JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

STRUCTURAL ENGINEERING STREAM

Finite Element Analysis of Concrete Encased I-Section Steel Column Exposed to Fire

By

Mohammed Jemal

A Thesis Submitted to the School of Graduate Studies of Jimma University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering (Structural Engineering)

May 2018

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Advisor: Dr. Temesgen Wondimu (PhD)

Co-Advisor: Eng. Habtamu G/medhin

May, 2018

Jimma, Ethiopia

DECLARATION

This thesis research is my original work and has not been presented for a Masters of Degree in any other University. All sources used in this thesis are duly acknowledged.

________________	_________________	_______________
Name	Signature	Date

This thesis work has been submitted for examination with my approval as university supervisor.

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Advisor’s Name	Signature	Date
________________	_________________	_______________
Co-Adviser’s Name	Signature	Date

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Abstract

This thesis presents finite element analysis of concrete encased I-section steel column exposed to fire by using 3D finite element (FE) software. The objective of this research was to investigate the Finite element analysis of concrete encased I-section steel column exposed to fire. In this research, two analyses have been employed thermal and mechanical analysis for the same x-section of concrete and different steel section of composite columns are conducted by exposing the surface to fire. The first analyses simulate non-linear transient heat transfer analysis from ISO 834 time-temperature curve to the surface of concrete column. The second analysis conducted non-linear stress analysis to simulate the structural behavior of the same column concrete but different steel size subjected to mechanical load and nodal temperature (as nodal temperature time history) has been calculated. The results of this research indicated that composite column as fire exposure time increase the material behavior degrades since the nodal temperature distribution increases when exposure time increase. The stress distribution of the column section has decreased; however, when the steel ratio decreases the fire duration has differently increased. In addition an increase in duration of fire exposure of the column, the compressive strength of concrete has decreased. At elevated temperatures is the composite column totally depending on the thickness of the steel section. Larger steel sections result in an increase in strength and stiffness at ambient temperatures, but more steel results mostly in a smaller concrete cover. As last it is concluded that the thickness of the steel section is the most determining factor in the temperature distribution. It is recommend that this study can lay a basis for Finite Element Analysis of fire effects in other structural elements i.e. the reinforced concrete, steel structure and composite column member as one side, two side and three side fire exposures are studies.

Key words*: heat transfer, fire, finite element, column, structural analysis*

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List of Acronyms and Abbreviation

Aa Area of the steel profile cross-section

Ac Area of the present concrete in the cross-section

As Total area of longitudinal reinforcement

B Width of the composite column cross-section

C Concrete cover

C_a Specific heat of steel

CDP Concrete damaged plasticity

D Overall depth

EBCS Ethiopian Building Code Standared

EC Europian code

E_a Elastic modulus of the steel of the profile

E_{cm} Elastic modulus of concrete

E_{cT} Modulus elasticity of concrete at elevated temperature

E_s Elastic modulus of the reinforcement at elevated temperatures

FE Finite Element

FEA Finite Element Analysis

FEM Finite Element Method

FRR Fire resistant rate

$F_{ck,t}(\theta)$ Characteristics tensile strength of concrete

$F_{c,\theta}$ Compressive strength

H Height of the composite column cross-section

I_a Second moment of area of the steel profile

I_c Second moment of area of the concrete

I_s Second moment of area of the reinforcement

L Length of the column

ISO International Organization for Standardization

NSC Normal strength concrete

t Time

CHAPTER ONE
INTRODUCTION

1.1 Background of the Study

Fire hazard is one of the biggest challenges that any building could face during its service life. If not properly designed and managed, a fire could lead to a large amount of destruction in terms of property, loss of life, money. Historically a prescriptive approach to structural fire safety in the form of codes has been utilized which helps to solve the problem to a certain extent by regulating design and construction quality. The validity of prescriptive approach and its level of safety is now a concern due to the development of performance-based approaches. A performance-based approach is a representation of the actual stages and developments that may occur in a structure during a fire event [1].

Steel elements, when unprotected, they behave poorly under fire conditions. The deterioration of the mechanical properties of the steel, and its high thermal conductivity lead to very low critical temperatures, and poor fire resistance. Fire protection materials can be used to improve the fire resistance of steel elements, but they may entail problems such as longer construction times, higher costs, increasing the structural elements' cross-section and aesthetic issues. Combining steel with other materials, as in composite structures, can be a solution. Composite steel and concrete structures are very popular nowadays because concrete can be used both as a fire protection and as a resistant material. Concrete can be used in partially or totally encased steel sections or to fill hollow steel sections. In the case of fire the concrete protects the steel part of the cross-section from excessive heating. The steel, on the other hand, reduces concrete spalling and cracking since the concrete is partially or totally encased in the element's cross-section [2].

Composite steel-concrete members can be made by a wide variety of cross-sections, but the most commonly used are concrete-encased I-shape steel and concrete-filled steel tubes. Although composite steel-concrete constructions have been used for more than a century, all their advantages were not fully understood at first; in the early twentieth century concrete was used as a fire protection material for the steel profile, but the performance improvement produced by the encasement was not yet considered. Nowadays, it is well known that these structural members exploit the synergistic action of both materials; steel provides strength, ductility, light weight and fast erection, whereas concrete provides stiffness, good performance at high temperatures and it is an economical material. In recent years, this type of composite members is being increasingly used in a wide range of applications, such as high-rise buildings, bridge piers and earthquake-resistant construction.

Composite column systems have become popular in tall building construction due to combining the rigidity of reinforced concrete with structural steel sections. Composite columns may be concrete encased steel columns or concrete-filled steel tube columns. In addition to the advantages of composite columns, concrete encased steel composite columns provide higher fire resistance compared to the conventional steel and concrete-filled steel tube columns that require additional protection against fire [3].

Sustainability of structures is a core issue in the construction industry .Exposure to fire or elevated temperature is an extreme condition that leads to change in materials properties. Consequently, change in overall is behavior of the structure .in construction industry, the provision of appropriate fire safety measures for structural members is an important aspect of design since fire represents one of the most sever environmental condition to which structures may be subjected in their lifetime [4].

The behavior of structure exposed to fire is usually described in terms of the concept of life of fire resistance which is the period under exposure to a standard fire temperature curve at which some prescribed form of limiting behavior occurs. Fire structure analysis is to predict the effect of fire in buildings, the fire resistance and the structure performance under heating and cooling caused by fire. The result of such analysis can be applied in the design of fire protection systems, in the evaluation of fire safety and as an addendum of experiment [5].

This research aims to explore Finite element analysis of concrete encased steel column section being exposed to fire for different time of exposure by using finite element software, ABAQUS for predicting the behavior of the composite column. Perspective design method is used and model is developed specifically for simple supported column exposed to ISO 834 standard time temperature curve at the face and the side columns. The behavior of the composite column discussed. To check the accuracy of FE model the result from FE model has been compared with the test result available in literature.

1.2 Statement of the Problem

Fire represents one of the most severe environmental conditions to which structures may be subjected. Therefore provision of appropriate fire safety measure for structural members is an important aspect of building design.

The strength and rigidity of steel are reduced with increase temperature and in addition to losing this properties, concrete suffer a reduction in area due to the “spalling” phenomenon. The composite system of concrete encased steel I-section, beyond increasing the structures load bearing capacity at room temperature allows for great exposure times to high temperature compare to the same material evaluated separately.

Sustainability of structures is a vital issue in the construction industry. Exposure to fire or elevated temperature is serious condition that leads to change in material properties; consequently, change in overall behavior is expected. Hence, buildings should be provided with sufficient structural fire resistance to with stand in such circumstance, or at least give occupants to scape before strength and or stability failure occurred in structural design of buildings in addition to normal gravity and lateral loads it is necessary to design the structure to safely resist exposer to fire. However it is usually necessary to guard against structural collapse for a given period of fire exposure.

Facts show that; our country has not much considering fire effect on structural member for these effects reduced the strength and durability of the structural members.

1.3. Objectives

1.3.1. General Objective

The general objective of this research is to investigate the Finite element analysis of concrete encased steel I-section exposed to fire.

1.3.2. Specific Objectives

The specific objectives of the study are as follows:

- To identify the effect of fire on thermal properties of concrete at different time exposure;
- To evaluate structural behavior of concrete encased steel section column when exposed to fire;
- To determine the temprature effect at the top part of the composite column;

1.4. Significance of the study

Analysis of the governing principles and basis of the fire dynamics, heat transfer and structural analysis problems involved in the study of the fire response of a concrete encased column member. The study hopes add knowledge on understanding the analysis of fire response of concrete encased I-section steel column using finite element methods. The findings of this research would hope to provide an insight for individuals who engaged in construction industry, designers, engineers and researchers to focus on this area. The outcome from the study aims to enrich valuable data or information about behavior of concrete encased I-section steel column under fire.

Ethiopia's construction industry will benefit from this study because of many structural high rise buildings, most often, have not considered fire effect on the structural member.

EBCS code dose not discuss about fire design of concrete structure deeply, but fire is the most severe environmental condition subjected to building structures and their life time. Exposure to fire or elevated temperature is an extreme condition that leads to change in materials properties: consequently, change in overall is expected. Therefore, this study will add valuable information on the behavior of concrete encased I-section steel column under fire to fill this gap.

1.5. Limitation of the study

The research has been limited by the following

- The absence of enough literature review.
- It has consumed much time to process the output value.

1.6. Structure of the Thesis

This thesis has been structured into five chapters. The first chapter focuses on the background of the study, statement of the problem, objective of the study and significance of the study. In chapter two literature reviews has been discussed, such as code review, effect of fire on structure, method of assessment of fire resistance and different types of fire modeling as temperature. Chapter three focuses on research methodology which includes material modeling at elevated temperature, finite element discretization of the column going to be analysis has been discussed.

Chapter four is devoted to result analysis and discussion of the research. Validation has been made by using finite element model to analyze test result; and discussions on result of thermal and structural analysis of composite column were also discussed. Chapter five, last chapter of the research, makes conclusion and recommendations.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

This chapter gives an overview of the basic principle of fire design. It shows the meaning of fire resistance, same code recommendation and design method for composite member, including design fires. The principal behavior of column under fire exposure is shown and the effects of elevated temperature on the material behavior of concrete, structural steel and reinforcing bars. Conducted a sensitivity analysis in order to determine the appropriateness of the guidelines provided by Euro code 3. The parameters of thermal conductivity, specific heat and emissivity were evaluated to determine the change in temperature of materials when subjected to a fire event. An equation for thermal conductivity variation for concrete was also proposed. For insulations having high thermal characteristic values, it has been suggested that the results due to the Euro code 3 formulations and the exact solution may differ significantly.

2.2 Fire Resistance

Fire resistance is used to characterize the performance of elements of structure in fire. The fire resistance is the time for which elements performs its functions under specified conditions. These functions may include the ability: not to collapse, to limit the spread of fire, to support other elements. All materials progressively lose their ability to support a load when they are heated. If components of a structure are heated sufficiently, they may collapse. The consequences of such a collapse may vary, depending on how critical the component is in controlling the overall behavior of the structure. In order to limit the threat that a fire poses to people in a building and to reduce the amount of damage that a fire may inflict, large buildings are divided into smaller fire compartments using fire resisting walls and floors. Parts of a fire compartment may be divided up by fire resisting construction to protect particular hazard within them. The performance of fire separating elements may rely heavily on the ability of the structure that supports them to continue to provide that support under fire conditions. The criticality is the degree to which the collapse of an individual structural element affects the performance of the structure as a whole. All main components of a structure are generally expected to exhibit. Fire resistance proportionate to the nature of the perceived risk. The nature of the risk is usually assessed on the basis of the size and proposed use of the building in which the structural element occurs, which is an important part of a fire safety risk analysis. It is important to realize that the fire resistance time does not express the time a structure might resist in a real fire, as the duration of an actual fire cannot be precisely specified. The construction in a building may perform satisfactory for a shorter or a longer period depending upon the characteristics of the fire [6].

Due to the thermal mass of concrete, composite columns always possess a higher fire resistance than corresponding steel columns. It may be recalled that composite columns were actually developed for their inherent high fire resistance). Composite columns are usually designed in the normal or 'cool' state and then checked under fire conditions. Additional reinforcement is sometimes required to achieve the target fire resistance. Some general rules on the structural performance of composite columns in fire are summarized as follows: The fire resistance of composite columns with concrete encased steel sections may be treated in the same way as reinforced concrete columns. The steel is insulated by an appropriate concrete cover and light reinforcement is also required in order to maintain the integrity of the concrete cover. In such cases, two and half-hour fire resistance can usually be achieved with the minimum concrete cover of 25 mm. For composite columns with concrete encased steel sections, the structural performance of the columns is very different in fire, as the flanges of the steel sections are exposed and less concrete acts as a 'heat shield'. In general, a fire resistance of up to two and half hour can be achieved if the strength of concrete is neglected in normal design. Additional reinforcement is often required to achieve more than two and half-hour fire resistance [7].

The fire performance of a structure member depends on the thermal and mechanical properties of the materials of which the building components is composed.as a result of the increase in temperature caused by the fire exposure, the strength of steel decreases along with its ability to resist deformation, and other property changes occur in the materials under prolonged exposure. Likewise, concrete is affected by exposure to fire and loss strength and stiffness with increase temperature. The performance of fire exposed structural members can be predict by structural mechanics analysis methods, comparable to those applied in ambient temperature design, except that the induced deformations and property changes need to be taken into consideration.

2.3. Code recommendations for fire design of composite column

This section gives an overview of the regulations concerning the design structure for fire resistance of different codes, with emphasis on the design of composite column.

2.3.1. Eurocode

Three levels of analysis are possible: member analysis, analysis of part of the structure, or analysis of the entire structure. In member analysis, a structural member is considered isolated and unaffected by indirect fire actions, except those resulting from thermal gradients. Indirect actions are actions that result from constrained thermal expansion of the members themselves, differing thermal expansion within statically indeterminate members, thermal gradients within cross sections, or thermal expansion of adjacent members. While this type of analysis is directly comparable with furnace tests and can be used to calculate fire rating or insulation thickness, it cannot capture the response of a structural frame or the development of alternative load paths in the entire structure. At the next level, analysis of parts of the structure, indirect actions within the subassembly are considered, but time-dependent interactions with other parts of the structure are not. In other words, the boundary conditions of the subassembly are assumed unchanged from those at ambient temperature. At the highest level, global structural analysis, indirect actions are considered throughout the structure. Changes in boundary conditions and connection fixity, development of new load paths, such as by catenary or membrane action, etc., are accounted for. This type of analysis usually requires the capability to handle nonlinear geometric and material behavior. The flowchart in Fig. 2-1 describes the design procedure outlined in the Eurocode performance-based codes [8].

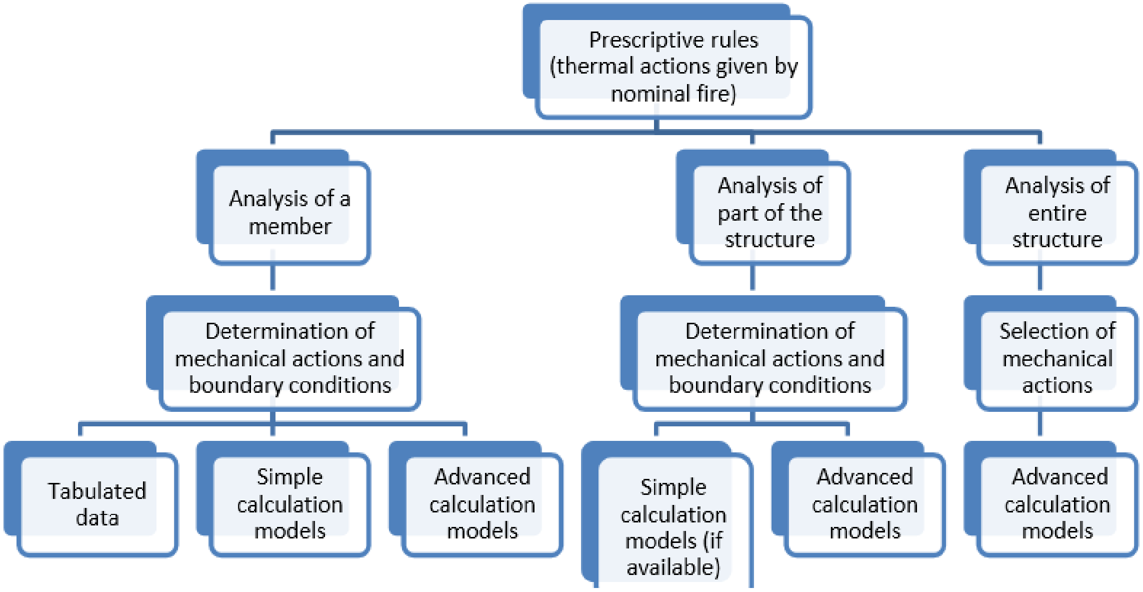


Fig 2-1:Design procedure according to the euro code prescriptive codes [8]

The Eurocode [8] also includes prescriptive design recommendations, as shown in Fig. 2-1. The prescriptive approach uses nominal fires to generate thermal actions, and the rest of the analysis is similar to the performance-based approach. The standard temperature-time curve is described in Chapter 3. Figure 2-1 lays out clearly the different types of analysis expected in fire design, corresponding to the level of individual members, parts of the structure, and the entire structure. For each type of analysis, the loads, boundary conditions and analytical models available are listed.

Euro code 1 part 1-2: “Actions on structures exposed to fire” [9] regulates calculation models for the determination of load effects and temperature. The fire scenario is treated as “exceptional action” and does not need to be superimposed with other load, Independent exceptional actions. For the fire design, different time- temperature curves are provided for the fire design, different time-temperature curves are provided for the determination of hot gas temperature.

Euro code 2 part1-2:- “Design of concrete structures- structural Fire Design” [10] deals with the design of concrete structures for the case of fire. It states the design values for material properties and combination factors for actions and treats methods of the passive and structural fire precautions; active fire protection methods are not included. For the determination of a sufficient fire rating, Euro code 2 [10] gives three alternatives of design methods:

- ✓ Tabulated data

Tabulated data gives minimum values for cross-sectional dimensions and the axial distances of the longitudinal reinforcement to the concrete surface. For beams, there is a distinction between simply supported and continuous beams. For statically determinate structures the axial distance of the reinforcement is determined such, that for the fire resistance time, the critical temperature in the steel bars is 500^0C. Reaching this critical temperature, the reinforcement reaches its yield stress if the load in the event of fire is less, the tabulated axial distance may be reduced.

- ✓ Simplified calculation methods

Euro code 2 provides several calculation methods to assess the ultimate load-bearing capacity of a heated cross section of the concrete members at any time for any fire exposure. These methods are based on a reduced cross- section consisting of cooler parts of the member. Therefore, the temperature profiles within the member and data of the temperature dependent changes of the material properties are needed. Simplified calculation method fire design for beam and slab is used when load is uniformly distributed and when design at normal temperature is depend on linear analysis.

