CALCULATION OF HEIGHT OF LIFT AND PLACING FREQUENCY IN CONCRETE DAM USING FINITE ELEMENT ANALYSIS

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Under the supervision of

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CERTIFICATE

This is to certify that the work which is being presented in the report tittle**” CALCULATION OF HEIGHT OF LIFT AND PLACING FREQUENCY IN CONCRETE DAM USING FINITE ELEMENT ANALYSIS”** in partial fulfillment of the award of degree of Master of Technology in Construction Management and submitted in Department of Civil Engineering, Jaypee university of Information technology, Waknaghat is an authentication record of work carried by **Akash Sethi** during a period from August 2017 to March 2018 under the supervision of **Mr. Bibhas Paul**, Assistant Professor, Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat.

The above statement is made correct to the best of my knowledge.

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DECLARATION

I hereby declare that the work reported in this project entitled” **CALCULATION OF HEIGHT OF LIFT AND PLACING FREQUENCY IN CONCRETE DAM USING FINITE ELEMENT ANALYSIS”** submitted at **Department of Civil Engineeering Jaypee University of Information Technology, Waknaghat** is an authentic record of my work carried under the supervision of Mr. Bibhas Paul (Assistant Professor). I have not submitted this work elsewhere for any other degree.

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Abstract

Construction of Dam requires concrete to be poured in large volume. The large volume of concrete placed in a concrete dam is subjected to high risk of thermal cracking due to internal heat generated by cement hydration. The thermal cracking decreases the durability of such massive structure. To tackle the problem, during the construction phase appropriate height of lift and the duration between two subsequent lifts is necessary. For lift calculation the thermal heat distribution was analyzed by three dimensional finite element model. The finite element software ABAQUS version 6.13 was used to study the thermal behavior of concrete in steady state and transient state for varying lift height. The study focuses on the thermal distribution in a lift height ranging 1.5 meters to 5 meters for a concrete block (5m x 5m). The temperature in each lift size is analyzed and appropriate lift height is decided. The maximum height of pour in one lift depends on the thermal gradient and the time required for the heat generated in the core to dissipate. The time required for placing the lift and the laying of next lift represents placing frequency in a dam structure. The placing frequency of next lift is decided on the basis of the heat dissipation rate of concrete. If the second lift is delayed, the lower is temperature attained by concrete but the time of construction also increases and thus the costs also go hand in hand. The properties of concrete used in dam model were taken from Indian Standard temperature control of mass concrete for dams IS 14591:1999.The density, thermal conductivity and specific heat were the main thermal properties taken into consideration for the model. The Placing temperature, the most important parameter for the temperature profile generated, was also used as input. The efficiency of a dam construction project lies with durability, the effectiveness of construction technique used and the time of construction, thus affecting the economy of the project.

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INTRODUCTION

1.1 General

ACI defines mass concrete as any volume of concrete having dimensions large adequate that require measures be taken to cope up with the generation of heat of hydration from cement and related change in volume to curtail cracking . The project describes the thermal distribution in mass concrete by finite element analysis. The thermal expansion is dependent on the thermal properties of concrete. The thermal properties like coefficient of thermal expansion, thermal conductivity, thermal diffusivity and specific heat of concrete are essential for the evaluation of concrete performance over time. Thermal expansion properties are important for analyzing the performance of concrete structures in or during fire conditions. The conductivity is output of the conductivity of individual constituent of concrete. The key factors that affect the conductivity are moisture content, type of aggregate, mix proportions, type of cement and the temperature of the concrete. Thermal diffusivity depends on the aggregate type, moisture content, degree of hydration of the cement paste, and exposure to drying. Specific heat represents the heat capability of concrete and rises with rise in moisture content of concrete and is affected by the mineralogical character of the aggregate, specific heat increases with an increase in temperature and also increases with a decrease in the density of concrete. There is a need to have an effective tool which can be utilized to accurately determine the temperature and stress development in mass concrete elements and the conditions at which cracking may develop, so that mass concrete can be properly specified , controlled and produced with minimum problems in service.

1.2 Introduction to dams

A dam is a barrier that stops or restricts the flow of water or underground streams. Reservoirs created by dams not only suppress floods but also provide water for activities such as irrigation, human consumption, industrial use, aquaculture, and navigability. Hydropower is often used in conjunction with dams to generate electricity. A dam can also be used to collect water or for storage of water which can be evenly distributed between locations. Dams generally serve the primary purpose of retaining water, while other structures such as floodgates or levees (also known as dikes) are used to manage or prevent water flow into specific land regions.

Manmade dams may be classified according to the type of construction material used, the methods used in construction, the slope or cross-section of the dam, the way the dam resists the forces of the water pressure behind it, the means used for controlling seepage and, occasionally, according to the purpose of the dam. Concrete dams may be categorized according to the designs used to resist the stress due to reservoir water pressure. Three common types of concrete dams are **gravity, buttress** and **arch.**

1.3 Arch Dam

An arch dam is a concrete dam that is curved upstream in plan. The arch dam is designed so that the force of the water against it, known as hydrostatic pressure, presses against the arch, compressing and strengthening the structure as it pushes into its foundation or abutments. An arch dam is most suitable for narrow canyons or gorges with steep walls of stable rock to support the structure and stresses. Since they are thinner than any other dam type, they require much less construction material, making them economical and practical in remote areas.

1.4 Need for Project

The project focuses on the construction of dam involving the calculation of lift and the frequency of placing of lift that helps in time management and cost management of a dam project. Minimizing the thermal heat is necessary as it depends for the money being invested in the repairs of cracks and fissures, and time being wasted on repairs.

1.5 Objectives of Project

From the above literature review following objectives can be concluded:-

1) To calculate the optimum lift height and placing frequency of concrete.
2) To find out the temperature distribution in concrete
3) To find out the maximum core temperatures reached in concrete in different lift height.
4) Optimize the construction schedule.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

The Dam construction involves the placement of concrete in large volumes. The large volume of concrete placed is subjected to generation of heat due to the hydration of cement. The main problem in dam construction is the thermal cracking due to the heat released during cement hydration. For this the quantity of concrete placed at a time needs to be controlled. In accordance with that a particular lift height and the frequency of placing a lift needs to be calculated. In this project, the literature undergone presents a method to calculate the lift height and the frequency of placing concrete, so that the thermal cracks are less generated and the construction too completes on time.

2.2 Mass Concrete

The thermal behavior of mass concrete differentiate it from other conventional concretes. There is a significant amount of temperature difference between the outer and inner surface of the structure. This might result in formation of cracks in concrete. The precise perceptive of mass concrete can efficiently control the temperature, thus saving effort, time and money.

2.2.1 Definition

The meaning of mass concrete vary in different countries as described below:

Korea: Dimensions of mass concrete depends upon structure type, the materials used, and the conditions during construction phase, but the standard provisions for concrete and slab thickness should be in between 80cm and 100cm. Also the wall width in a restrained foundation should be greater than 50cm. In addition, according to architectural provision, the structures having sizes greater than 100cm are known as mass concrete.

Japan: The thickness of a slab is larger than 80cm~100cm and the thickness of a wall of restrained foundation greater than 50cm in the civil society concrete standard specifications. According to the architect society the construction standard specifications say the smallest cross member is larger than 80cm, and the external and internal temperature difference due to heat of hydration is over 25°C.

USA: according to ACI 116R, mass concrete is defined 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.

Vaidya et.al., (2015) studied the temperature distribution in concrete when exposed to extreme temperatures. The concrete was exposed to boiling water at one face and the ambient temperature at the other face. The main focus of the study was to know the behavior of concrete when exposed to in spent fuel tanks or fire. Mechanical properties such as flexural and compressive strength were measured. The transient thermal analysis was done, as it is time dependent and the results were compared with the experimental data.

The thermal distribution was simulated by ABAQUS ver. 6.12, a finite element software and the concrete thermal properties were adopted from Euro code 2. The heat flux was calculated During the measurement of temperature three RTD sensors were placed at depths of 40mm, 80mm and 135mm in a cubical block of 150mm side. The results from the simulation were measured with the experimental data and verified. The temperature distribution and the properties to be used for the thermal analysis were studied.

Yanmin et.al., (2012) studied the composite raft foundation of a section of Yisui expressway and analyzed it by ABAQUS software. The results were compared with the actual results. The 3-D heat conduction equation was considered and suitable boundary conditions were applied. The raft consists of three sections from top to bottom and temperature at different points in all three sections was noted. Temperature was also noted at different time intervals. The results plot shows similar results of ABAQUS modeling and experimental results. Thus the model established can be used to simulate actual temperature in a raft foundation or other concrete structures. The maximum temperatures were observed at the centre of raft.

Eduardo M.R. Fairbairn et.al., (2004) studied optimizing of construction in a mass concrete structure using genetic algorithms. The optimization criteria for this include material types, placing temperature, the height of lift and the frequency of lift placement. A small hydropower was studied and the construction phase was optimized. The chemically, thermally and mechanically prepared model was used considering cracking, thermal stresses and transient hydration. This paper presents a new procedure to help in the decision of construction process. Knowing the lift height and the frequency of lift placement can help to decrease the thermal stresses generated in the concrete further leading to lesser cracks.

(Kim,2010) conducted the study that focused on determination of proper lift thickness of block of concrete in a concrete dam. Also focus is on the potential replacement of type IV cement using fly ash. The distribution of temperature and thermal cracks were analyzed by Finite element software ANSYS ver. 12 in steady and transient state. The main challenge in mass concrete is maximum lift height that should be attained without creating thermally induced cracks as well as the time between the placing of the next layer.

The study also bring out the uses of fly ash, hydration of Portland cement, factors influencing the hydration, thermal stress,etc. The comparison of simulation data with experimental data was also done and the results of both were plotted. From the tests and simulation lift height of 1.5metres was chosen . The lift height of 2metres was having 23% probability of crack generation. Major economic benefits can be attained by synchronizing the lift height and its placement frequency.

Jin Keun kim et.al., (2001) studied the effects of pipe cooling systems in mass concrete. Main problems that we face today during construction of dams and other massive concrete structures are the heat reduction and temperature history prediction. For thermal analysis of heat of hydration in structure having pipe cooling a finite element three dimensional program was developed. A line element for the modeling of pipe was chosen. For calculating changing cooling water temperature, the theory of internal flow was applied. The results from the modeling and results measured from the concrete footing of bridge named Seo-Hae in Korea were compared.

J. Noorzaei et.al., (2006) studied the heat generation and stresses in Kinta RCC Dam which is a roller compacted dam. The study’s main focus is to verify the two dimensional code prepared using finite element with the values of the dam. The true values of thermal properties and climatic conditions were used in the analysis.

Thermocouples were installed in the dam body to measure the temperature at different time intervals.

Piyius et.al., (2017) conducted a study on thermal stresses generated in mass concrete with piped water cooling in early age. The heat evolved for the period of the hydration of cement may not dissipate evenly due to the larger size and low thermal conductivity that mass concrete possess. Implanted cooling pipes, which circulate water, are commonly used for the removal of heat from the core of concrete. This study shows experimentally that forced cooling helps in reduction of inner temperature considerably; however, it lead to reversal of thermal gradient surrounding the cooling pipe.

This study conducted a three-dimensional finite-element simulation of the hydration heat in concrete with a forced cooling system, modeling the circulating water with three-dimensional elements with diffusion and dispersion properties which accurately predict the experimentally observed temperature profile.

Finite-element analysis also indicates the presence of high thermal stresses in concrete near the cooling pipe, mainly due to the extreme temperature gradient and temperature fluctuations. The results suggest a careful monitoring of heat removal using forced cooling to avoid a large thermal gradient and the likelihood of cracking. Because of forced cooling, the temperature of the concrete near the cooling pipe was lower; however, it increased rather rapidly away from the pipe, which gave rise to a temperature gradient of approximately 17°C. Such a high thermal gradient during early ages is likely to initiate cracking in the concrete around the cooling pipe.

Faria et.al., (2006) has done modeling of concrete in early stages. The growing demand of High performance concrete has also created the issue of large changes in volume of concrete thermally and due to shrinkage. The study focuses on the thermal and mechanical analysis of a concrete slab restrained by strong supporting piles. The model is based on the framework of finite element involving the heat production due to the hydration reaction of cement, evolving property of concrete and early age creep. The results from the finite element modeling were compared and validated with the actual in situ casting results.

Waleed et.al., (2004) studied the effect of placement schedule of concrete in mass concrete structures. The thermal and structural responses of the RCC Dam were studied.

The finite element computer code named STARD with other relationships was used for the determination of temperature and stresses in the Dam. The Roodbar RCC dam was considered as a large scale practical project.

The birth and death technique of finite element was adopted in the simulation and the procedure was repeated until the final lift was not casted. The factors such as daily temperature variation, initial foundation rock temperature, placement temperature of different layers, etc. The study concluded that the construction of concrete dam if started in warm season can lead to higher final temperatures thus higher thermal stresses and thermal cracks may propagate throughout the entire body mainly near the foundation of structure.

M. Ishikawa, (1991) studied thermal stress analysis of a concrete dam. It states that the finite elements should be added to the model according to the construction schedule of concrete and the elastic modulus should be increased with time. The thermal stresses were calculated by the user's subroutine. The stress distribution in different lift heights was modeled and the values of thermal stresses were known.

The three dimensional element was used for the analysis where the top surface of the lift was exposed to the convection boundary condition and the side surfaces to the conduction boundary. The placing of one layer over the other include the birth and death technique of finite element.

Manseer et.al., (2008) studied the effect of heat of hydration on mass concrete for cast-in-place concrete piles. The models of software ABAQUS and Schmidt were used to predict the peak temperatures in core of cast-in-place piles. The procedure includes casting of five piles with different diameters and of fourteen different concrete mixes with varying percentage of flyash. The results show that the modeling done with ABAQUS showed better and accurate results. The study describes the properties of concrete and the values that can be used in the modeling of thermal distribution in concrete.

The specifications limits were developed accordingly with the ABAQUS data due to the accuracy of model. The adiabatic system used to calculate the thermal properties were independent of the ambient temperatures. The maximum allowable initial temperature was 60°C.

Du et.al., (2004) conducted a study on the problems experienced in controlling temperature for mass concrete of baglihar Gravity dam with construction using long blocks. The thermal cracking mainly depends on the mass and size of the construction blocks, the materials used, measures taken for temperature control and construction method used. In case of long lock construction strict temperature measures are to be taken for temperature control. The minimizing of cracks in a construction will decrease the cost incurred in repairing of cracks. The costs of grouting cracks and sealing them is also reduced.

During the construction phase of dam various cases of cracking were detected in most of cases where water over toppled the casted concrete. The creation of thermal shock in concrete leads to formation of cracks. In this paper the measures taken to control temperature are summarized, the cracks formed and the remedial measures taken are discussed.

