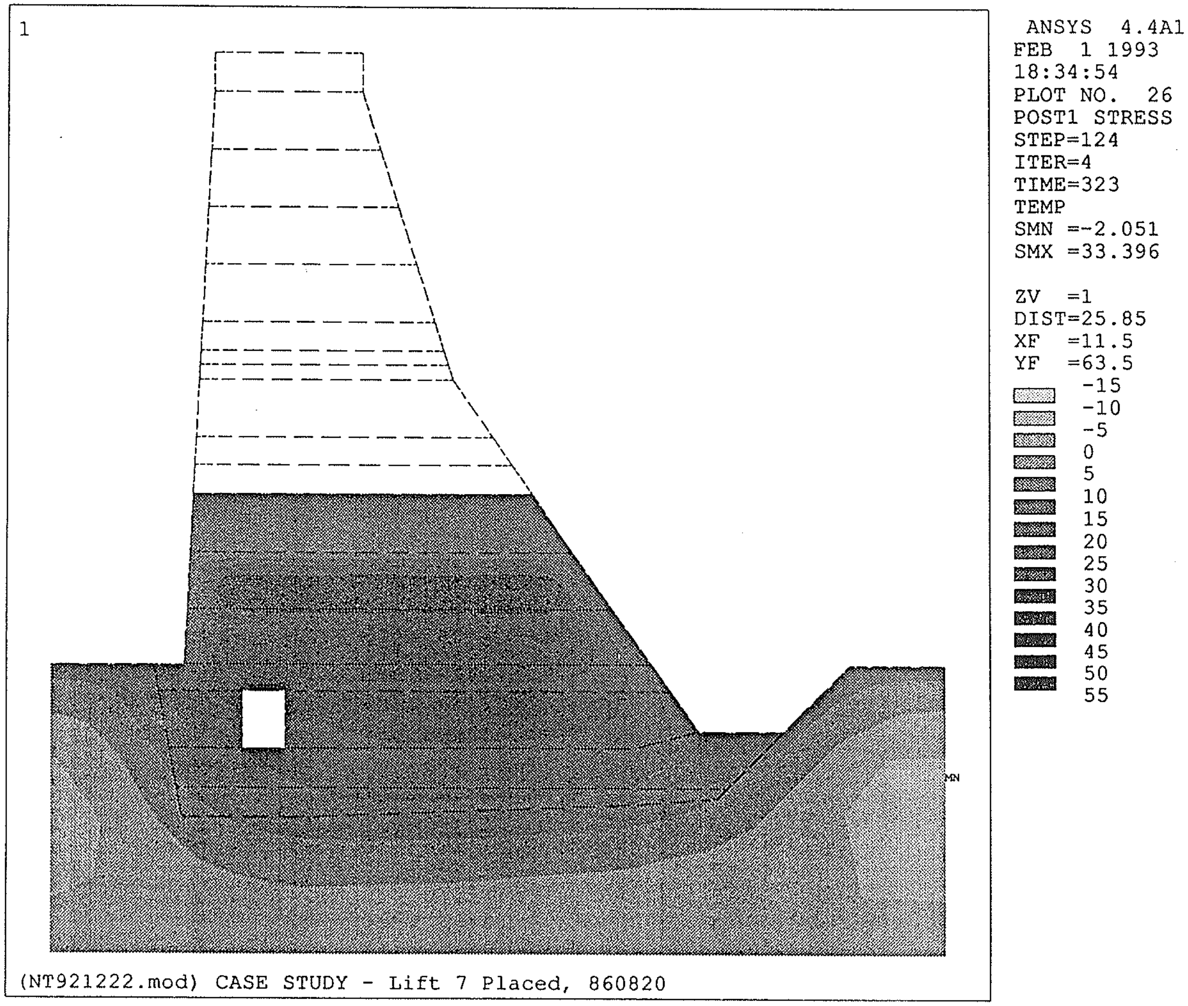

FIGURE I.11 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 860820 (Day of Placement of Lift NT2-7)

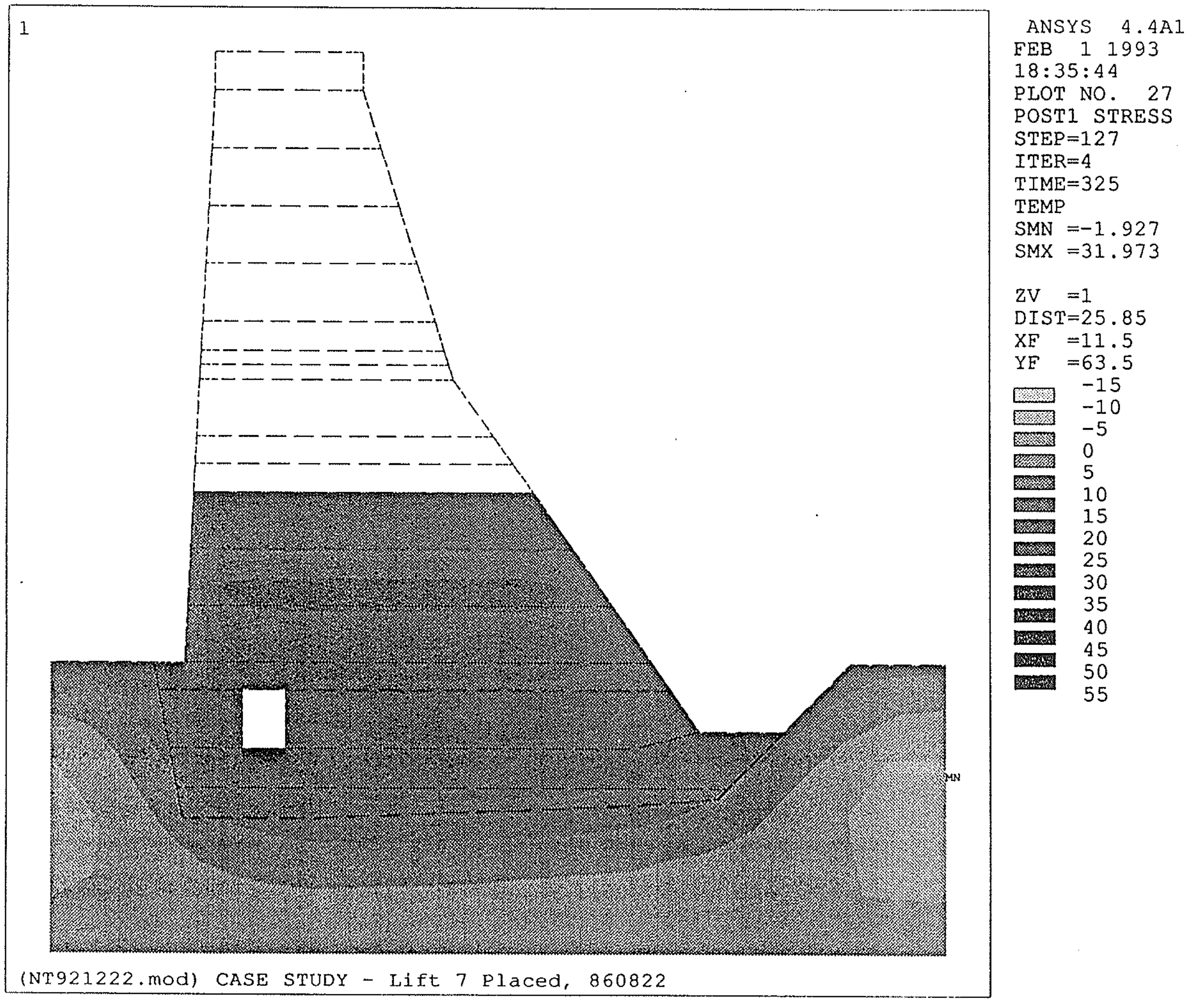

FIGURE I.12 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 860822 (2 Days after Placement of Lift NT2-7)

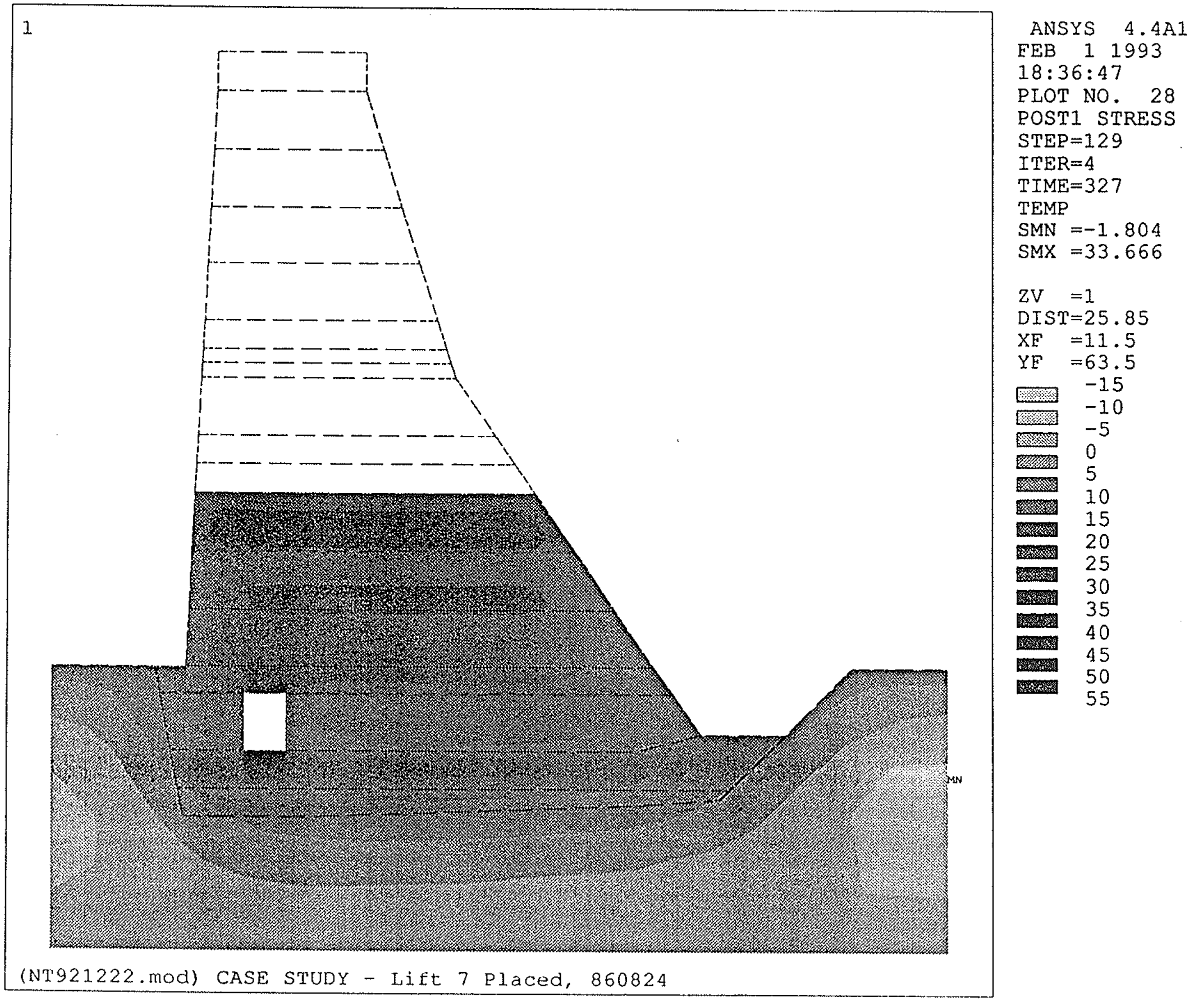

FIGURE I.13 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 860824 (4 Days after Placement of Lift NT2-7)

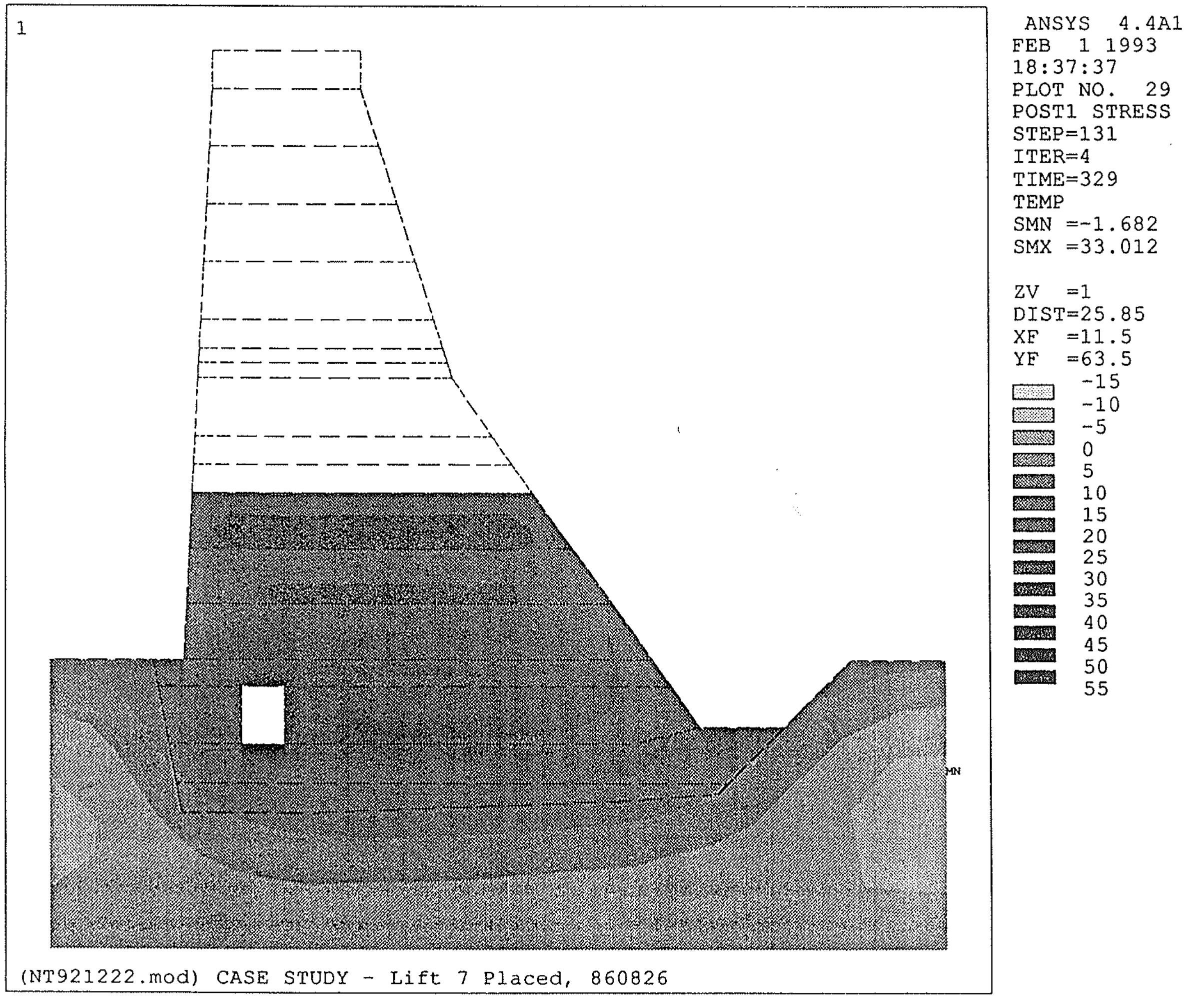

FIGURE I.14 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 860826 (6 Days after Placement of Lift NT2-7)