- ✓ Advanced calculation methods

Advanced calculation methods can be used for the simulation of the structural behavior of single members, pars of the structure, or the entire structure. The advanced calculation methods provide a realistic analysis of the structures exposed to fire. They are based on fundamental physical behavior leading to a reliable approximation of the expected behavior under fire conditions. Thermal analysis shall be based on principles and assumptions of the theory of heat transfer and include the temperature dependent thermal properties of the materials. Mechanical analysis shall be based on the principles and assumptions of the theory of structural mechanics, taking in to account the changes of mechanical properties with temperature. Non-linear geometrical effects and the effects of thermally induced strains and stresses shall be considered, as well as all strains due to the temperature, mechanical properties of concrete, reinforcing steel and structural steel when they are subjected to elevated temperatures.

Eurocode 4 [11]. Design of composite steel and concrete structures – Part 1-2: General rules - structural fire design Simple calculation models are given for slabs, beams and columns of steel-concrete composite construction under standard fire exposure. Columns are assumed to be heated all around, whereas beams supporting floors are heated from the three lower sides. For composite slabs and beams, the bending design resistance is governed by plastic theory (or ultimate strength), whereby the concrete contribution is modeled by the rectangular stress block and the tension reinforcement is at yield. Material properties are multiplied by a reduction factor that is a function of temperature. For composite beam-slab systems with full shear connection, Eurocode 4 Part 1.2 [11] method consists in obtaining the temperature distribution in the cross section exposed to a standard fire, dividing the section into slices of approximately the same temperature, calculating the plastic bending moment of each cross sectional slice, and summing them up. A protected composite slab is assumed to have fulfilled its load bearing function R if the temperature of the steel sheet is less than or equal to 350°C when heated from below by a standard fire.

In case of design by partial shear connection in a fire situation, the variation of longitudinal shear forces in function of the heating needs to be considered. For composite beams with no concrete encasement around the beam, the temperature of the stud connectors and of the concrete may be taken as 80 % and 40 % respectively of the temperature of the upper flange of the beam. If the beam is partially encased in concrete, it may be assumed that there is no reduction in the shear resistance of the connectors welded to the effective width of the upper flange. The limiting temperature approach can be used. Reflecting the lower heating rate of the shear connectors, EC4-1-2 specifies a higher limiting temperature for partial shear connections than for full shear connections [11].

Composite columns

EN4-1-2 gives a detailed fire design method for composite columns. Three approaches are presented: 1) tabulated data, 2) simple calculations, and 3) advanced calculations.

Design tables are available for a limited range of load ratios and steel sections, and steel columns of buckling length less than 4.5 m. Simple calculation methods are also limited to buckling lengths less than 4.5 m, but can be used for any section and any load ratio. Tabulated data are available for columns heated all around by a standard fire, with the same temperature distribution over their whole length. The tables account for the column load level, which is the ratio between the relevant design effect of actions in fire and the design resistance for ambient temperature.

Under “simple calculations” for columns, the design value of the plastic resistance for axial compression in fire is the sum of the contributions of the steel profile, the reinforcing bars and the concrete, with material properties reduced at elevated temperature. A complicated step by step approach is necessary, whereby, at each value of column strain, the plastic resistance and the Euler buckling load is calculated. The Euler buckling load is evaluated using the tangent modulus at the appropriate column strain and temperature. When the plastic resistance equals the Euler buckling load, that load is the design compressive strength of the composite column.

Advanced calculation methods are based on fundamental physical behavior and provide a realistic analysis of structures exposed to fire. They account for mechanical actions, geometrical imperfections, thermal actions, temperature-dependent material properties, geometric non-linear effects and nonlinear material properties, including the effects of unloading. The influence of moisture migration on the thermal response of the concrete and the fire insulation may be neglected [11].

2.3.2. British standard code BS 8110-2:1985

Fire resistance of element of structure or whole structure is to be determined from one of three methods.

- ✓ Tabulated data:-fire resistance of structure can be determined from guideline given for the construction by research establishment and published
- ✓ Fire test:- direct application result of fire resistance test of element of structure.
- ✓ Fire engineering calculation :- calculating fire resistance of structure. Not applicable for wall and column.

2.3.3. ACI216.1-07/TMS 0216-07

Code requirements for determining the fire resistance of concrete and masonry assemblies. For concrete structures, fire resistance can be achieved by providing the appropriate depth of structural element and thickness of concrete cover depending on their function. ACI 216.1 and ACI 318 provide tables with various assemblies of building materials and finishes providing specific fire endurance.

Fire resistance rating is measured in terms of hours of exposure to the standard fire defined by ASTM E119 e.g., the fire rating for siliceous aggregate concrete with a minimum equivalent thickness of five inches (127mm) is two hours. Formulas are provided to calculate the equivalent thickness of non- uniform sections, such as ribbed or undulating panels, and section consisting of multiple layers. The code also gives minimum cover thickness to protect passive steel reinforcement against fire. Distinction is made between restrained and non- restrained members. Most cast-in-place or precast construction is restrained, whereas single spans and simply-supported end spends of multiple stories are unrestrained. Normal design procedures for concrete structures apply, with the material properties as functions of rapture [12].

2.3.4 New Zealand Building Regulations 1992, reprinted 10 April 2012

There are seven Acceptable Solutions (AS), listed in Table 2-1, that is deemed to comply with the New Zealand Building Code. As stated at the beginning of this chapter, the New Zealand Building Code shares with all codes the same principles on structural design for fire, namely, to limit risks to the individual and society, to directly exposed or neighboring property, and to the environment. Following is some of the Commentary attached to the AS, which go into greater detail.

Table 2-1: Acceptable Solutions (AS), New Zealand Building Code [8].

	Applies to	Risk group	Description
C/AS1	Single household units and small multi-unit dwellings	SH	Houses, townhouses and small multi-unit dwellings.
C/AS2	Non-institutional buildings for sleeping	SM	Permanent accommodation, e.g., apartments; transient accommodation, e.g., hotels, motels, hostels, backpackers; education accommodation.
C/AS3	Care or detention facilities	SI	Institutions, hospitals (excluding special facilities), residential care, resthomes, medical day treatment (using sedation), detention facilities (excluding prisons).
C/AS4	Public access and educational facilities	CA	Crowds, halls, recreation centers, public libraries (< 2.4 m storage height), cinemas, shops, personal services, schools, restaurants and cafes, early childhood centers.
C/AS5	Business, commercial and low-level storage buildings	WB	Offices, laboratories, workshops, manufacturing (excluding foamed plastics), factories, processing, cool stores (capable of < 3.0 m storage height) and other storage buildings capable of < 5.0 m storage height, light aircraft hangars.
C/AS6	High-level storage and other high-risk buildings	WS	Warehouses (capable of ≥ 5.0 m storage height), cools stores (capable of ≥ 3.0 m storage height), trading and bulk retail (≥ 3.0 m storage height).
C/AS7	Vehicle storage and parking buildings	VP	Vehicle parking – within a building or a separate building.

General principles External walls and roofs must be constructed to avoid vertical and horizontal fire spread.

The necessary protection may be achieved by one or more of:

a) Separation distance between buildings;

b) Using building elements that have a fire resistance rating (FRR);

c) Restricting the use of combustible surface finishes;

d) Limiting the areas of external walls and roofs that are close to a title boundary and that do not have an FRR;

e) Providing parapets, spandrels or aprons; and

f) Protecting the building with an automatic fire sprinkler system.

Fire resistance ratings

To prevent fire spread or structural collapse, the Acceptable Solutions require building elements to have FRRs. The level of FRR required depends on the risk group of the building. An FRR comprises three numbers, which give time values in minutes for structural adequacy, integrity and insulation:

a) Structural adequacy is usually provided by primary elements within a firecell. (A firecell is any space including a group of contiguous spaces on the same or different levels within a building, which is enclosed by any combination of fire separations, external walls, roofs, and floors.) Primary elements include building elements which are part of the structure, and those providing support to other elements with an FRR within the same or adjacent firecells. Examples are: columns, beams, floors and walls (which may also be fire separations).

b) Integrity is usually provided by secondary elements. Examples are fire separations, which are internal partitions and floors. Primary elements forming an integral part of a fire separation are also rated for integrity.

c) Insulation applies to fire separations and is required where the transmission of heat through the element may endanger occupants on the other side or cause fire to spread to other firecells or adjacent buildings. For example, insulation is necessary for fire separation between sleeping spaces, or for protecting a safe path.

General requirements for FRRs When applying FRRs to building elements such as walls and columns, it is necessary to consider the face of the element that will be exposed to fire. For example, if the required FRR is different on each side of the separation, the higher of the required ratings applies to both sides of the separation. In the case of floors, it is only required to rate the floor on the underside, as it is unusual for fires to burn through a floor and spread downwards. Columns, beams and other structural framing elements must either have the same FRR as the element they are attached to, or be designed so that, if they do collapse during a fire, this would not cause the collapse of the fire rated element. [8]

Stability of building elements having an FRR

Vertical stability

For building elements required to have an FRR:

a) Primary elements in a vertical orientation (e.g., walls and columns) shall be rated for structural adequacy under the design dead and live loads and any additional loads caused by the fire.

b) Primary elements in a horizontal orientation (e.g., floors and beams) shall be supported by primary elements with at least an equivalent structural adequacy rating.

Horizontal stability

Building elements required to have an FRR shall**:**

a) Be cantilevered from a structural base having an equal or greater FRR.

b) Be supported within the fire cell by other building elements having an equal or greater FRR.

c) Be supported by primary elements outside the fire cell.

2.4. Material behavior at elevated temperature

Concrete has excellent fire resistance properties and maintains its integrity and strength in very high temperatures. The thermal properties of concrete depend upon the aggregate type used, due to chemical changes (crystal structure) in aggregate compounds.

Steel is arguably the most important structural material in modern construction. Steel is used in construction as structural steel or as reinforcing steel for composite structure. Structural steel is considered considerably more vulnerable to fire than reinforcing steels which are encased in concrete which has good insulating properties and so protects reinforcing steels from significant losses in strength. Steels are very good conductors and tend to be used in thin sections. They are, therefore, liable to heat up very quickly in fires if not insulated. Due to these reasons most main structural steel members are required to be insulated in current design codes. The rate of heating depends upon the parameters of thermal conductivity, specific heat and density. The density of steel is approximately 7850 kg/m^3. The thermal conductivity of steel is approx. 54 W/mK at room temperature and reduces to about half this value at 800◦C. Figure 1 shows the variation of thermal conductivity with temperature. For simple calculations the specific heat of steel can be taken as approximately 600 J/kg◦K.

Concrete has excellent fire resistance properties and maintains its integrity and strength in very high temperatures. The thermal properties of concrete depend upon the aggregate type used, due to chemical changes (crystal structure) in aggregate compounds. Three common types are; Siliceous aggregates (gravel, granite, flint), calcareous aggregates (limestone) and lightweight aggregates made from sintered fuel ash (Lytag) and expanded clay. Siliceous aggregate concretes have a tendency to spall due to high thermal conductivity of such aggregate. Calcareous aggregate concretes are relatively more stable. Lightweight concrete (LWC) has the best thermal properties of all, i.e. less than half the thermal conductivity (0.8 W/m k) of normal weight concrete (NWC) and consequently loses its strength at a considerably lower rate. The thermal diffusivity of LWC is only slightly lower than NWC, so the extra fire resistance in LWC comes not so much from reduced temperatures, but from the stability of the light weight aggregates at high temperatures. The typical density of NWC is 2400 kg/m^3 and that of LWC is 1850 kg/m^3. NWC initially expands with rise of temperature but progressive loss of moisture from the cement paste causes it to shrink and helps to offset thermal expansion of aggregate. Heat is used up in drying and thus reducing further the rate of temperature rise of the concrete surface, which is low to start with due to poor conductivity. The loss of strength due to dehydration is quite often confined to the surface layers [13].

The behavior of concrete in fire is not easily defined or modeled. Concrete is far from being a homogenous material, consisting of cement, aggregate, sand, steel (or other) reinforcement and each of these components have a different reaction to thermal exposure in itself. Furthermore, a member exposed to fire, experiences steep thermal gradients over its cross-section. This is mainly a consequence of the shape of concrete sections and their thermal emissivity, more than the thermal conductivity as most people think [14].

2.5 Effect of fire on the structural member

Fire action on concrete structure can be regarded as a thermal action imposing temperature gradient throughout the structural elements. These temperature gradient have two main effects on the behavior of the structure: first they increase thermal expansions of the material which in the case of restraint structure it may lead to formation of restraint forces able to cause an anticipated collapse and secondly the temperature has a deteriorating influence in concrete and reinforcement properties, meaning that as temperature is reached higher the material load bearing capacity decrease.

Firstly, the materials characteristics of the members are modified when the temperature rises. The strength as well as the stiffness of both the concrete and the steel is reduced.in facts, even the whole

Stress-strain diagram is modified .the thermal properties as thermal conductivity and specific heat are also changed within change in temperature. However, these changes are not particularly relevant for the reinforcement since its amount is generally too low to affect the overall temperature distribution. All these effects can be seen in section where the variation of the material properties of concrete and steel with temperature are given in accordance with the Eurocode. Not directly covered by the Eurocode is the bond strength between the concrete and steel, which also reduces with increase in temperature [10].

2.5.1 Deterioration of the mechanical properties of concrete and steel

Concrete is a complex multiphase composite material, i.e., a kind of man-made stone created by mixing cement, aggregates and water. The sands, stones and crystals in cement paste and un hydrated cement grains compose the elastic skeleton of concrete to sustain external loads and fire. The propagation of micro-cracks greatly influences the mechanical properties of concrete. Because it takes several years for cement paste to harden, the strength and deformation of concrete will vary with time. Furthermore, the deformation will gradually increase with time if the concrete is subjected to sustained loads [15]. When subjected to high temperature, concrete under goes on a complex process of physical and chemical transformations. Some of these changes are reversible and other non-reversible upon cooling, meaning that concrete properties shall not remain the same after and before fire [16].The effect of fire (elevated temperature) on steel is characterized by a significant loss both in stiffness and in strength. Because of this, an important feature related to the resistance of composite structure subjected to fire, is the presence of a sufficient concrete layer providing cover to the reinforcement, in order to slow down the heating process in the steel rebar. When the temperature in reinforcement reaches 700^{o}C, its load-bearing capacity may be reduced by 20% 0f the ambient condition value [17].

2.5.2. Spalling

In addition to thermal, mechanical, and deformation properties, another property that has a significant influence on the fire performance of a concrete structural member is spalling [18]. This property is unique to concrete and can be a governing factor in determining the fire resistance of an RC structural member [19]. Spalling is defined as the breaking up of layers (pieces) of concrete from the surface of a concrete member when it is exposed to high and rapidly rising temperatures such as those encountered in fires. The spalling can occur soon after exposure to rapid heating and can be accompanied by violent explosions or it may happen during later stages of fire when concrete has become so weak after heating such that, when cracks develop, pieces of concrete fall off from the surface of concrete member. The consequences are limited as long as the extent of damage is small, but extensive spalling may lead to early loss of stability and integrity. Further, spalling exposes deeper layers of concrete to fire temperatures, thereby increasing the rate of transmission of heat to the inner layers of the member, including the reinforcement bar and structural steel. When the reinforcement bar and structural steel is directly exposed to fire, the temperatures in the reinforcement bar and structural steel rise at a very high rate leading to a faster decrease in strength (capacity) of the structural member. The loss of strength in the reinforcement, combined with the loss of concrete due to spalling, significantly decreases the fire resistance of a structural member [20, 21].

Spalling is defined as the breaking of layers (pieces) of concrete from the surface of the concrete elements when it is exposed to high and rapidly rising temperatures. The spalling can occurs soon after exposure to heat and can be accompanied by violent explosions, or it may happen when concrete has become so weak after heating that, when cracking develops, pieces fall off the surface. The consequences may be limited as long as the extent of the damage is small, but extensive spalling may lead to early loss of stability and integrity due to exposed reinforcement and penetration of partitions. The extent of spalling is influenced by fire intensity, load intensity, strength and porosity of concrete mix, density, aggregate type, and internal moisture content of the concrete. Significant spalling can occur if the concrete has high moisture contents and is exposed to a rapid growth fire [22].

2.6 Design equation for comparing fire severity with fire resistance

The fundamental step is designing structures for fire safety is to verify that the fire resistance of the structure for each part of the structure) is greater than the severity of the fire to which the structure is fire resistance ≥ fire severity

Fire resistance is a measurement of the ability of the structure to resist collapse, fire spread, or other failure during exposure to a fire of specified severity.

Fire severity is a measurement of the destructive impact of a fire, or a measurement of the force or temperature that could cause collapse or other failure as a result of the fire exposed. This verification required that:

As shown in table, there are three alternative methods of comparing fire severity with fire resistance. The verification may be in the time domain, the temperature domain or the strength domain using different units, which can be confusing if not understood clearly. The first two domain are based on the fire resistance rating (FRR), which is time, to failure under standard fire condition, expressed indifferent units but giving the same result. The third domain (strength) is most often used with realistic fires where it has to be shown that the structure will not fail at any point during the full process of fire development and decay.

Table 2-2: Three alternative methods of comparing fire severity with fire resistance

Domain	Units	Fire resistance ≥ Fire severity
Time	Minutes or Hours	Time to failure(FRR) ≥fire duration as calculated or specified by code
Temperature	^{o}C	Temperature to cause failure ≥maximum temperature reached during the fire
Strength	kN or kN.m	Load capacity(strength/stability) at elevated temperature ≥applied load during the fire

2.7 Fire modeling as temperature

Nominal curves are idealized simplified fires represented by a temperature-time relation. Precisely, they are denominated this manner because they have no dependence neither on the fire load density nor the compartment boundary conditions. These curves were initially developed for fire resistance furnace tests for the assessment and classification of structural members and materials. Although the fire resistance time determined by means of these tests does not represent the real time that the structural element can resist until collapse, it serves as a standard pattern to compare the effectiveness of different structural solutions. Figure 2-2 displays the different types of fire curves [23].

The time-temperature curve used in fire resistance tests is called the standard fire. Several models of time-temperature relationship are available for the simulation of fire for design purpose: the standard time temperature curve from ASTM E119 and ISO 834 are compared for in fig .they are seen to be rather similar all other international fire resistance test standards specify similar time –temperature curves.