Sanda Randovanovic, (1998) studied the key issues that are related to rehabilitation of cracked concrete dams that start leaking. For this the deep understanding of stresses mixed up in failure at peak loads. The study on construction joints was done as dam fails on these joints only. The increase in thermal stresses during early ages of dam construction leads to the failure of dam. Two models were developed as transient model and transient stress model to forecast behavior of concrete. The model was first prepared on a small basis and then size of specimen was increased and the effect of increasing size was captured.

Chapter 3

THERMAL ANALYSIS

3.1 Introduction

The maximum temperature in mass concrete structures due to hydration heat has a great impact on determining the lift thickness which impacts economic savings and construction period. Large lift thickness proves economical. Also it increases the pace of construction but can induce thermal cracks resulting in reduction of concrete durability. For dealing with the above problem and finding out thermal distribution for varying placement lift heights in a concrete dam, thermal analysis was performed.

ABAQUS ver.6.13, finite element software, was used for the analysis. A concrete block having width 5metres, length 5metres and height varying from 1.5metres to 5metres with same temperature and boundary conditions was modeled in software. Finally, temperature distribution using thermal analysis of different lift thicknesses 1.5metres, 2 metres, 2.5metres and so on upto 5metres was done.

The convection coefficients, external air temperatures, lift placement thickness, internal heat generation rate of concrete, material properties, and thermal boundary conditions were the main input parameters used in the analysis.

Temperature distribution in mass concrete is commonly a time dependent processes that is transient because there is a change in temperatures with time. The heat generated for the duration of cement hydration and change in atmospheric temperatures considerably affects thermal behavior of concrete. Abaqus is software designed for the computer aided design as well as finite element analysis of various problems. The Abaqus full version comprise of five software packages as mentioned below.

1) Abaqus/CAE: - Also recognized as Complete Abaqus Environment. It is software used for analysis of components, assemblies and modeling purposes and viewed in visualization mode
2) Abaqus/Standard:- A software application that uses implicit integration scheme for the analysis of finite element.

3) Abaqus/Explicit: - It is unique reason Finite element solver, which employs explicit integration method for solving non-linear systems with several complex contacts under transient loading.
4) Abaqus /CFD: - Also known as Computational Fluid Dynamics. This provides advanced computable fluid dynamic capability with wide-ranging support for preprocessing and post processing provided in Abaqus/CAE.
5) Abaqus/Electromagnetic: - It is Electromagnetics software, which helps in solving sophisticated computable electromagnetic problems.

3.2 Classification of Finite Elements in ABAQUS

There are various types of elements that can be implied to define geometry in ABAQUS and special elements are used for application of different conditions depending on problem type. The first letter of the name of element signify to which family the element belong such as C3D8 is a 3D 8noded linear isoparametric element, S6 is a 6 node triangular shell element. The elements differ from 2D to 3D. These are further classified as under the following five criterions.

3.2.1 Family

The type of modeling done in ABAQUS requires the different family for elements in the analysis. A Beam analysis requires a Beam family whereas a truss analysis requires a truss family. Thus the elements are classified based on the families as in Figure 3.1. The geometry that a family assumes differentiates it from other families.

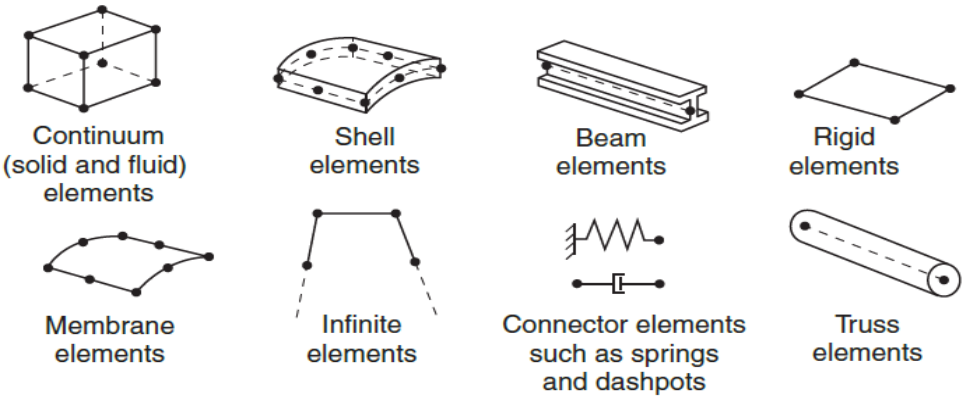


Figure 3.1 Element families

3.2.2 Degree of freedom

Degree of freedom are elementary variables that are calculated throughout analysis. For stress-displacement model degrees of freedom can be shown as translations and, for the shell elements, pipe elements , and beam elements, the rotations at all nodes are known. For the simulation of heat transfer it is the temperature at different nodes; for combined thermal stress analysis the temperature ones exist with those of displacement at all nodes. Couple thermal-stress analysis and heat transfer analysis thus need to make use of dissimilar elements compared to stress analysis as the degree of freedom is not similar in both cases.

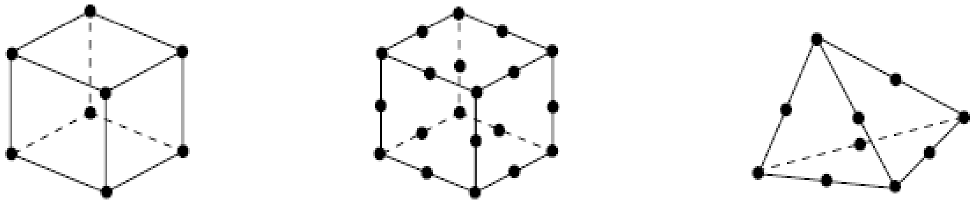
3.2.3 Number of nodes

The nodes of the element are the main points for the calculation of displacement and degrees of freedom. At any different point in element, the displacements can be achieved by interpolation done with reference to the nodal displacements. Generally, the number of nodes that are used in the model determines the interpolation order used in the element.

1) Elements that have nodes only at their corners, such as the 8-node brick shown in Figure (below), use linear interpolation in each direction and are often called linear elements or first-order elements
2) In Abaqus/Standard elements with mid side nodes, such as the 20-node brick shown in Figure (b) below, use quadratic interpolation and are often called quadratic elements or second-order elements
3) Modified triangular or tetrahedral elements with mid side nodes, such as the 10-node tetrahedron shown in Figure (c) below, use a modified second-order interpolation and are often called modified or modified second-order elements.

3.2.4 Formulation

Formulation refers to mathematical hypothesis meant to describe the behavior of element. The depiction of behavior of the element in Lagrangian deforms with material. In the substitute Eulerian otherwise spatial, the element description is preset within space when the material is flowing through. Eulerian methods are generally used in simulations of fluid mechanics. Abaqus uses Eulerian elements for modeling convective



(a) Linear element
(8-node brick, C3D8)

(b) Quadratic element
(20-node brick, C3D20)

(c) Modified second-order element
(10-node tetrahedron, C3D10M)

Figure 3.2 Linear Brick, Quadratic brick and Modified tetrahedral elements

heat transfer. In stress and displacement analyses the Explicit part of Abaqus also offer Eulerian elements for multi materials to be used in Adaptive meshing. Abaqus/Explicit brings together the features of Eulerian and Lagrangian analyses in their pure form and allows the movement of element being independent of the material. Other stress-displacement elements that Abaqus uses are mostly based on Lagrangian formulation. In Abaqus/Explicit the elements of Eulerian type can interrelate with the elements of Lagrangian during common contact. To house various type of behavior, several element families of Abaqus contain elements of dissimilar formulations. For example, the element family of conventional shell is of three types: one appropriate for the analysis of general use shell, second for thin shells, and the last one used by thick shells. In adding up, Abaqus also offering continuum shell elements, having nodal connectivity such as continuum elements except they are formulated for modeling behavior of shell with minimum one element through thickness of shell. Various families of element in Abaqus/Standard are having have standard formulation and some of alternative formulations too. An additional character occurring at last of the element name identifies elements having substitute formulations. Such as families of continuum, beam, plus those of truss element comprise members having hybrid formulation (dealing with incompressible or else inextensible behavior). For elements of lower order; lump mass formulation is used in Abaqus/Standard whereas Abaqus/Explicit uses lump mass formulation on behalf of every element. Therefore, mass moments of inertia values can diverge from its theoretical values, for coarse meshes particularly. Abaqus/CFD whereas involves hybrid elements to evade well defined div-stability issues emerging in incompressible flow. It also allows the adding up in degrees of freedom based on procedure settings such as the optional energy equation and turbulence models

3.2.5 Integration

The numerical techniques are used by Abaqus for integrating a variety of quantities over the every element’s volume, hence allowing full generality in the behavior of material. Applying Gaussian quadrature in favor of most elements, the response of material is evaluated by Abaqus at every integration point. A few continuum elements are capable of using full integration or a reduced one, a option that affects the accuracy of a problem. The letter R is used for denoting elements with reduced integration. For example, a 4-node element CAX4R, is in reduced-integration, is axisymmetric, and a solid element. The properties of a shell element, a pipe one, and a beam element can be defined as behavior of general section considered at once; otherwise integration of every element cross section can be done numerically, consequently the tracking of nonlinear behavior of material linked with nonlinear response can be done accurately as required.

3.3 Transient Thermal Analysis

For the good simulation of any real model various different factors are there that can influence the thermal behavior of concrete in initial stages and have to be included in the algorithm. Some of them include block size of concrete, formwork influence on concrete, the hydration heat as heat load and many other factors that can be considered while performing analysis.

The transient thermal analysis means time dependent analysis. The output values in this type of analysis change in accordance with time. The transient thermal processes are very common in nature. For the analysis we have to induce loads that depend on time. Heat induced from cement hydration and the heat loss both depend on time. The daily change in ambient temperature is ignored. The base of concrete placement is considered isolated as very less heat is transferred to the ground. The analysis was done for a shorter period as short time gives better and accurate results.

The analysis consist of two different time steps as one is the heat generation and the latter is the heat loss. Heat loss step starts after the heat in the heat generation has ceased and become constant. In the heat loss step the temperature of the concrete reduces accordingly to the ambient temperature assumed. For each step the loads must be defined as a function of time.

3.3.1 Differential Equation

The heat balance equation is most important to consider while doing in the analysis. Fourier Equation of heat conduction expressed by equation below can be used to describe the governing equation of heat transfer used in the model in global Cartesian system.

$$\rho C_p \frac{\partial T}{\partial t} = q + \frac{\partial T}{\partial x}(k_x \frac{\partial T}{\partial x}) + \frac{\partial T}{\partial y}(k_y \frac{\partial T}{\partial y}) + \frac{\partial T}{\partial z}(k_z \frac{\partial T}{\partial z}) \tag{3.1}$$

where

k_x, k_y and k_z - thermal conductivity coefficients in x, y and z direction;

T - function representing temperature,

q - rate of heat generation per unit volume,

p - density in kg/m^3,

c_p - specific heat in kJ/kg °C, and

t - time.

The coefficients of thermal conductivity in three directions is assumed to be constant.

3.4 Analysis Algorithm

The thermal behavior of concrete is observed in the model needs to be performed on the basis of the following algorithm. The steps to be followed are included in the algorithm. Thermal load in form of hydration heat is applied in first step. The minimum time increment of 3 hours is given for the analysis. The number of steps multiplied by the time increment gives the total time required for the lift to cool.

The thermal analysis algorithm is given by the flowchart below. The same procedure can be applied if consecutive lifts are to be placed.

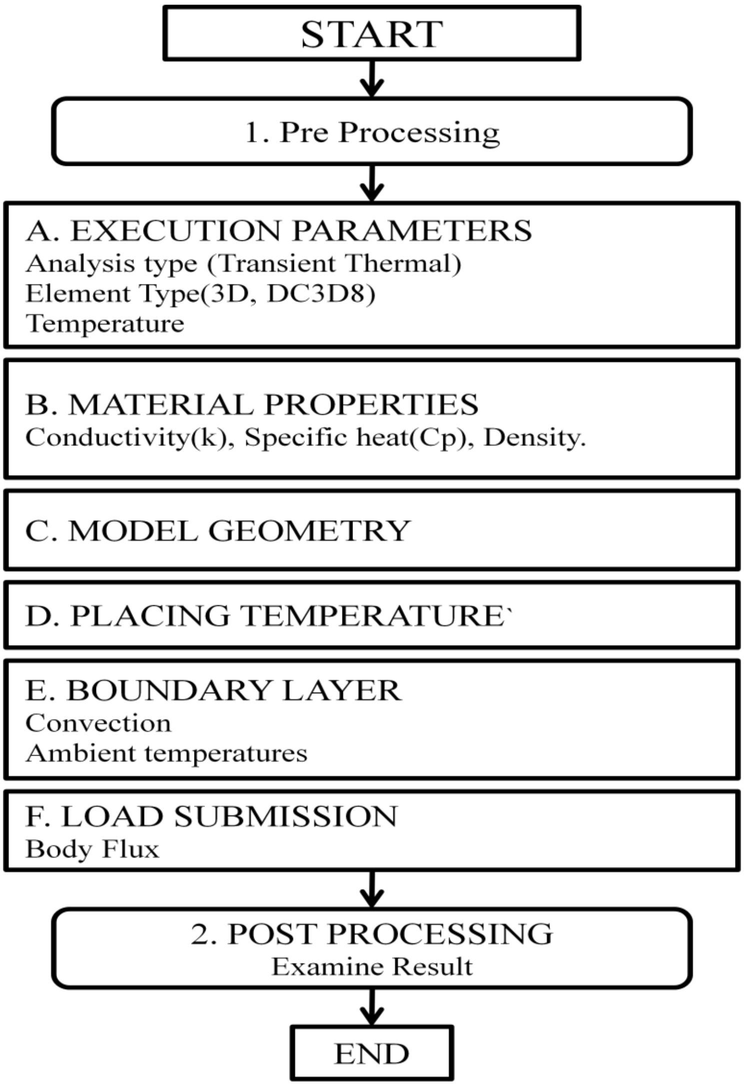


Figure 3.3 Algorithm for thermal analysis in abaqus

3.5 Execution Parameters

In the algorithm, the initial step is defining the execution parameters. These parameters include the type of analysis, the element type, the material properties, model geometry, concrete placing temperature, load steps and the boundary conditions.

Execution parameters for the analysis in this model are the type of analysis and the kind of element used in the analysis. The analysis type is thermal analysis that calculates the thermal quantities required in the model output. The important thermal properties that need to be known in the analysis is temperature at different time interval and its distribution in concrete.

During the analysis the element chosen must possess thermal properties. The analysis is three-dimensional. An 8-node linear heat transfer brick DC3D8 was chosen for analysis. The elements of the model were hexagonal.

The initial temperature or placement temperature is the temperature during concrete placement in the formwork. In areas where the ambient temperatures are low, the concrete needs to be used with a lower placement temperature. For larger concrete placements the concrete needs to be cool so ice cold water is added to lower the temperature of concrete as required.