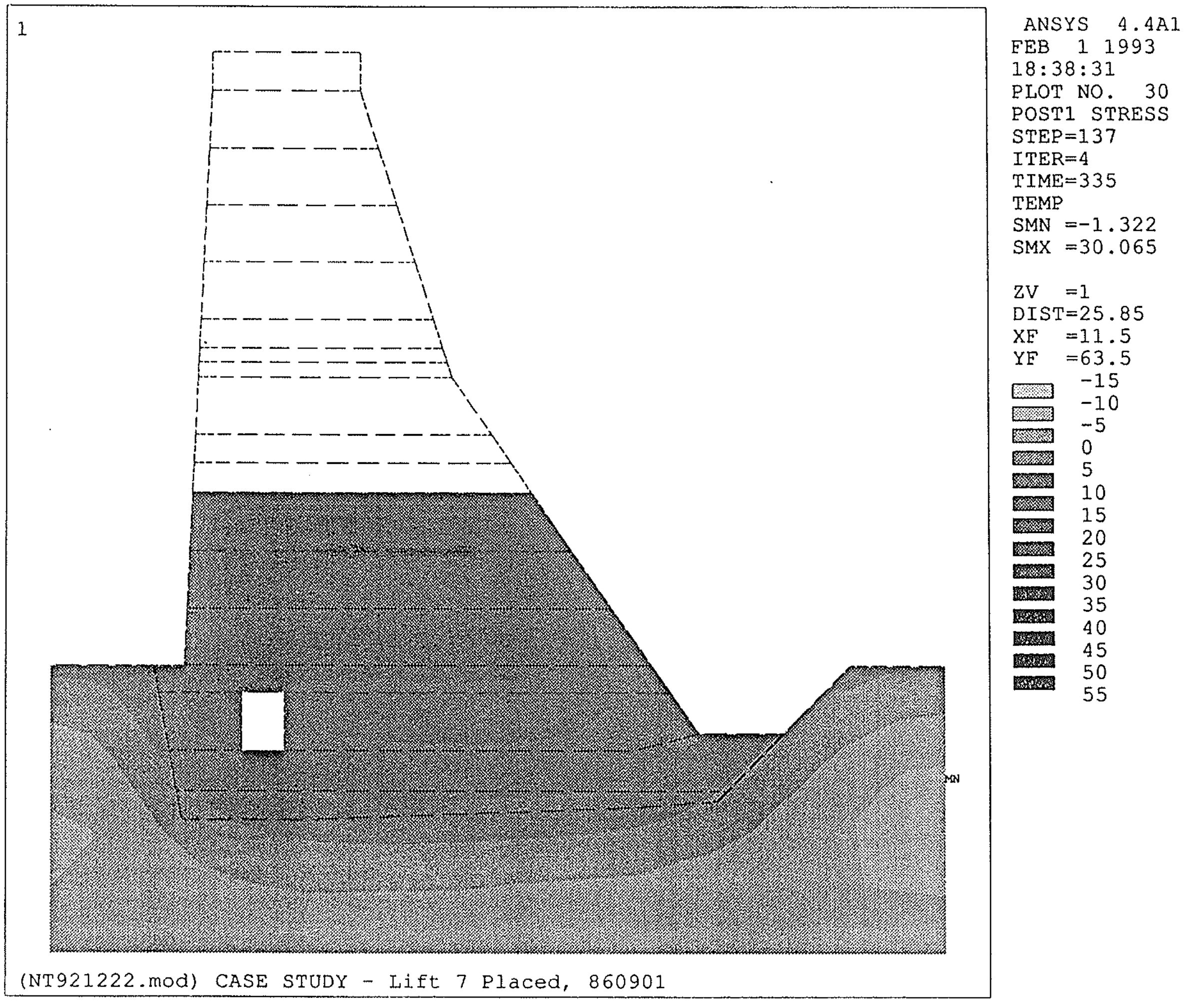

FIGURE I.15 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 860901 (12 Days after Placement of Lift NT2-7)

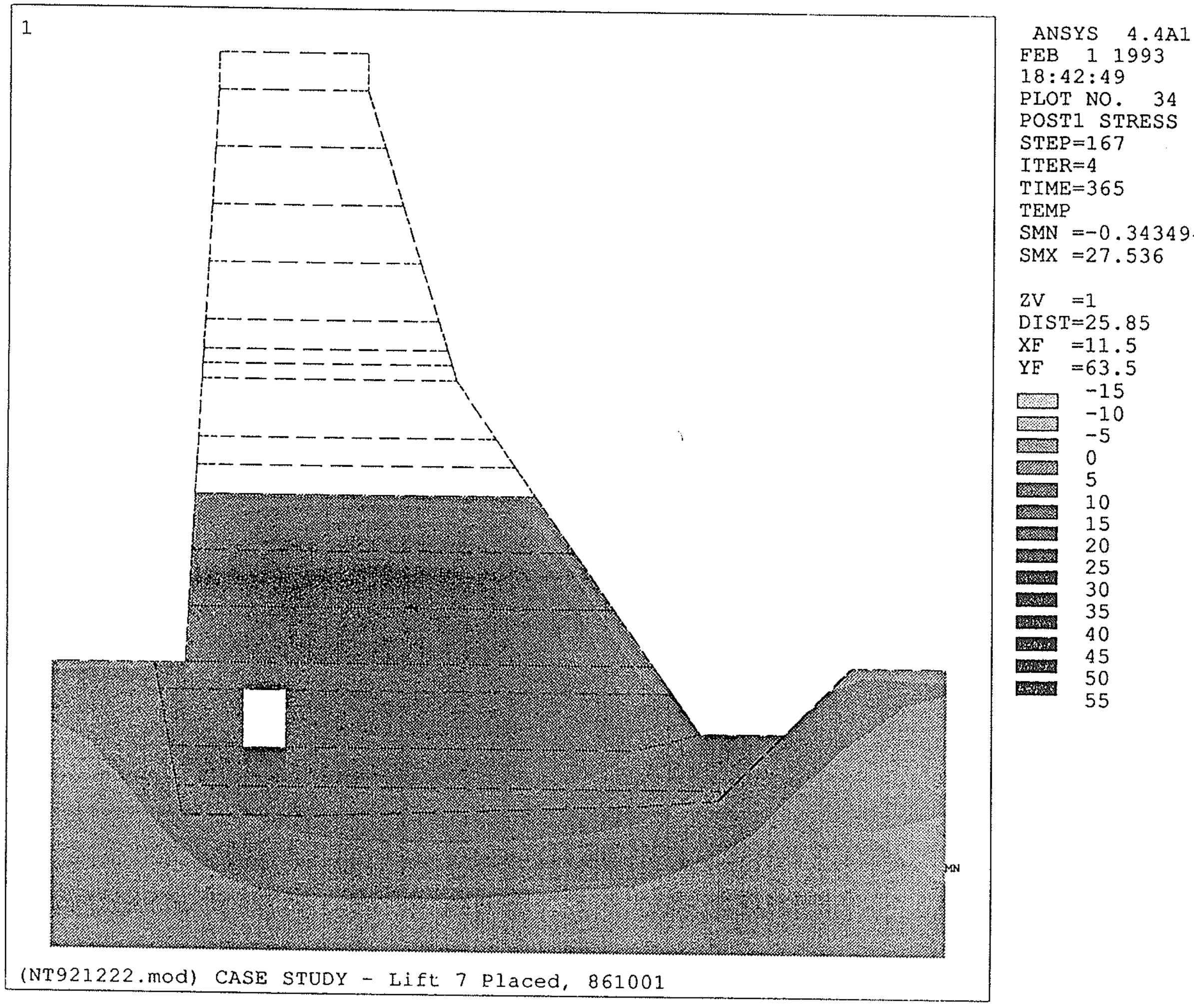

FIGURE I.16 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 861001 (42 Days after Placement of Lift NT2-7)

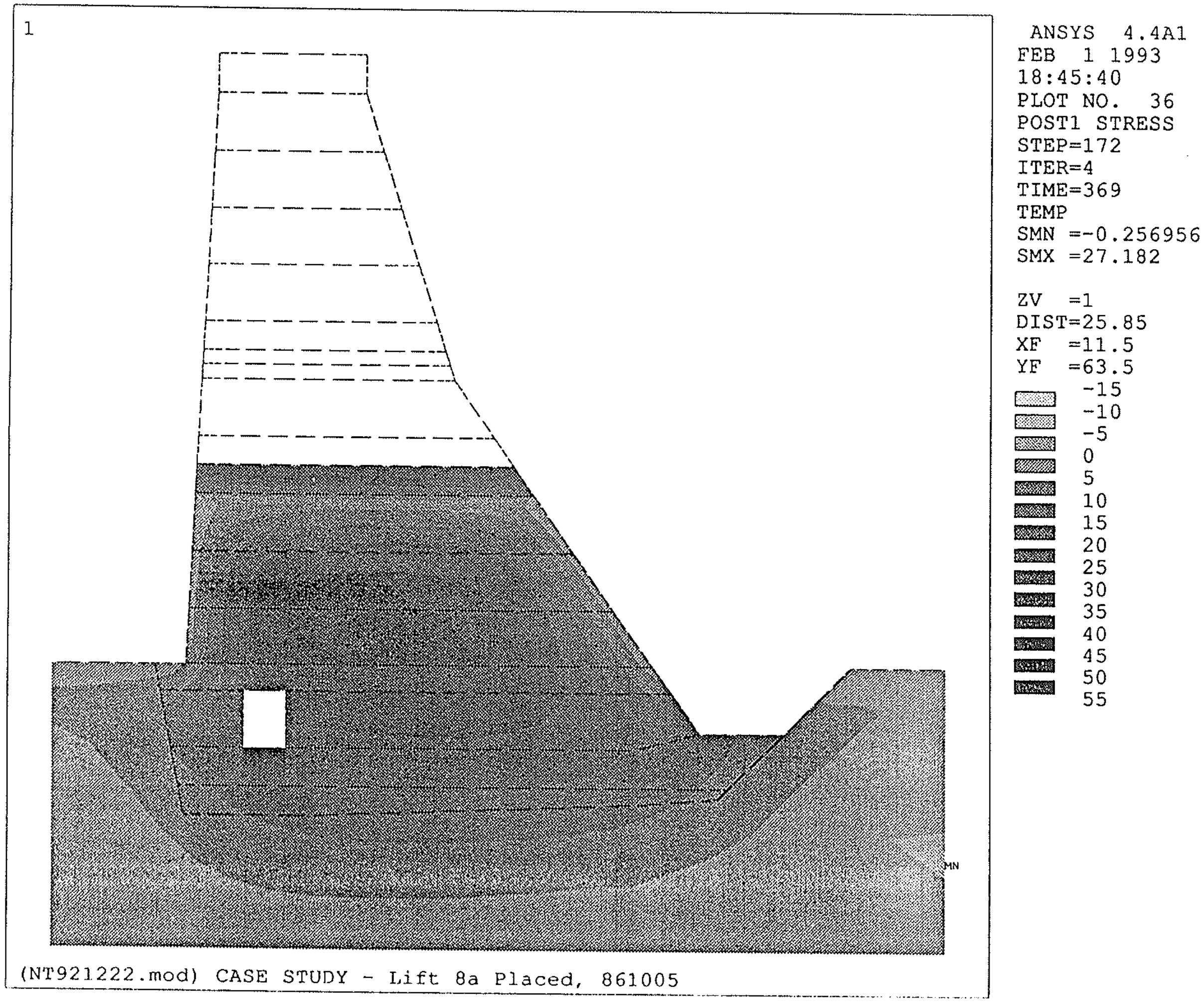

FIGURE I.17 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 861005 (1 Day after Placement of Lift NT2-8a)

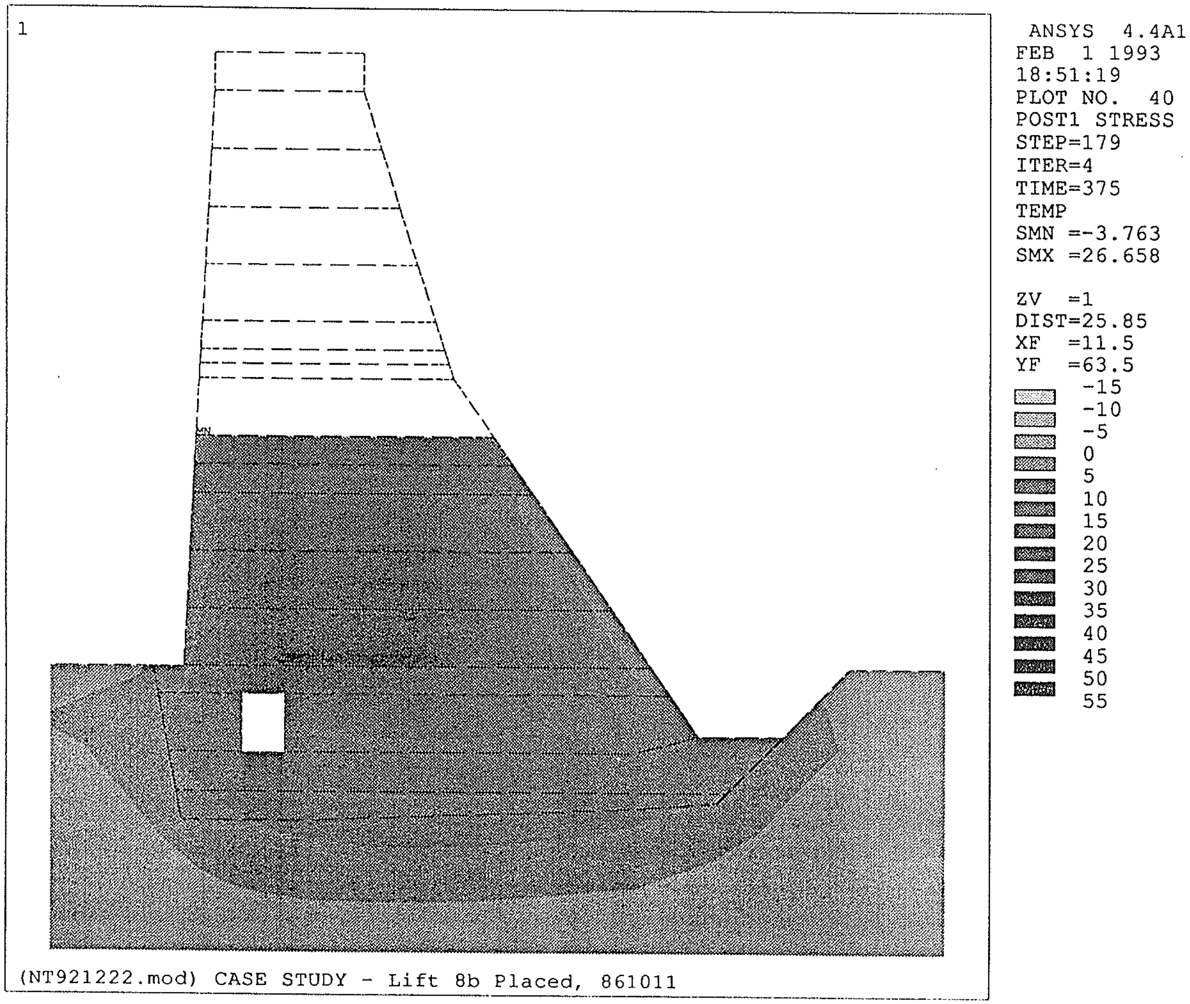

FIGURE I.18 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 861011 (3 Days after Placement of Lift NT2-8b)

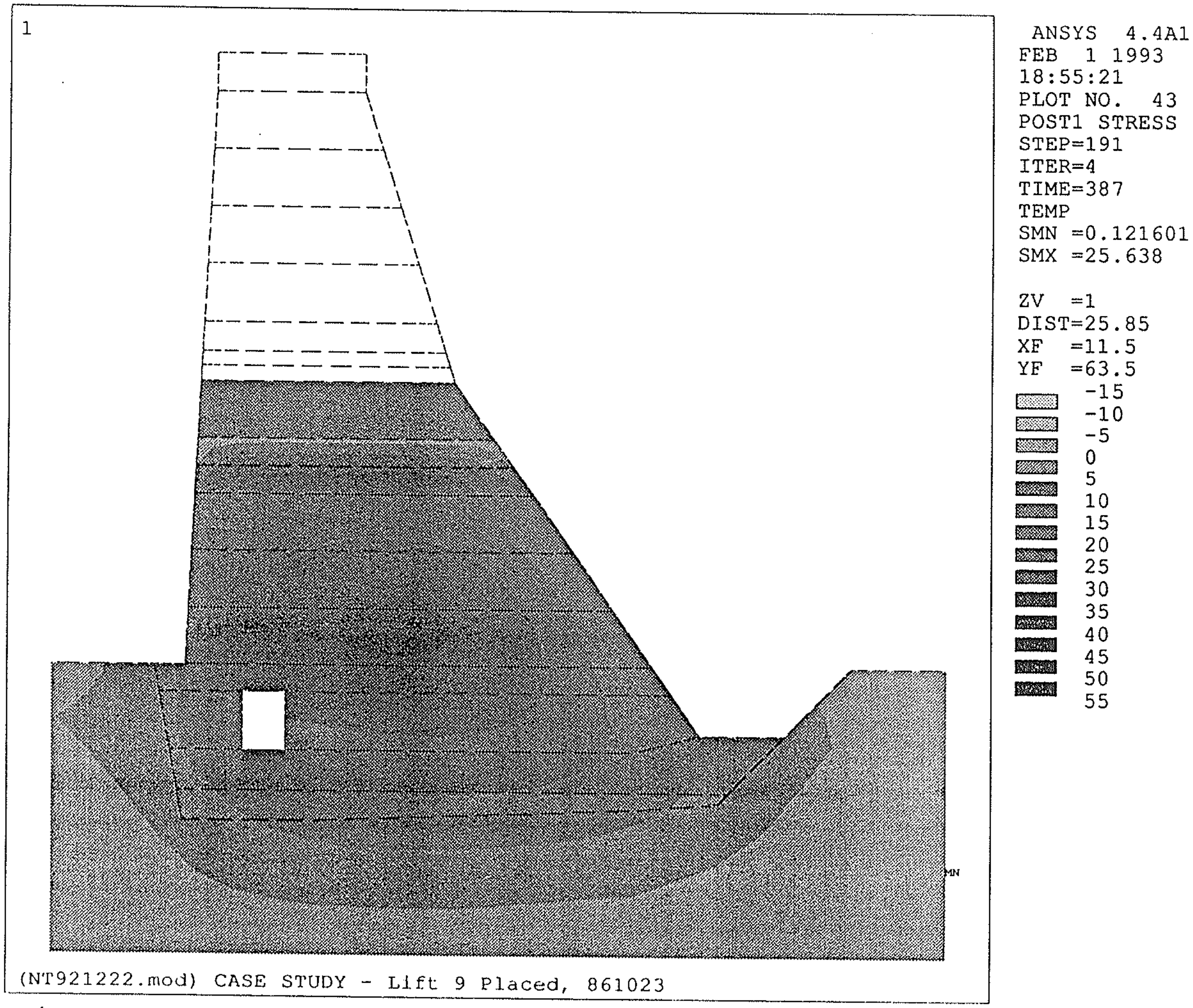

FIGURE I.19 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 861023 (Day of Placement of Lift NT2-9)