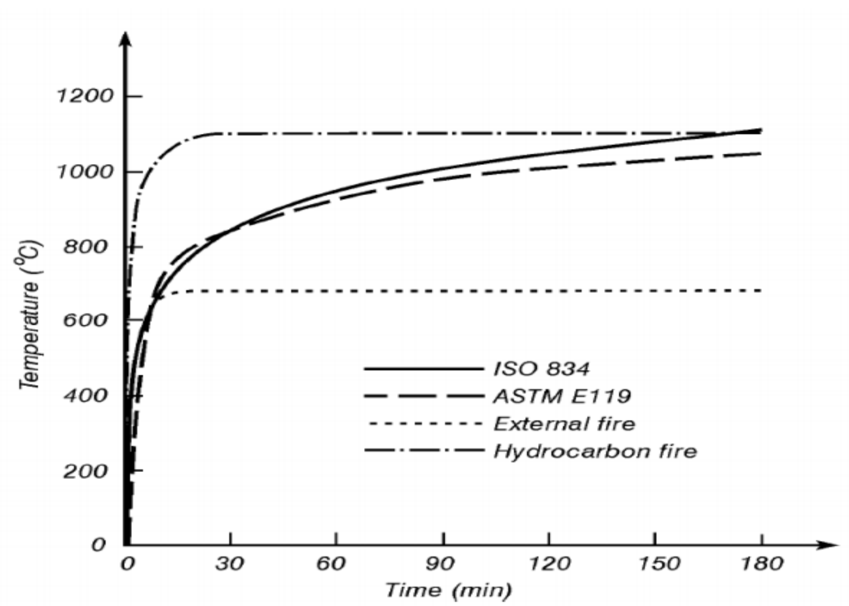


Fig 2-2: Time-temperature standard curve for different fire model [23]

The best known and most widely used is the standard ISO 834 fire curve [23] which represents a fully developed fire and assumes that the temperature in a fire compartment is uniform and that it increases indefinitely according to a logarithmic relationship with time, thus not having descending branch. Despite its limitations, this nominal standard fire curve has been incorporated into a wide number of design codes as a basis for their prescriptive methods and, by force, the most usual performance based design (PBD) approaches have been also developed based on the results and observations from standard fire tests [24].

The ASTM E119 curve is defined by a number of discrete points, which are shown in table 3 along with the corresponding ISO 834 temperature [23]. Several equations approximating the ASTM E119 curve are given by [25]. The simplest of both given the temperature T (^{o} C) as. A time-temperature curve Figure 2-2 is defined and used in a furnace to heat the element to be tested, which is also loaded to the appropriate load condition specified under nationally recognized structural design criteria. A close approximation of the ASTM E119 curve is provided by [14]. The ISO 834 Standard temperature-time curve from fig.2-2 which is very close to ASTM E119:

$$T=750(1- e^{-3.79553}\sqrt{th}) + 170.41 \sqrt{th} +20 \qquad \text{2.1}$$

Where T = temperature ℃ and t_h = time in hours.

Table 2-3: ASTM E119 AND ISO 834 Time-Temperature curve

time	ASTM E119 TEMPRATURE (^{o}C)	ISO - 834 TEMPRATURE (^{o}C)
0	20	20
5	538	576
10	704	678
30	834	842
60	927	945
120	1010	1049
240	1093	1153
480	1260	1257

Fire design curves

Fire design is rather complex as it is influenced by an infinite amount of different phenomena and parameters. For instance there will be a difference if the fire is in a closed room or in outside conditions, due to the presence of wind, humidity, etc. For a structural analysis it is of course necessary that these different fires can be expressed analytically. This is done according to Eurocode1[23]. Three different types of standard curves are suggested: the standard temperature-time curve, the external fire curve and the hydrocarbon fire curve. The equations shown in this section are extracted from Eurocode 1 [26]. The time (t) which appears in this equation is expressed in minutes.

1. Standard temperature-time curve

The gas temperature in the compartment of the fire (T) in function of time is given (in °C) by:

The ISO-834 fire is the basis of most fire resistance tests and is defined according to the following equation

$$T = 345 * \log_{10}(8t + 1) + 20 \quad \text{.......2.2}$$

Where t is the time (minute)

For such a standard fire the convection coefficient (αc) is taken equal to 25 W/(m²K). This corresponds to the typical convection coefficient for air.

2. Hydrocarbon fire curve

This fire curve is used in compartments where there is a risk that the fire can be increased by flammable vapors or liquids. The temperature in these compartments will increase much faster than in normal fire conditions. The gas temperature in the compartment (Θg) in function of time is given (in °C) by:

The hydrocarbon fire curve according to EC1 should be used, where the structural member is engulfed in flames from a large pool fire. The hydrocarbon fire curve is defined as follows:

Hydrocarbon fire curve:

$$T = 1080 * (1 - 0.325e^{-0.167t} - 0.675e^{-2,5t}) + 20 \quad \text{.......2.3}$$

Where t is the time (minute)

Structural members located outside a burning compartment will be exposed to lower temperature than the members inside a compartment will be unless they are engulfed in flames.

3. External fire curve

The external fire curve is used as a nominal temperature-time curve for elements which are not directly subjected to the fire. This can be a wall which is located beneath a fire compartment. The gas temperature near the member (T) in function of time is given (in °C) by:

External fire curve;

$$T = 660 * (1 - 0.687e^{-0.32t} - 0.313e^{-3.8t}) + 20 \quad \ldots\ldots 2.4$$

The convection coefficient (α_c) is taken equal to 50 W/(m²K). This higher convection coefficient is due to the presence of the flammables.

While the standard fire curve represents a typical building fire based upon a cellulosic fire, the hydrocarbon fire curve represents fuel fires with an initial rapid temperature rise which can be originated in offshores and petrochemical industries. The external fire curve is meant to be used for the evaluation of a fire affecting the outer surface of separating outside walls (i.e. facades). These members may result affected by the plume of smoke and flames going through the facade openings coming from an adjacent compartment or from a cubicle situated below the external member [24].

2.8 The concept of structural fire advanced calculation methods

The Eurocode 2 [5] states that the advanced calculation methods for structural fire analysis shall provide a realistic analysis of structures subjected to fire, based on fundamental physical behavior leading to the a realistic approximation of the expected behavior of the relevant structural component exposed to fire. These methods are able to be applied to the whole structure, part of the structure or to single elements analysis.

The advanced calculation methods also called thermo-mechanical include two calculation steps; the thermal analysis dedicated to the evaluation of temperature evolution within structural elements, and the mechanical analysis considering the effect of temperature .the thermal response analysis shall be based on the acknowledged principles and the material temperature dependent thermal properties. The mechanical response analysis shall be based on the acknowledged principles and assumption of the theory of structural mechanics, considering the effect of the mechanical properties deterioration with temperature [5].

Reinforcement steel modeling

Steel is the homogeneous material and the stress-strain behavior can be assumed to be identical in tension and compression. Steel bar in reinforced concrete members are normally long and relatively slender and therefore they can be generally assumed to be capable of transmitting axial force only [22].

2.9 The concept of thermal analysis

Thermal analysis is the first step analysis done based on fundamental heat transfer principles to generate temperature profile with in the cross section which is known as heat transfer analysis. Heat transfer analysis is used to obtain the transient temperature field of structural composite column exposed to fire. The three mode of heat transfer, namely convection, radiation and conduction should be appropriate considered.

The thermal analysis is an essential component for calculating fire resistance because the load capacity of a structural member/assembly depends on its internal temperature. When a column is exposed to fire, a temperature gradient occurs within the column. The temperature distribution in the cross section of the elements exposed to fire can be calculated using the Theory of Heat Transfer. The governing differential equation for the conductive heat transfer is [27].

$$\frac{\partial}{\partial x}(\lambda x\frac{\partial T}{\partial x})+\frac{\partial}{\partial y}(\lambda y\frac{\partial T}{\partial y})+\frac{\partial}{\partial z}(\lambda z\frac{\partial T}{\partial z})=\rho c\frac{\partial T}{\partial t} \quad \ldots\ldots\ldots\ldots\ldots\ldots..2.5$$

where:

λ - is the thermal conductivity (temperature dependent)

ρ - is the density of material (temperature dependent)

c - is the specific heat (temperature dependent).

Fire boundary conditions can be modeled in terms of both convective and radiative heat transfer mechanisms. The heat flow caused by convection is:

$$q_c = h_c * (T_m - T_f) \quad \text{...2.6}$$

where:

h_c- is the coefficient of convection (for surface exposed to fire h_c= 25 W/m^2 K, and for an unexposed surface h_c = 9 W/m^2 K). These values are recommended in Eurocode 1 [1]

T_m - is the temperature at the boundary of the element.

T_f - is the temperature of fluid around the element.

The heat flow caused by radiation is:

$$q_r = \Phi \varepsilon \sigma_c ({T_{m,a}}^4 - {T_{f,a}}^4) = h_r (T_m - T_f) \quad \text{...2.7}$$

$$h_r = \Phi \varepsilon \sigma_c ({T_{m,a}}^2 - {T_{f,a}}^2)(T_{m,a} - T_{f,a}) \quad \text{...2.8}$$

where:

h_r =is the coefficient of radiation (temperature dependent)

Φ = is the radiation view factor (recommended: V = 0)

ε = is the resultant coefficient of emission

σ_c- is the Stefan-Boltzmann constant.`

$T_{m,a}$- is the absolute temperature of the surface.

$T_{f,a}$- is the absolute gas temperature.

Using a typical Galerkin finite element approach, Equation 2.9 assumes the form

$$\int_V N[\lambda x \frac{\partial T}{\partial X} + \lambda y \frac{\partial T}{\partial Y} + \lambda z \frac{\partial T}{\partial \overline{Z}} - \rho C \frac{\partial T}{\partial t}]dV = 0 \quad \text{...2.9}$$

where the approximation field function is expressed in terms of the interpolation function as:

$$T = N * T_e \quad \text{...2.10}$$

The problem is completely solved through equation 2.10, by applying initial and boundary conditions. The presented heat transfer equation is a part of the computer program ABAQUS [28] that was used in this study. The program is based on the finite element method and the following assumptions are made: fire can be modeled by a single valued gas temperature history: ISO 834 or other fire model; no contact resistance to heat transmission occurs at the interface between the reinforcing steel and concrete; fire boundary conditions can be modeled in terms of both convective and radiating heat transfer mechanisms; temperature dependent material. Properties are known and are recommended in Eurocode 4 [11], while cracks appear, or same parts of the element crush, heat penetrates in the cross section easier, which is neglected in this study. It is assumed that the changes in the element internal energy, caused by changes in the temperature field of the element cross section, do not influence the work of the internal forces and in each time step the heat flow analysis is separable and parallel with the structural analysis.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

As it has been described in chapter one, the goal of this research is finite element analysis of encased concrete I-section steel column exposed to fire. This chapter is devoted to describing the finite element method used in this study. It focused on modeling of material properties at elevated temperature for both thermal and mechanical properties. The procedure used in this study is summarized in figure 3-1 shows.

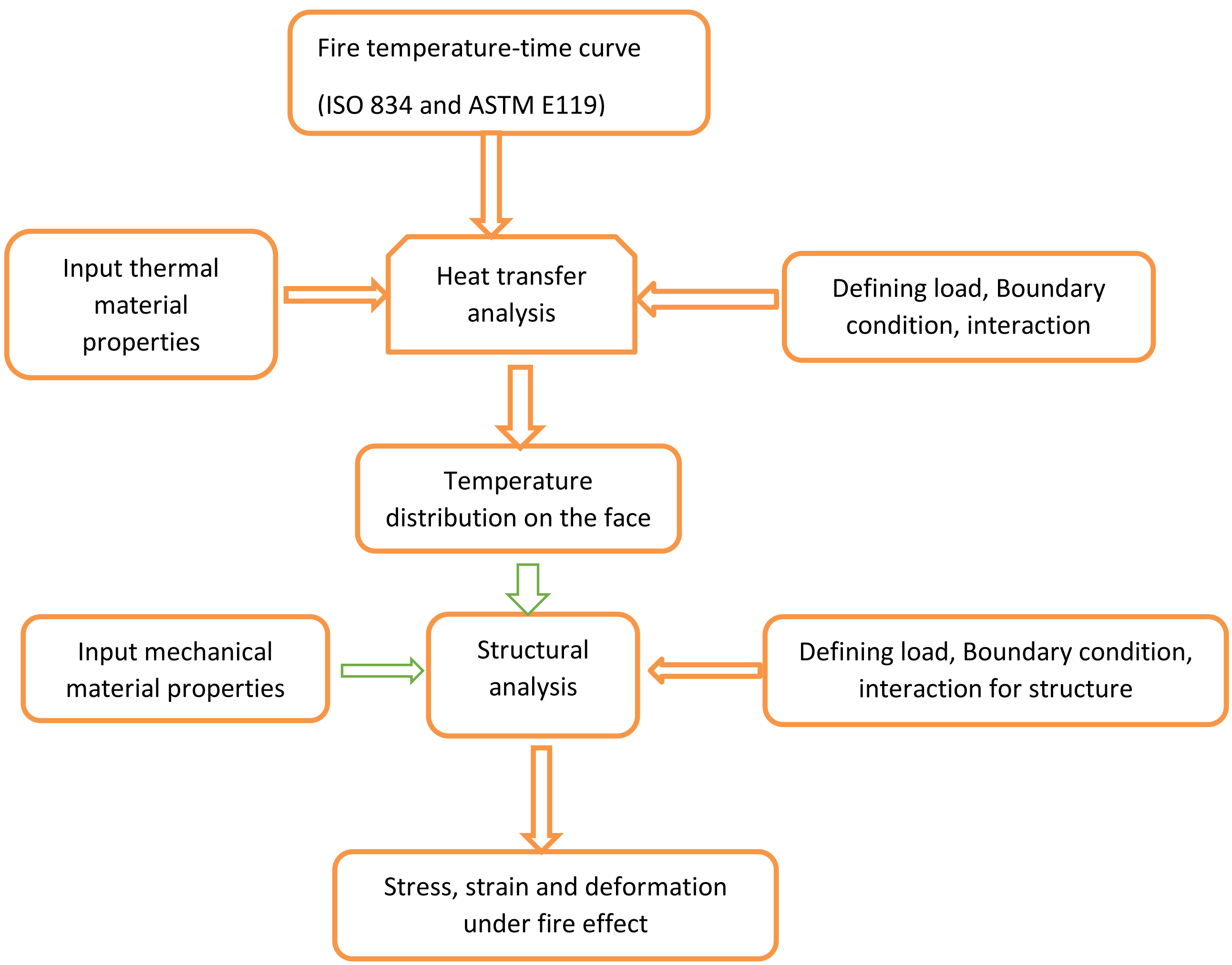


Fig 3-1:Overall procedure Finite Element modeling

3.2 Study setting

In this study the first step is to analysis the thermal (heat transfer) obtained the nodal temperature (temperature-time curve) for a certain node at the concrete cross section for this case, have taken the same cross-section of concrete.

The second step is to identify the effect of fire on the composite column in different size of I-section steel and the same square cross-section concrete materials has employed.so the result from the analysis has to be drawn by the table and figure in chapter four..

3.3 Exploratory Research

This study was analyzed in the way that important and exact information was gathered from study design methodologies. The study has been conducted by using analytical method at a theoretical level by using concrete encased I-section steel column under fire. The analysis on the findings of the stress, strain and deformation under fire effect column member models by using the ABAQUS Software. Therefore, the objective of the research had been achieved in accordance with the methodologies outlined below.

- To investigate the Finite element analysis of concrete encased I-section steel exposed to fire.
- To identify the effect of fire on thermal properties of concrete at different time exposure.
- To evaluate structural behavior of concrete encased steel I-section column expose to fire.

3.4 Study Variables

The study used both dependent and independent variables so as to assess in this research which displays the effect of fire on concrete encased I-section steel column.

3.4.1 Dependent variable

In this case, the dependent variable which was the output and its result depend on the independent variables which directly related to the general objectives. Thus the dependent variables of the study are stress and deformation.

3.4.2. Independent variables

These independent variables were more related with specific objectives but each specific objective was affecting one another. The independent variables which are measured and manipulated to determine its relationship to observed phenomena were selected and listed below.

- fire duration
- Temperature change
- Steel ratio

3.5 Study Procedures

The procedures include:

1. Heat transfer analysis of the concrete column for different time exposure.
2. Analysis of the concrete encased steel I-section column for different steel section and fire duration.

Finally, conclusions and recommendations were drawn following the results of the parametric study.

3.6. Data Collection Procedure

The data collection processes have been done from the output of ISO-standard temperature-time curve. The temperature-time curve analysis was carried out in ABAQUS software using the Non-Linear transient heat transfer analysis for composite column which is the same cross-section of concrete in different steel size has been employed. Then the data which was collected from each case was taken from the Eurocode.

3.7. Data Analysis and Presentation

After the data has been properly collected from each case; it was processed and analyzed those data using data sheet, tables, charts and graphs. And finally presenting and interpreting the outputs was formulated. Analytical formulas and graphical charts were developed.

3.8. Ethical Consideration

While doing anything concerned research without any harm and oppressed of the community in the study setting and area, rather with great respects.

3.9. Data Quality Assurance

The quality of data collection was assured without any hesitations because the researcher has been following secondary source of data collection which is simulated from the ABAQUS software. Therefore; the assurance of those data are highly recognized and those data are true.

3.10. Scope of the Research

The Scope has been limited by the following

Studying the effect of fire encased concrete I-section steel composite column considering the following parametrs:

- Studying the heat transfer of the concrete column.
- Studying the mechanical analysis of the composite column.
- The studying was made at the theoretical level.

3.11. Plan for Dissemination of Findings

Dissemination of findings is important so that results can be used to improve engineering and technological industries. After the research paper has been finished, the output is going to be disseminated in different ways like; final presentation, internal seminar inside Jimma Institute of Technology and also if it is possible the thesis will publish on journal articles, book chapters and other publications.

3.12. Material Properties and Analysis

3.12.1 Material properties at elevated temperatures

The thermal properties concern the characteristics which define the thermal response of the element. Material properties in case of a fire design are divided in mechanical and thermal properties. Mechanical properties are characteristics which define the inelastic behavior of materials when a load and temperature were applied. The material properties as a function of temperature as used by ABAQUS to simulate the non-linear temperature dependent material properties of both structural steel, reinforced bar and concrete. Different studies conducted over the past few decades have led to a dealing with all understanding of the thermal and mechanical properties of concrete, structural steel and reinforced bar at elevated temperature. The modeling of the behavior of concrete and steel in the present FE model is discussed in this section based on this information.

3.12.1.1 Steel thermal properties

This section describes the thermal properties of steel as used by ABAQUS taken from the Eurocode 3 [11].

Thermal conductivity (λ)

Thermal conductivity is the measure of how rapidly the given material will conduct heat. For steel; thermal conductivity is a function of both temperature and the composition of the steel. That means the thermal conductivity of steel assumed to be high enough to allow the assumption that normal size sections have a uniform temperature throughout the cross-section. The Eurocode 3 suggests the following linear approximation for thermal conductivity for most structural steel, as shown in Figure 3-2.