3.6 Model Geometry

The model consists of a rectangular block with dimensions of 5metres length, 5metres width and heights of 1.5metres, 2metres, 2.5metres, 3metres, 3.5metres, 4metres, 4.5metres and 5metres. Each model has the same properties of concrete, boundary conditions and load case. The temperature values that are to be noted are taken from the centre, one-third and two-third of the length. The meshing is done using hexagonal elements in heat transfer mode. The element's global size of 0.5m is chosen. This was done by the convergence of mesh analysis. This saves computer and human time and gives accurate results.

3.7 Material Properties

The properties of concrete used for the thermal analysis are mainly thermal conductivity, density of concrete, specific heat and convective heat transfer coefficients. As only thermal analysis and heat distribution is to be done only these above described properties are sufficient.

The determination of properties of concrete especially the thermal quantities is quite a tough task as most of them are dependent on concrete composition, its age and temperature. The range in which these properties lie is large. For example the thermal conductivity of concrete varies from 4.97 to 15.55 kJ/hr-m°C for saturated concrete from temperatures of 10°C to 65°C, whereas the value of specific heat varies from 0.84 to 1.17J/kg/°C.

3.7.1 Density

The density is the measure of the unit weight of concrete. Concrete being a mixture of cement, sand, aggregates, and some supplementary materials like fly ash, admixtures, slag, etc contribute to the varying density of concrete when used in various proportions.

The density is measured in kilogram per cubic meter. The value of Density used in the analysis was 2610 kg/m^3.

3.7.2 Thermal Conductivity

Thermal conductivity of a material is its ability of heat conduction through it or we can say that it is a measure of rate of heat flow. It is measured in units of Joules per meter second degree Celsius. The range in which thermal conductivity lies is very wide due to the variety in composition of concrete, its cement type, aggregate type, water content, etc. The air in concrete acts as an insulator and reduces the flow of heat to the atmosphere, leading to lower values of thermal conductivity.

The thermal conductivity is among main parameters used in the analysis. The value used in the analysis is 2.235 J/m-sec°C.

3.7.3 Specific Heat

Specific heat is the measure of heat capacity. The heat amount required to increase the temperature of 1 gram of a substance by 1 degree Celsius. The factors that influence the specific heat are the water used and the temperature. The value of Specific heat used in the analysis is 0.857 kJ/kg°C.

3.8 Placement Temperature

The placement temperature in mass concrete is utmost importance as the lower the temperature of concrete at the time of placement the lower is maximum temperature reached by the concrete after the hydration of cement. For cooling the concrete either cold water is added or chunks of ice are added to the freshly prepared concrete.

In the analysis, the temperature of placement was chosen as 15.5°C.

3.9 Step Time

The step time is the time for which the analysis has to run. In the analysis two steps are used. First step is heat generation in concrete and second is the heat loss that starts just after the heat generation step. The temperature of concrete has to be checked every 3 hours so the time interval is chosen as 3 hours. The number of iterations in the analysis is of fixed type.

The number of fixed can be estimated by the following formulae as in

$$\text{Maximum number of iterations} = \frac{\text{Total Time}}{\text{Increment Size}} \qquad 3.2$$

The increment size for the analysis was chosen as 3 hours or 10800 seconds. The time required for the heat of hydration to complete and concrete to reach its peak value was estimated from the analysis and after that the heat loss step was applied. The time period of each lift heights was different. The maximum and minimum temperatures at a particular time interval for different lift heights are recorded.

3.10 Boundary Condition

The boundaries are the important component while doing the thermal analysis. The transient analysis uses mainly three boundary conditions as temperature boundary, and thermal transfer boundary. The thermal boundary is observed on the surface of concrete, so convection mode is applied. Convection mode is applied in cases where the heat is flowing from body to the environment or a fluid.

Convection depends on the curing methods, wind speed and temperature variation.

The Newton's Law of cooling as below can describe the effect of convection boundary

$$q = h.A.(T_s - T_a) \qquad 3.3$$

Where

q: heat flow

h: Convection coefficient

A: Area

T_S: Surface Temperature

T_a: Air Temperature

The convection coefficient used in the present model was 22.833 KJ/m^{2}h°C.

3.11 Internal Heat Generation Rates

The temperature profile of concrete induced by the heat of hydration is analyzed using the boundary conditions, initial placement conditions, and rate of internal heat generation. The internal heat rate due to cement hydration is calculated in every interval of the analysis algorithm. These values are obtained from time after concrete placement temperature because the heat generation pattern depends only on time. Internal heat generation can be calculated by the adiabatic temperature rise equation because the temperature near the center of the mass concrete is almost equal to the adiabatic temperature.

The magnitude of the adiabatic temperature rise and the shape of the curve can vary significantly depending on the particular concrete mixture. The adiabatic temperature rise equation is displayed as an exponential function.

$$T(t) = K(1 - e^{-\alpha t}) \qquad 3.4$$

where
T is amount of adiabatic temperature rise at time (°C)
α is the coefficient of temperature rise (reaction rate)
K is the amount of adiabatic temperature rise (°C)
T is time (day).

The amount of heat generated per unit volume can be obtained by

$$Q(t) = C_p \rho T(t) = K C_p \rho (1 - e^{-\alpha t}) \qquad 3.5$$

The equation representing generation of heat in the model is represented by equation

$$Q(t) = 27.6592(1 - e^{(-0.5428(t-0.3229)^{0.5203})}) \qquad 3.6$$

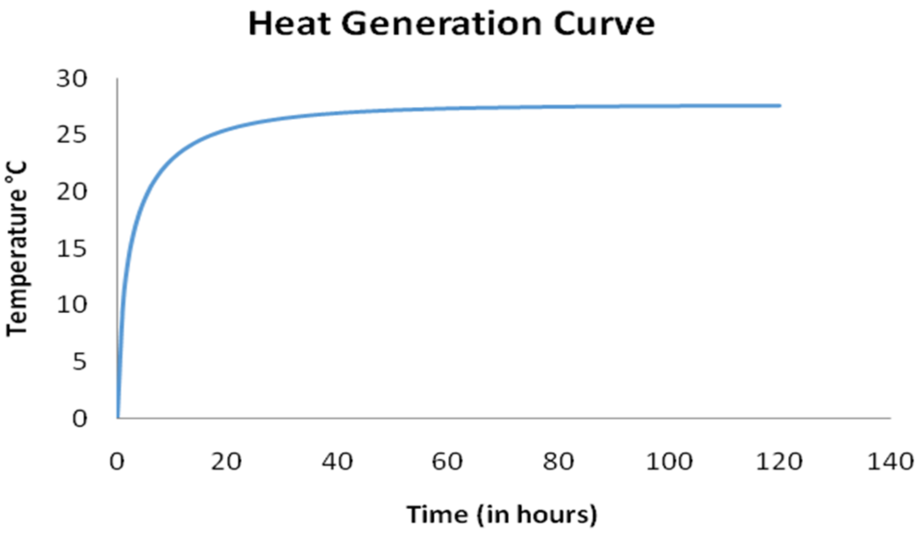


Figure.3.4 Heat Generation Curve

3.12 Load Steps

The loads that are given in the analysis are in the form of body flux. The heat generated in the concrete body due to cement hydration is given as a body flux combined with the amplitude heat generation. The body flux acts according to the amplitude given and the heat rises in the body accordingly. The amplitude was given as shown in above equation 3.6.

3.13 Meshing

The mesh in a finite element analysis is a group of small elements of uniform size that combine to form the desired shape of model. The finer the mesh the greater is the accuracy of the modeling result. The problem with very fine mesh size is that the analysis consumes more time. The solution of large execution time is to choose an optimum size of the mesh. It helps in reduction of analysis time. Thus for the optimum size of the mesh the convergence analysis is done.

Table 3.1 Mesh Convergence values

Mesh Size (m)	**Temperature (°C)**
5	25.38
2.5	25.37
1	30.22
0.5	30.11
0.25	30.09
0.1	30.08

In convergence study the mesh size is reduced from larger size to a finer mesh to see the changes in the output results. Optimum Size of mesh was analyzed by Convergence analysis and the curve was plotted to know the optimum mesh size for less time for processing as the results were same. Optimum Size of 0.5m was chosen for mesh

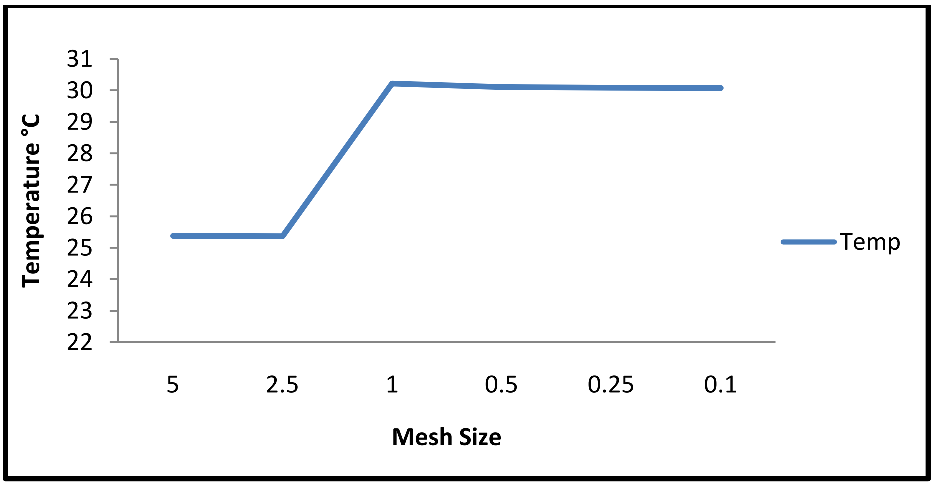


Figure 3.5 Mesh Convergence Curve

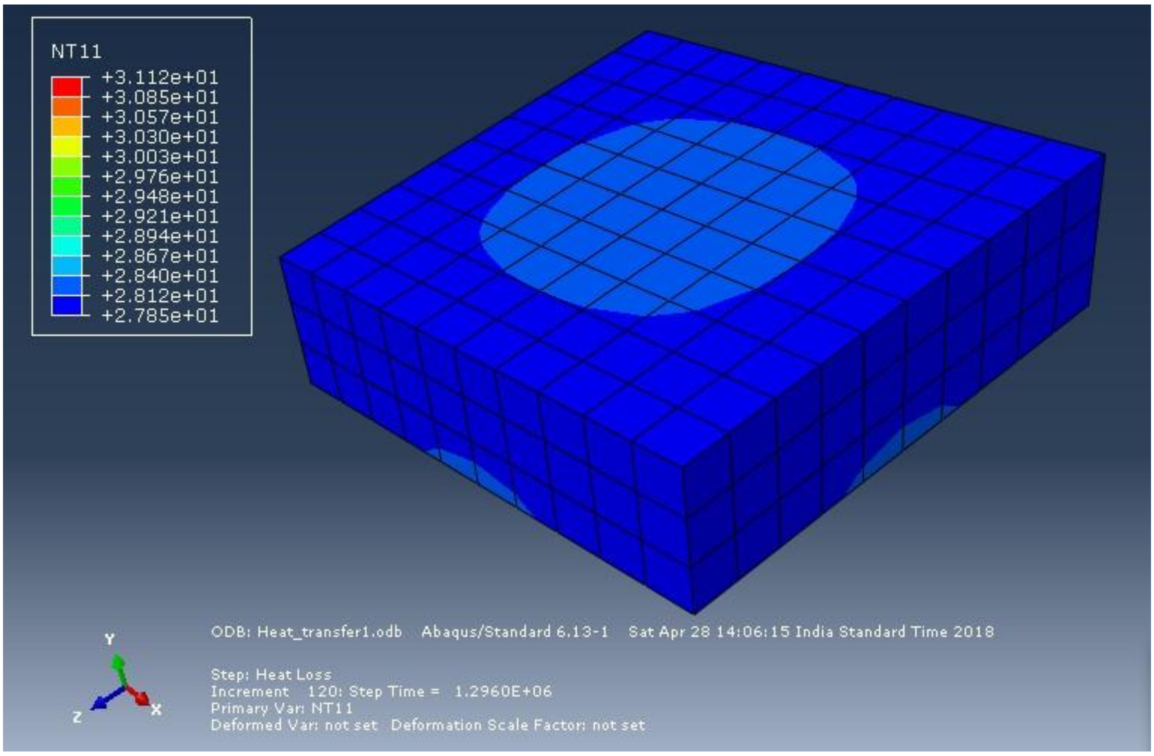
Chapter 4

POST PROCESSING AND RESULTS

The modeling software ABAQUS was used for the analysis. In the modeling the values for thermal conductivity, specific heat, density, convection coefficients, placement temperature, and the ambient temperature wee kept same. Only the values of the height of lift were changed from 1.5 metres to 5 metres.

4.1 1.5m Lift height

Initially the lift height of 1.5metres was chosen for the analysis. The isometric view in model for a lift height of 1.5 metres is shown in Figure 4.1 Isometric view of 1.5 metres lift height.