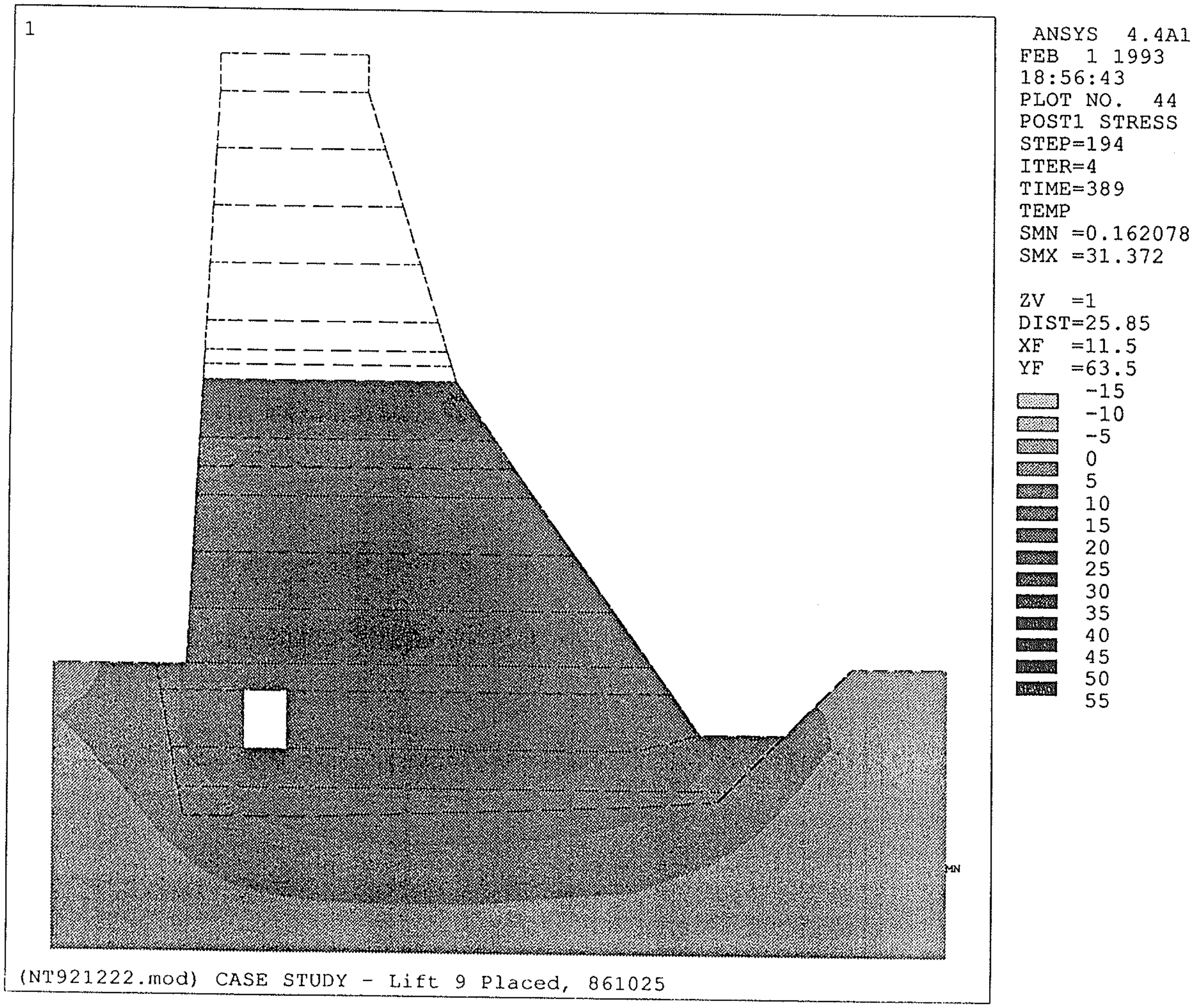

FIGURE I.20 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 861025 (2 Days after Placement of Lift NT2-9)

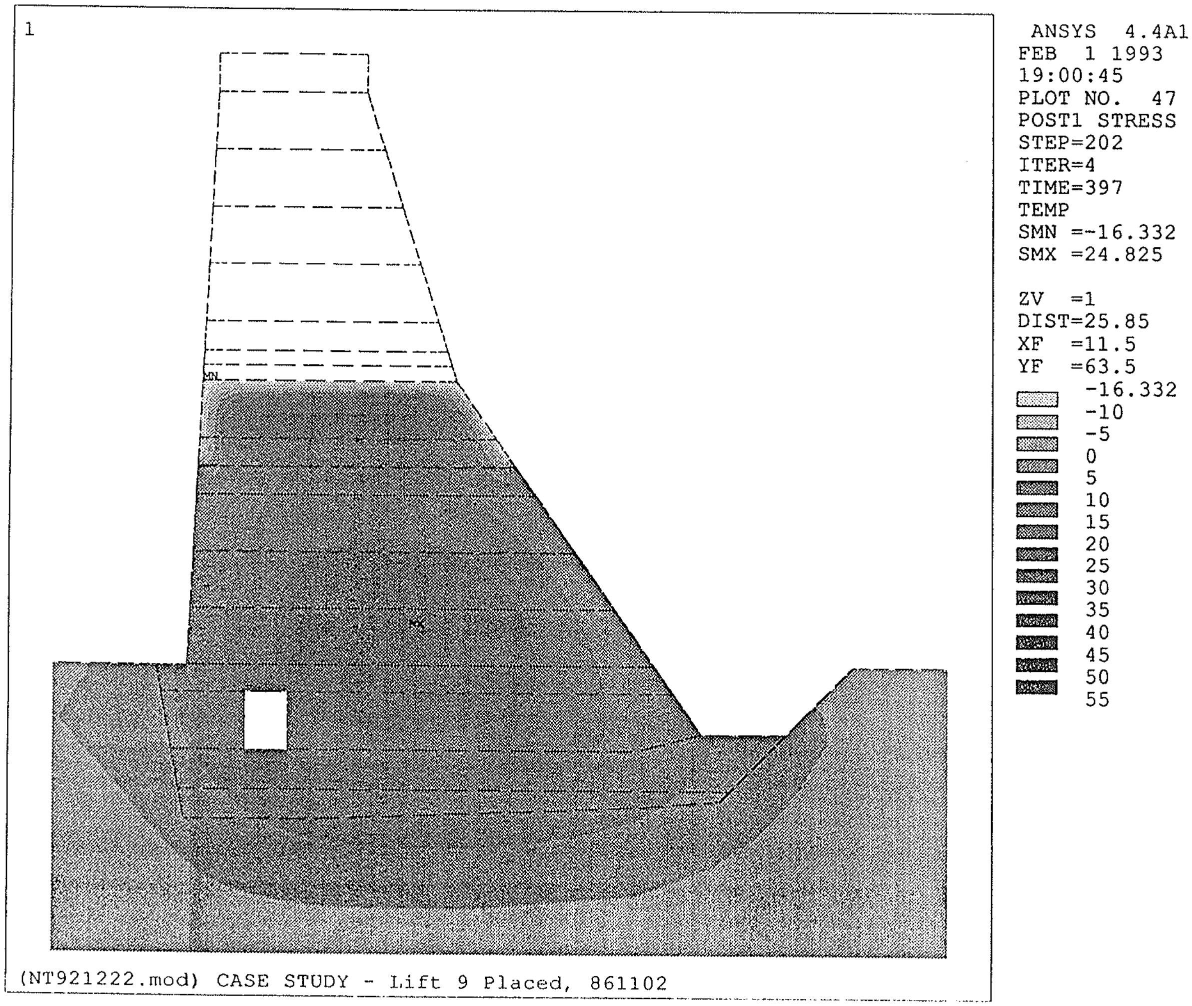

FIGURE I.21 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 861102 (10 Days after Placement of Lift NT2-9)

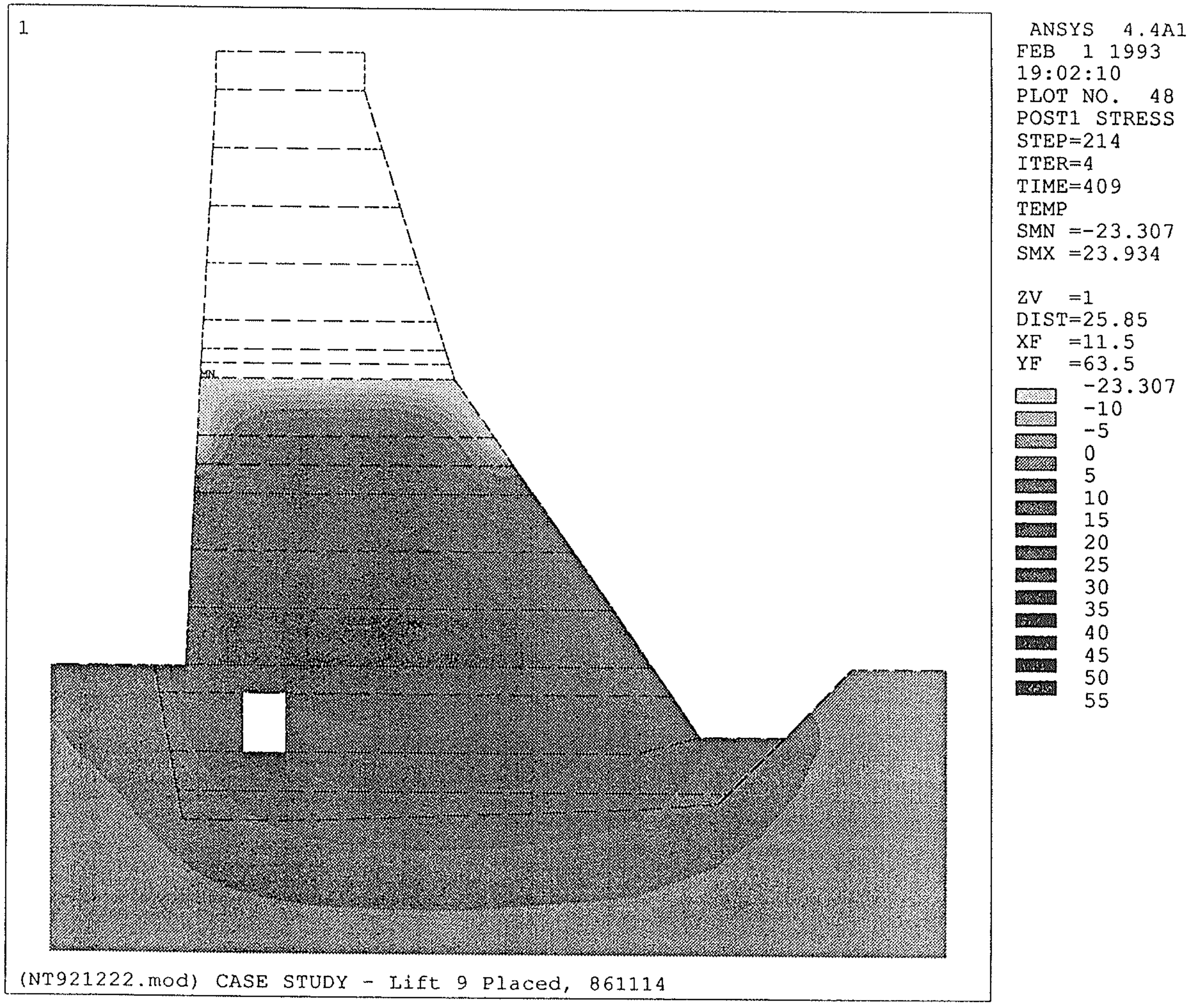

FIGURE I.22 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 861114 (22 Days after Placement of Lift NT2-9)

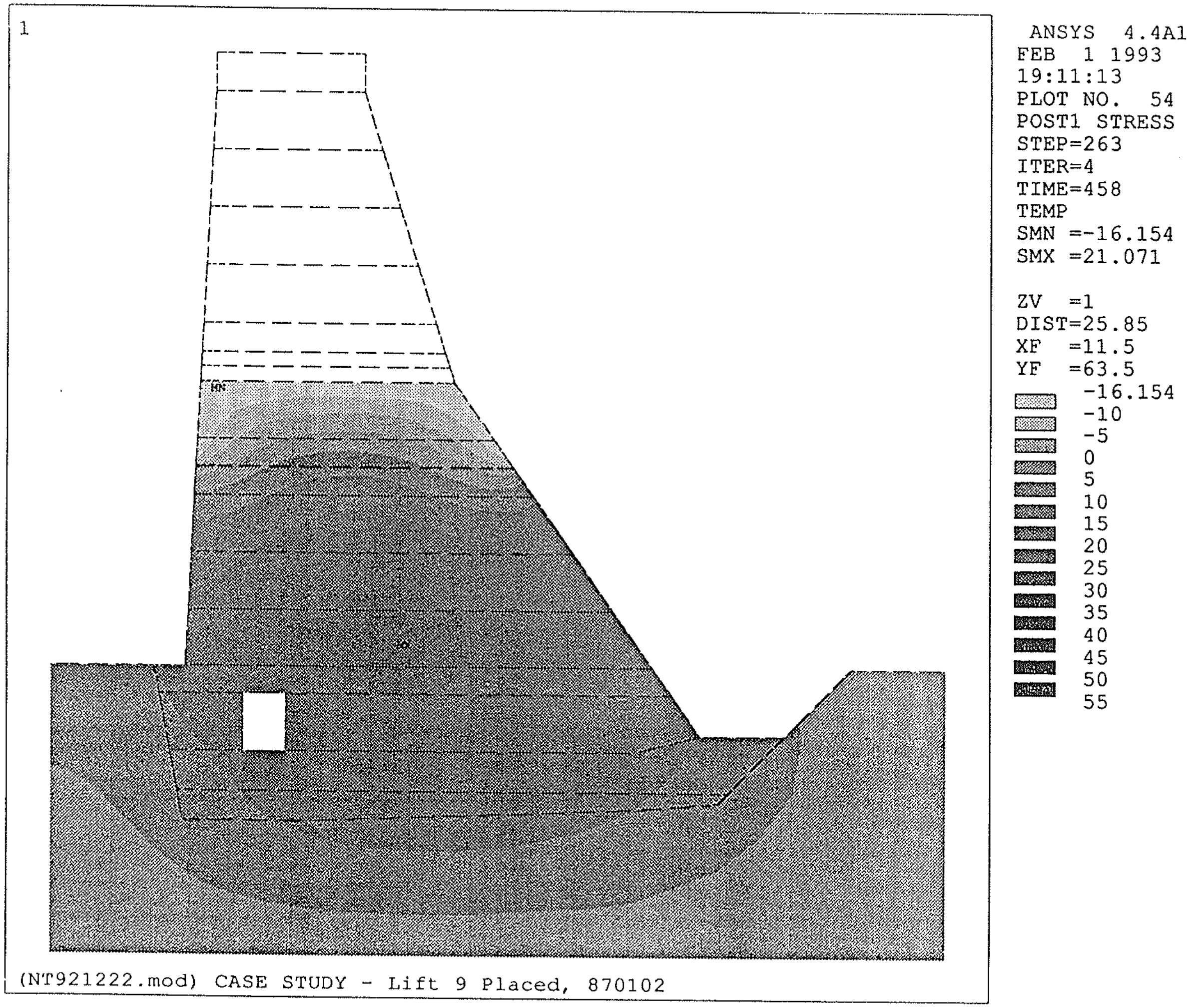

FIGURE I.23 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 870102 (71 Days after Placement of Lift NT2-9)