$\lambda = 54 - (0.0333 \times T)$ for $800\,^{o}C > T \geq 20\,^{o}C$ ………………….. 3.1

$\lambda = 27.3$ for $1200\,^{o}C > T \geq 800\,^{o}C$ …………………..3.2

Where T is the steel temperature

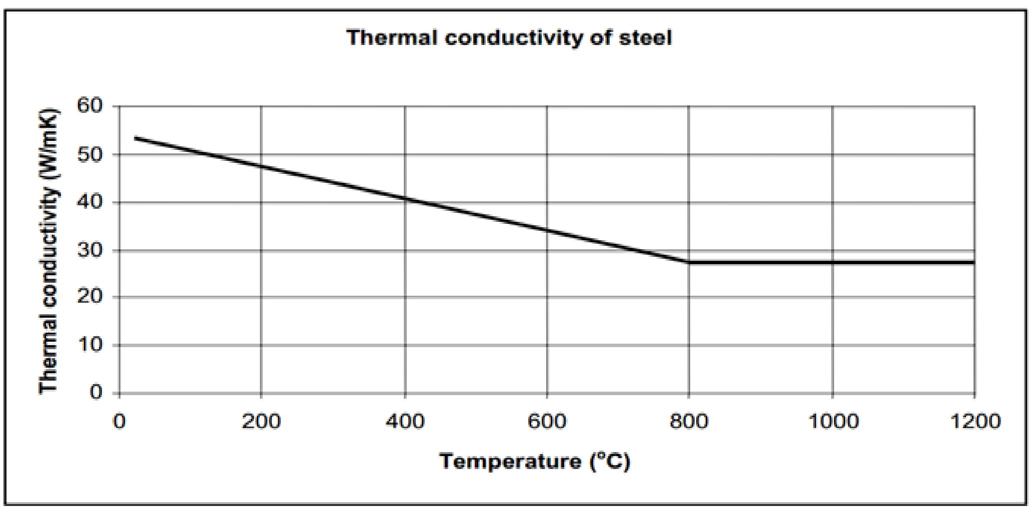


Fig 3-2: Thermal conductivity of steel as a function of temperature [29].

Steel density

The density of the steel is remaining essentially constant with temperature is assumed to be $7850 kg/m^3 k$.

Specific heat

Specific heat is the measure of the materials ability to absorb heat. For steel, specific heat is a function of temperature and is independent of the composition of steel. Specific heat of steel as the function of temperature is plotted in figure 3-3.

$C_p = 425 + 0.773\,T - 1.69\times10^{-3}\,T^2 + 2.22\times10^{-6}\,T^3$ for $600\,^oC > T \geq 20\,^oC$ …………3.3

$C_p = 666 + 13002/(738 - T)$ for $735\,^oC > T \geq 600\,^oC$ …………3.4

$C_p = 545 + 17820/(T - 731)$ for $900\,^oC > T \geq 735\,^oC$ ………… 3.5

$C_p = 650$ for $1200\,^oC > T \geq 900\,^oC$ 3.6

The sharp peak in the Eurocode 3 suggested specific heat equations of steel at 730 ^{o}C as seen in Figure 3-3, is due to a metallurgical change in the steel crystal structure.

Where T is steel temperature

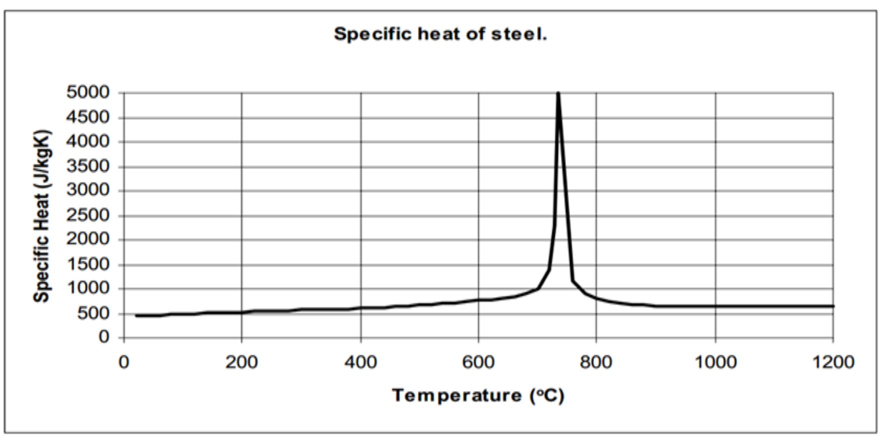


Fig 3-3: specific heat of steel as the function of temperature [29]

Thermal elongation

Thermal elongation is defined as the increase in member length divided by the member initial length; Δl/l. The thermal strain of heated steel is determine as equation 3.7,3.8,3.9 with reference to the initial length at 20 ^{o}C. ABAQUS software determines thermal elongation of steel using the following Eurocode3 equations and the respective graphical representation is presented in figure 3-4 below.

$\Delta l/l = 1.2 \times 10^{-5}\, T + 0.4 \times 10^{-8}\, T^{2} - 2.416 \times 10^{-4}$ For 750 ^{o}C > T ≥20 ^{o}C ………… 3.7

$\Delta l/l = 1.1 \times 10^{-2}$ For 860 ^{o}C > T ≥750 ^{o}C ………… 3.8

$\Delta l/l = 2 \times 10^{-5}\, T - 6.2 \times 10^{-3}$ For 1200 ^{o}C > T ≥860 ^{o}C …………..3.9

Where T is the steel temperature. These equations are shown graphically in Figure 3-4.

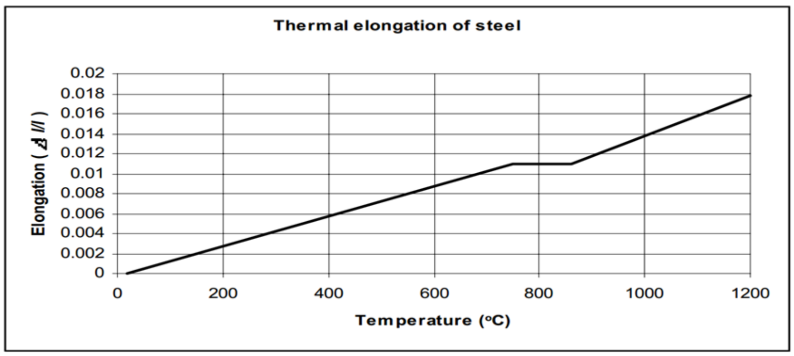


Fig 3-4: Thermal elongation of steel with temperature[29]

3.12.1.2 Concrete Thermal properties

This section summary the thermal properties of concrete assumed by ABAQUS software as recommended by the Eurocode 2 [10]. A siliceous aggregate concrete is assumed.

Thermal conductivity

Thermal conductivity is the ability of materials to conduct heat. It is defined as the ratio of the heat flux to temperature gradients. Thermal conductivity of concrete dependent upon the aggregate type and the temperature of the concrete. The following equation is the Eurocode2 [10] recommended thermal conductivity equation for siliceous aggregate, and is shown graphically in Figure 3-5.

$$\lambda c = 2 - \frac{0.24T}{120} + 0.012(\frac{T}{120})2(W/mK)$$ for 1200 ^{o}C > T ≥20 ^{o}C ……. ……..3.10

Where T is the temperature of the concrete.

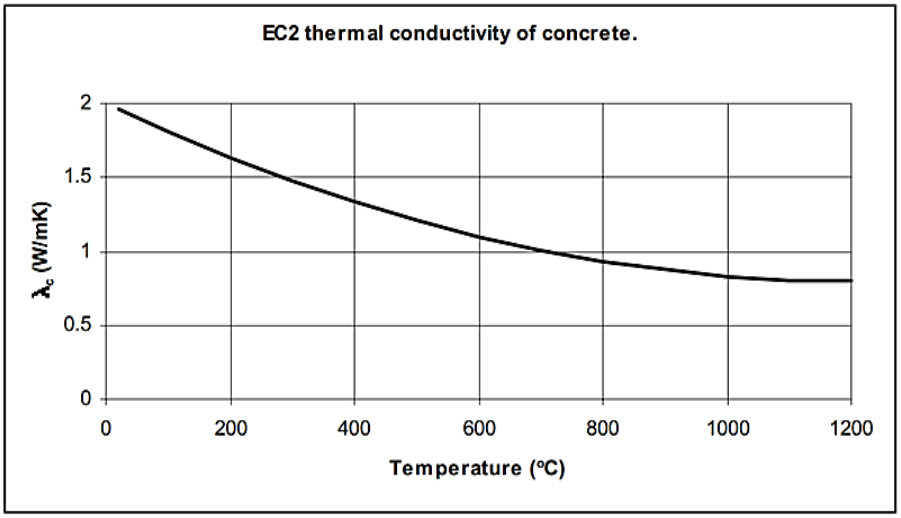


Fig 3-5: Thermal conductivity of concrete with temperature[29]

Specific heat

The specific heat of concrete varies mainly with the moisture content. The moisture within the concrete causes a peak between 100 °C and 200 °C due to the water being driven off. The Eurocode recommends the following relationship for calculation of concrete's specific heat.

$$Cp = 900 + \frac{80T}{120} - 4(\frac{T}{120})2(JkgK)$$ For 100 °C > T ≥20 °C, and; 1200 °C >T ≥200 °C …3.11

Where T is the temperature of the concrete.

However, as shown by Figure 3-6, there is a peak between 100 °C and 200 °C due to water being driven off. This peak must be included with the above equation in the temperature range of 100 °C to 200 °C.

C_p, peak= 1875 (JkgK) For 2% moisture by weight; 100 °C > T ≥20 °C ……………..3.12

C_c, peak= 2750 (JkgK) For 4% moisture by weight, 100 °C > T ≥20 °C ………………3.13

Where T is the temperature of the concrete.

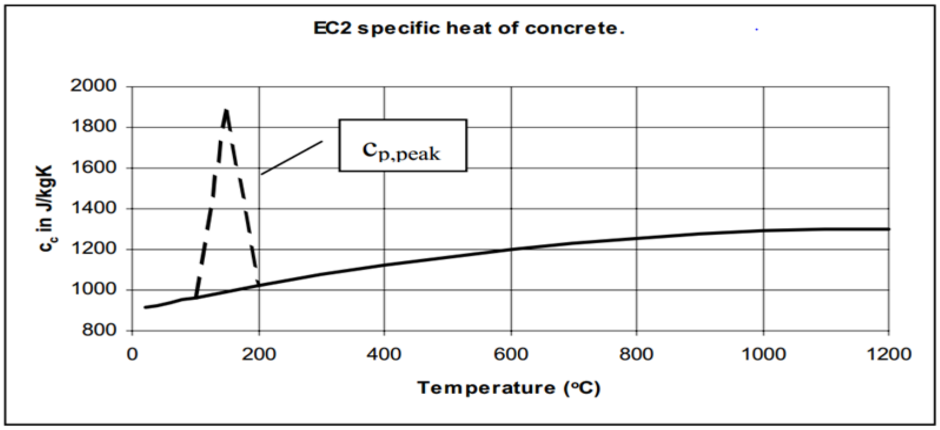


Fig 3-6: Specific heat of concrete with temperature[29]

Thermal elongation

Eurocode 3 [30] recommends the following equation for siliceous concrete. This thermal elongation and temperature relationship is non-linear until 700 °C, where it becomes constant. This equation is shown graphically in Figure 3-7.

$(\Delta l/l) = -1.8 \times 10\text{-}4 + (9.0 \times 10\text{-}6)\, T + (2.3 \times 10^{-11})\, T^3$ For 700 °C > T ≥20 °C …………3.14

$(\Delta l/l) = 14 \times 10^{-3}$ For 1200 °C > T ≥700 °C ……….3.15

Where T is the temperature of the concrete

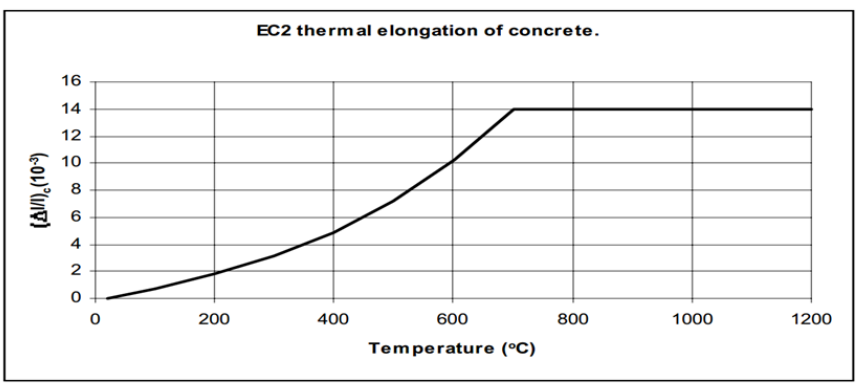


Fig 3-7: Thermal elongation of concrete with temperature[29]

3.12.2 Mechanical properties of concrete

At elevated temperature the mechanical behavior of concrete is complex, involving strong non linearity, different failure mechanism under compression and tension (crushing or cracking) and other temperature-time dependent effect such as thermal expansion and creep. Concrete time – dependent mechanical properties including compressive and tension strength, modulus of elasticity, Poisson's ratio and component of strain are discussed in this section.

3.12.2.1 Strain components

The strain components at any stress level for high temperature may be modeled using the superposition theory where by the total strain is considered to be the sum of various stain components.

$\varepsilon_{tot} = \varepsilon_{\sigma}(\bar{\sigma},\sigma,\theta) + \varepsilon_{th}(\theta) + \varepsilon_{tr,cr}(\sigma,\theta,t)$..3.16

Where ε_{tot}=total strain ε_{σ}=the stress-related strain ε_{th}=the thermal strain $\varepsilon_{tr,cr}$=is the transient creep strain often called load induced thermal strain, θ=is the temperature, t=is the time σ=stress $\bar{\sigma}$ =the stress history

3.12.2.2 Stress-related stress

The stress-related strain is a function of the applied stress and the temperature.it include the elastic and plastic components of strain.

3.12.2.3 Compressive strength of concrete

Compressive strength of concrete decreases with increasing of temperature. It can be seen that concrete with siliceous aggregates undergoes a rapid loss in strength at a temperature around 450^{o}C ,whereas for calcareous and lightweight concretes the strength reduction does not occurs until a temperature around 700^{o}C [31].

The strength-temperature relationship defined in Eurocode [20] for concretes with siliceous and calcareous aggregate is plotted in figure 3-8 and also described under stress-related strain on table 3-1.

The stress-strain behavior for concrete under compression at elevated temperatures is determined by two parameters: the compressive strength at a certain temperature $f_{c,\theta}$ and the corresponding strain $\varepsilon_{c1,\theta}$.The stress-strain distribution is shown in Figure 3-8. The stress of the first branch $\varepsilon \leq \varepsilon_{c1,\theta}$ is given by:

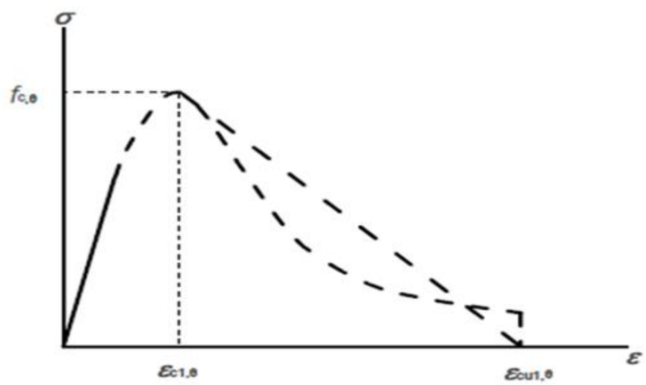


Fig 3-8:Stress-strain relationship of concrere in case of elevated temperatures[29]

$$\sigma(\theta) = \frac{3 * \varepsilon * f_{c,\theta}}{\varepsilon_{c1,\theta}(2 + (\frac{\varepsilon}{\varepsilon_{c1,\theta}})^3)} \quad ....3.17$$

Table 3-1: The stress-strain diagram at elevated temperature depending on the aggregate [29]

Concrete temp. θ	Siliceous aggregates			Calcareous aggregates		
	$f_{c,\theta} / f_{ck}$	$\varepsilon_{c1,\theta}$	$\varepsilon_{cu1,\theta}$	$f_{c,\theta} / f_{ck}$	$\varepsilon_{c1,\theta}$	$\varepsilon_{cu1,\theta}$
[°C]	[-]	[-]	[-]	[-]	[-]	[-]
1	2	3	4	5	6	7
20	1,00	0,0025	0,0200	1,00	0,0025	0,0200
100	1,00	0,0040	0,0225	1,00	0,0040	0,0225
200	0,95	0,0055	0,0250	0,97	0,0055	0,0250
300	0,85	0,0070	0,0275	0,91	0,0070	0,0275
400	0,75	0,0100	0,0300	0,85	0,0100	0,0300
500	0,60	0,0150	0,0325	0,74	0,0150	0,0325
600	0,45	0,0250	0,0350	0,60	0,0250	0,0350
700	0,30	0,0250	0,0375	0,43	0,0250	0,0375
800	0,15	0,0250	0,0400	0,27	0,0250	0,0400
900	0,08	0,0250	0,0425	0,15	0,0250	0,0425
1000	0,04	0,0250	0,0450	0,06	0,0250	0,0450
1100	0,01	0,0250	0,0475	0,02	0,0250	0,0475
1200	0,00	-	-	0,00	-	-

Once the comperessive strength is reached, a linear branch is assumed in the stress-strain diagram until the ultimate strain is reached.Values for the stress-strain diagram can be extracted from using the initial characteristic compressive strength.

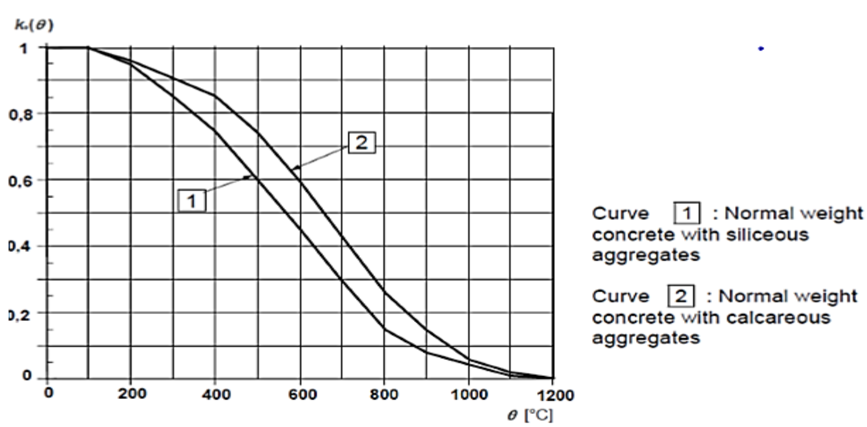


Fig 3-9: The reduction concrete comperesive strength with temperature[29]

3.12.2.4 Tensile strength of concrete

The tensile strength of concrete also decreases with increasing temperature. Compared to the compressive strength, the tensile strength shows a greater relative decrease and thus, is more responsive to the effects of temperature. The tensile strength is affected by the mix portions and significantly by the type of aggregate. The decrease in tensile strength of calcareous aggregate concrete is twice as high as for siliceous aggregate concrete at 500^{o}C [31].