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ODB: Heat_transfer1.odb    Abaqus/Standard 6.13-1    Sat Apr 28 14:06:15 India Standard Time 2018

Step: Heat Loss
Increment    120: Step Time =   1.2960E+06
Primary Var: NT11
Deformed Var: not set   Deformation Scale Factor: not set
```

Figure 4.1 Isometric view of 1.5 metres lift height

The heat distribution in Figure 4.2 Heat Distribution in 1.5 metres lift in X-Plane depicts the heat distribution in 1.5 metres lift height. The colour ranges from red indicating the maximum temperatures to blue having minimum temperatures. The maximum temperature of 39.70°C reached in the model is shown in Figure 4.3 Temperature variation with Depth in 1.5metres lift height. The temperature was noted with the increasing depth.

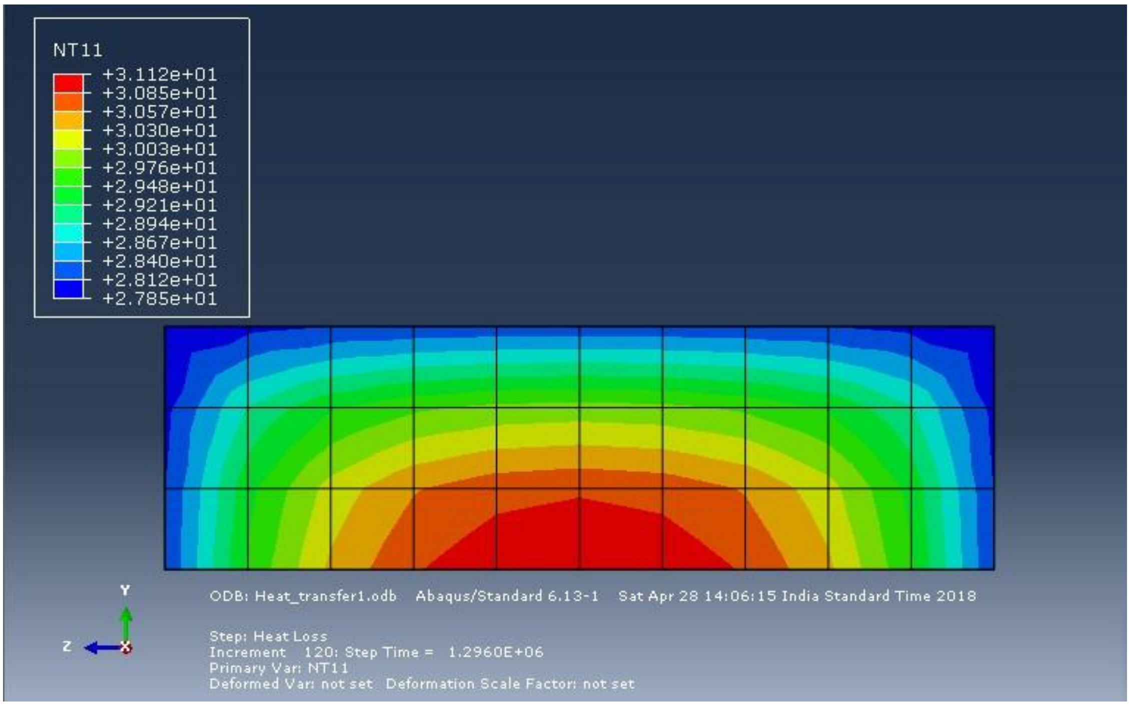


Figure 4.2 Heat Distribution in 1.5 metres lift in X-Plane

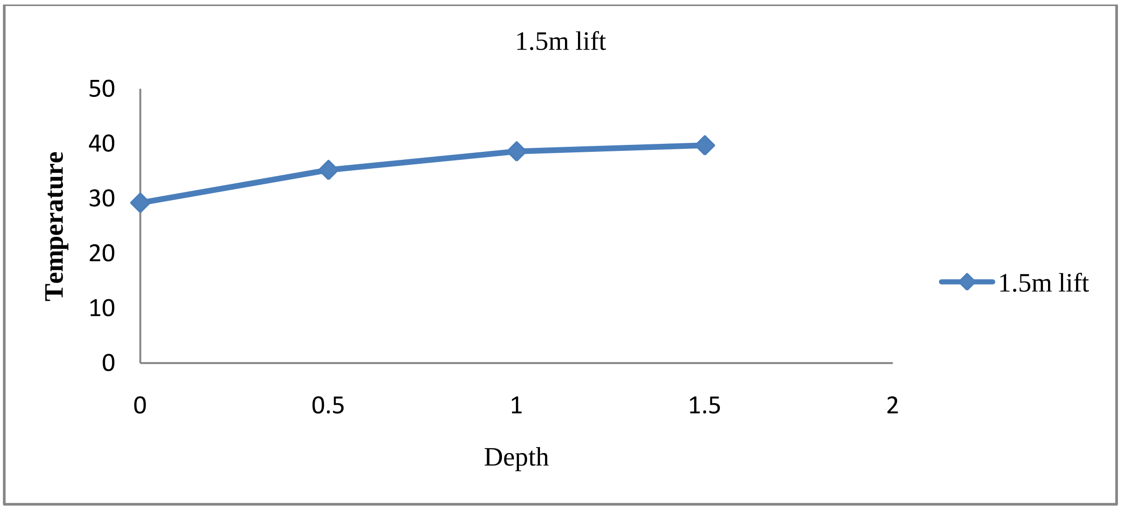


Figure 4.3 Temperature variation with Depth in 1.5metres lift height

The maximum and minimum temperatures in lift height of 1.5metres is shown below where the maximum temperatures reaches to 39.70 °C and minimum temperature to 27.85 °C, whereas the maximum stable temperature of 31.12 °C.

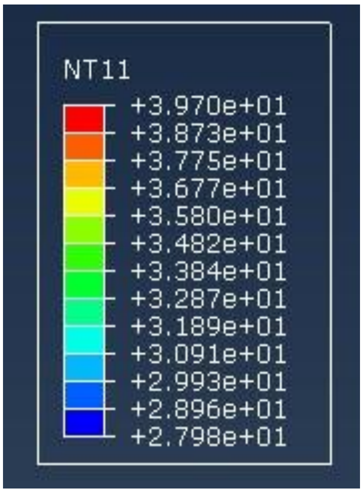


Figure 4.4 Maximum Temperature in 1.5m lift

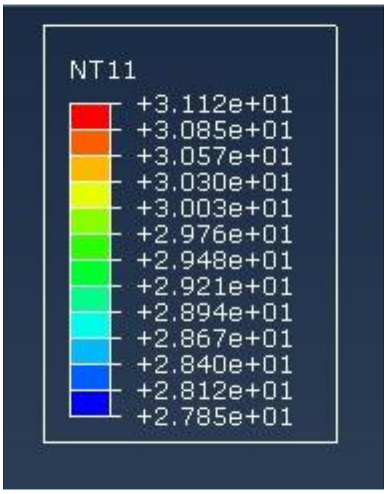
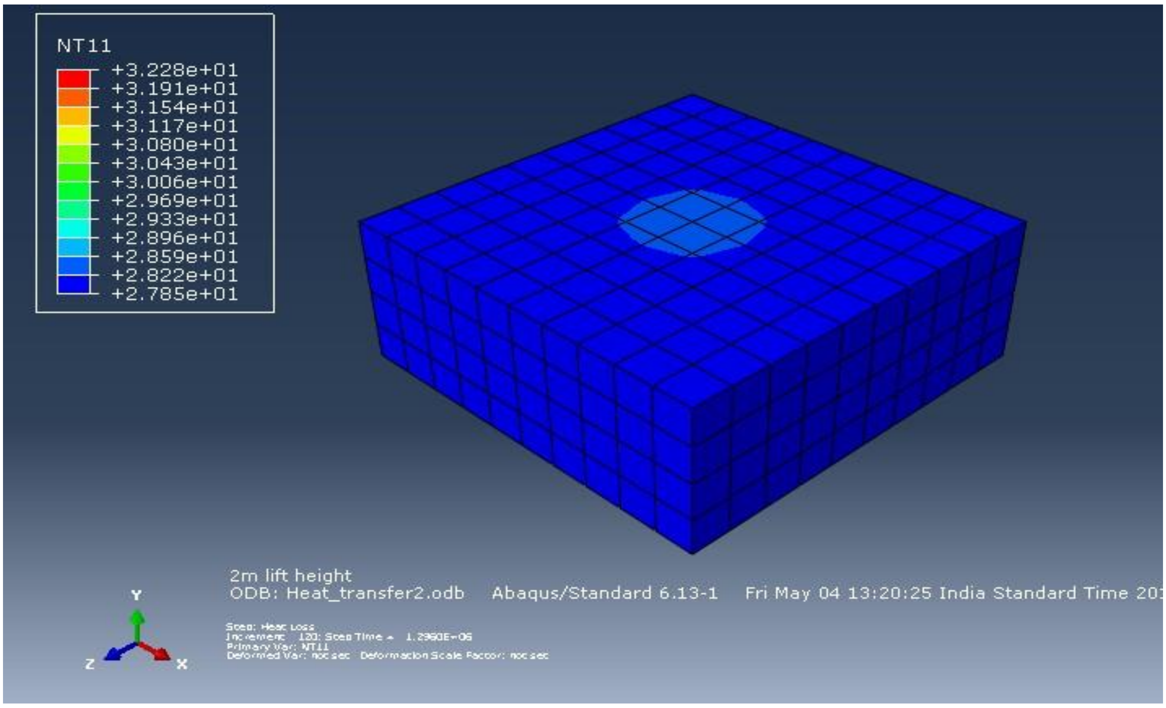


Figure 4.5 Final steady temperature in 1.5m lift

4.2 2 metres Lift height

The lift height of model was increased to 2 metres and the results of the analysis were plotted. The isometric view of model is shown in Figure 4.6 Isometric view of 2 metres lift height. The variation in heat distribution is clearly visible on the top surface of the model.



2m lift height
ODB: Heat_transfer2.odb   Abaqus/Standard 6.13-1   Fri May 04 13:20:25 India Standard Time 20

Step: Heat Loss
Increment 120: Step Time = 1.2960E+06
Primary Var: NT11
Deformed Var: not set   Deformation Scale Factor: not set

Figure 4.6 Isometric view of 2 metres lift height

The heat distribution in Figure 4.2 Heat Distribution in 1.5 metres lift in X-Plane depicts the heat distribution in 2 metres lift height. The colour ranges from red indicating the maximum temperatures to blue having minimum temperatures. The maximum temperature of 43.82°C reached in the model is shown in Figure 4.3 Temperature variation with Depth in 1.5metres lift height. The temperature in 2 metres lift height was 4.12 °C higher than the 1.5 metres lift height. The temperature was noted with the increasing depth.

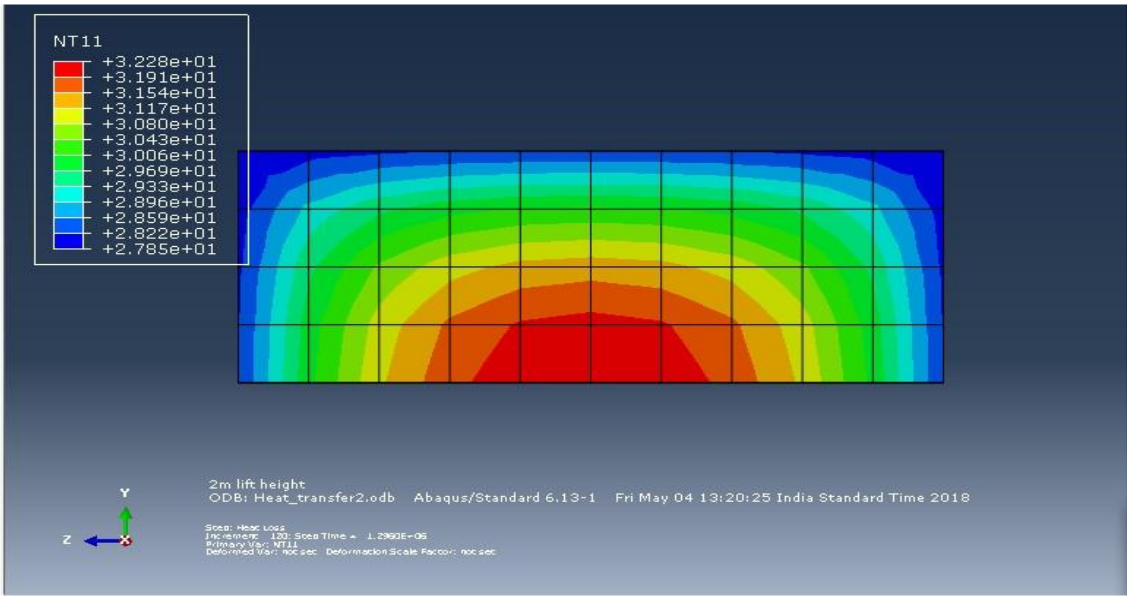


Figure 4.7 Heat Distribution in 2 metres lift in X-Plane

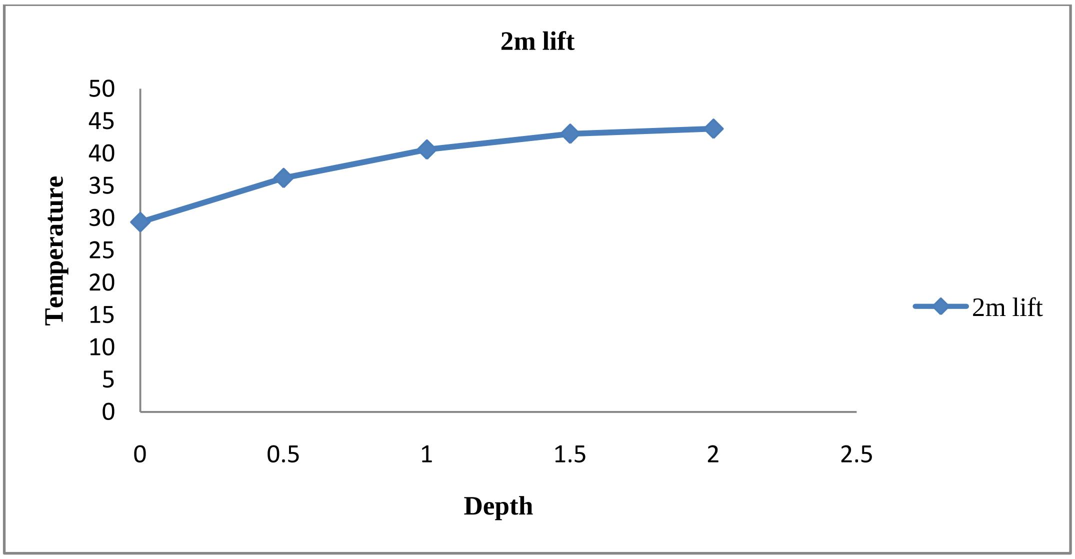


Figure 4.8 Temperature variation with Depth in 2 metres lift height