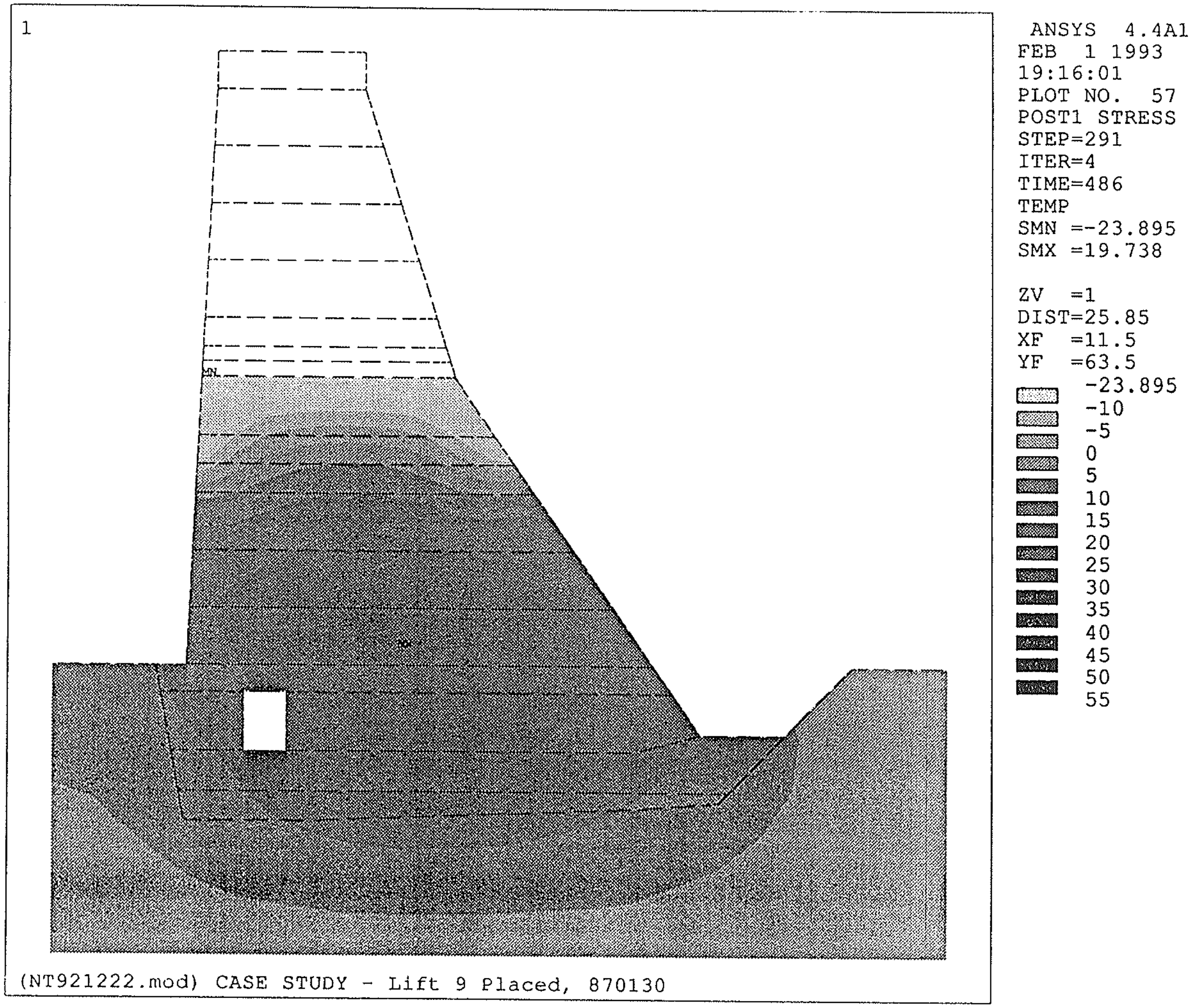

FIGURE I.24 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 870130 (99 Days after Placement of Lift NT2-9)

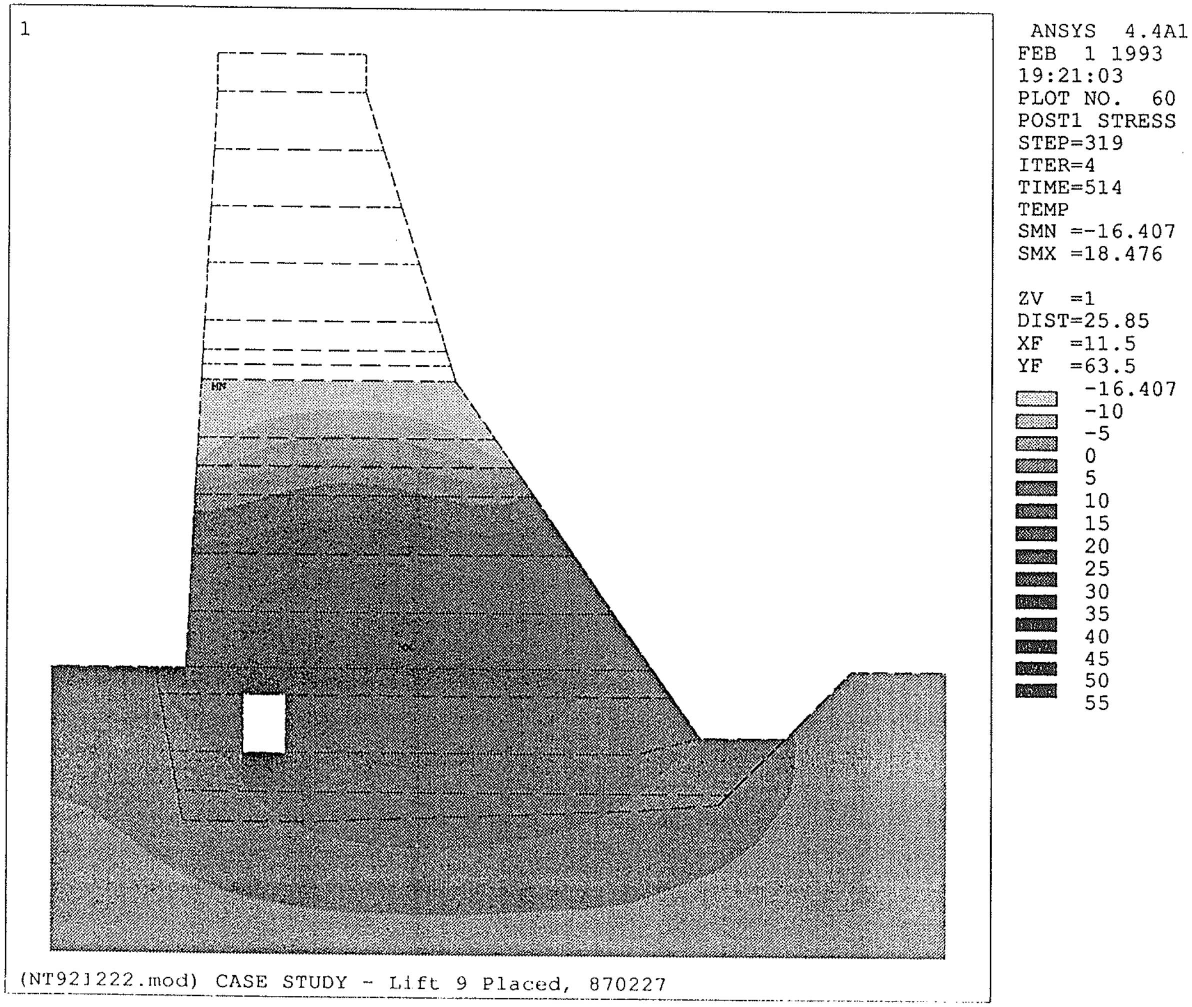

FIGURE I.25 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 870227 (127 Days after Placement of Lift NT2-9)

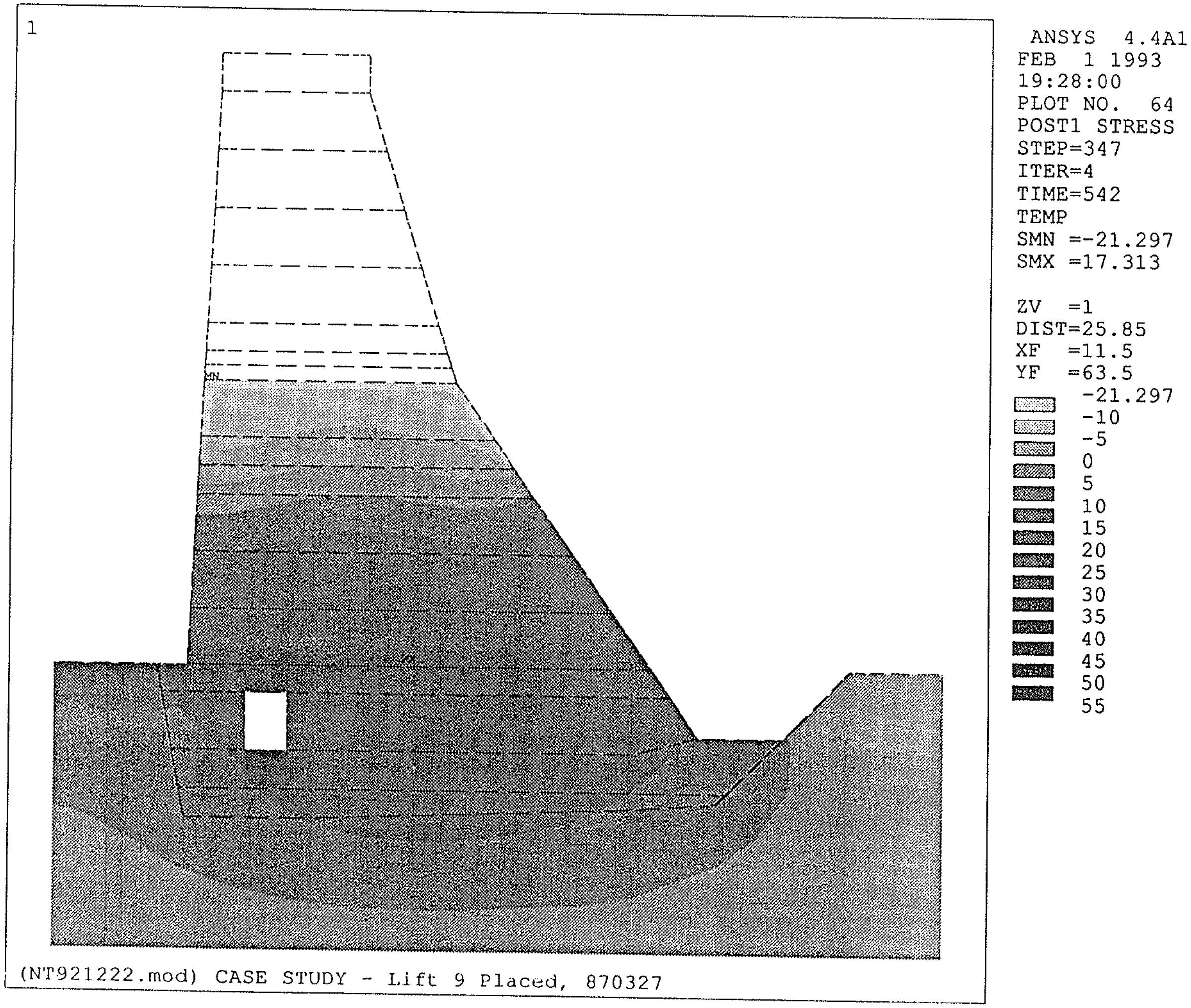

FIGURE I.26 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 870327 (155 Days after Placement of Lift NT2-9)

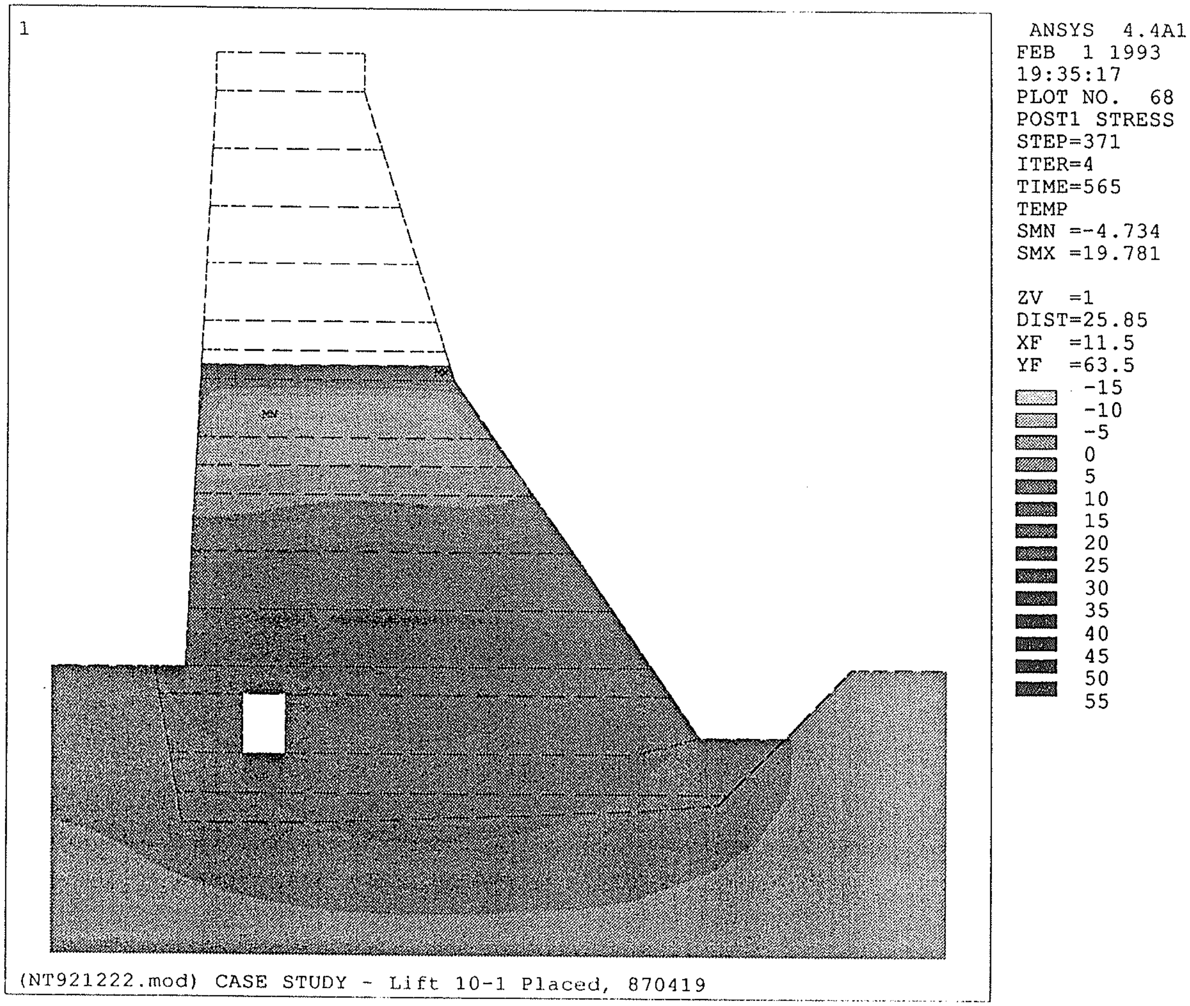

FIGURE I.27 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 870419 (2 Days after Placement of Lift NT2-10-1)