Eurocode [20] recommends taking the tensile strength at zero as a conservative assumption. If it is necessary to take account of the tensile strength, as is mostly the case in the design of concrete elements the tensile strength of concrete can be neglected, but when it is chosen to take the tensile strength in to account. The following equation for strength reduction may be used

$$f_{ck,t}(\theta) = k_{ck,t}(\theta) * f_{ck,t} \quad \text{...3.18}$$

where $k_{ck,t}$ is defined as

$$k_{ck,t}(\theta) = 1.0 \text{ For } 20^o C \le \theta \le 100^o C \quad \text{...3.19}$$

$$k_{ck,t}(\theta) = 1.0 - 1.0(\theta - 100)/500 \quad \text{for} \quad 100^o C \le \theta \le 600^o C \quad \text{............................3.20}$$

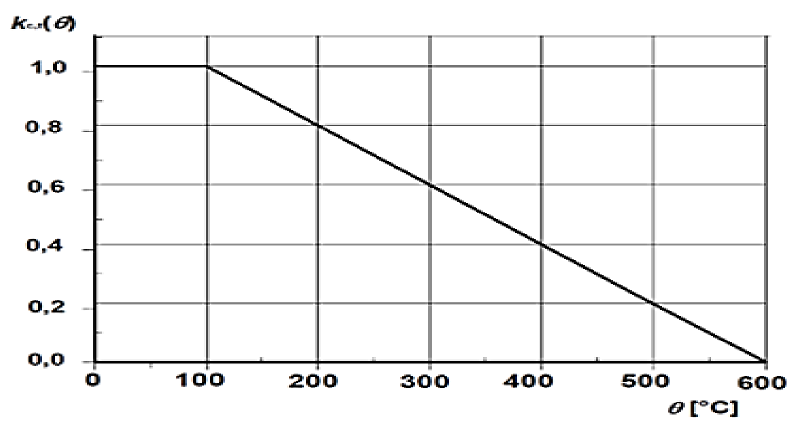


Fig 3-10: Coeffiecient in case of tensile force with temperature[29]

3.12.2.5 Thermal strain

Thermal strain is the free thermal expansion resulting from fire temperature.it is mainly influenced by the type and amount of aggregate. Thermal strain of unstressed specimens is caused by the elongation of concrete.

The Eurocode [26] the strength and deformation properties of uniaxial stressed concrete at elevated temperatures as seen in fig below.

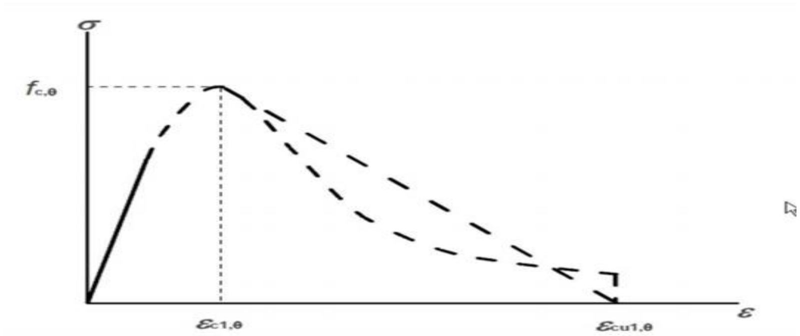


Fig 3-11: Stress-strain relationship of concrete according to EC2 [29]

$$\sigma(\theta) = \frac{3 * \varepsilon * f_{c,\theta}}{\varepsilon_{c1,\theta}(2 + (\frac{\varepsilon}{\varepsilon_{c1,\theta}})^3)} \quad \text{for } \varepsilon \le \varepsilon_{c1,\theta} \text{ ....3.21}$$

$f_{c,\theta,}\varepsilon_{c1,\theta} and \varepsilon_{cu,\theta}$ Taken from the above figure 3-11 Values for the main parameters of stress-strain curves of normal weight concrete with siliceous aggregates [17].

When considering natural fires, thus including the cooling phase, the stress-strain model presented in figure 3.11 should be modified and possible strength recovery should not be taken into account [29].

3.12.2.6 Transient strain /creep

Transient strain develops under stress when the temperature increases. It accounts for the effect of temperature change, which will produce instability of the material and activate the reactions responsible for the decomposition [32].Transient creep is seated in the cement paste and restrained by the aggregates. Transient creep only occurs during first heating and is irrecoverable [33].Transient creep cannot be evaluated from tests and therefore has to be calculated according to equation 3.21.

$$\varepsilon_{tr} = \varepsilon - \varepsilon_{th} - \varepsilon_{\sigma} - \varepsilon_{cr} \text{ ……………..3.21}$$

3.12.2.7 Modulus of Elasticity of Concrete

Modulus of elasticity is the ratio of stress to strain. Because the stress–strain relationship of concrete under axial compression is a curve, the modulus of elasticity is a variable. It can be depicted in three ways, i.e., initial modulus of elasticity, secant modulus, and tangent modulus, whose values are tanα0, tanα1 and tanα as shown in Figure 3-12 respectively.

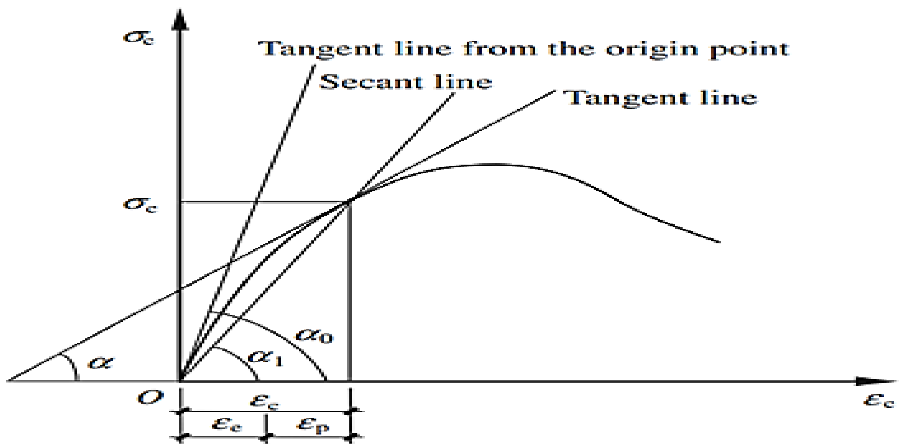


Fig 3-12 depiction of concrete elastic modulus[29]

The modulus of elasticity of concrete generally means the initial modulus of elasticity, denoted by Ec. Based on the regression analysis of experimental data, the modulus of elasticity has a relation with cube strength as follows:

$$Ec = \frac{10}{2.2 + \frac{34.7}{\text{fcu}}} (N/mm2) \quad \text{..3.22}$$

During heating the modulus of elasticity decrease. This is due to the breakage of bonds in the microstructure of cement paste as well as to the increase of short-time creep at increasing temperature [34].

$$E_{cT} = 1.0 * E_c \quad \text{for } 20^{o}\text{C} \le \Theta \le 100^{o}\text{C} \text{..3.23}$$

$$E_{cT} = (1.015 - 0.00154\theta + 2*10^{-7}\theta^2 + 3*10^{-10}\theta^3)E_c \quad \text{for } 100^{o}C \le \theta \le 1000^{o}C \text{ ....3.24}$$

$$E_{cT} = 0 \quad \text{for } \theta \ge 1000^{o}C \quad \text{...3.25}$$

3.12.2.8 Poisson's ratio

Based on the test data of marechal [35] and a model proposed by Elghazouli and Izzuddin [36], the Poisson's ratio of concrete is taken as 0.2 at 20^{o}C and to remain constant until 150^{o}C.beyond the latter temperature, the Poisson's ratio is assumed to decrease linearly to 0.1 at 400^{o}C and to further decrease linearly down to zero at 1200^{o}C .In this research constant Poisson's ratio 0.2 has been used.

3.12.3 Material properties for steel at elevated temperatures

The method to deal with changing steel characteristics is given in Eurocode 3 part 1-2. A summary is made in this section.

3.12.3.1 Steel yield stress, proportionality limit and elastic modulus

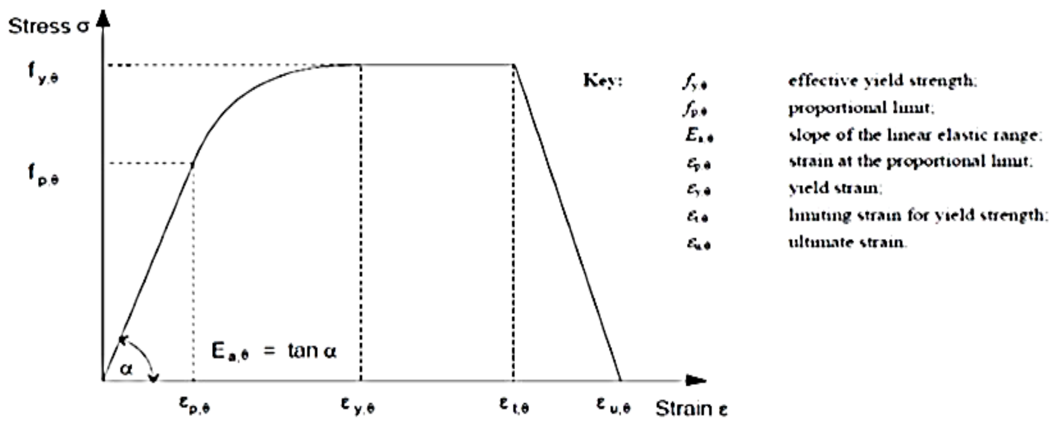


Fig 3-13: Stress-strain diagram for steel at elevated temperatures[29]

The simplified stress-strain behavior of steel at elevated temperatures can be expressed as a combination of different analytical expression. As long as the stress does not reach the proportional limit, the relation between steel stress and steel strain can be expressed by the typical elastic relationship:

$$\sigma_a = E_{a,\theta} * \varepsilon_a \qquad \text{..3.26}$$

Reaching the proportional limit the stress-strain behavior becomes non-linear. This does not correspond with yielding of the steel; the stress-strain relationship is given by:

$$\sigma_a = f_{p,\theta} - c + \frac{b}{a} * \sqrt{a^2 - (\varepsilon_{y,\theta} - \varepsilon_a)^2} \quad \text{......3.27}$$

$$c = \frac{(f_{y,\theta} - f_{p,\theta})^2}{(\varepsilon_{y,\theta} - \varepsilon_{p,\theta}) * E_{a,\theta} - 2 * (f_{y,\theta} - f_{p.\theta})} \quad \text{......3.28}$$

$$a = \sqrt{(\varepsilon_{y,\theta} - \varepsilon_{p,\theta}) * (\varepsilon_{y,\theta} - \varepsilon_{p,\theta} + c/E_{a,\theta}} \quad \text{......3.29}$$

$$b = \sqrt{c * (\varepsilon_{y,\theta} - \varepsilon_{p,\theta}) * E_{a,\theta} + c^2} \quad \text{......3.30}$$

Once the yield stress is reached ($f_{y,\theta}$),the strain will increase while the stress remains constant until the limiting strain for yielding ($\varepsilon_{t,\theta}$) is reached. Beyond this the steel will start failing until the ultimate strain ($\varepsilon_{u,\theta}$) is reached. The stress-strain behavior is assumed to be linear between the limit and ultimate strain. The values for the yield strain, ultimate strain and limiting strain for yielding are fixed and shown in table 3-3. The strain at the proportional from its limit can be obtained from its definition. The proportional limit can be obtained as the last point on the stress-strain diagram, where its behavior is proportional.

$$\varepsilon_{p,\theta} = \frac{f_{p,\theta}}{E_{a,\theta}} \quad \text{......3.31}$$

Table 3-3: Determining points on the stress-strain diagram.

$\varepsilon_{y,\theta}$	0.02
$\varepsilon_{t,\theta}$	0.15
$\varepsilon_{u,\theta}$	0.20

The yield stress at elevated temperature ($f_{y,\theta}$) is given by:

$$f_{p,\theta} = K_{p,\theta} * f_y \quad \text{......3.32}$$

f_y=characteristics yield stress of steel at ambient temperature.

$K_{y,\theta}$=yield stress reduction factor of the construction steel.

The proportional stress at elevated temperature ($f_{p,\theta}$) is given by:

$$f_{p,\theta} = K_{p,\theta} * f_y \quad \text{......3.33}$$

With $k_{p,\theta}$=proportional stress reduction factor of the construction steel.

The elastic modulus at elevated temperature is given by:

$$E_{a,\theta} = K_{E,\theta} * E_a \quad \text{.....} 3.34$$

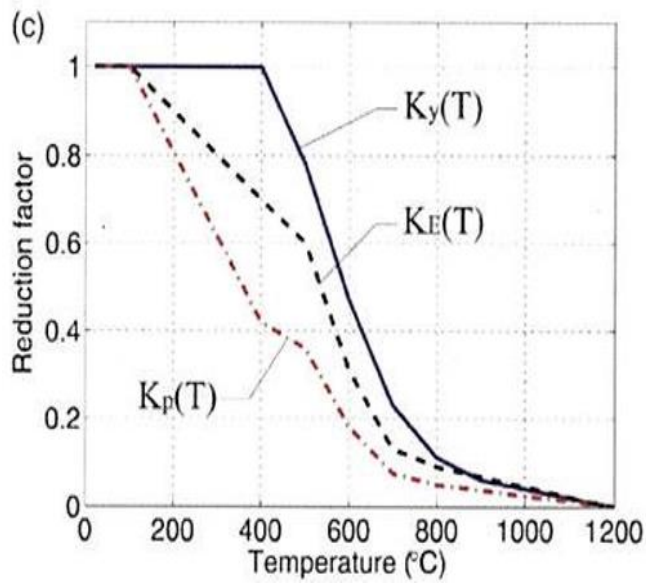
With E_a=characteristics elastic modulus of the construction steel at ambient temperatures.

$K_{E,\theta}$=elastic modulus reduction factor of the construction steel.

The reduction factor are given in table 3-4.

Table 3-4: Reduction factors for the stress-strain relationship at elevated temperature for steel from Eurocode 3[11]

Temperature °C	$K_y(T)$	$K_p(T)$	$K_E(T)$
20	1.000	1.000	1.000
100	1.000	1.000	1.000
200	1.000	0.807	0.900
300	1.000	0.613	0.800
400	1.000	0.420	0.700
500	0.780	0.360	0.600
600	0.470	0.180	0.310
700	0.230	0.075	0.130
800	0.110	0.050	0.090
900	0.060	0.038	0.068
1000	0.040	0.025	0.045
1100	0.020	0.013	0.023
1200	0	0	0



$$K_p(T) = \frac{F_p(T)}{F_{p0}}$$

$$K_y(T) = \frac{F_y(T)}{F_{y0}}$$

$$K_E(T) = \frac{E(T)}{E_0}$$

F_p = proportional limit
F_y = yield stress
E = Young's modulus

Fig 3-14: Reduction factors for the stress-strain relationship at elevated temperature for steel from Eurocode 3 [11]

3.13.3.2 Proof and yield strength and the proportional elastic limit

Steel at ambient temperatures typically has very well defined yield strength, however at elevated temperatures the point of yield is no longer well defined. Buchanan (2001) reports that the use of proof strength maybe used as the effective yield strength of steel at elevated temperatures. Proof strength is taken as the point of the stress strain curve intersecting with a line passing through 1% strain at the same slope as the linear portion of the stress strain curve, as shown on Figure 3-15.

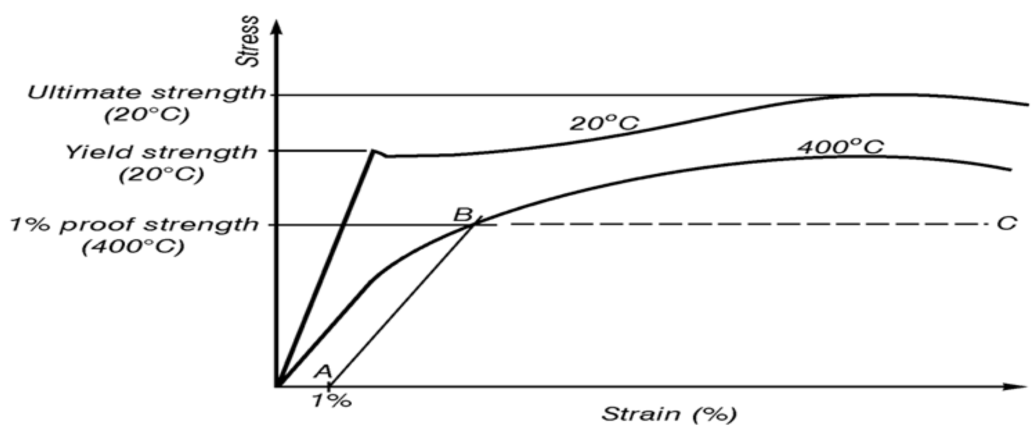


Fig 3-15: Stress strain curves for steel illustrating yield strength and proof strength[37]

The proportional limit is the point of the stress strain curve where strain is no longer linear with stress. That is, the proportional limit is the limit of elastic behavior of steel at elevated temperatures.

3.13.3.3 Strain components

The total strain of steel can be calculated as the sum of three strain components similar to the total strain of concrete according to the following formula [38].

$$\varepsilon = \varepsilon_{th}(T) + \varepsilon_{\sigma}(\sigma,T) + \varepsilon_{cr}(\sigma,T,t) \quad \text{.....} 3.35$$

Where ε =total strain

ε_{cr} =Creep strain

ε_{th} =thermal strain

T =Temperature

ε_{σ} =stress related strain

σ =Stress

3.13.3.4 Thermal strain

The thermal strain of steel is equivalent to the thermal expansion coefficient describe in the above

3.13.3.5 Stress related strain

Figure 3-16 shows typical stress-strain curve for structural steel elements at elevated temperatures. It can be seen that the yield plateau becomes less noticeable with temperature rise and disappears at about 300^{o}C.The ultimate strength increase slightly at moderate temperature before decreasing at higher temperature [38].

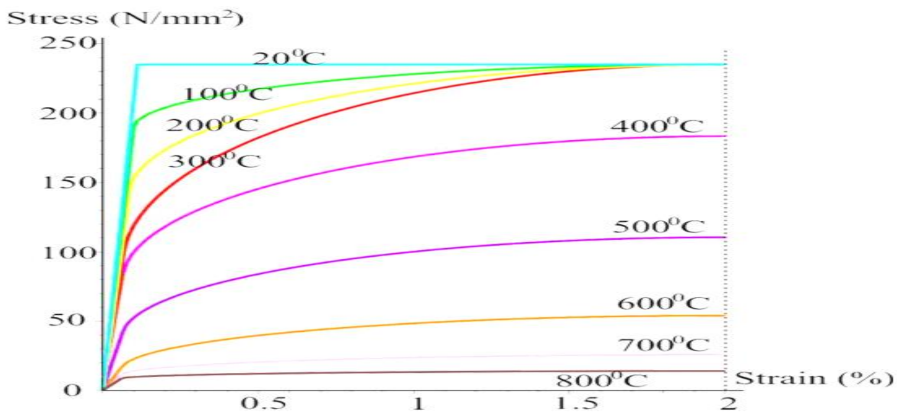


Fig 3-16: Stress strain r/n derived from stress controlled and strain controlling test respectively [29]

3.14 Contact Configuration

It was assumed a tangential friction coefficient of 0.2 for the contact behavior in tangential direction and a hard contact (full transmission of compressive forces and no transmission of tensile force) for the contact behavior in normal direction between the steel profile and the concrete. The surface to surface contact method was used because this one gives a good convergence rate and it is much less sensitive to the choice of master and slave surfaces. As well as that, the penalty method was defined as the contact property between the steel and the concrete. All other connection of the restraining frame and between the longitudinal reinforcement and the concrete were model using tie constraint option in ABAQUS. This method combines the two parts in all degrees of freedom at the connected region. Such signification significantly reduces additional contact configuration and converging challenges.