The maximum and minimum temperatures in lift height of 2 metres is shown below where the maximum temperatures reaches to 43.82 °C and minimum temperature to 27.98 °C, whereas the maximum stable temperature of 32.28 °C.

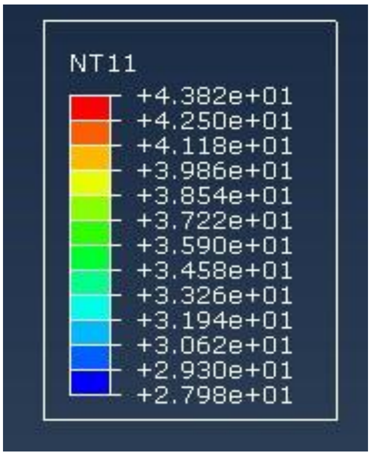


Figure 4.9 Maximum Temperature in 2m lift

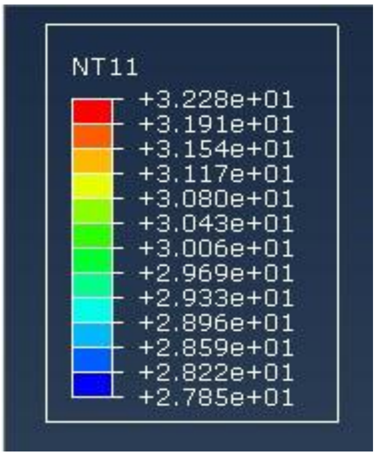


Figure 4.10 Final Temperature in 2m lift

4.3 2.5m Lift height

The lift height of model was increased to 2.5 metres and the results of the analysis were plotted. The isometric view of model is shown in Figure 4.6 Isometric view of 2 metres lift height. The variation in heat distribution is not clearly visible on the top surface of the model due to increasing depth.

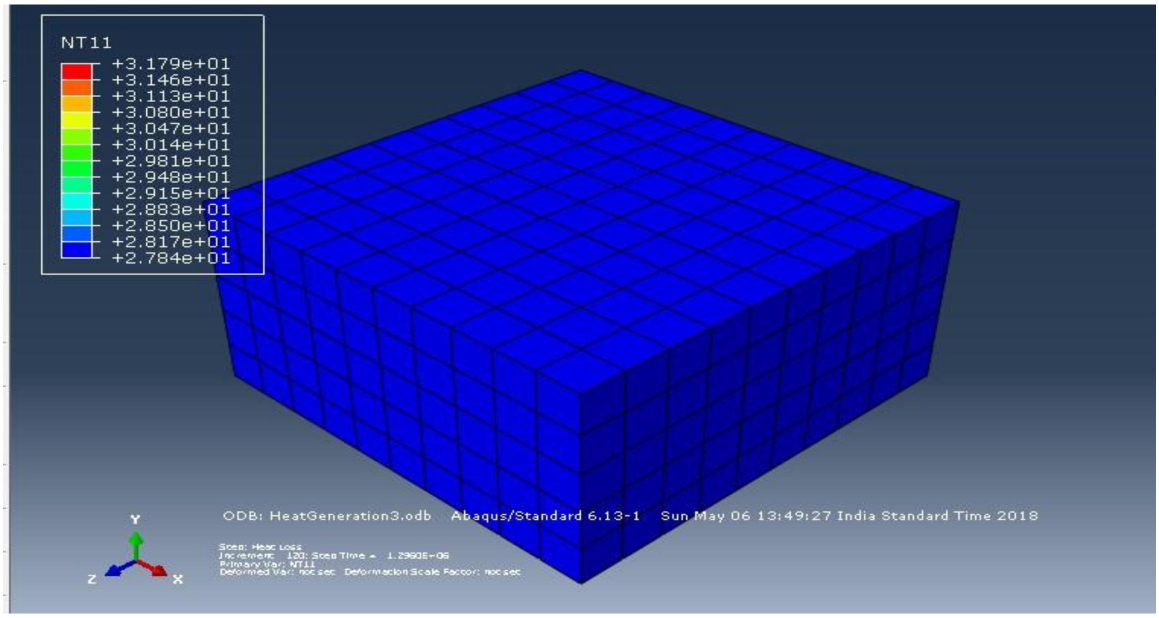


Figure 4.11 Isometric view of 2.5 metres lift height

The heat distribution shown below depicts the heat distribution in 2.5 metres lift height. The colour ranges from red indicating the maximum temperatures to blue having minimum temperatures. The maximum temperature of 46.75 °C reached in the model is shown in Figure 4.13. The temperature was noted with the increasing depth.

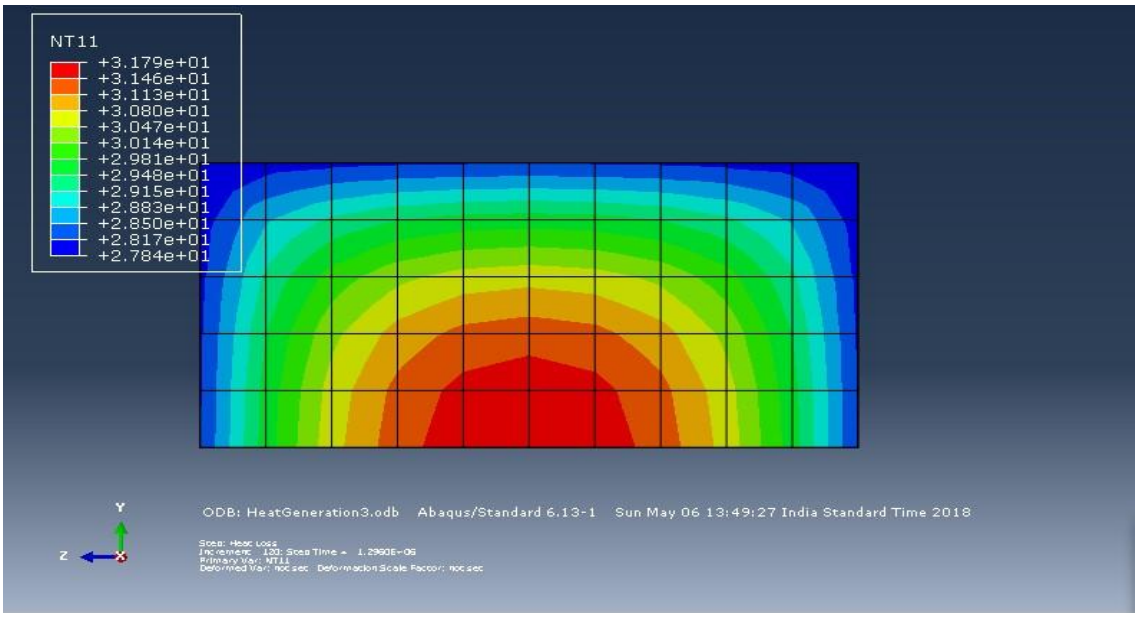


Figure 4.12 Heat Distribution in 2.5 metres lift in X-Plane

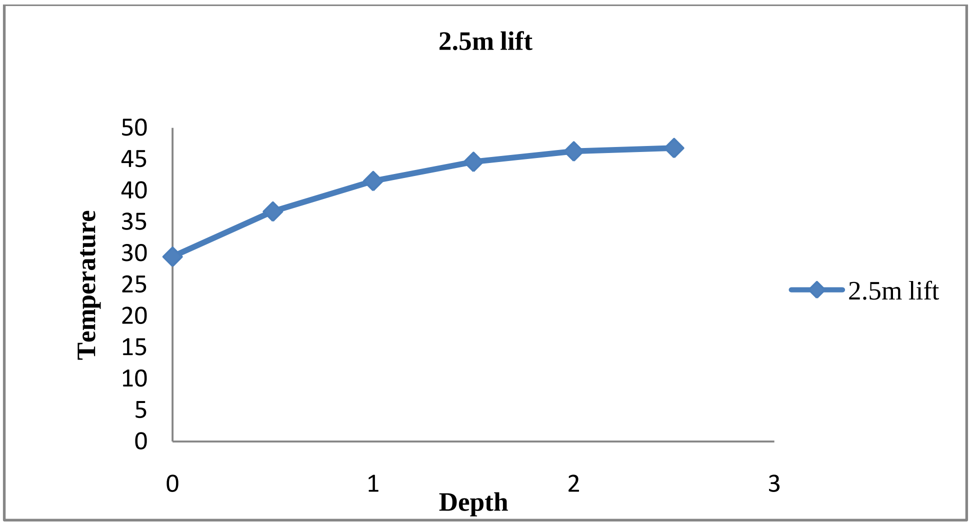


Figure 4.13 Temperature variation with Depth in 2.5 metres lift height

The maximum and minimum temperatures in lift height of 2.5 metres is shown below where the maximum temperatures reaches to 46.75 °C and minimum temperature to 27.84 °C, whereas the maximum stable temperature of 31.79 °C.

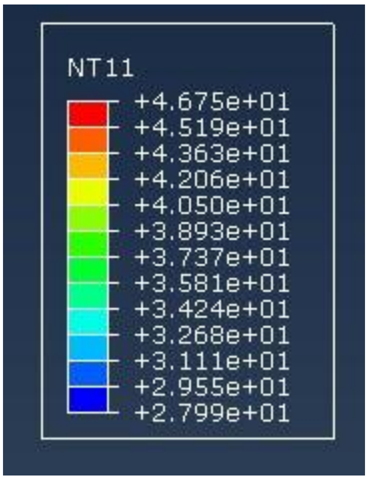


Figure 4.14 Maximum Temperature in 2.5m lift

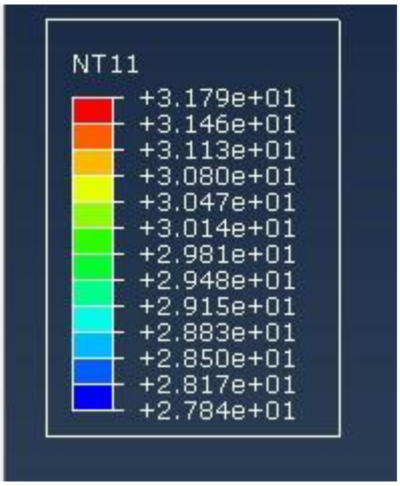


Figure 4.15 Final Temperature in 2.5m lift

4.4 3m Lift height

The lift height of model was increased to 3 metres and the results of the analysis were plotted. The isometric view of model is shown in Figure 4.16. The variation in heat distribution is not clearly visible on the top surface of the model due to increasing depth.

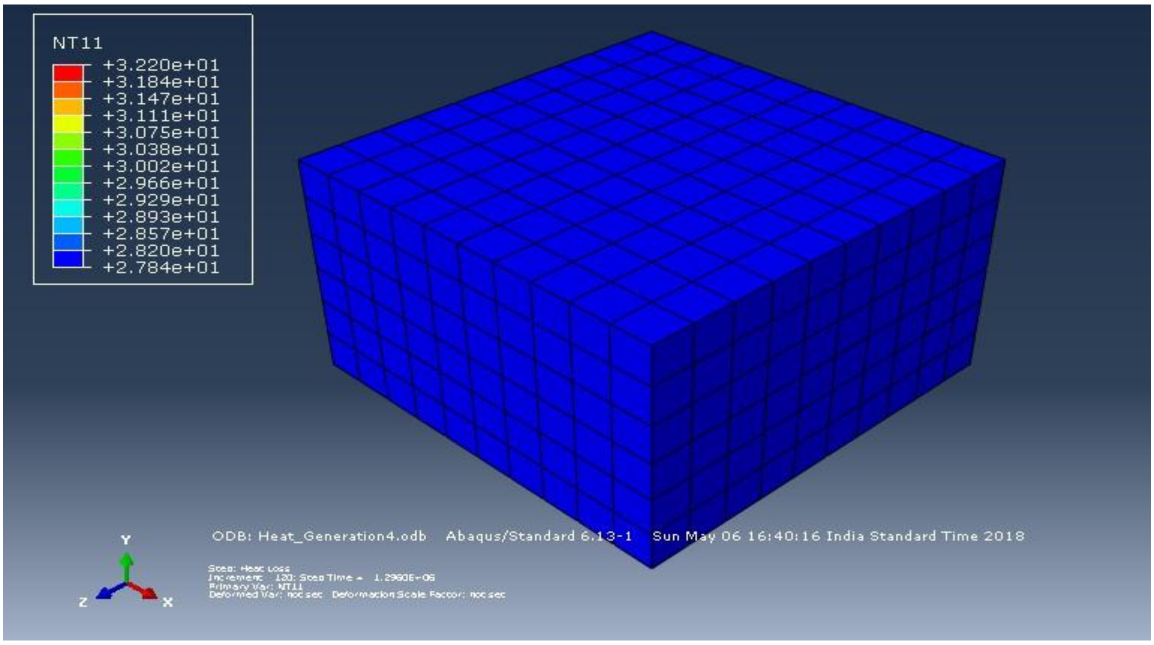


Figure 4.16 Isometric view of 3 metres lift height

The heat distribution in Figure 4.17 depicts the heat distribution in 3 metres lift height. The colour ranges from red indicating the maximum temperatures to blue having minimum temperatures. The maximum temperature of 48.74°C reached in the model is shown in Figure 4.18. The temperature was noted with the increasing depth.

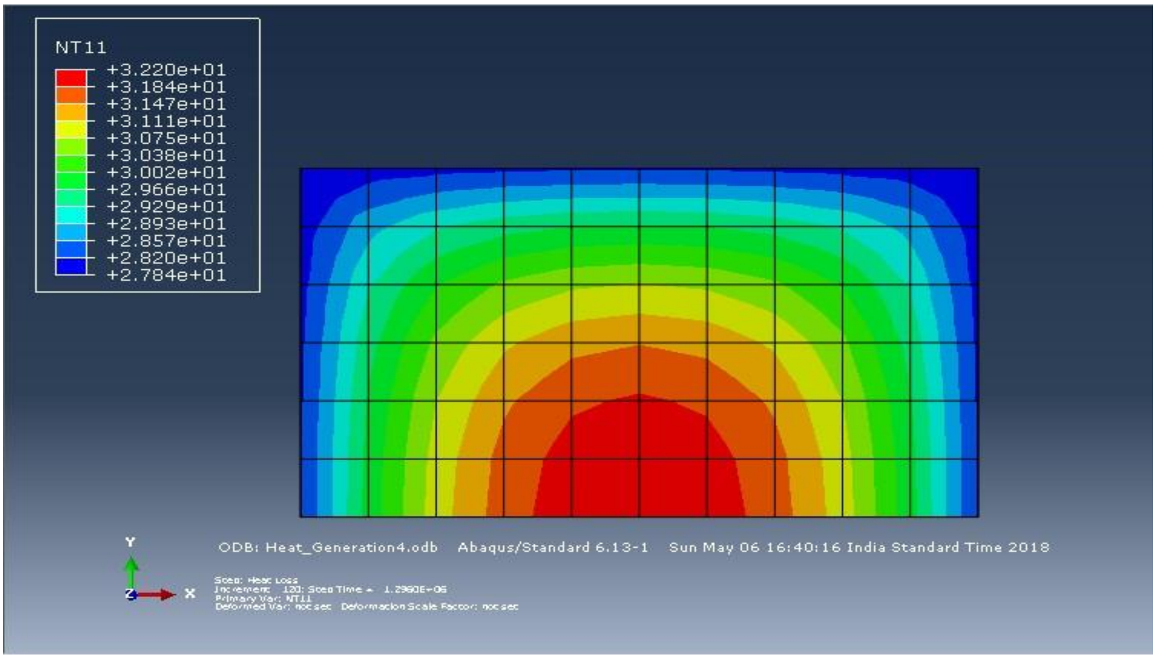


Figure 4.17 Heat Distribution in 3 metres lift in X-Plane

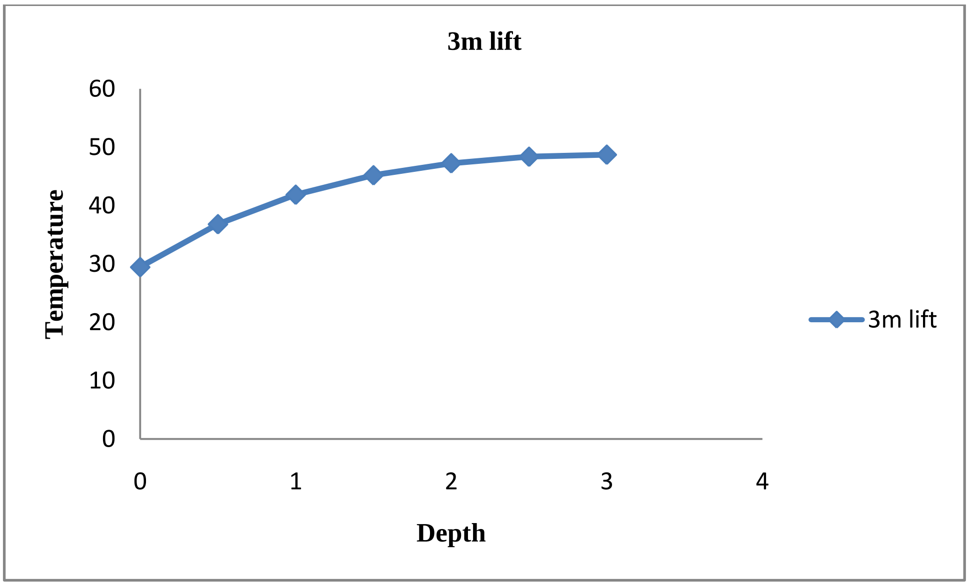


Figure 4.18 Temperature variation with Depth in 3 metres lift height

The maximum and minimum temperatures in lift height of 3 metres is shown below where the maximum temperatures reaches to 48.74 °C and minimum temperature to 27.85 °C, whereas the maximum stable temperature of 32.20 °C.