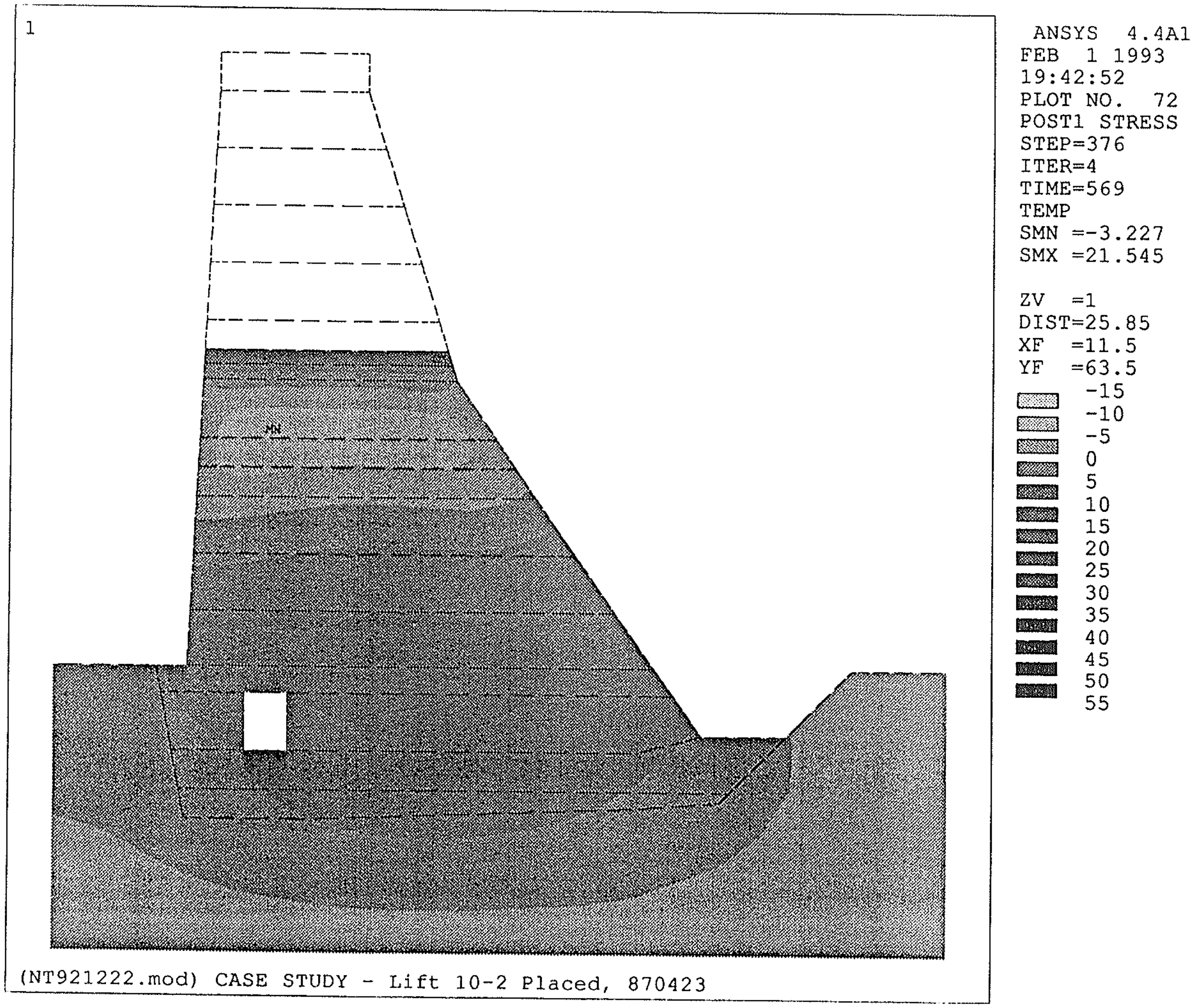

FIGURE I.28 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 870423 (1 Day after Placement of Lift NT2-10-2)

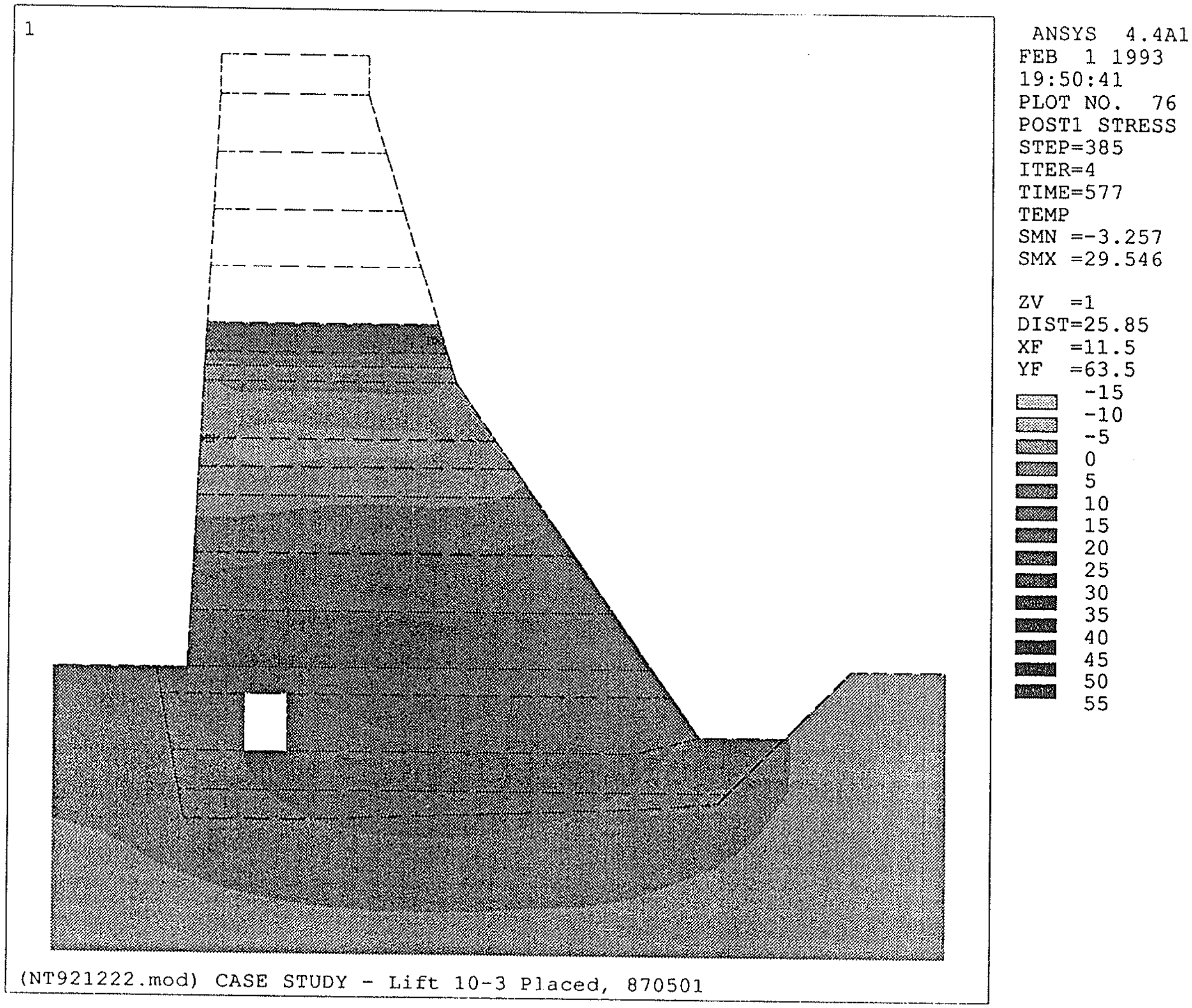

FIGURE I.29 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 870501 (2 Days after Placement of Lift NT2-10-3)

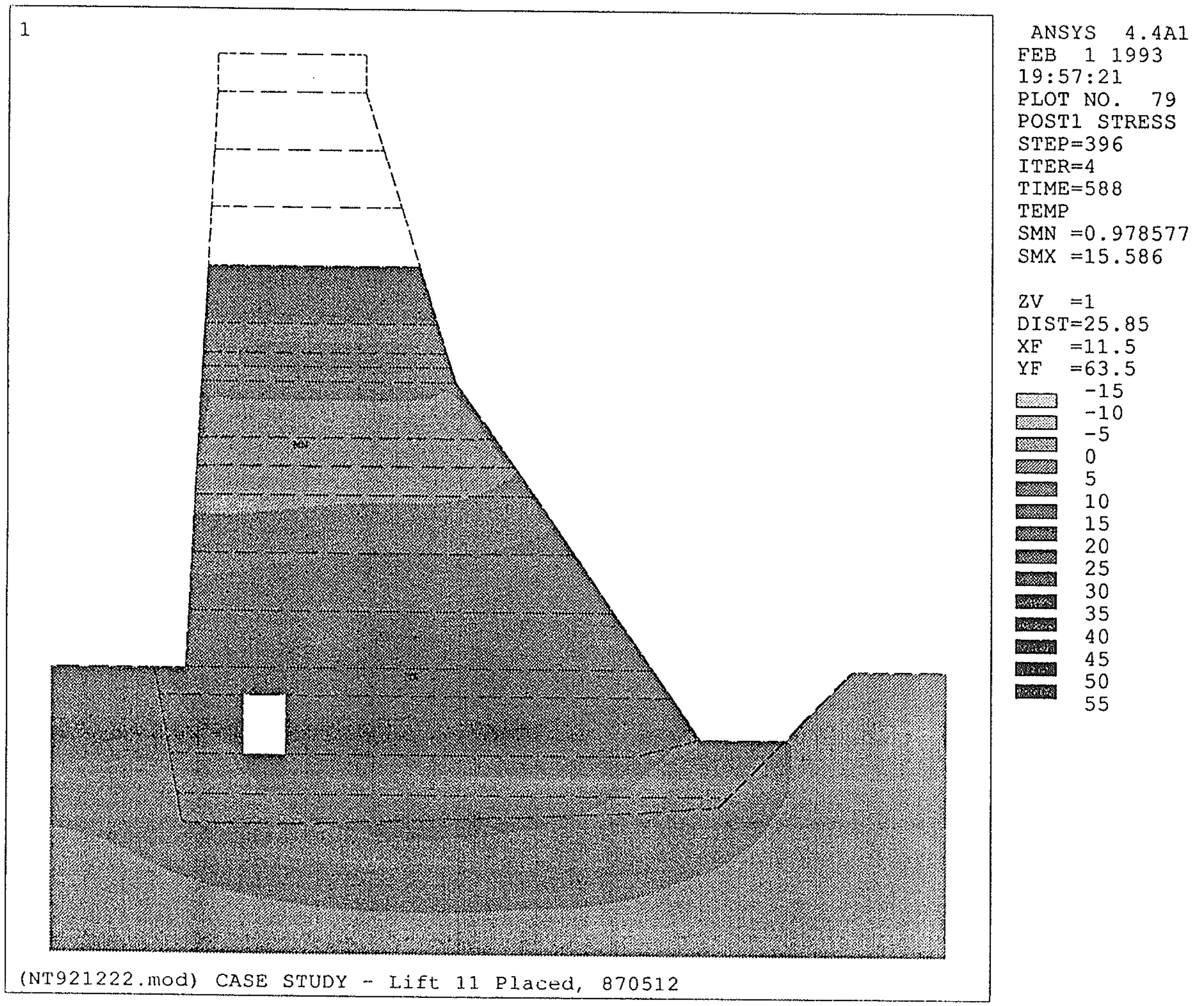

FIGURE I.30 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 870512 (Day of Placement of Lift NT2-11)

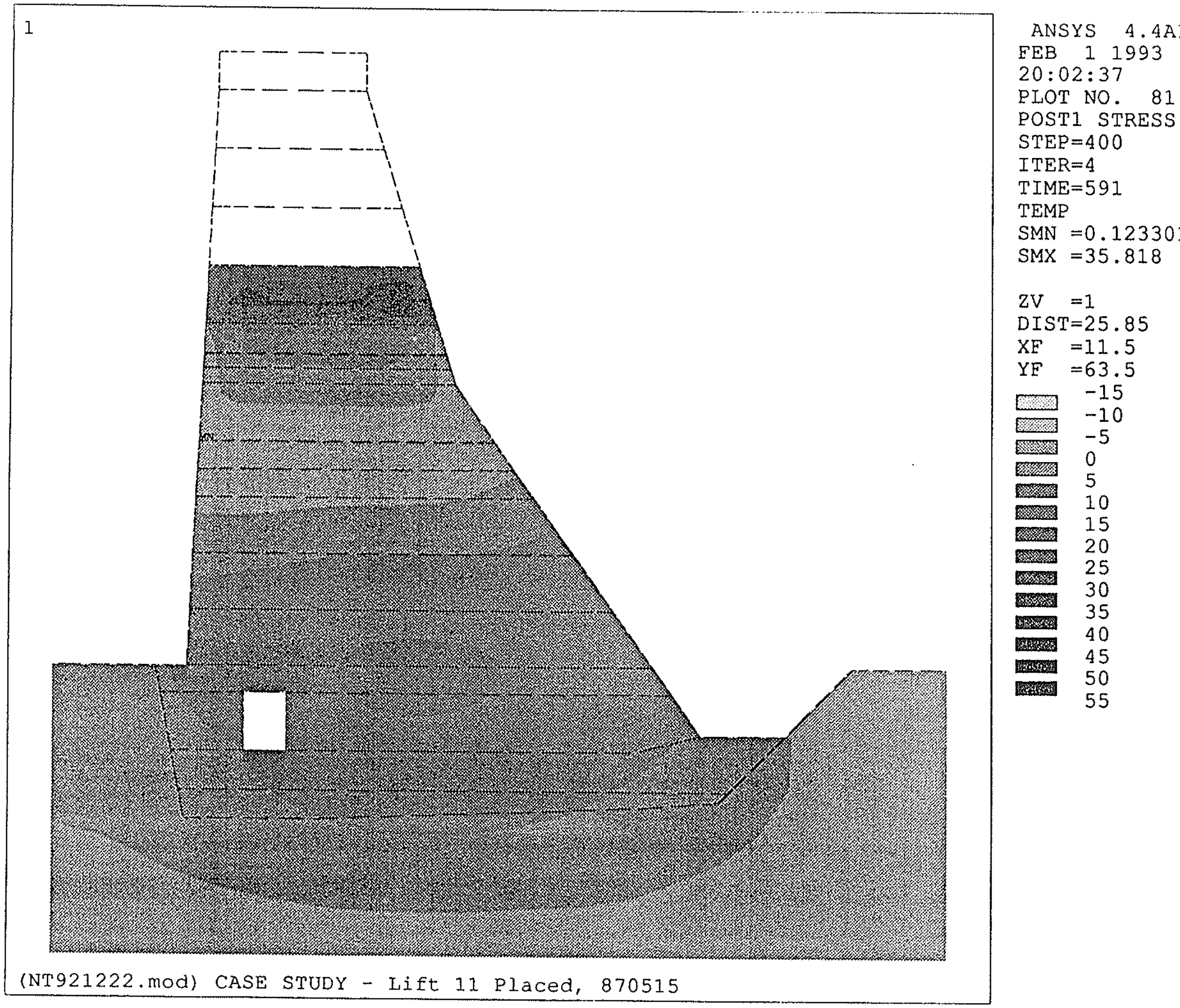

FIGURE I.31 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 870515 (3 Days after Placement of Lift NT2-11)

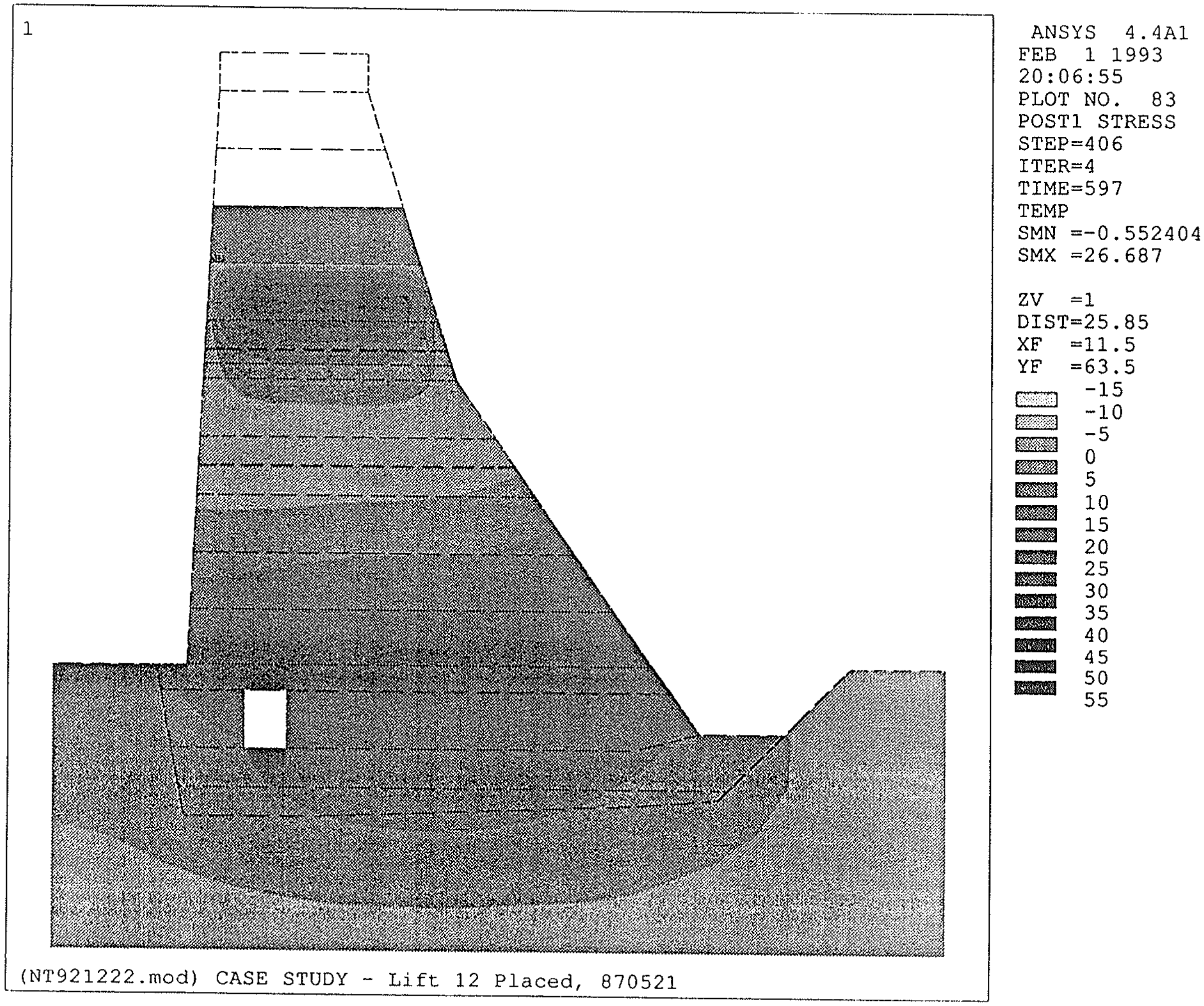

FIGURE I.32 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 870521 (Day of Placement of Lift NT2-12)