In the current investigation the embedded technique was used to create a bond between concrete and steel reinforcement. The steel rebar's referred to as the "embedded region "and the concrete part is referred to as the 'host region" in this technique, the translation degree of freedom of the embedded part nodes becomes constrained to the value of the corresponding degree of freedom of the host part elements. After assembling the components the simulated components should be connected to each other.

3.15 Finite element type and mesh size of the model

A three-dimensional numerical model for simulating the fire effect of concrete encased section steel columns was developed employing the general purpose nonlinear finite element analysis package ABAQUS.

The model was meshed with three-dimensional eight-node solid elements for both the structural steel, the encased concrete and the reinforcing bars. The mesh density was controlled to have a maximum element size of 50 mm for concrete and 25mm for steel (reinforced steel and structural steel) what proved to be sufficient to predict with enough accuracy the thermal and mechanical behavior of the columns under fire.

The elements have three degrees of freedom per node and suitable to all the column components since local buckling of the structural steel is prevented by the surrounding concrete elements. The element type used for thermal analysis were 3D eight-node continuum (DC3D8) the stress element used were C3D8R which is defined as a three dimensional (3D), continuum (C), hexahedral and an eight–node brick element with reduced integration (R) hourglass control and first-order (linear) interpolation for concrete and 3D model a three node quadratic T3D3 truss element has been used for reinforcing steel and structural steel.

3.16 Loading and boundary condition

The heat transfer analysis was carried out by applying the ISO-834 temperature-time curve in to node of all side of column as amplitude tabulated data for exposed side 20^{o}C as load. Heat transfer analysis is independent of support boundary condition and load, since no displacement is involved, in case of structure it has pin support at the two ends but at the top it has the value for y-axis because of it knows the vertical deflection. The structure also exposed to the pressure load at the top part of the column.

3.17 Thermal action

The fire action was defined in ABAQUS program by two types of surface, namely, film condition and conduction to ambient. Corresponding respectively to heat transfer by convection and conduction. Film condition was considered with 25 w/m^2k.

3.18 Geometric Modeling

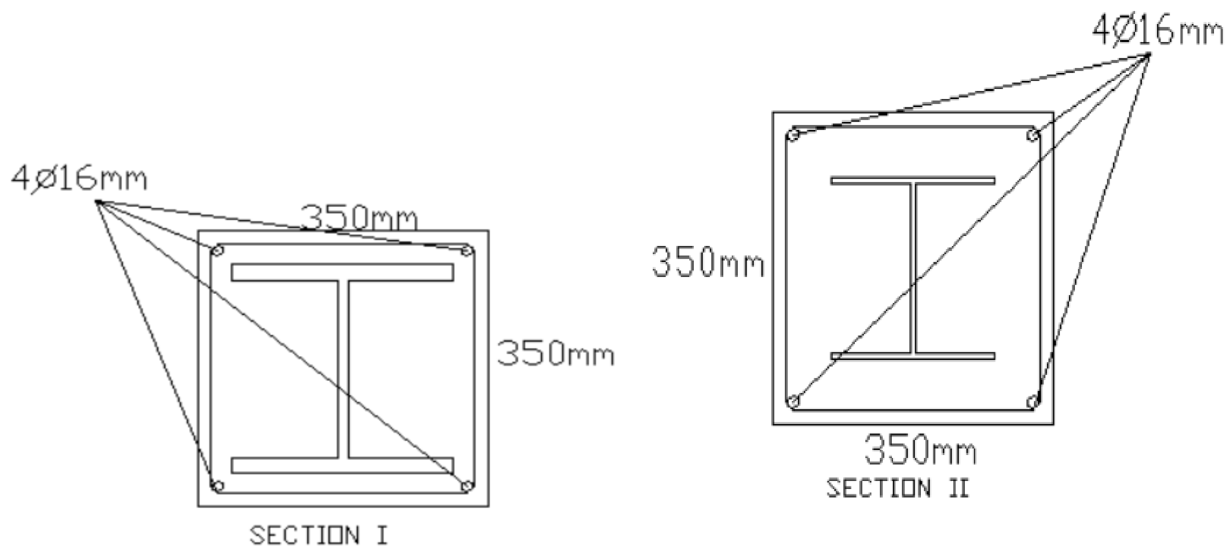
The structural system modeled in this study is simply supported column under the pressure load. The dimension were length 4300mm, depth 350 mm and width 350 mm of square cross-section, as shown in Figure 3-17, for the reinforcement bar used were 16mm diameter and stirrup 8mm diameter were used. Four longitudinal bars of 16 mm diameter were placed around the profile steel sections with a 25 mm concrete cover. The bars were tied with 8mm stirrups at a spacing of 100 mm throughout the length of the column. The nominal yield strength of the longitudinal reinforcing bars was 400 N/mm^2, and the nominal yield strength of the stirrups was 300 N/mm^2.

3.18.1 Used cross-sections in the parameter study

Column geometry

Table 3-5: Structural steel properties and concrete cross section

Dimension of concrete	Steel section	Depth of section	Width of section	Thickness of web(mm)	Thickness of flange(mm)	Area of steel (mm^2)	Section and steel ratio
350*350	254*254*107	266.7	258.8	12.8	20.5	13499.76	I,0.124
350*350	203*203*46	203.2	203.6	7.2	6.8	4134.08	II,0.035
350*350	152*152*23	152.4	152.2	5.8	6.8	2874.96	III,0.024



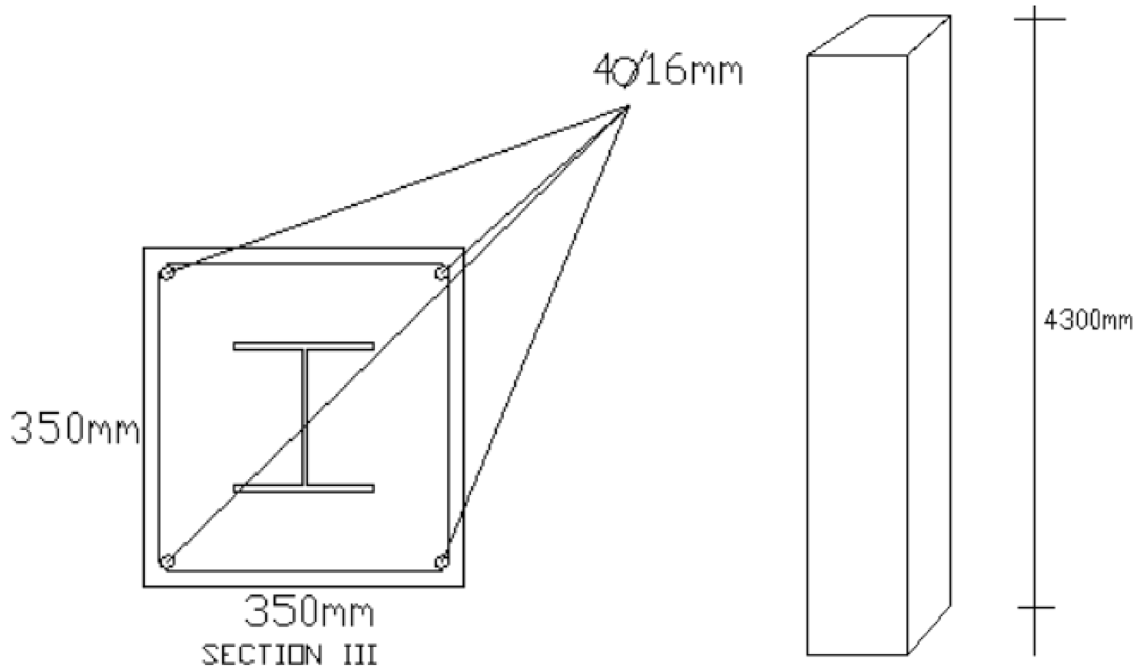


Fig 3-17: Detail of section I, II, III cross section

3.19 Material modeling in ABAQUS

3.19.1 Concrete modeling in ABAQUS

There are three different constitutive models for the analysis of concrete provided in ABAQUS: Each model is designed to provide a general capability for modeling structural steel and reinforcing steel.

The smeared crack model:-is intended for application in which the concrete is subjected to essentially monotonic straining and a material point exhibits either tensile cracking or compressive crushing. Plastic strain in compression is controlled by a compression on yield surface. Cracking is assumed to be the most important aspect of the behavior and the representation of cracking and post cracking an isotropic behavior dominates the modeling.

The brittle cracking model:-is intended for application in which the concrete behavior is dominated by tensile cracking and compressive failure is not important. The model includes consideration of the anisotropy induced by craking.in compression; the model assumes elastic behavior. A simple brittle failure criterion is available to allow the removal of elements from a mesh.

The concrete damaged plastic model:-is based on the assumption of scalar (isotropic) damage and is designed for application in which the concrete subjected to arbitrary loading conditions, such as individual load, cyclic loading and dynamic loading and so on. The model takes into consideration the degradation of the elastic stiffness induced by plastic straining both in tension and compression .the concrete damaged plasticity model has been used for the concrete in the study.

The CDP model needs a complete stress-strain curve of concrete under compression to define the compressive behavior. The stress-strain curve of concrete under compression to define beyond the ultimate stress into the strain softening region. Two parameters are required to be defined in the tabular format, namely compressive stress σ_c (i.e yield stress) and inelastic strain ε_c^{in}, inelastic strain is total strain minus elastic strain.

$$\varepsilon_c^{in} = \varepsilon_c - \varepsilon_{oc}^{el} \quad \text{...3.37}$$

Where $$\varepsilon_{oc}^{el} = \frac{\sigma_c}{E_o} \quad \text{...3.38}$$

E_o=is young modulus of concrete

Once hardening data are given in terms of inelastic strain instead of plastic strain, ABAQUS automatically converts the inelastic strain in to plastic strain using the relationship below.

$$\varepsilon_c^{-pl} = \varepsilon_c^{-in} - \left(\frac{d_c}{1-d_c}\right) * \frac{\sigma_c}{E_o} \quad \text{...3.39}$$

In the absence of compressive damage (dc) $\varepsilon_c^{-pl} = \varepsilon_c^{-in}$ the slope is constant E_o and the behavior is assumed to be linear, thus by assuming the tensile ultimate stress to be equal 5-10% of the ultimate unconfined uniaxial.

The stress-strain relations are governed by scalar damaged elasticity:

$$\sigma = (1-d) D_o^{el} * \varepsilon_c - \varepsilon_{oc}^{el} = D^{el} * (\varepsilon_c - \varepsilon_{oc}^{el}) \quad \text{...3.40}$$

$$D^{el} = (1-d) * D_o^{el} \qquad 3.41$$

Where D_o^{el} is the initial (un damaged) elastic stiffness of the material $D^{el}=(1\text{-}d)$ D_o^{el} is the degraded elastic stiffness; and d is the scalar stiffness degradation variable, which can take values in the range from zero (undamaged variable) to one (fully damaged material) and known as dc for concrete under compression. Damage associated with the failure mechanisms of the concrete (cracking and crushing) therefore result in the elastic stiffness. For this paper scalar damaged or stiffness degradation of compression is accounted. ABAQUS uses the elastic definition to determine the material response until the material reaches the defined cracking stress, after which the non-linear behavior of the materials governs. These material properties are defined using the elastic command within the ABAQUS software package. For this behavior, the modulus of elasticity is defined for concrete (E_o) as well as the Poisson's ratio (v),the poisons ratio of concrete is 0.2 and E_o=32GPa for concrete C-25 Mpa. To properly define the CDP, many different commands need to be utilized. The first of these is the damage plasticity command which defines the five plastic damage parameters define under:

Appendix B Mechanical properties for table B-1-1 up to Table B-1-5

3.19.2 Reinforcing steel and structural steel modeling

Steel is a homogeneous material and the stress-strain behavior can be assumed to be identical in tension and compression. Steel bar in reinforced concrete member are normally long and relatively slender and therefore, they can be generally assumed to be capable of transmitting axial force only.

The reinforcement was assumed to be elastic until yielding. After yielding plastic behavior was assumed with a 2% strain hardening. First yield occurs at 347.8Mpa.the material then harden to 400Mpa at 1% strain, after which is plastic. Assuming that the young's modulus is 210Gpa.the plastic strain values must be zero at yielding point. Plastic strain was computed from Stress-strain relationship given from Eurocode. Temperature dependent yield Stress-strain, young modulus of elasticity of steel is given in appendix B.

Appendix B steel properties for table B-2-1 up to Table B-2-3

3.20 Analysis procedure in ABAQUS

In this research two different approaches can be considered when conducting the thermal-mechanical analysis of the model. The first analysis was thermal analysis in this case to perform the heat transfer analysis on the concrete column. In this type of analysis, the Temperature/time solution is dependent on the temperature field but there is no inverse dependency. This type of analysis can be run as long as the thermal resistance at the concrete boundary is thought to be independent from the gap clearance. The second approach, highly non-linear to perform a fully coupled thermal-stress analysis, assuming that the thermal resistance on the steel-concrete boundary is a function of the gap clearance. The gap conductance will decrease as the two contacting surfaces progressively separate from each other due to the thermal expansion differentials. In that case, the thermal and mechanical solutions affect each other strongly and the stress/displacement and temperature fields must be solved simultaneously.

There are two different models were needed: a heat transfer model and a mechanical model. The analysis was performed by first conducting a pure heat transfer analysis for computing the temperature field and afterwards a stress/deformation analysis for calculating the structural response.

Nodal temperatures were stored as a function of time in the heat transfer analysis results and then read into the stress analysis as a predefined field. Having obtained accurate enough results through a simple sequentially coupled thermal-stress analysis, as it will be demonstrated later on in the validation section, it can be concluded that there is no need to perform a fully coupled analysis, which is highly time-consuming and in most occasions leads to convergence problems.

3.20.1 Thermal analysis

The concrete grade is c-25 in all case the density, conductivity and specific heat at elevated temperature for these material are available in the eurocodes and are used in the analysis.ISO 834 standared fire is supposed to act on the whole surface of the composite column. Emissivity of 0.7 is used for steel and concrete surface and convection factor is 25 W/m^2k as stated in the Eurocodes for the ISO 834 standard fire.Concrete were modeled with the DC3D8 brick elements of ABAQUS.

For conducting the thermal analysis, the standard ISO-834 or ASTM-E119 fire curve, depending on the specimen studied, was applied to the exposed surface of the encased concrete I-section steel column specimens as a thermal load, through the convection heat transfer mechanisms. In those cases where the fire curve applied at the test deviated from the reference, the real furnace temperature-time curve reported in the literature was used, since this can be an important source of error when validating the model. Heat can only transfer through the cross-section and along the length of the column. The fire temperature is assumed to follow the ISO-834 fire curve, with the sides, front and rare perimeter of the column exposed to fire. The fire temperature is consistent on the sides and front perimeter of the column. Grids of finite elements are used to calculate the temperature distribution across the cross section considered.

In this study reinforcing steel, structural steel and stirrup are not considered in heat transfer analysis because it has no significantly effect on temperature distribution across the section. The Eurocode 3 temperature dependent thermal properties (thermal conductivity, specific heat and density) of concrete were built in the program, list in the appendix A.

Appendix A thermal properties for table A-1-1 and Table A-1-2

3.20.2 Mechanical analysis

Mechanical analysis is the second steps of analysis conducted in this study to determine the structural response of the encased concrete steel I-section column exposed to fire. Finite element ABAQUS software is used to predict the structural response to the temperature increase. The nodal temperature from the time varying nodal temperature data from the heat transfer analysis is applied as a boundary condition on the structural response model analysis.

A nonlinear stress analysis was afterwards conducted using the same FEM package, accounting for the nodal temperature-time curves previously calculated in the thermal model.

The finite element meshes and the node numbering were different as those used in the thermal analysis model because of mesh density. The three-dimensional eight-node solid element C3D8R with reduced integration was used to mesh the encased concrete and the structural steel. The longitudinal steel bars for the reinforced specimens were modeled by means of two-node T3D2 truss elements with both nodes tied to their corresponding concrete nodes. The choice of the relevant properties of the mechanical model, such as the constitutive laws at elevated temperatures, the values of the thermal expansion coefficient for both concrete and steel, the initial imperfection of the column specimens or the frictional contact at the steel-concrete interface has been discussed.

CHAPTER FOUR
RESULT AND DISCUSSION

4.1 Introduction

In this chapter the result from all models are displayed in figure and diagram. From the heat transfer analysis a temperature distribution is derived from the temperature at the node from the mechanical analysis the result focus on the mid part of the column, stress along s11 and stress misses in concrete for composite column. Each model has been considered in heat transfer analysis and mechanical analysis. All results that represent temperature data originates from the heat transfer analysis, while all other data is taken from the mechanical analysis.

4.2 Validations

For the validation of steel reinforced concrete (SRC) under fire by Chao Zhang et.al [14], were selected and analyzed the experimental value getting from the validation are compared with the simulation by ABAQUS software.