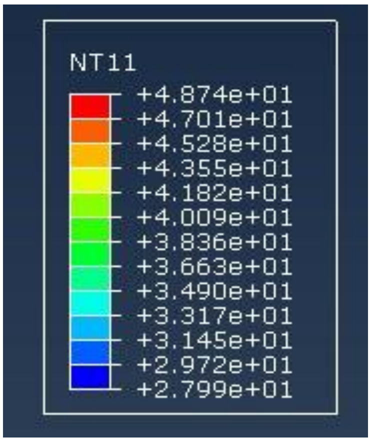


Figure 4.19 Maximum Temperature in 3m lift

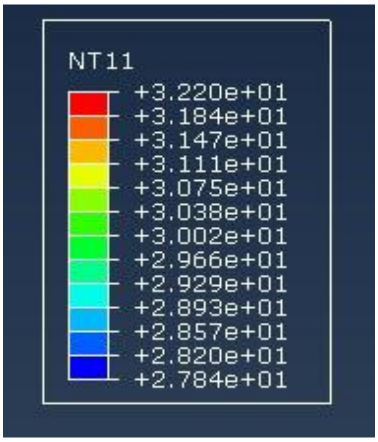


Figure 4.20 Final Temperature in 3m lift

4.5 3.5m Lift Height

The lift height of model was increased to 3.5 metres and the results of the analysis were plotted. The isometric view of model is shown in Figure 4.21. The variation in heat distribution is not clearly visible on the top surface of the model due to increasing depth.

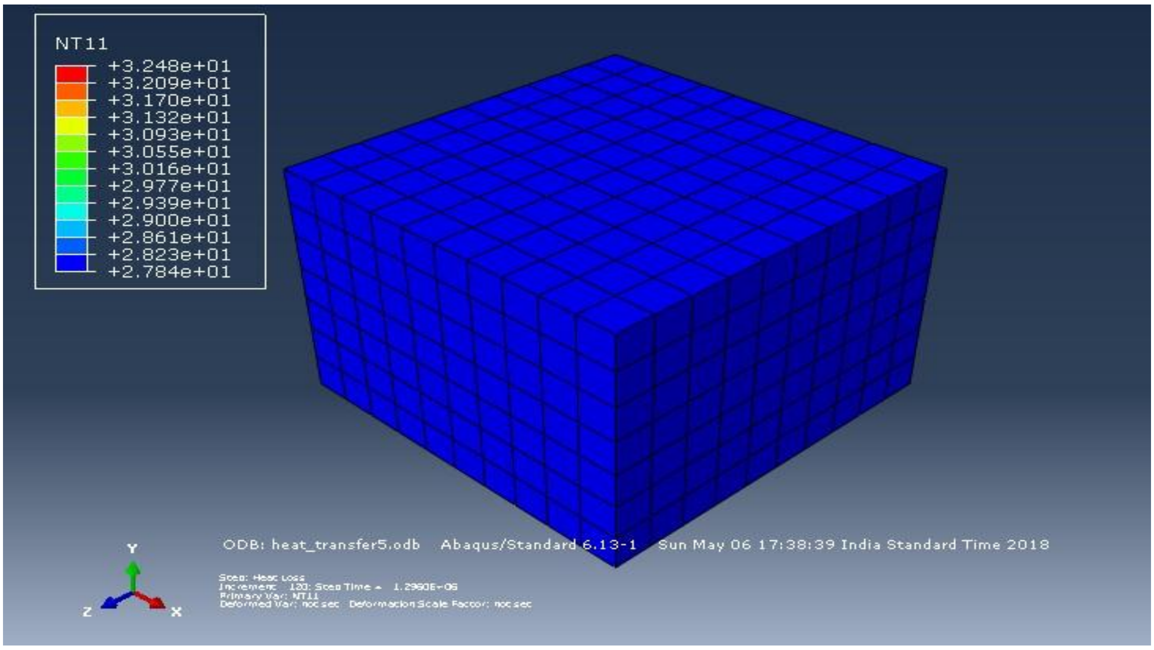


Figure 4.21 Isometric view of 3.5 metres lift height

The heat distribution in Figure 4.22 depicts the heat distribution in 3.5 metres lift height. The colour ranges from red indicating the maximum temperatures to blue having minimum temperatures. The maximum temperature of 50.05 °C reached in the model is shown in Figure 4.23. The temperature was noted with the increasing depth.

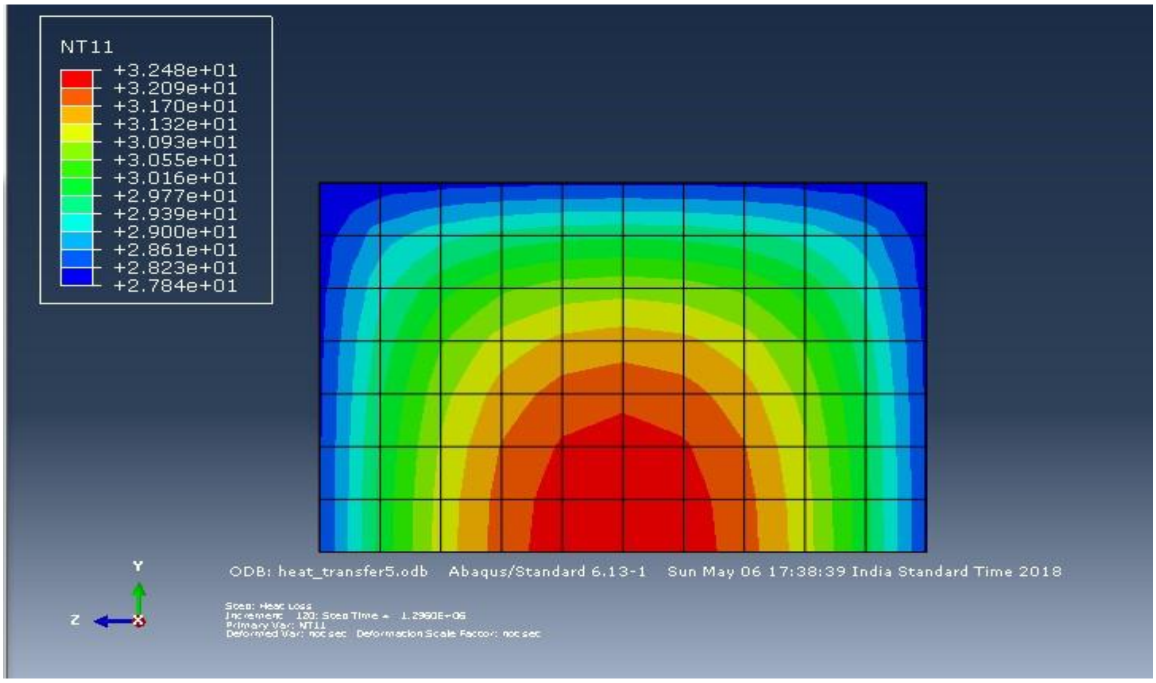


Figure 4.22 Heat Distribution in 3.5 metres lift in X-Plane

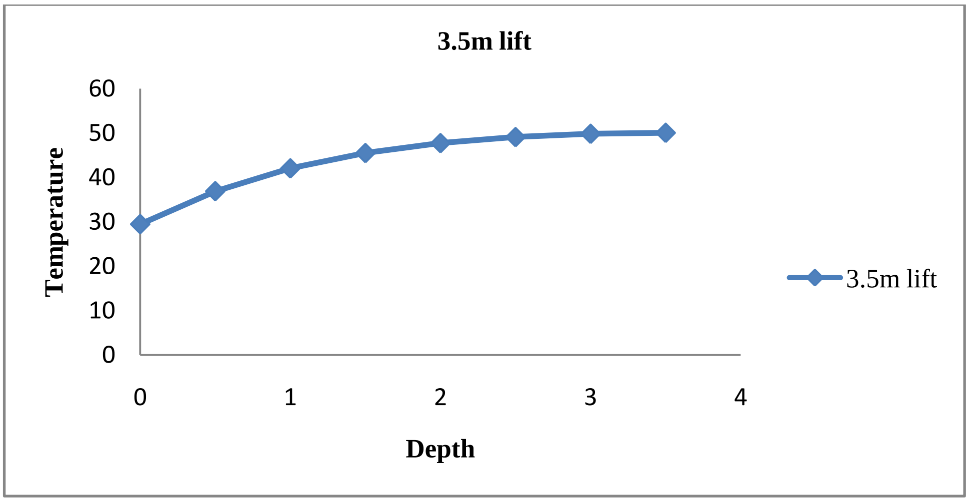


Figure 4.23 Temperature variation with Depth in 3.5 metres lift height

The maximum and minimum temperatures in lift height of 3.5 metres is shown below where the maximum temperatures reaches to 50.05 °C and minimum temperature to 27.84 °C, whereas the maximum stable temperature of 32.48 °C.

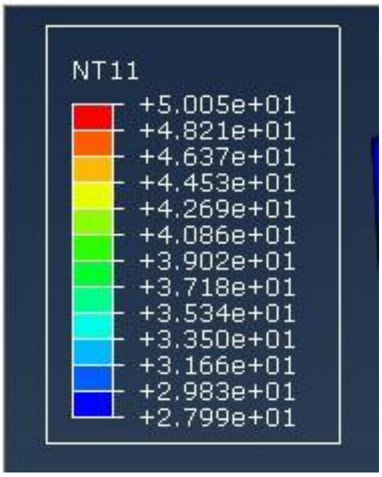


Figure 4.24 Maximum Temperature in 3.5m lift

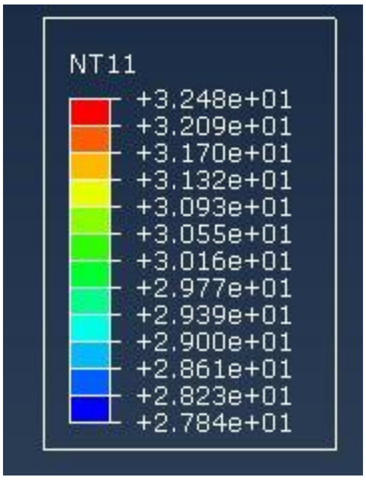
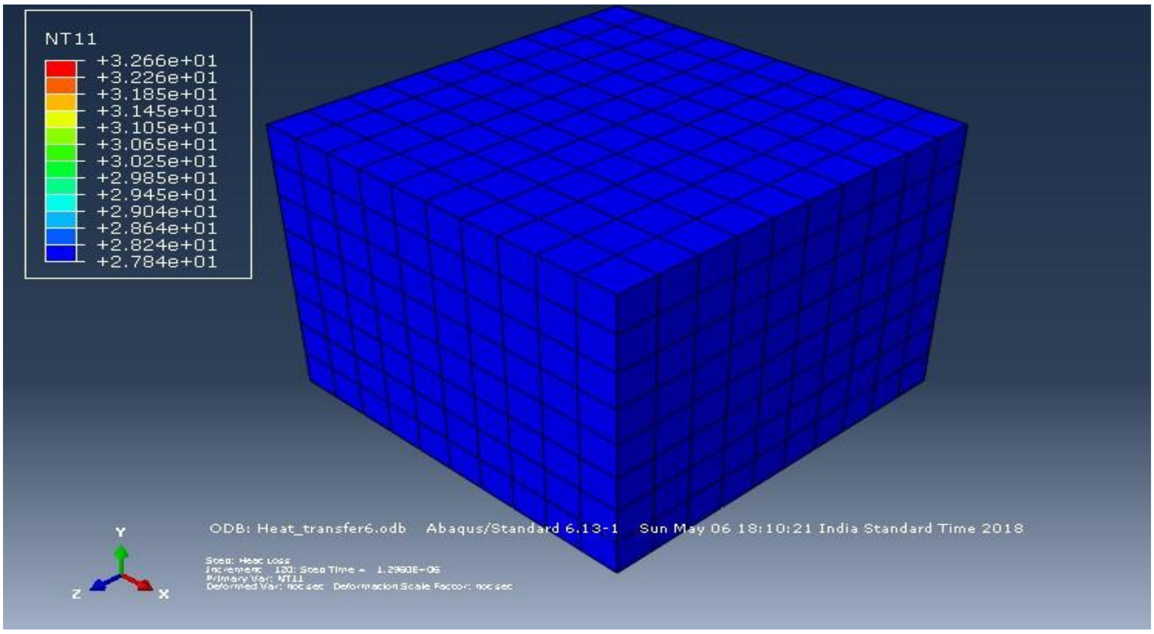


Figure 4.25 Final Temperature in 3.54m lift

4.6 4m Lift height

The lift height of model was increased to 4 metres and the results of the analysis were plotted. The isometric view of model is shown in Figure 4.26. The variation in heat distribution is not clearly visible on the top surface of the model in this view due to the increase in depth of the model.



ODB: Heat_transfer6.odb Abaqus/Standard 6.13-1 Sun May 06 18:10:21 India Standard Time 2018

Step: Heat Loss
Increment 120: Step Time = 1.296E+06
Primary Var: NT11
Deformed Var: not set Deformation Scale Factor: not set

Figure 4.26 Isometric view of 4 metres lift height

The heat distribution in Figure 4.27 depicts the heat distribution in 4 metres lift height. The colour ranges from red indicating the maximum temperatures to blue having minimum temperatures. The maximum temperature of 50.90 °C reached in the model is shown in Figure 4.28. The temperature was noted with the increasing depth.

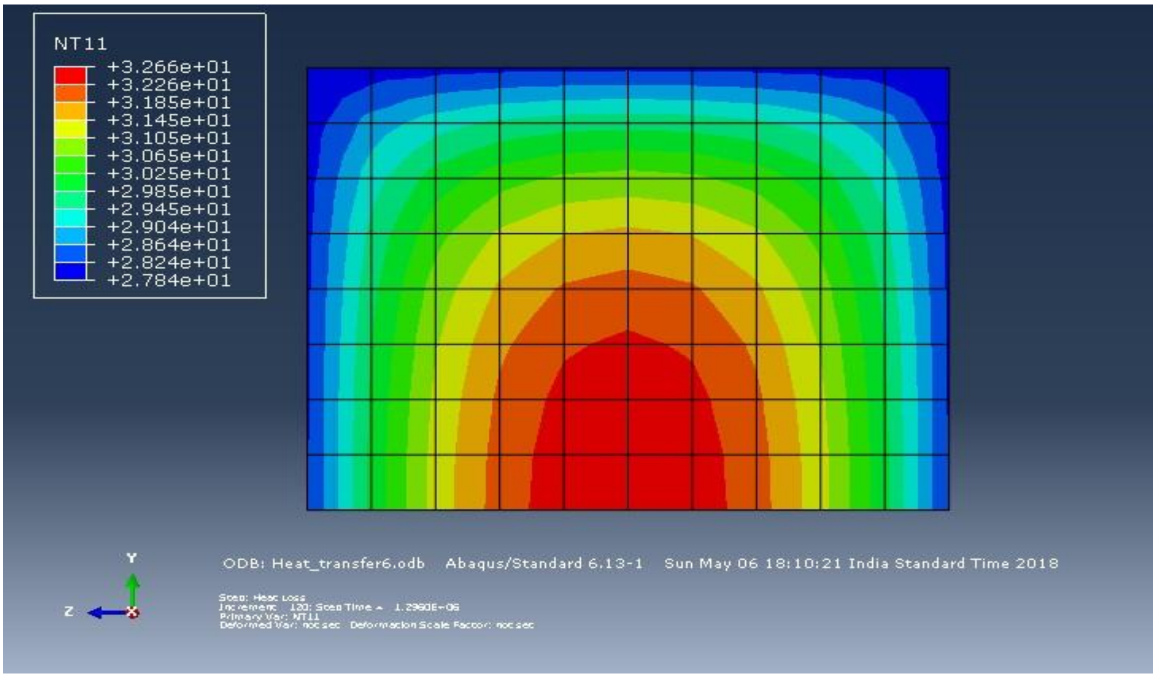


Figure 4.27 Heat Distribution in 4 metres lift in X-Plane

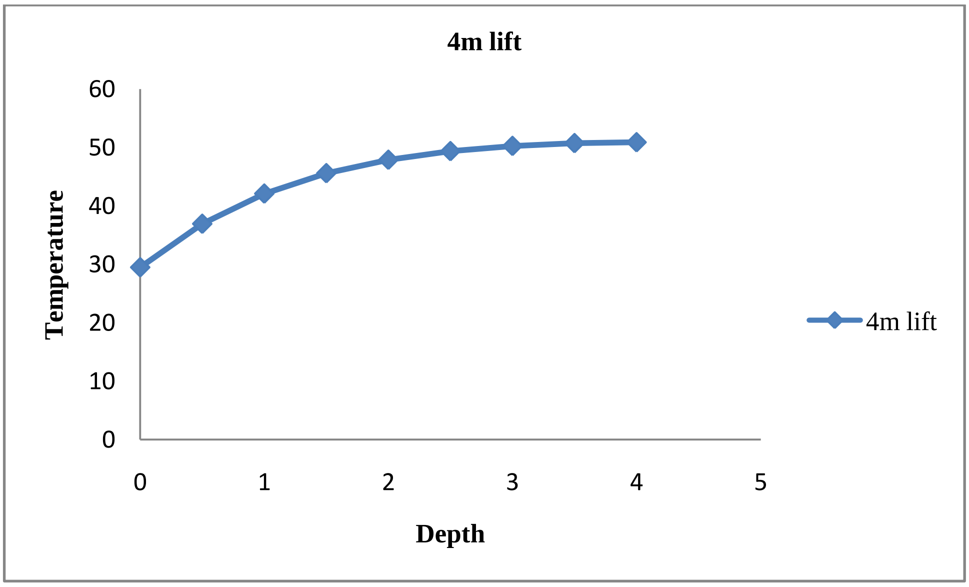


Figure 4.28 Temperature variation with Depth in 4 metres lift height