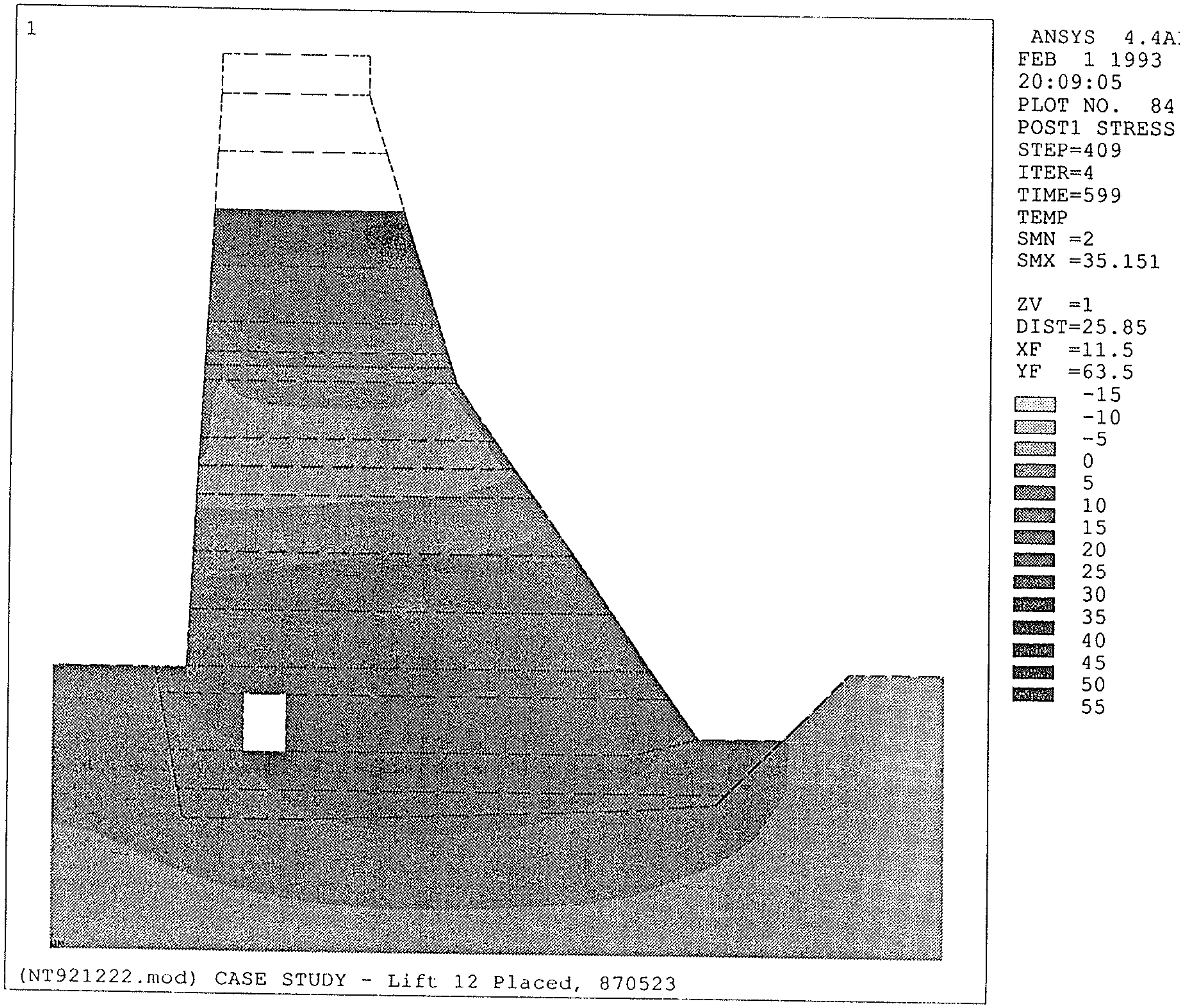

FIGURE I.33 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 870523 (2 Days after Placement of Lift NT2-12)

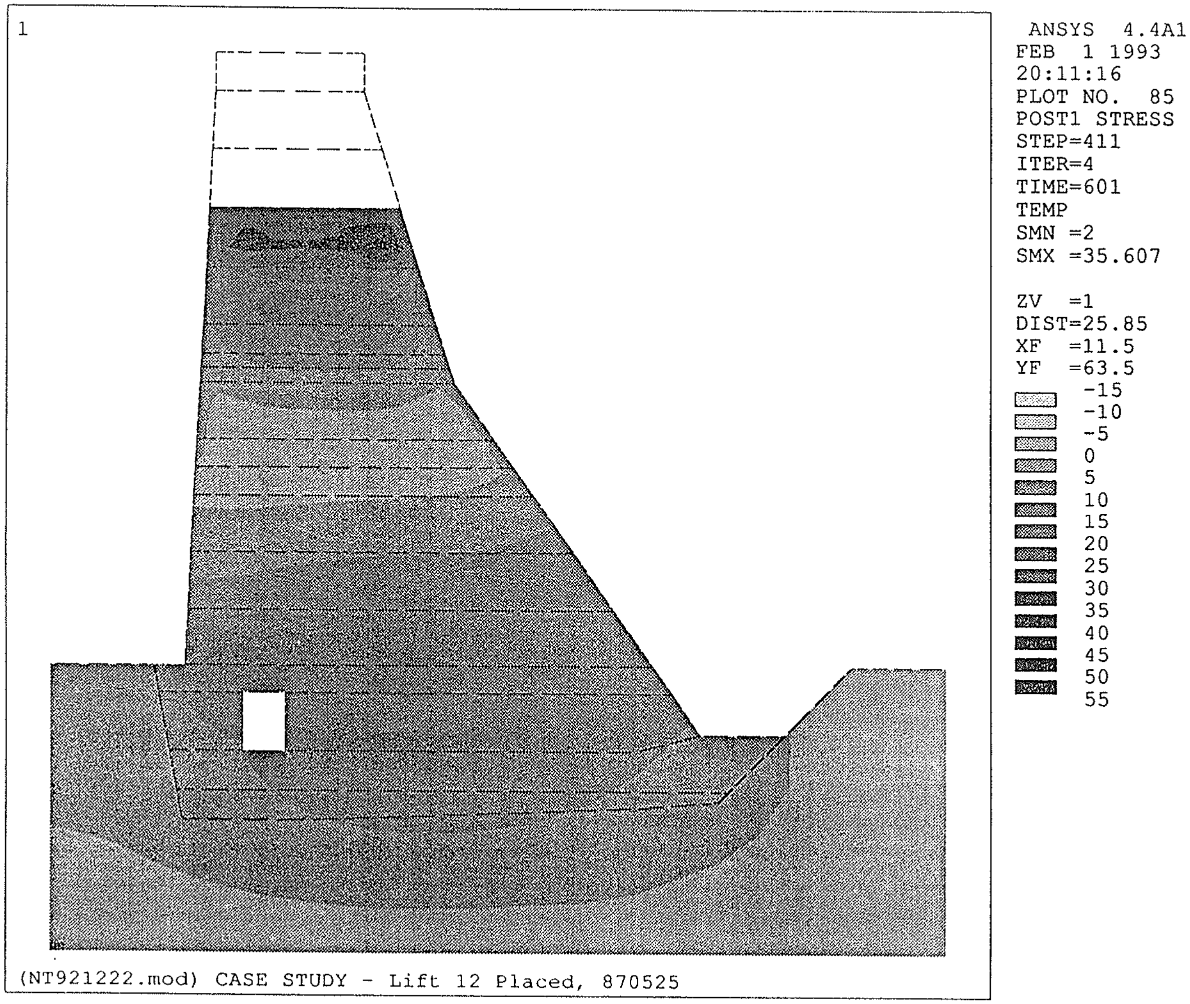

FIGURE I.34 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 870525 (4 Days after Placement of Lift NT2-12)

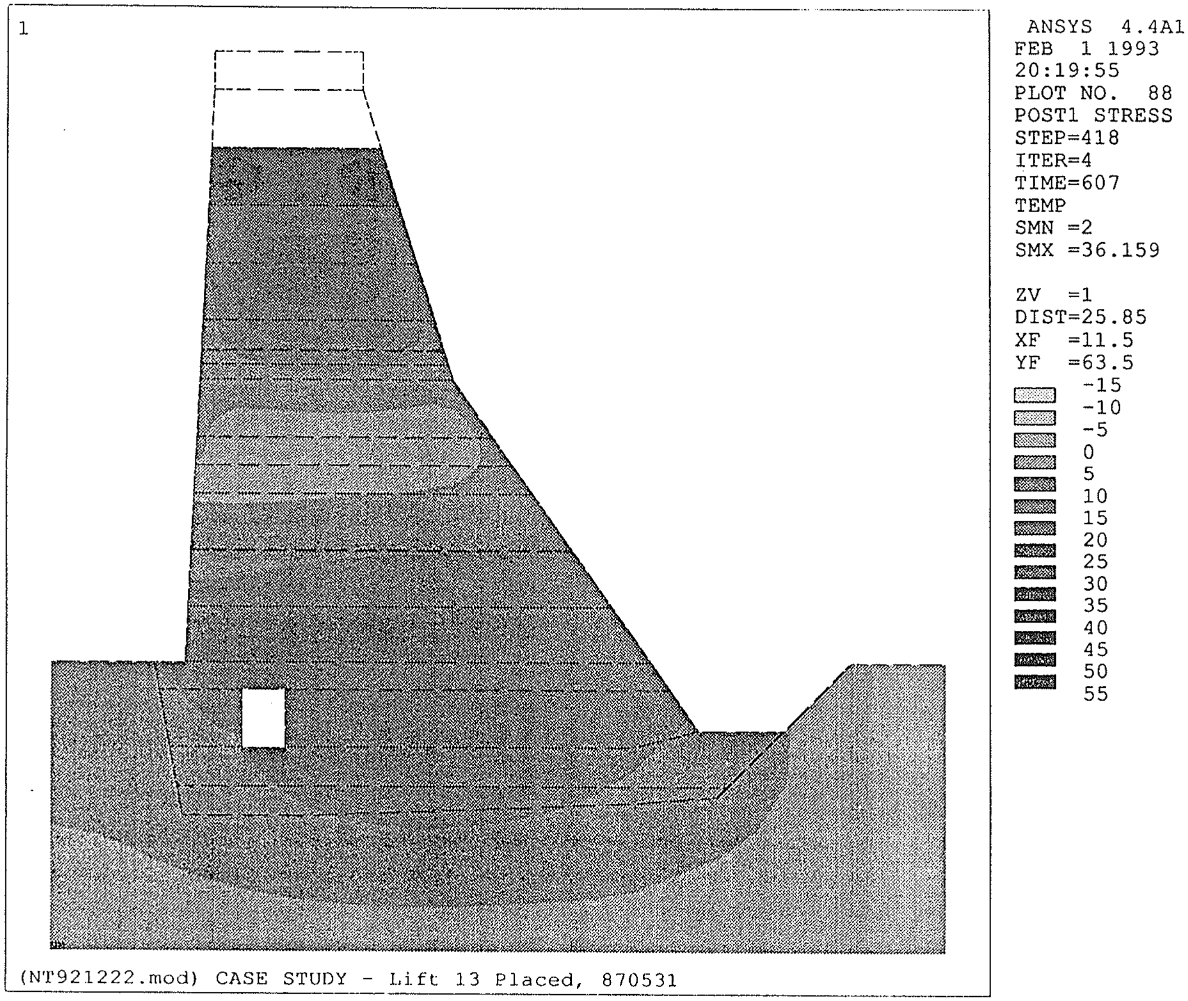

FIGURE I.35 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 870531 (2 Days after Placement of Lift NT2-13)

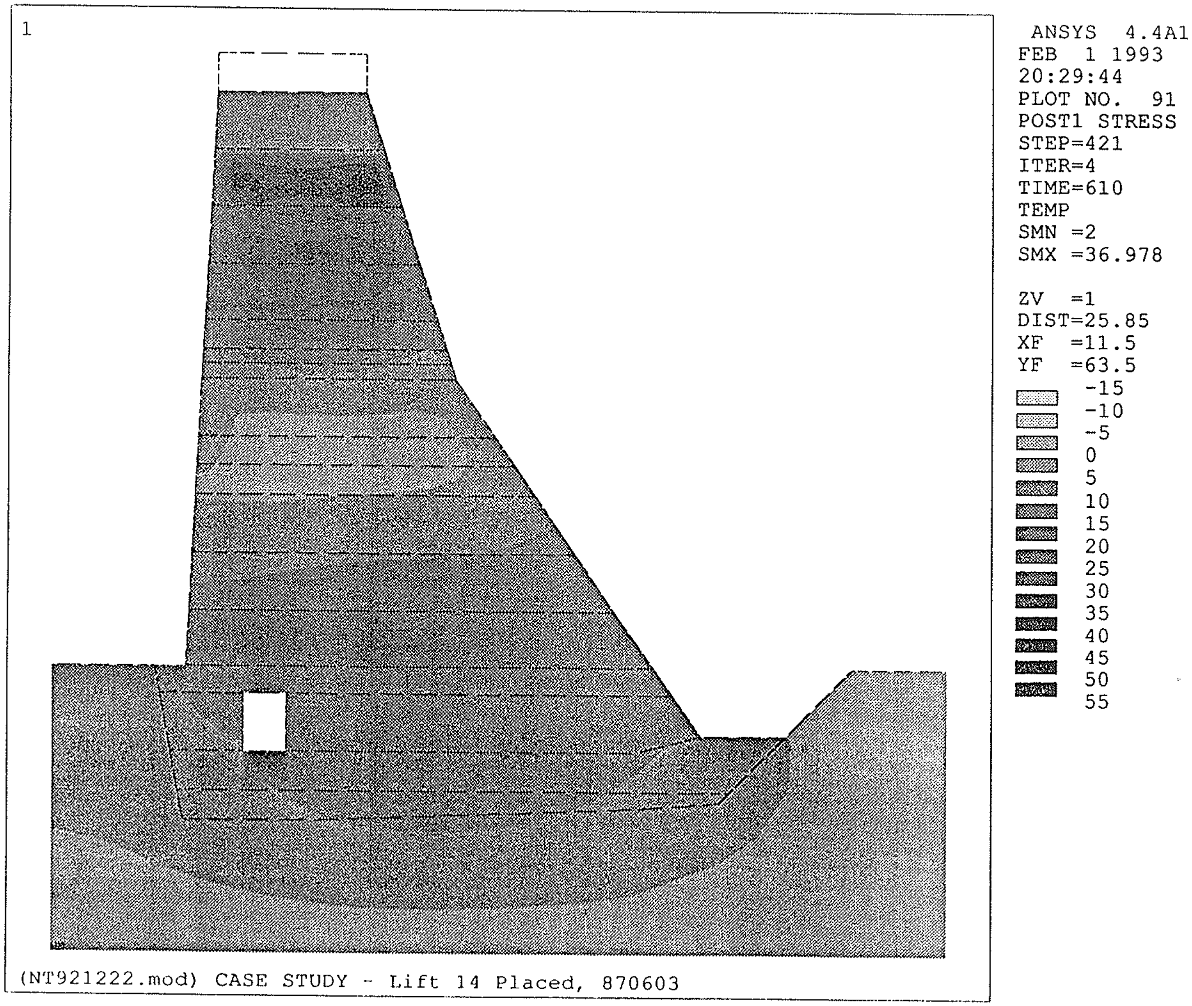

FIGURE I.36 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 870603 (Day of Placement of Lift NT2-14)