Cross-section

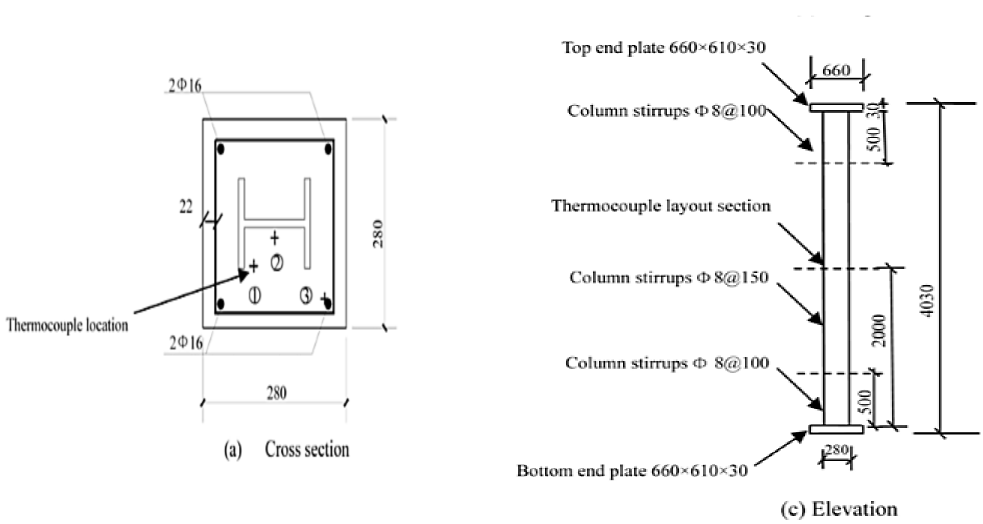


Fig 4-1: Cross-section and elevation of SRC column

The cross-section of concrete, structural steel and reinforcement detail shown in the above figure 4-1.Four longitudinal bars of 16 mm diameter were placed around the profile steel sections with a 30 mm concrete cover. The bars were tied with 8mm stirrups at a spacing of 150 mm in the central zone of 2,300 mm long and at 100 mm spacing within 500 mm from both ends of the column. The nominal yield strength of the longitudinal reinforcing bars was 400 N/mm^2, and the nominal yield strength of the stirrups was 300 N/mm^2 and 200000MPa modulus of elasticity. The concrete cube strength is 23.1MPa and 29000MPa with modulus of elasticity of concrete. During the test the load is applied at the top part of the column subjected to 2000kN.All materials input and models have done with the procedure according present FE model. The Nodal Temperature verses fire exposure time and displacement verses fire exposure time of column selected from validation in figure 4-2.

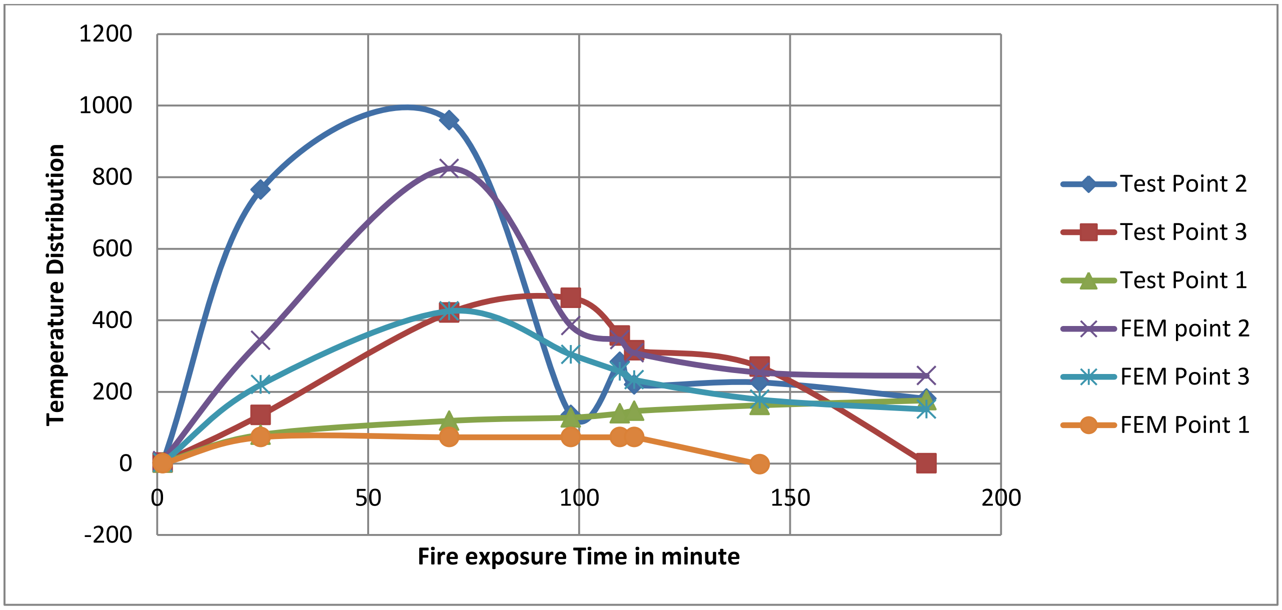


Fig 4-2: Comparisons of the SRC column tested by Chao Zhang et.al [14]: Predict and measured temperature at various temperatures

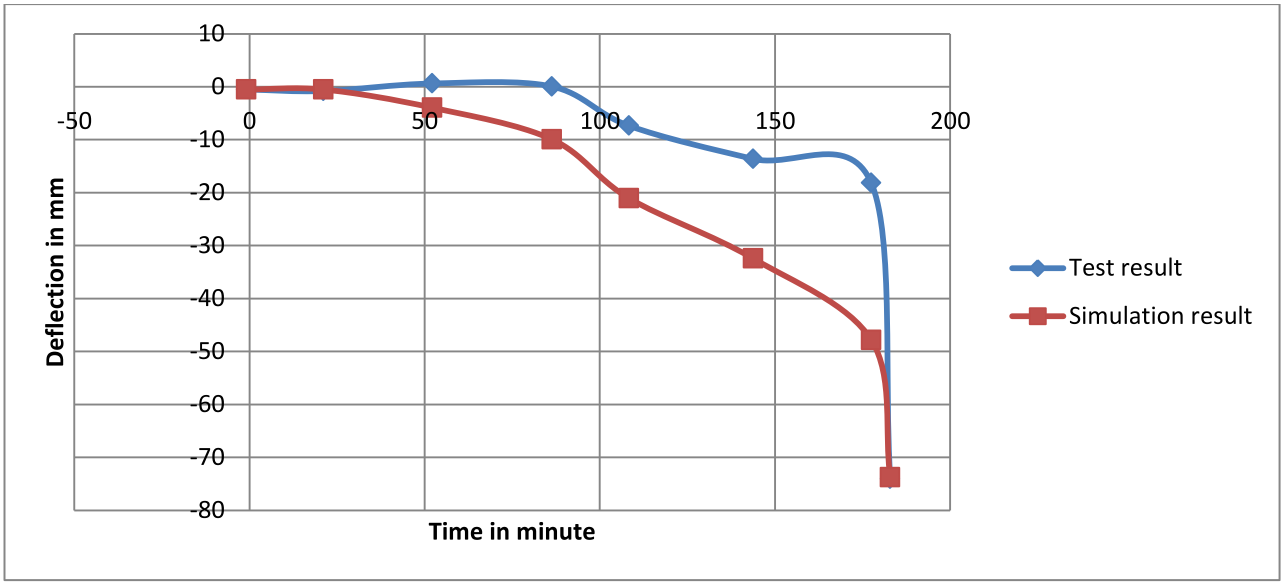


Fig 4-3: Comparisons of the SRC column tested by Chao Zhang et.al [14]: The predict and measured deflection at mid-point of column

As can be seen from the above figure 4-3, results from test and FE model are almost close to each other. But it is not quite the same. For example in case of heat transfer analysis slight difference, even if it is not significant is observed. The results from test are very limited because it is very difficult to properly reproduce in a furnace the real structural restraint, continuity and to simulate the realistic load level. Also in this test the moisture content of column are considered but in FE model for heat analysis specific heat of concrete was taken for dry concrete.

4.3 Result of the encased concrete I-section steel column

4.3.1 Thermal results

Thermal results are used for the determination of nodal temperature distribution along the cross section of the column. The dimension of the column cross-section are the same for different section of steel profile sheet used for this research, here is given from chapter three the geometrical modeling have been shown. The value of nodal temperature is uniform longitudinally along all axes but different at the cross-section. The thermal effect of structural steel, reinforcing steel and stirrup does not considered the nodal temperature distribution of the encased concrete I-section steel column. The results from ABAQUS are presented below at different point of the column x-sections for fire exposure of 30, 60, 90 and 120 minutes in the heat transfer analysis of the column section. The temperature distribution in a concrete-encased steel composite column is compared with the temperature distribution in a concrete cross-section with the same outer dimensions. From the heat transfer analysis of the column member has 5568 the number of Node, 4214 the number of element and the element type is DC3D8 were used to model the concrete.

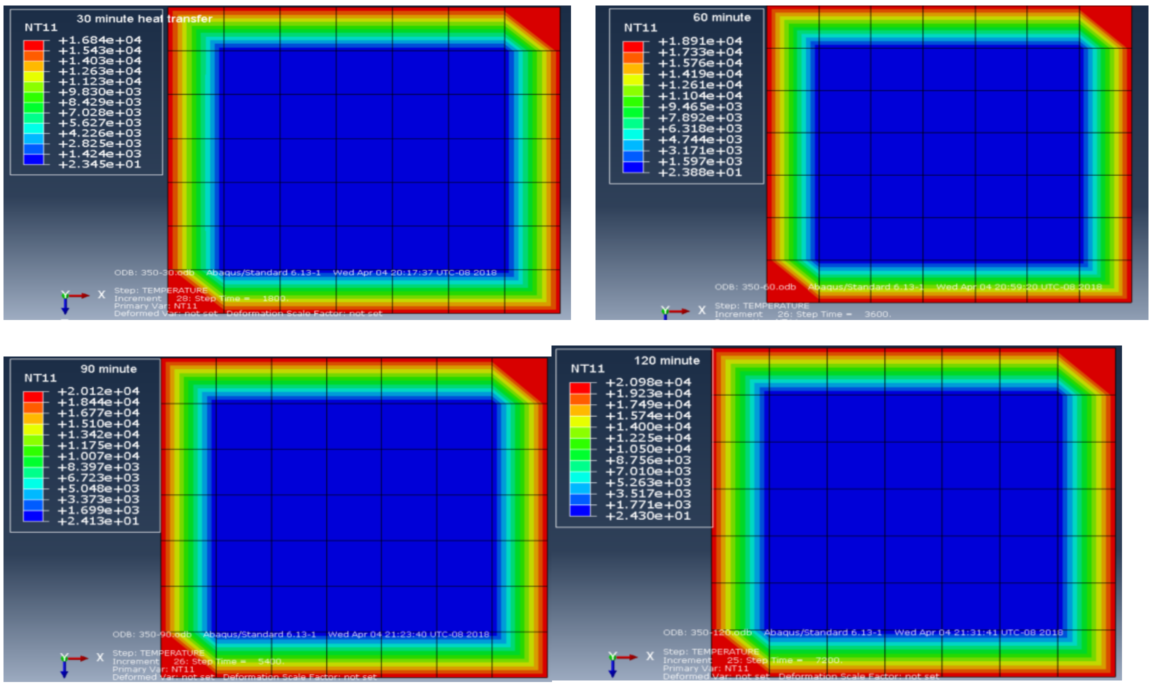


Fig 4-4: screen shot of thermal analysis result

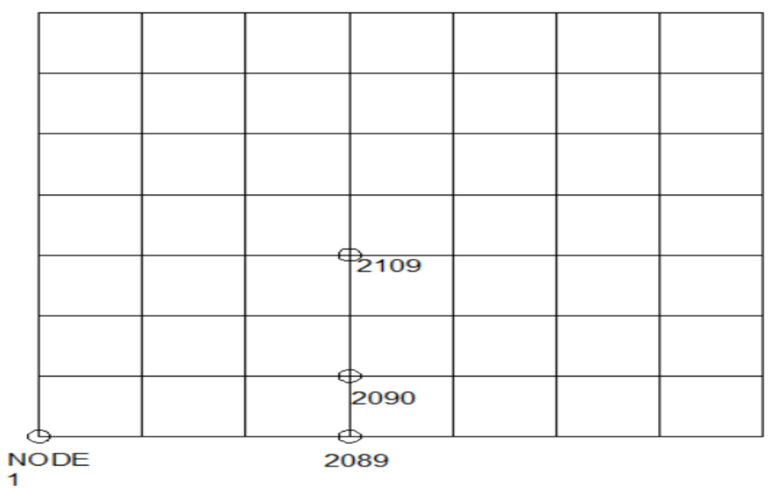


Fig 4-5: Column cross section at the top part

Column cross section at Top part of the column with different Node

Table 4-1: Temperatures for different time exposure.

Node	Time in minute	Fire Temperature (^{o}C)
1	30	16835.1
2089		16834.8
2090		31.6671
2109		23.4513
1	60	18906.1
2089		18905.9
2090		33.0901
2109		23.8772
1	90	20119.2
2089		20119
2090		33.9222
2109		24.1267
1	120	20980.3
2089		20980.1
2090		34.5122
2109		24.3039

From thermal analysis nodal temperature –time curve were obtained. As expected the result indicate that as time of fire exposure increased temperature distribution value also increased as shown above on table 4.1 above at different node different temperature is obtained for different time of exposure, in detail nodal temperature-time is given for selected node in appendix C: Table C-1-1.

4.3.2 Result from analysis of thermal and gravity load

Here are the result obtained from composite column analysis under the application of thermal and gravity loads are presented. The results focus on deflection,stress along x (S11),stress mises and load in concrete for composite column.In structural analysis 12174 number of elements, 18062 number of nodes and Element types: C3D8R for concrete and T3D2 for steel.

4.3.3 Result from composite column analysis

The result obtain from 3D FE analysis used for structural analysis are presented below as figure and diagram. In detail the value obtained as output are given in table in appendix D. The Output of stress misses and S11 screenshot result from the ABAQUS software for as sample section I

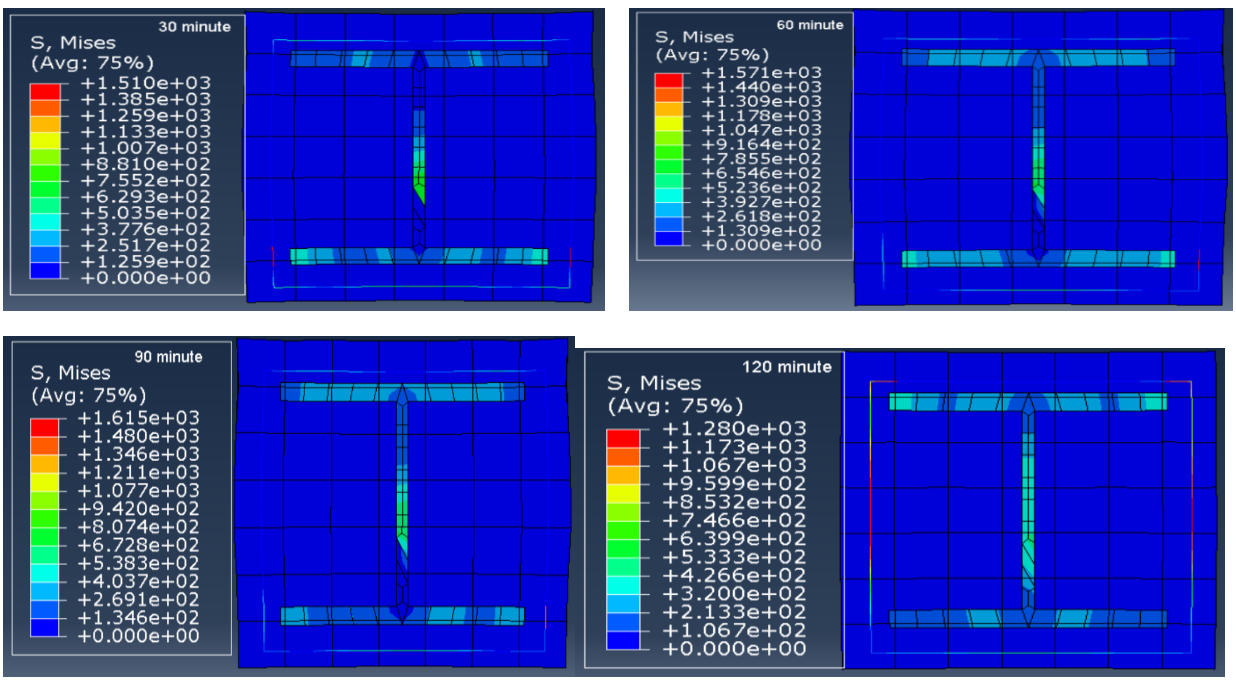


Fig 4-6: Screenshot of stress misses composite column

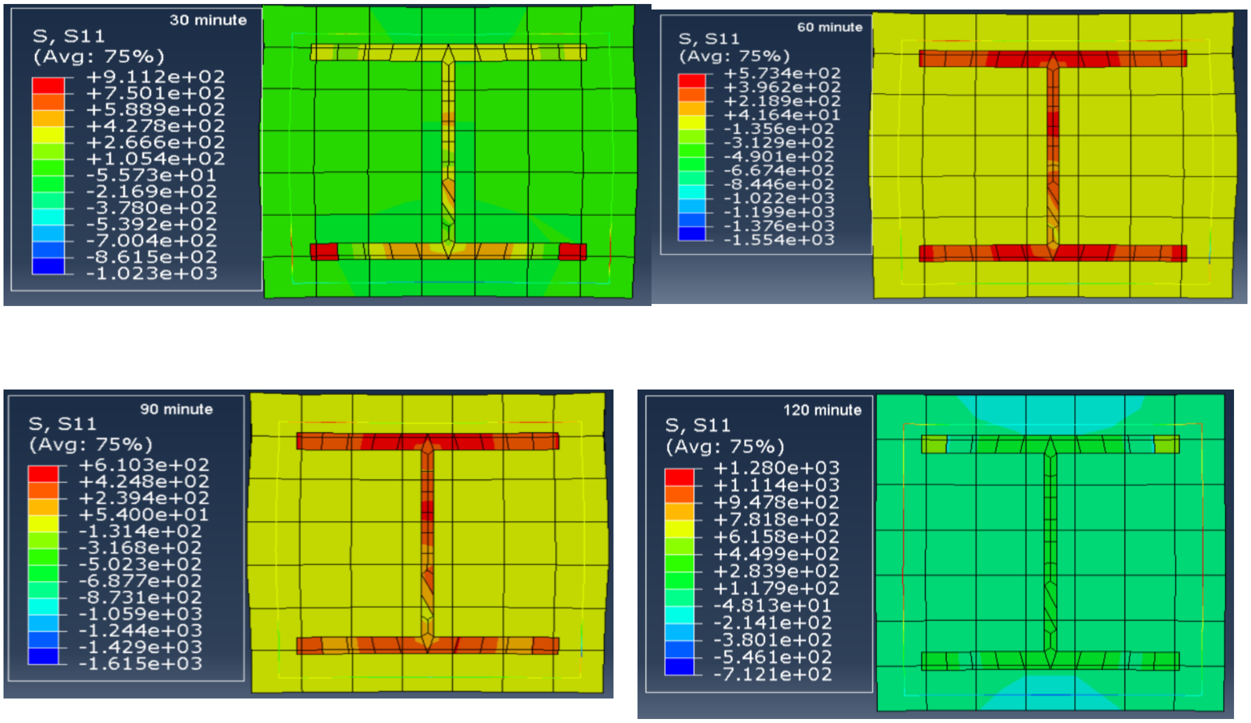


Fig 4-7: Screenshot of S11 composite column

As seen from Figure 4-6 and Figure 4-7 stress distribution variation along column x-section are shown.