The maximum and minimum temperatures in lift height of 4metres is shown below where the maximum temperatures reaches to 51.46 °C and minimum temperature to 27.85 °C, whereas the maximum stable temperature of 32.78 °C.

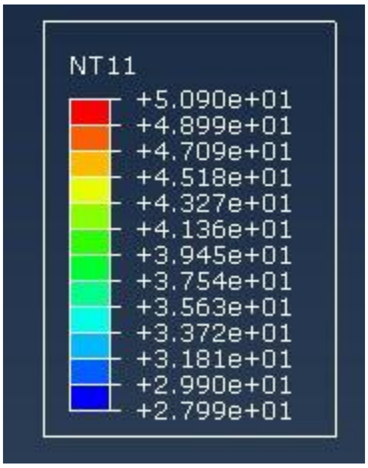


Figure 4.29 Maximum Temperature in 4m lift

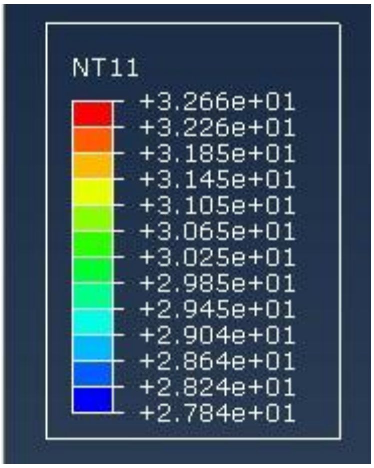


Figure 4.30 Final Temperature in 4m lift

4.7 4.5m Lift height

The lift height of model was increased to 4.5 metres and the results of the analysis were plotted. The isometric view of model is shown in Figure 4.31. The variation in heat distribution is not clearly visible on the top surface of the model due to the greater height and lower heat dissipation in concrete.

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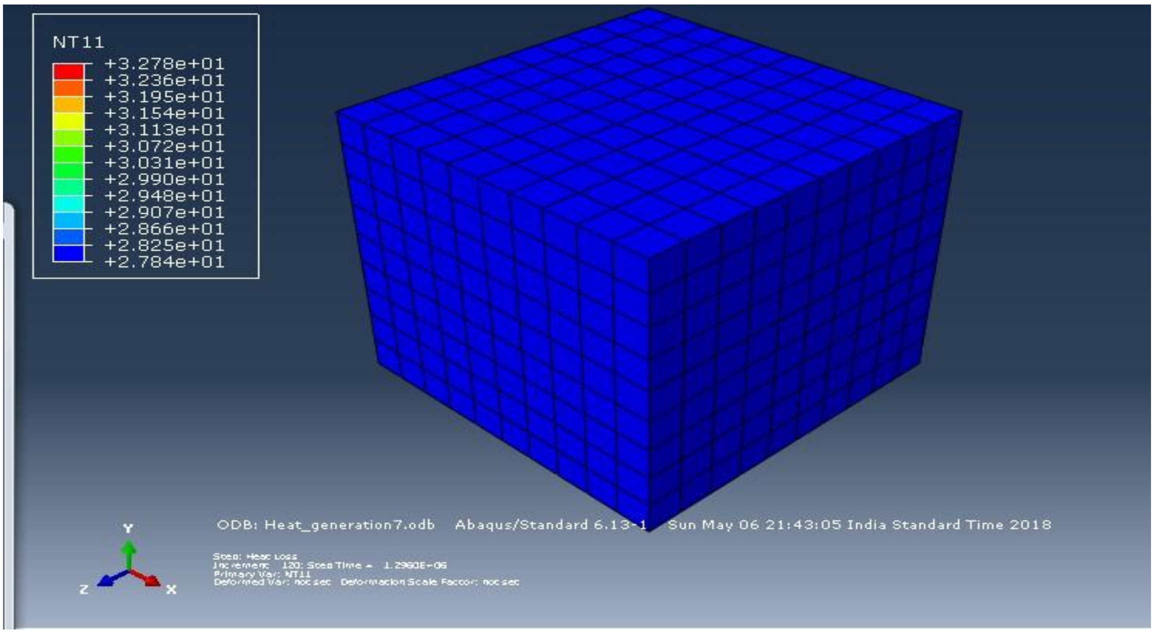


Figure 4.31 Isometric view of 4.5 metres lift height

The heat distribution in Figure 4.32 depicts the heat distribution in 4.5 metres lift height. The colour ranges from red indicating the maximum temperatures to blue having minimum temperatures. The maximum temperature of 51.46 °C reached in the model is shown in Figure 4.33. The temperature was noted with the increasing depth.

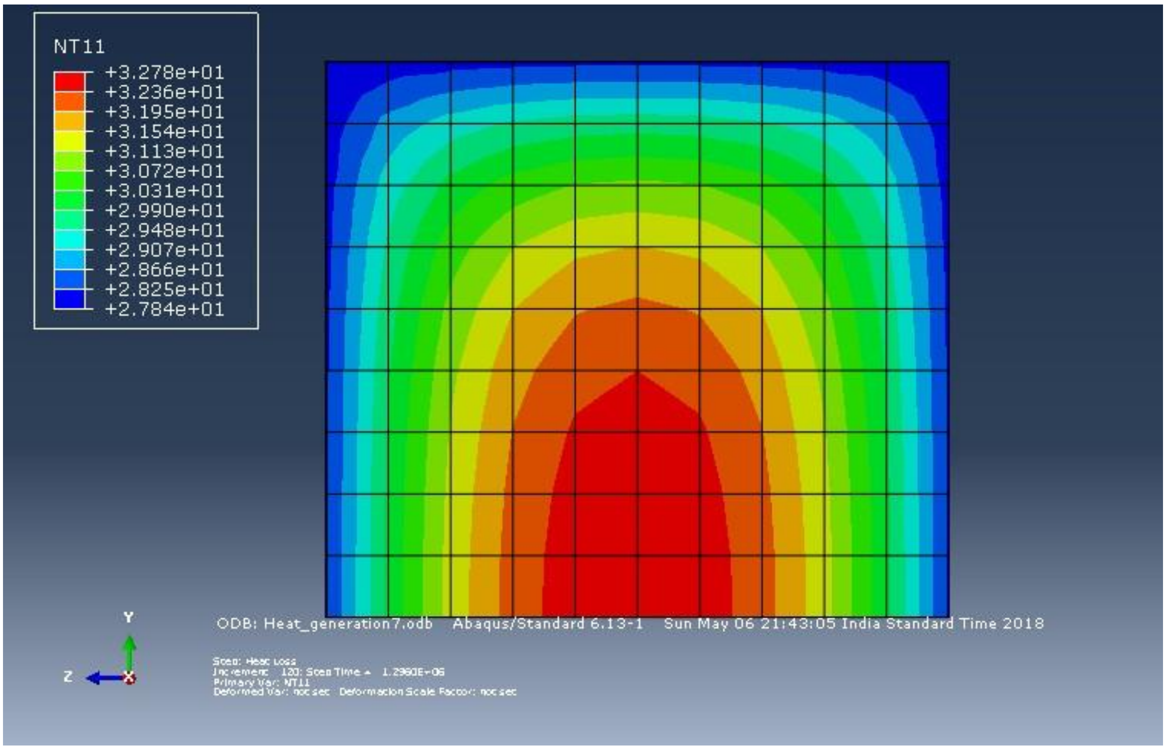


Figure 4.32 Heat Distribution in 4.5 metres lift in X-Plane

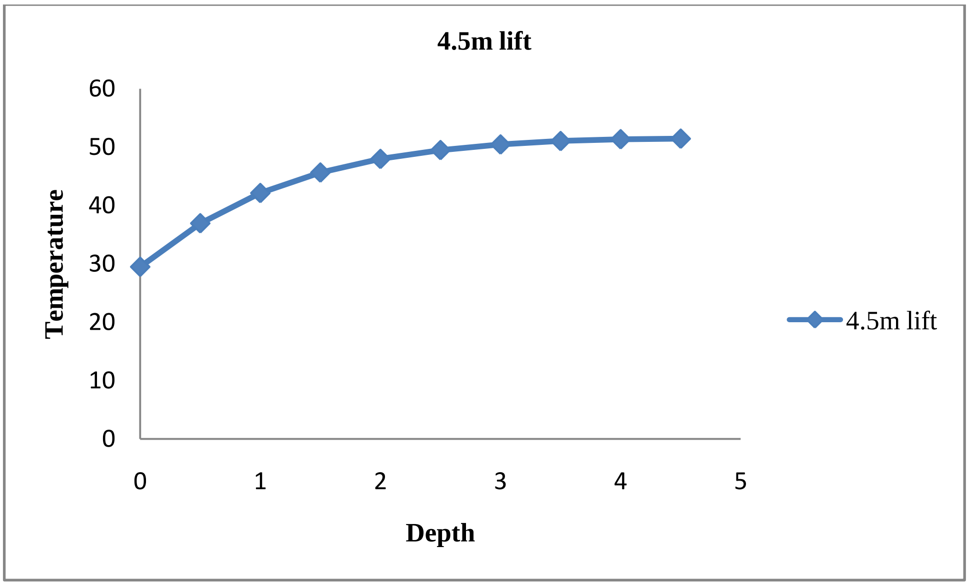


Figure 4.33 Temperature variation with Depth in 4.5 metres lift height

The maximum and minimum temperatures in lift height of 4.5metres is shown below where the maximum temperatures reaches to 51.46 °C and minimum temperature to 27.85 °C, whereas the maximum stable temperature of 32.78 °C.

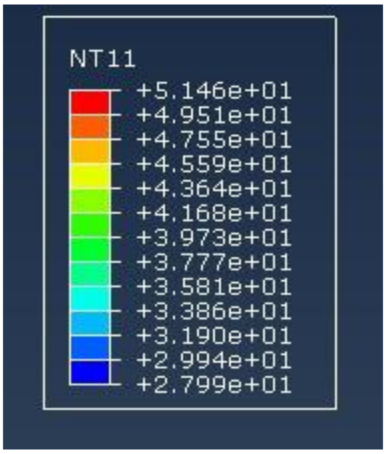


Figure 4.34 Maximum Temperature in 4.5m lift

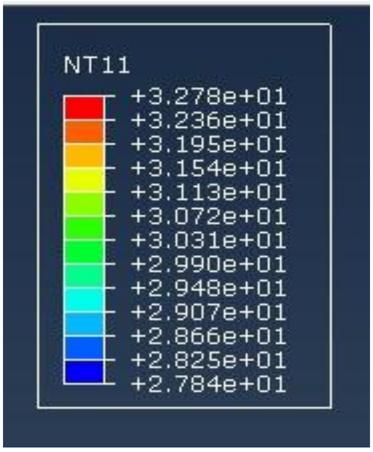
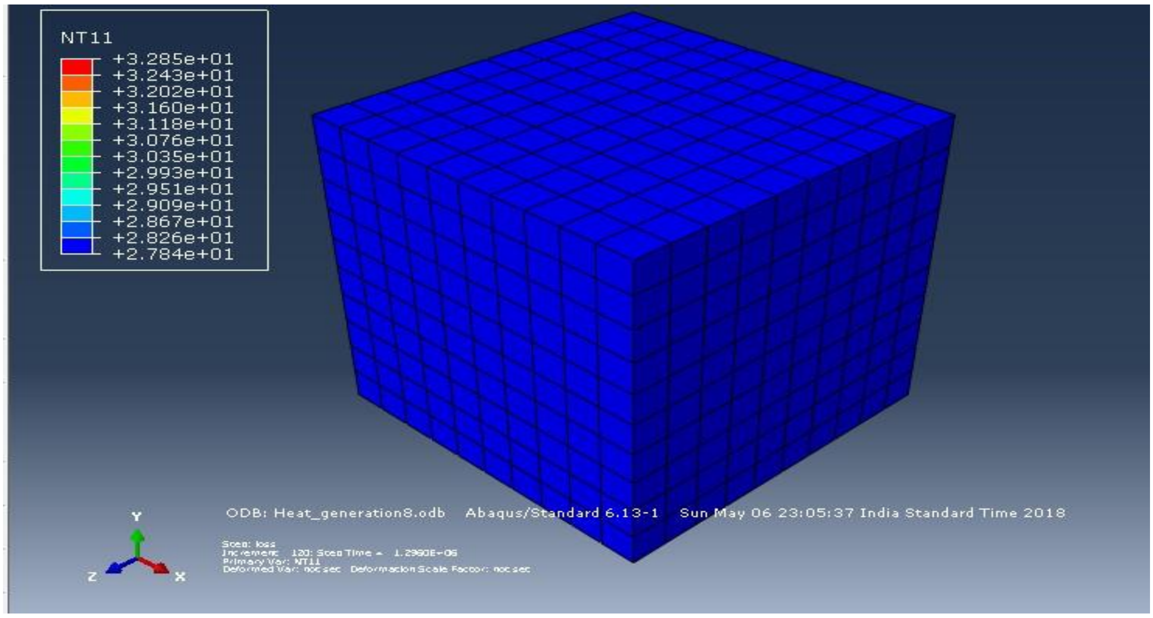


Figure 4.35 Final Temperature in 4.5m lift

4.8 5m Lift Height

The lift height of model was increased to 5 metres and the results of the analysis were plotted. The isometric view of model is shown in Figure 4.36. The variation in heat distribution is not clearly visible on the top surface due to heat accumulation at centre and lower heat dissipation of concrete.



ODB: Heat_generation8.odb Abaqus/Standard 6.13-1 Sun May 06 23:05:37 India Standard Time 2018

Step: loss
Increment 120: Step Time = 1.2960E+06
Primary Var: NT11
Deformed Var: not set Deformation Scale Factor: not set

Figure 4.36 Isometric view of 5 metres lift height

The heat distribution in Figure 4.37 depicts the heat distribution in 5 metres lift height. The colour ranges from red indicating the maximum temperatures to blue having minimum temperatures. The maximum temperature of 51.83°C reached in the model is shown in Figure 4.38. The temperature was noted with the increasing depth.

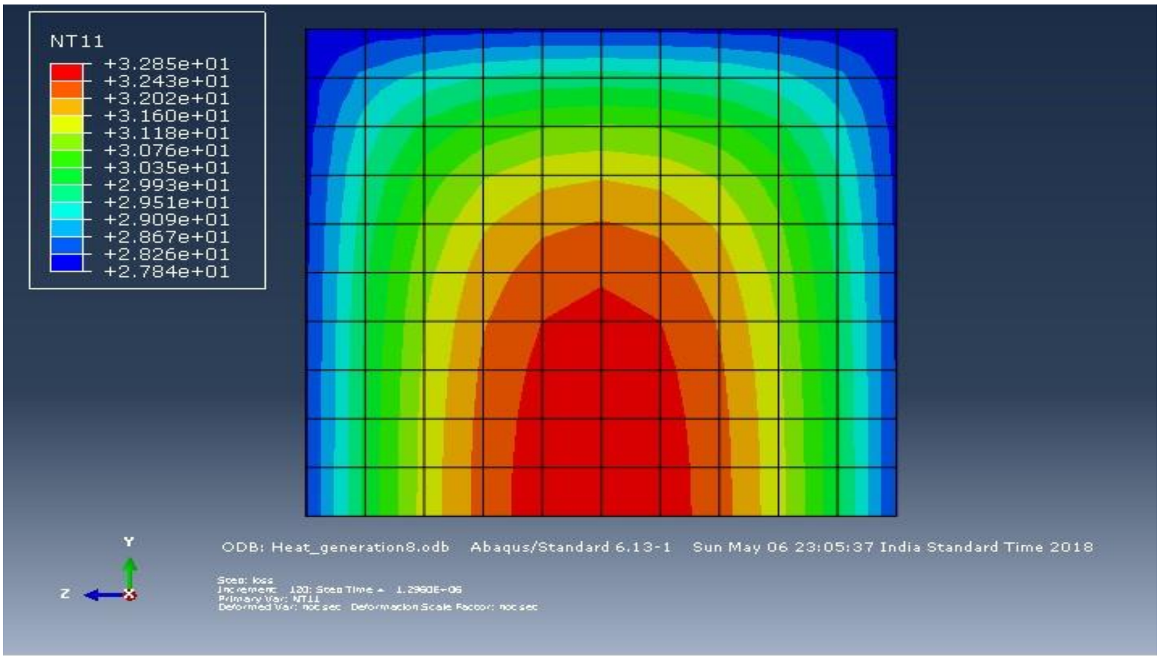


Figure 4.37 Heat Distribution in 5 metres lift in X-Plane

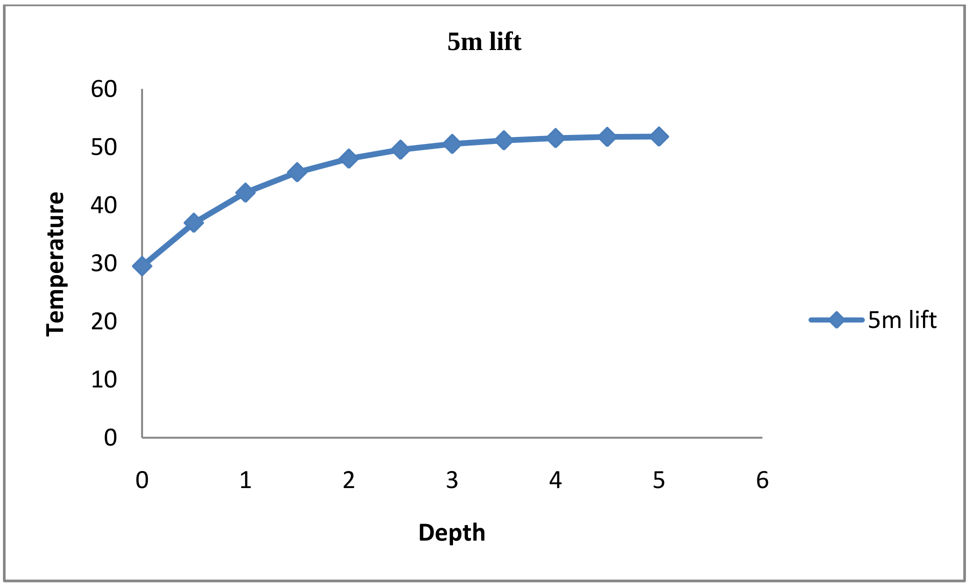