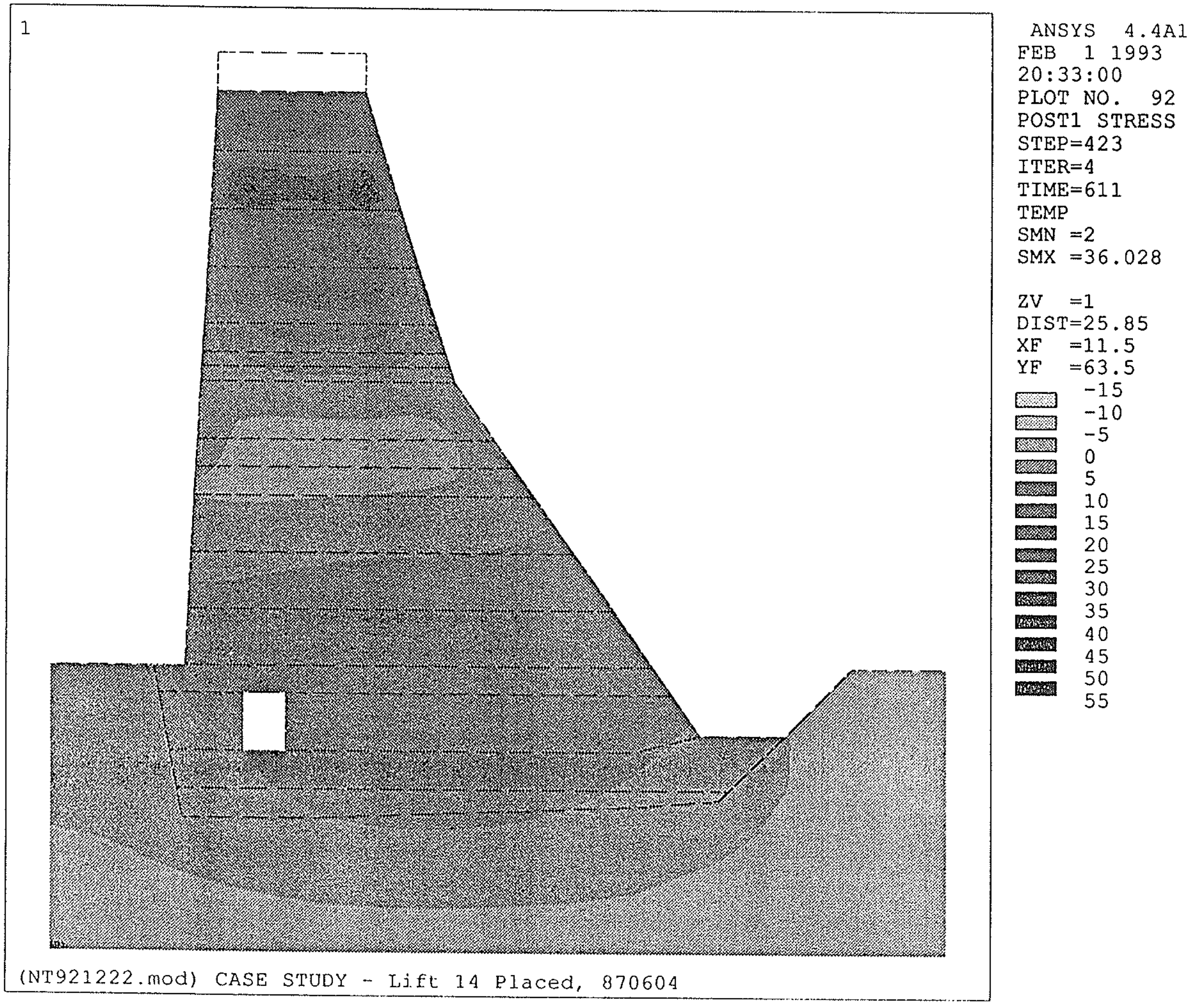

FIGURE I.37 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 870604 (1 Day after Placement of Lift NT2-14)

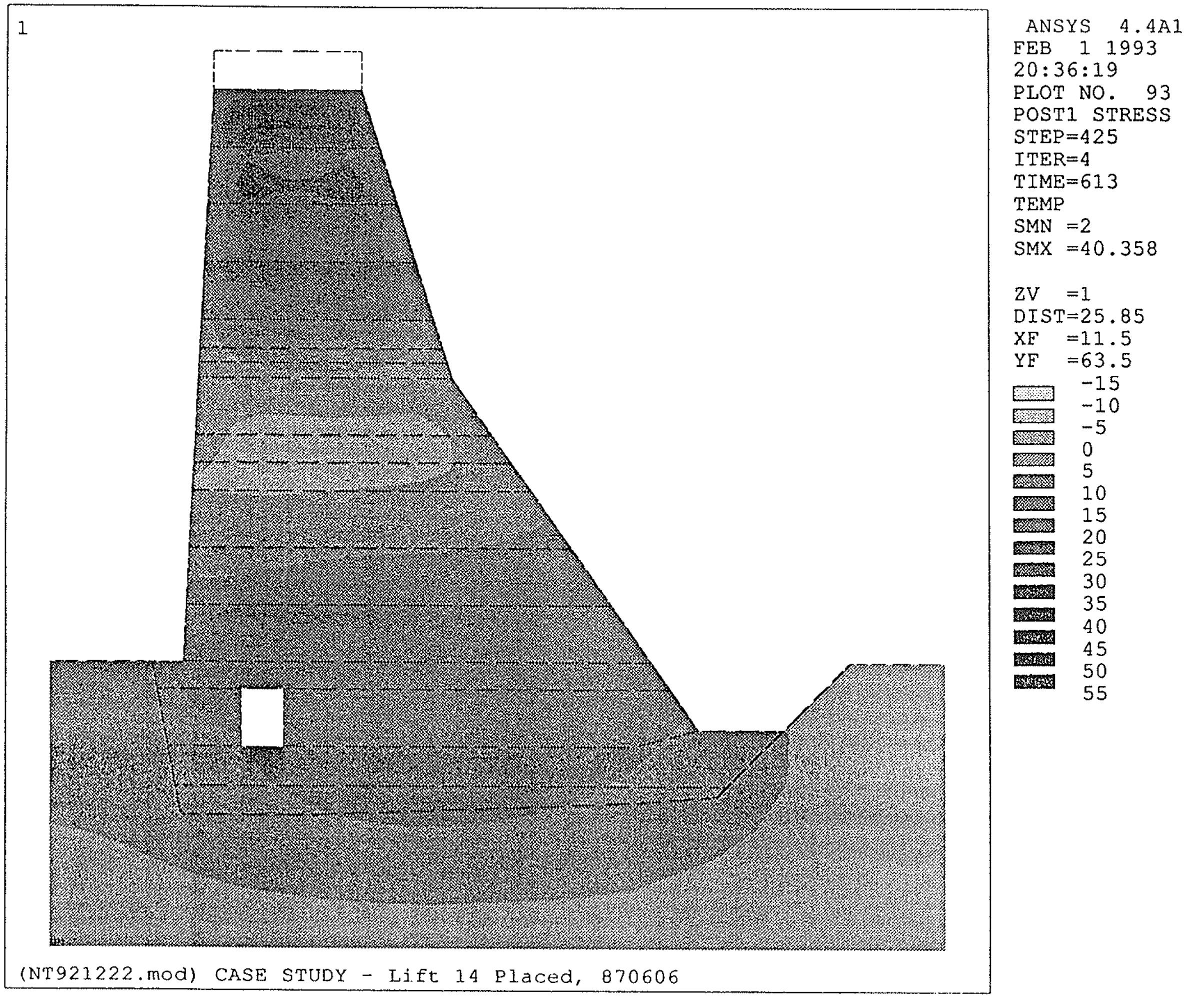

FIGURE I.38 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 870606 (3 Days after Placement of Lift NT2-14)

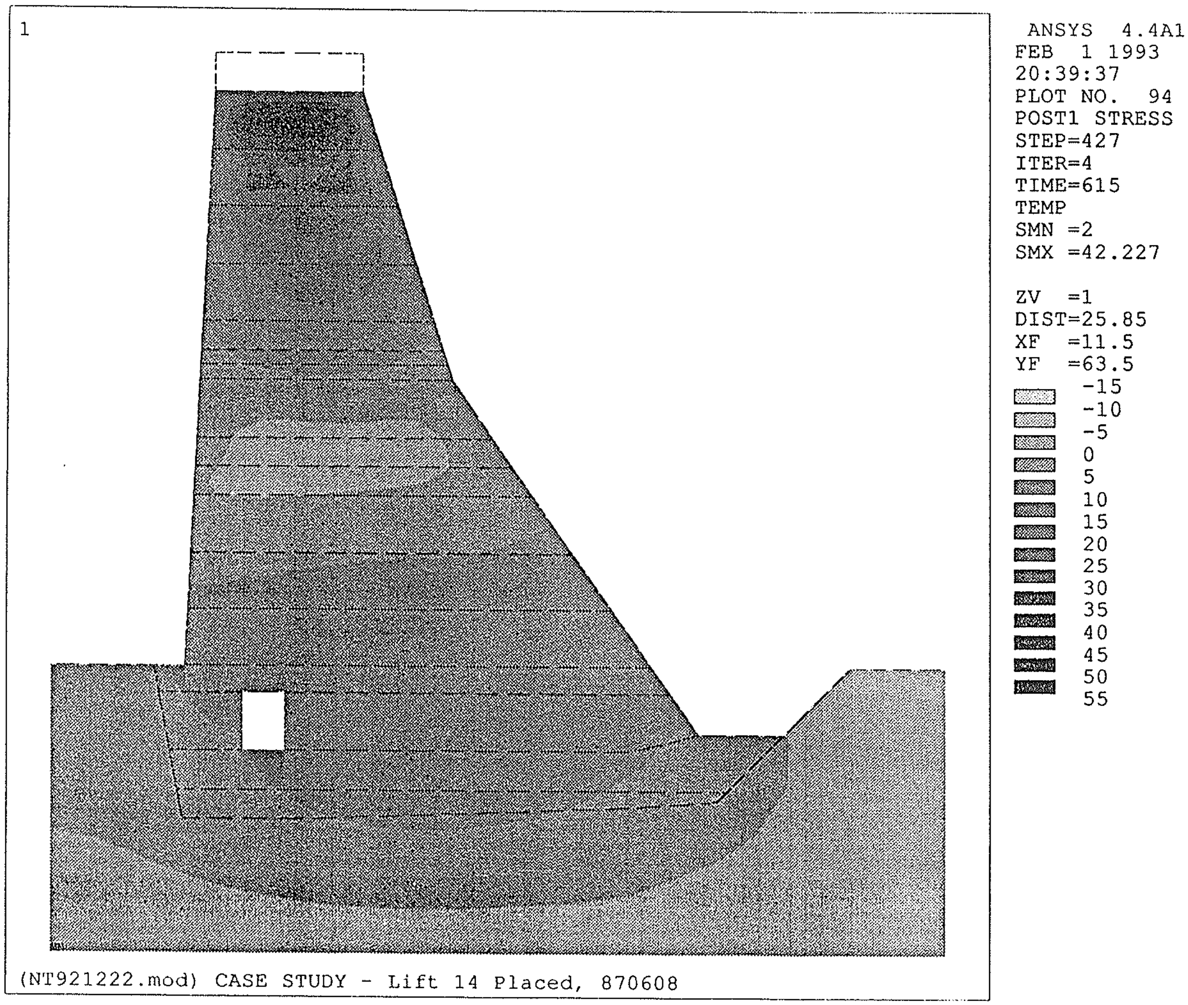

FIGURE I.39 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 870608 (5 Days after Placement of Lift NT2-14)

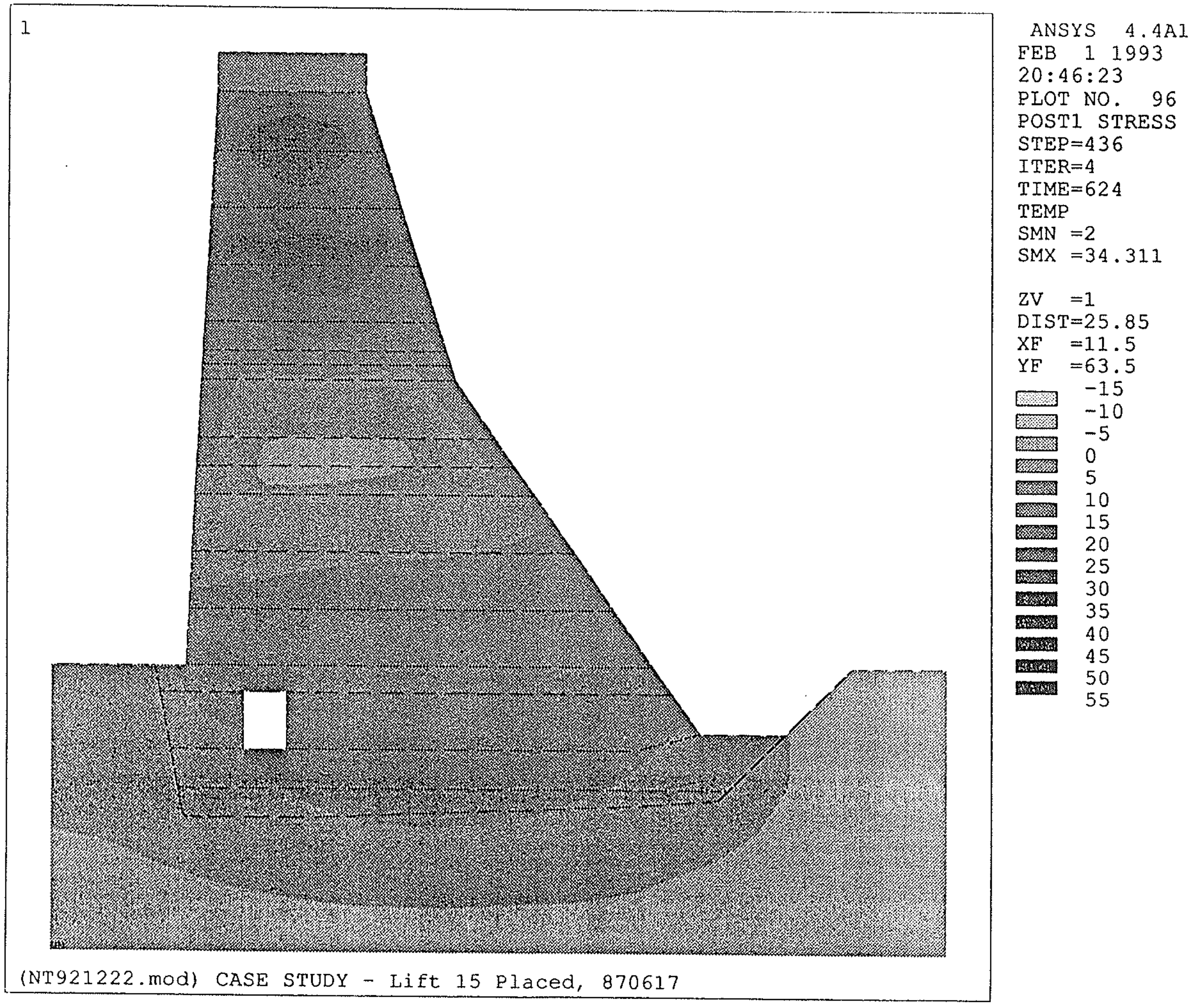

FIGURE I.40 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 870617 (Day of Placement of Lift NT2-15)

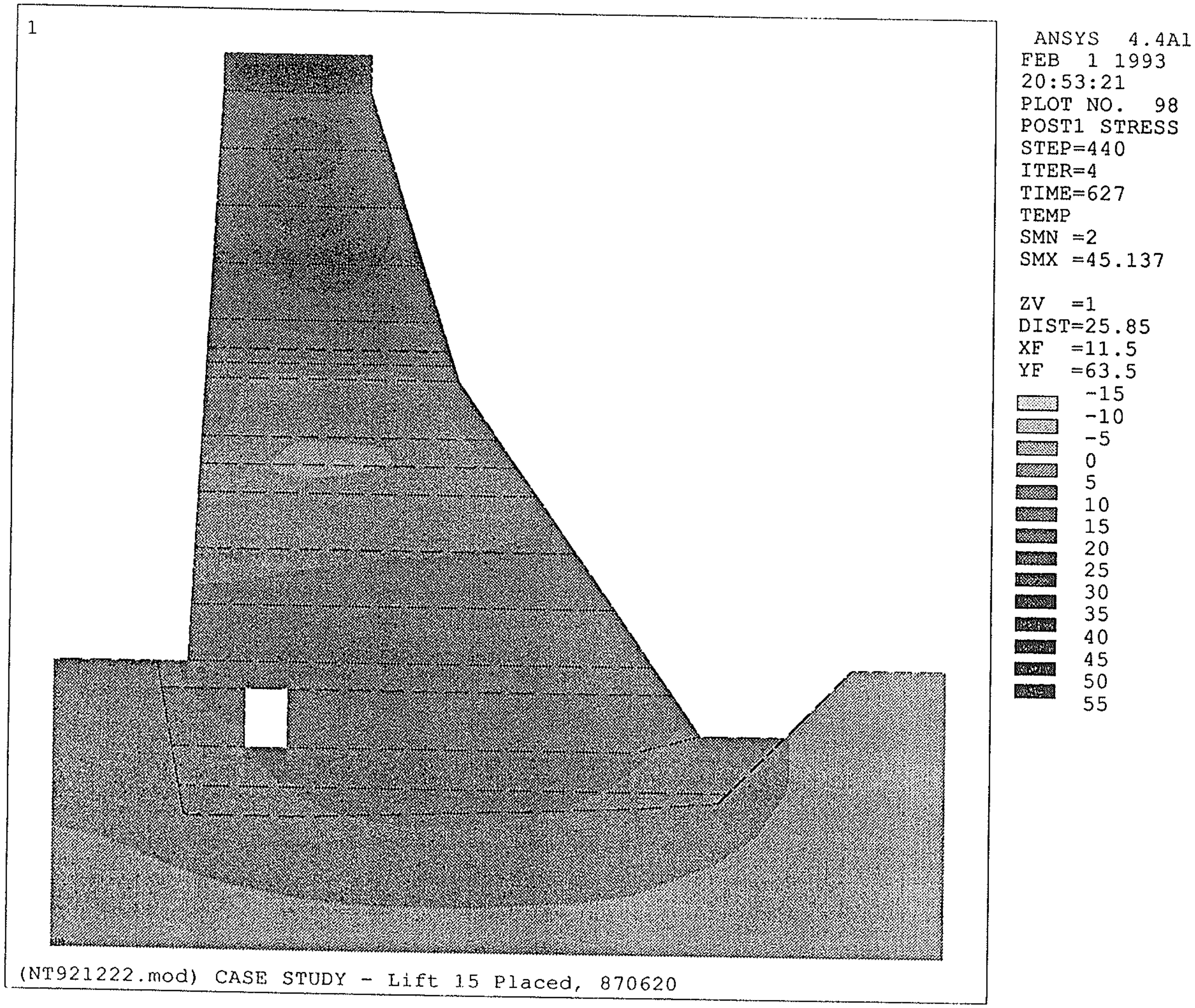

FIGURE I.41 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 870620 (3 Days after Placement of Lift NT2-15)

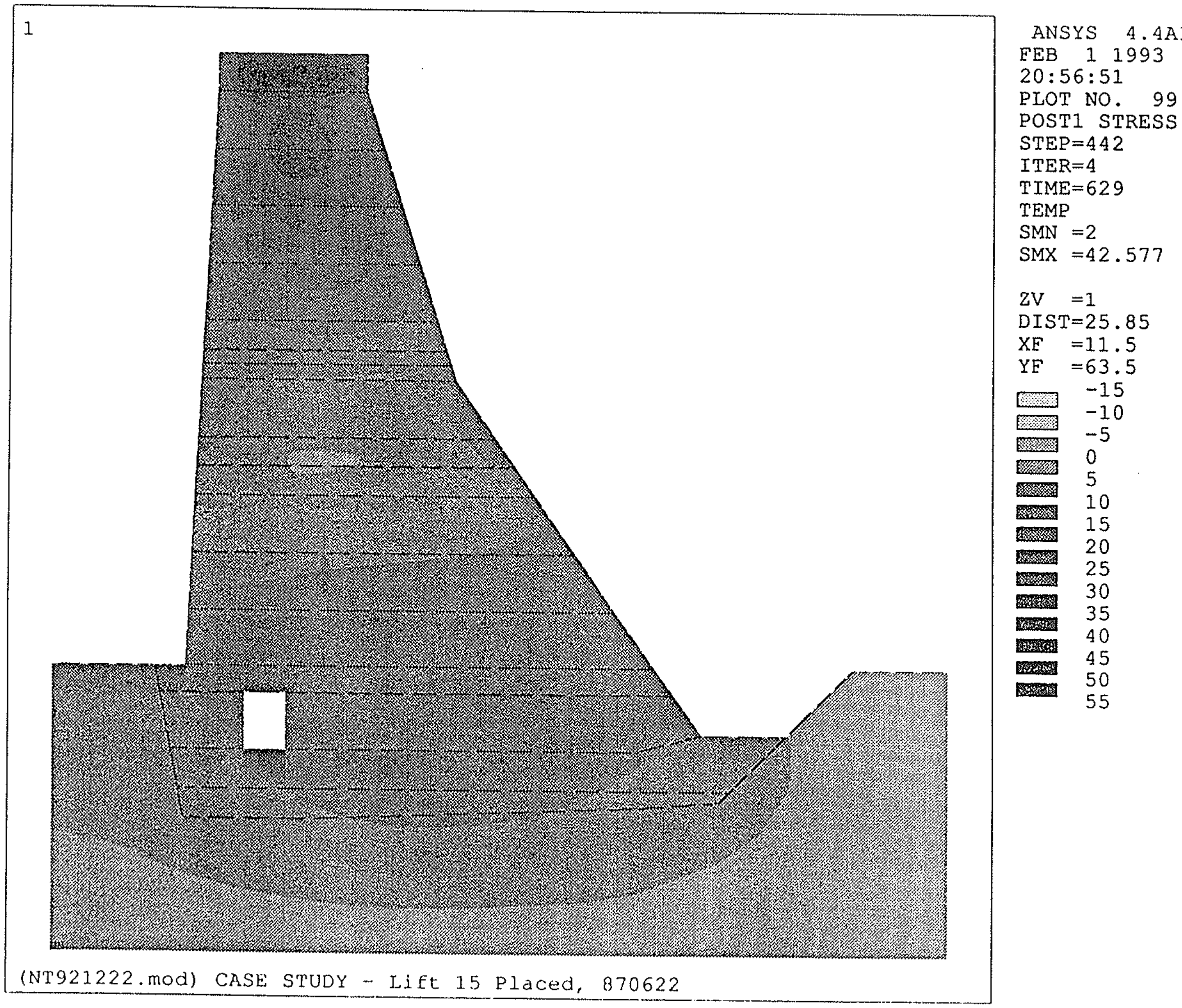

FIGURE I.42 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 870622 (5 Days after Placement of Lift NT2-15)

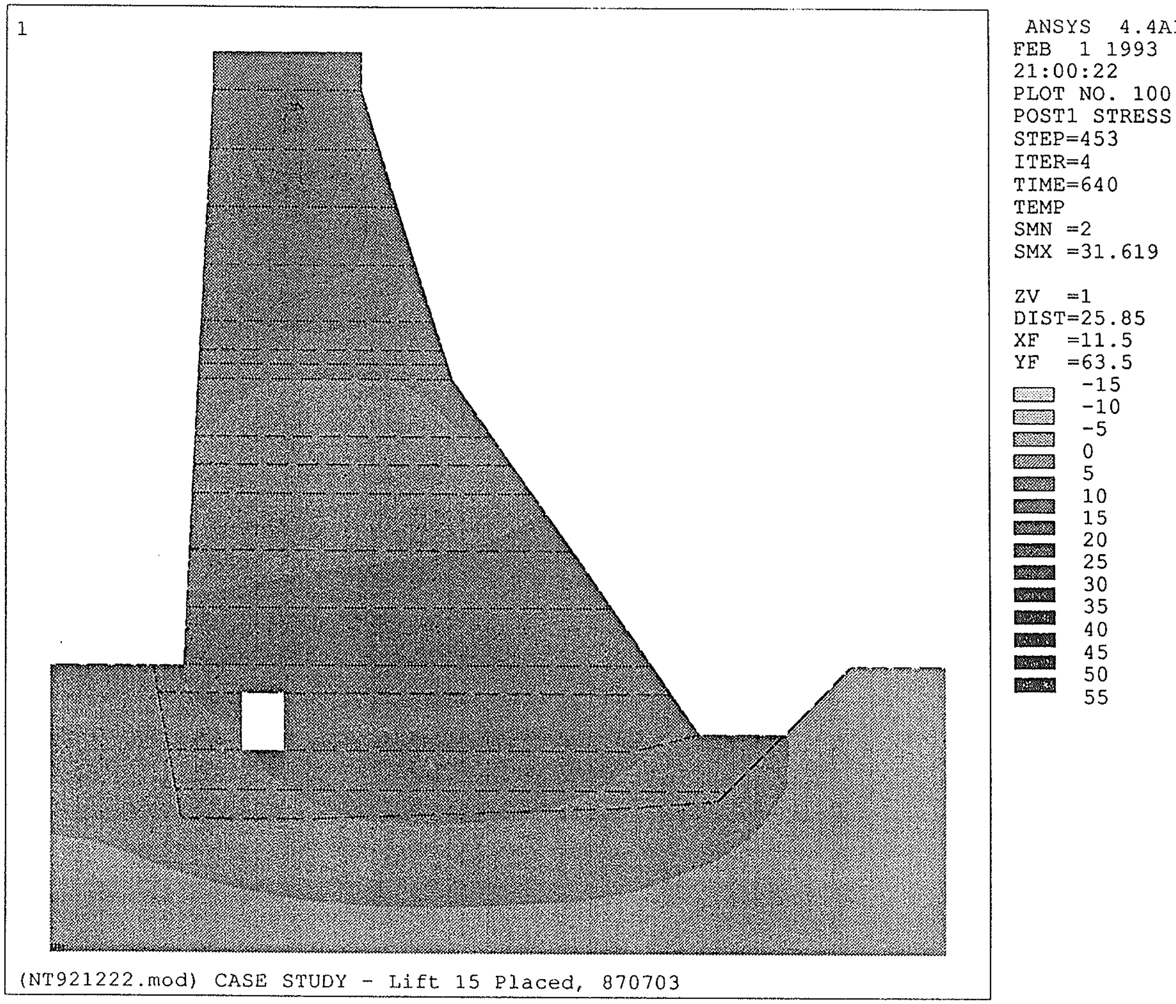

FIGURE I.43 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 870703 (16 Days after Placement of Lift NT2-15)

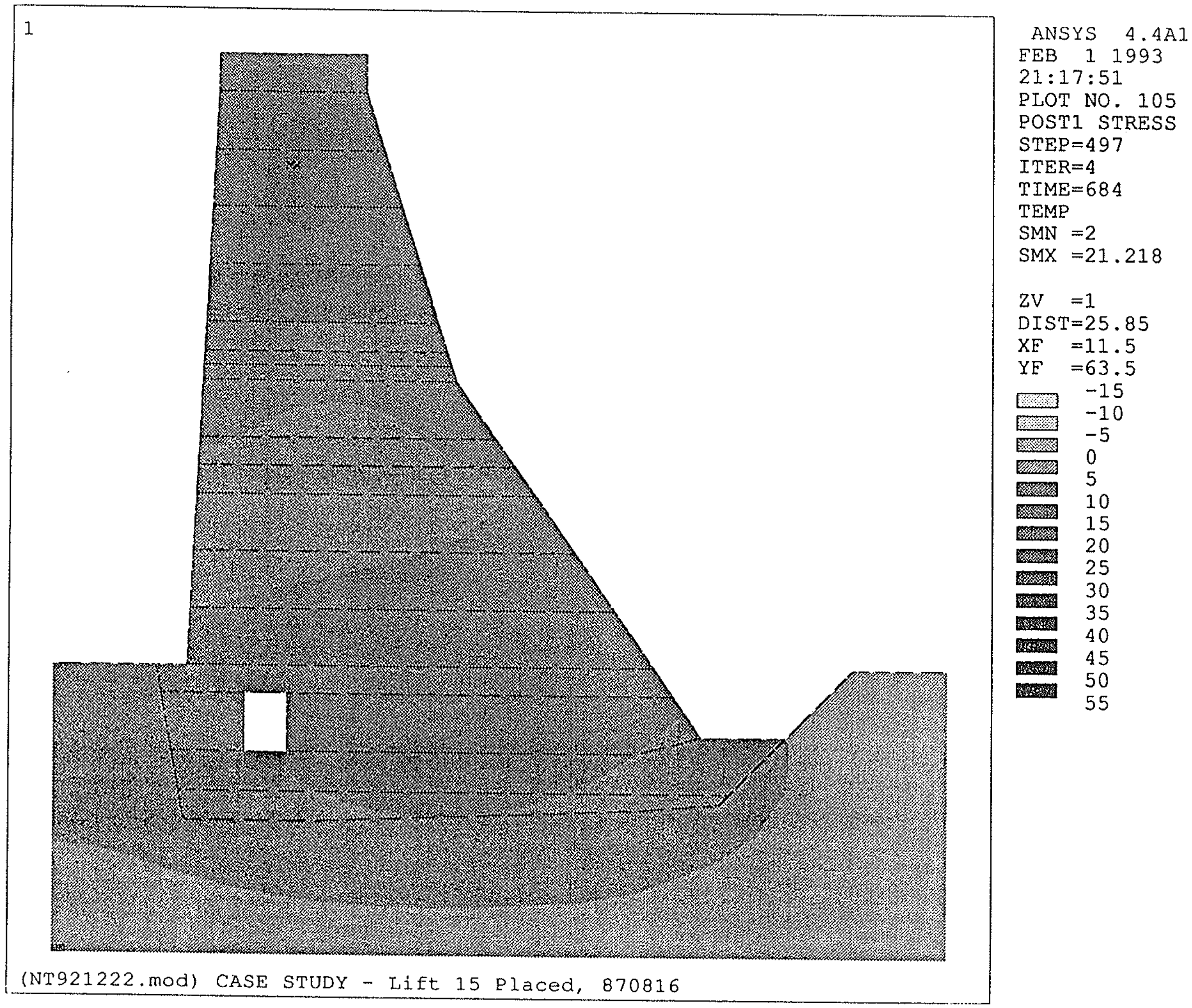

FIGURE I.44 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 870816 (60 Days after Placement of Lift NT2-15)

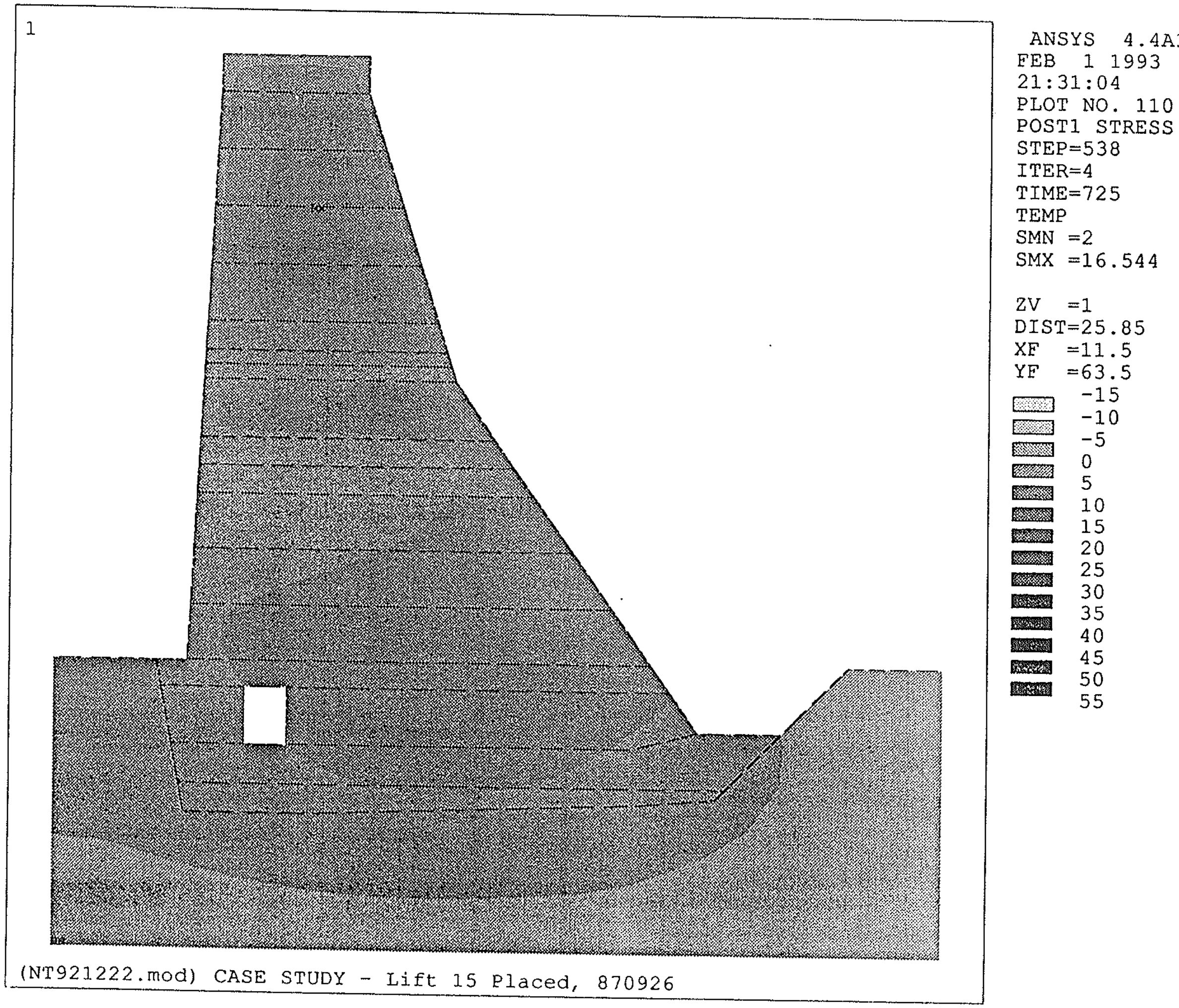

FIGURE I.45 - Thermal Contour Plot of Case Study Dam at Analysis Time Corresponding to 870926 (101 Days after Placement of Lift NT2-15)