Figure 4.38 Temperature variation with Depth in 5 metres lift height

The maximum and minimum temperatures in lift height of 5metres is shown below where the maximum temperatures reaches to 51.83 °C and minimum temperature to 27.85 °C, whereas the maximum stable temperature of 32.85 °C.

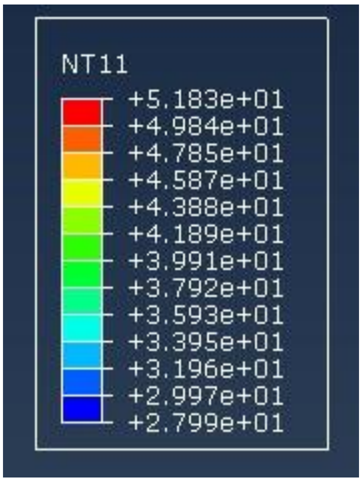


Figure 4.39 Maximum Temperature in 5m lift

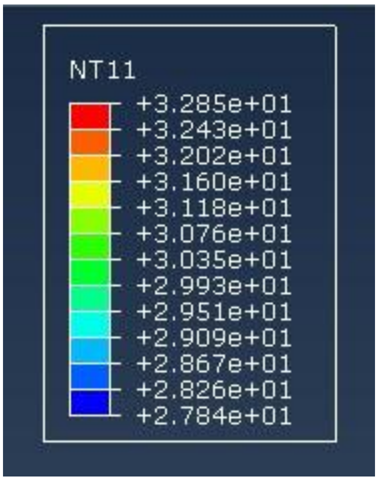


Figure 4.40 Final Temperature in 5m lift

4.9 Variation of lift temperatures

The variation of temperature with varying lift heights was noted and the values of temperature were plotted as shown below. The initial temperatures were same as the ambient temperature was same in different lift heights. The temperature increases from lift height of 1.5 metres to 5 metres such that there is a gradual difference between the temperatures of both the lift heights.

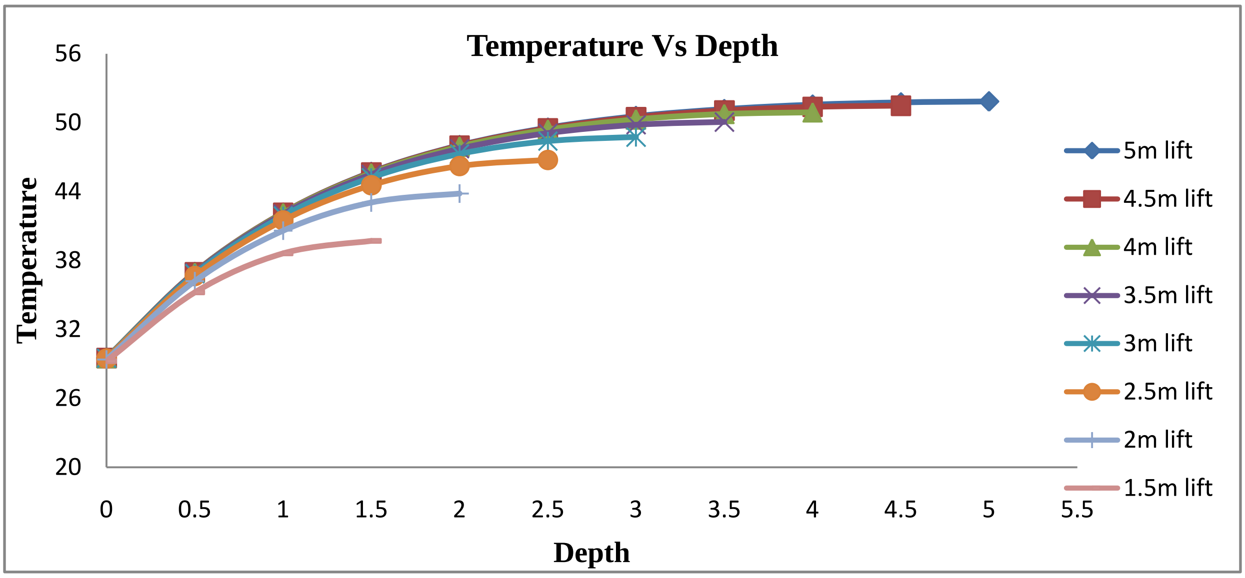


Figure 4.41 Temperature rise in varying lift height

The temperature differential between the minimum and maximum temperatures in concrete should not be greater than 20°C. Temperatures greater than the permissible limit will induce thermal cracks in concrete. If large lift heights needs to be achieved then strict measures for controlling temperature needs to be taken to control thermal cracks. The minimum and maximum temperatures along with the temperature differential are given in table below.

Table 4.1 Peak and Min Temperature in lifts

Sr. No.	Lift Height	Minimum Temperature	Maximum Temperature	Temperature difference
1	1.5	29.23	39.70	10.46
2	2	29.38	43.82	14.43
3	2.5	29.45	46.75	17.29
4	3	29.48	48.73	19.25
5	3.5	29.49	50.04	20.55
6	4	29.50	50.90	21.40
7	4.5	29.50	51.46	21.96
8	5	29.50	51.82	22.32

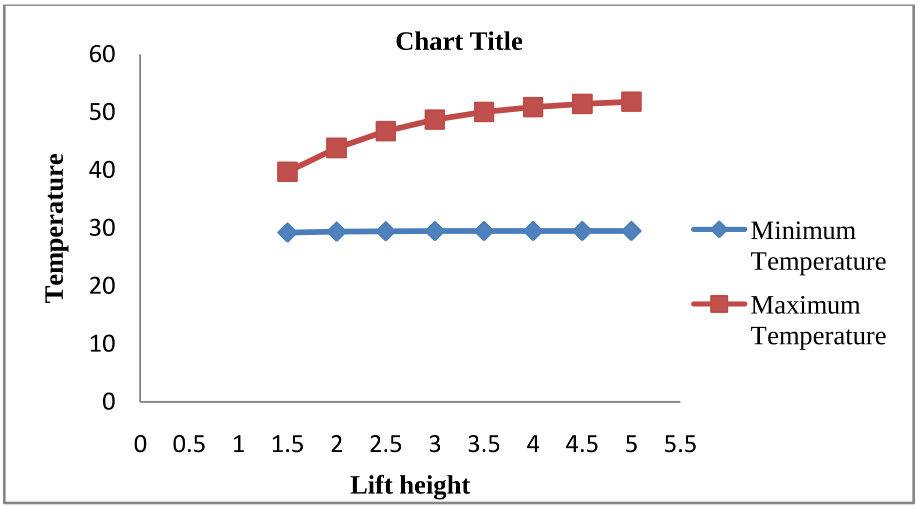


Figure 4.42 Min and Max Temp in lifts

Chapter 5

CONCLUSION AND FUTURE SCOPE

The points that can be concluded from the study are:-

- The lift height of 3m can be achieved according to this analysis.
- The temperature differential between minimum and maximum concrete temperature is under 20°C.
- As the height of lift increases there is a gradual increase in the maximum temperatures of concrete core.
- The minimum temperature reached in concrete remains same in all the cases of lift due to the ambient temperature.

The study can be helpful in future:-

- Mass concreting structures such as dams, tunnels, large foundations, etc for proper heat dissipation.
- Estimating the quantity of concrete to be placed at a time can be optimized for faster construction.
- Formwork design for faster Construction.
- Optimization of cost of construction cost and schedule.
- Experimental verification of results obtained from analysis.
- Network Optimization.
- Cost Optimization.

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