Stress missies verses Width of section I

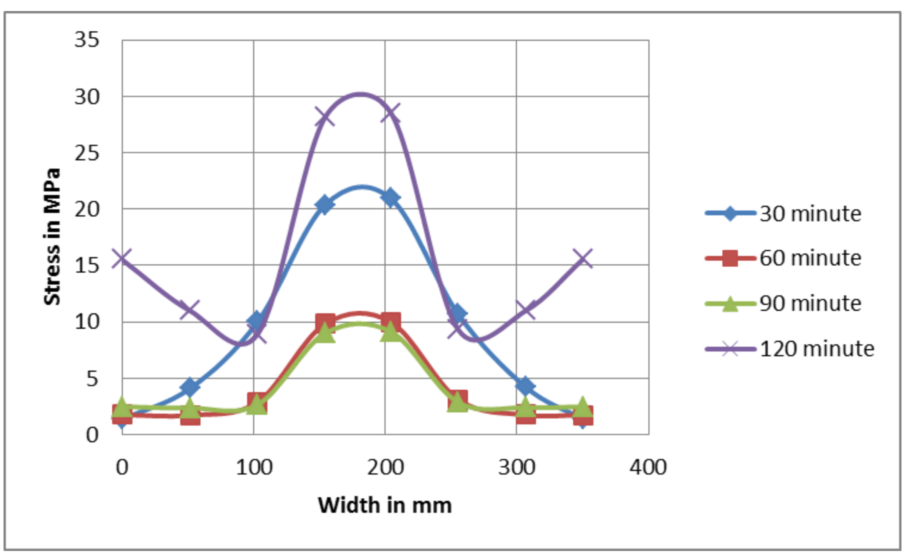


Fig 4-8: Stress misses distribution along the width for section I

At the side of the x-section the stress misses decrease and the center of the cross-section the stress distribution has increase because of the fire temperature acts at the side of the surface and at the center of the column there is the steel section. The time exposure at 120 minute the maximum stress is obtained at the center of the column and the sides. From 30 -90 minute time exposure the stress distribution along the side of the column member has overlap.

S11 verses width cross-section at section I

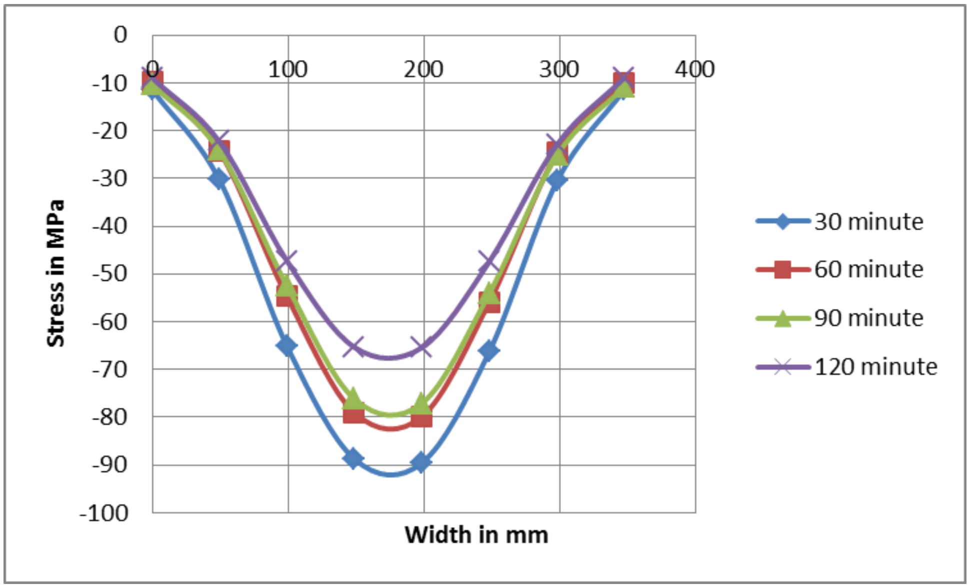


Fig 4-9: stress distribution along the width for section I

The above figure 4-9 shows the stress distribution at the major axis the side of the column exposed by fire the stress distribution is increase. The time exposure at 30 minute fire the stress is minimum at the interior part of the column and at 120 minute time exposure the stress distribution has been maximum compare to other time exposure.

Stress verses Width of steel flange at section I

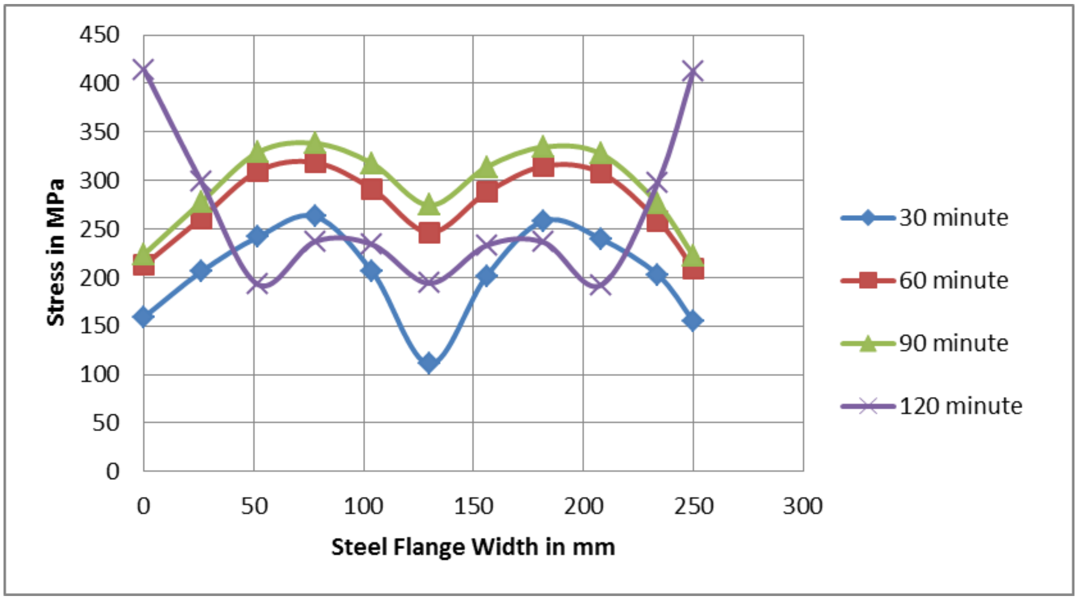


Fig 4-10: stress distribution along the steel top flange for section I

In case of steel flange the stress distribution has increase the fire duration also increase up to 90 minute time exposure nevertheless at 120 minute time duration the stress has decrease compare to the other fire exposure.

Load verses Width of cross-section at section I

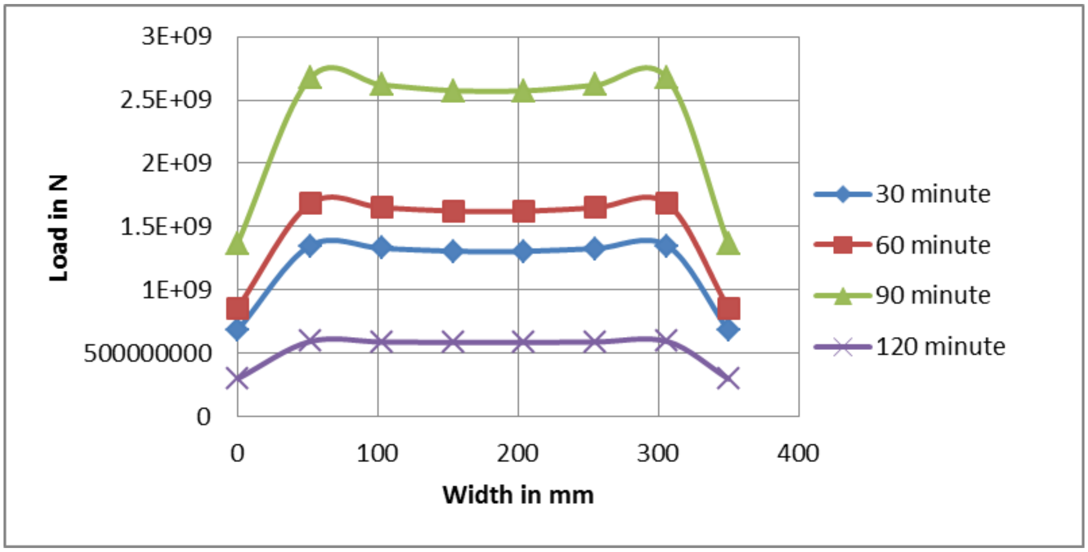


Fig 4-11: load effect along the width for section I

In the above figure 4-11 they were the load distribution along the x-section at all side of the column is decrease and at the interior part of the x-section is maximum in all fire duration. At 90 minute the load act on the column is maximum and at 120 minute the fire exposure is minimum.

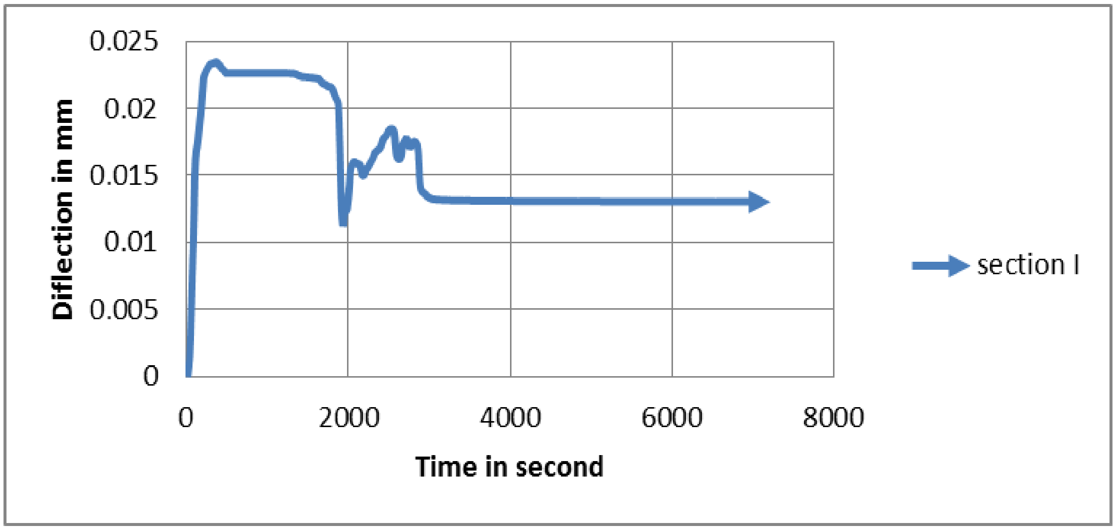


Fig 4-12: Deflection-Time exposure of composite column for section I

As shown above in Figure 4-12, the deflection of composite column has increased as temperature increases up to the time of 1800 second. After this the displacement is decreases up to 7200 seconds.in case of this the resistance is high because of it has high steel ratio for section I.so for the steel ratio for section I is 0.124 the deflection has been 0.023 mm it is small deflection.

Section II result

Stress misses verses Width of cross-section at Section II

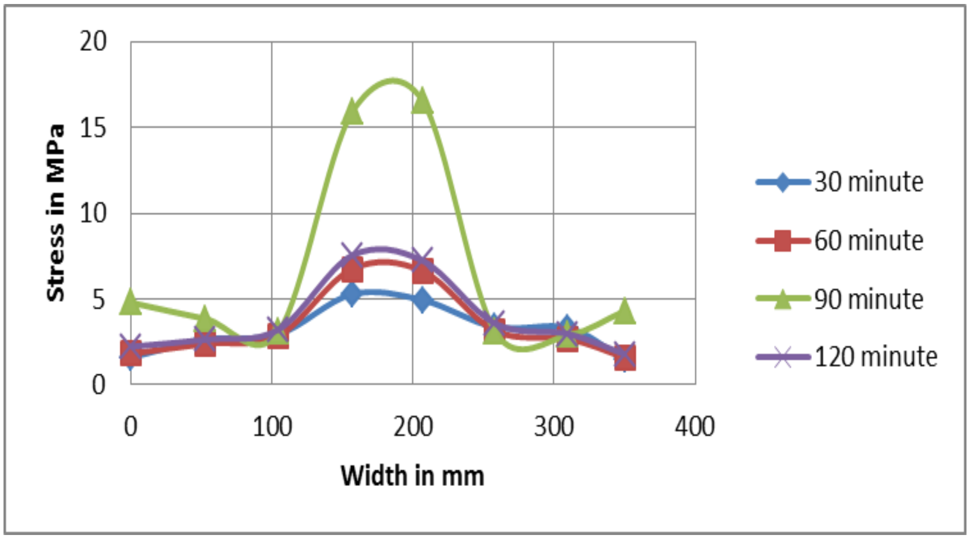


Fig 4-13: Stress misses distribution along width of composite column for section II

In the above figure 4-13 the stress distribution for fire duration is maximum at 90 minute at the interior part of the column member and at 30 minute time exposure the stress distribution is lower at the center of the column. Generally, the stress is minimum around the sides and maximum at the interior part of the x-section.

Stress verses width of column at section II

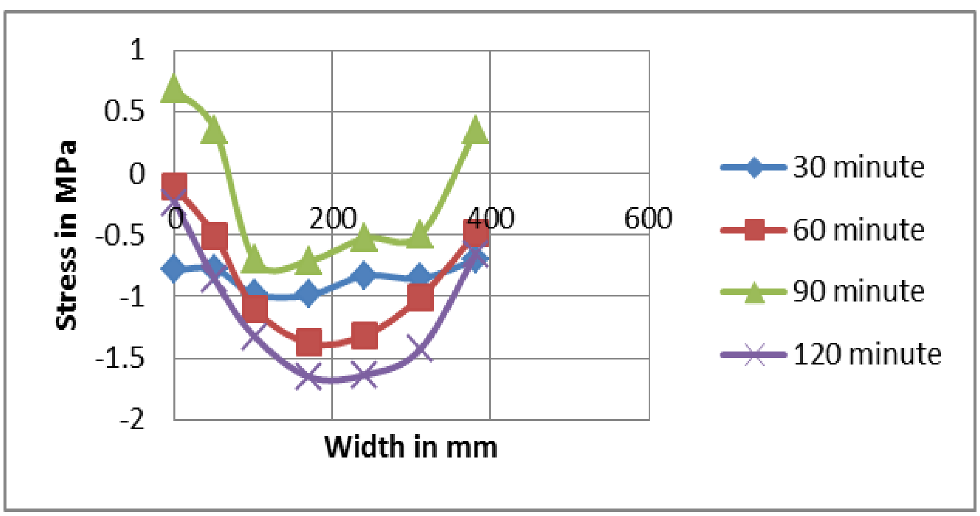


Fig 4-14: Stress distribution along width of composite column for section II

From the above Fig 4-14, the stress distribution is depends on the time duration exposure so the stress is maximum at 90 minute time exposure and minimum at 120 minute time exposure.

Load verses width of column at section II

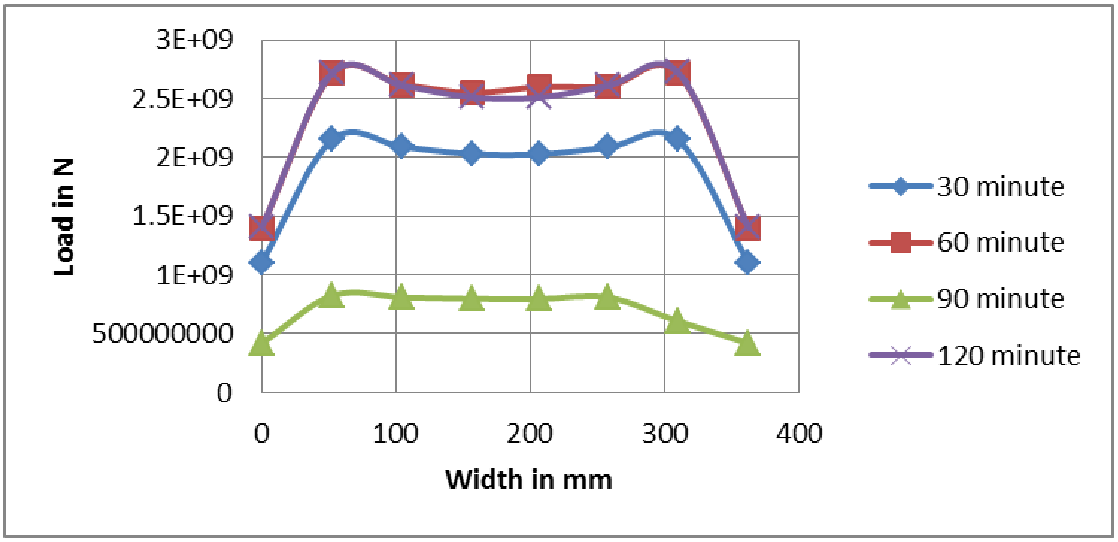


Fig 4-15: load-width of composite column for section II

From the above figure 4-15 at the sides of the cross-section of the column the load is decrease and at the interior part the load distribution has been increased for all fire duration exposure. The 90 minute time exposure the load distribution along the width is decrease and at 90 and 120 minute time exposure the load distribution has increased and also overlaps.

Stress verses Width of steel flange of column at Section II

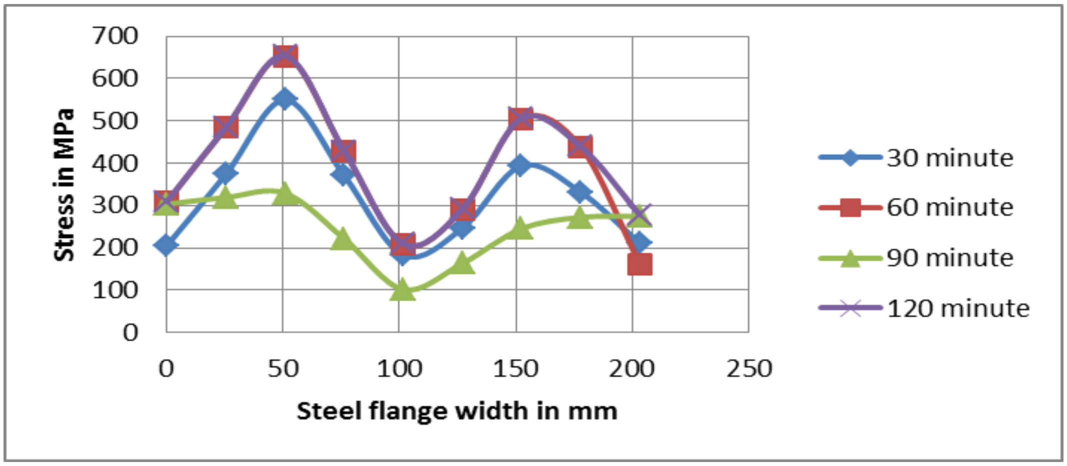


Fig 4-16: Stress misses distribution along width flange of composite column for section II

From the above figure 4-16 the stress distribution has been minimum at the time exposure of 90 minute and at 120 minute time exposure the stress distribution has maximum. The stress distribution at the side of the flange section is decreased at both sides of the column cross-section.

Deflection verses time exposure at section II

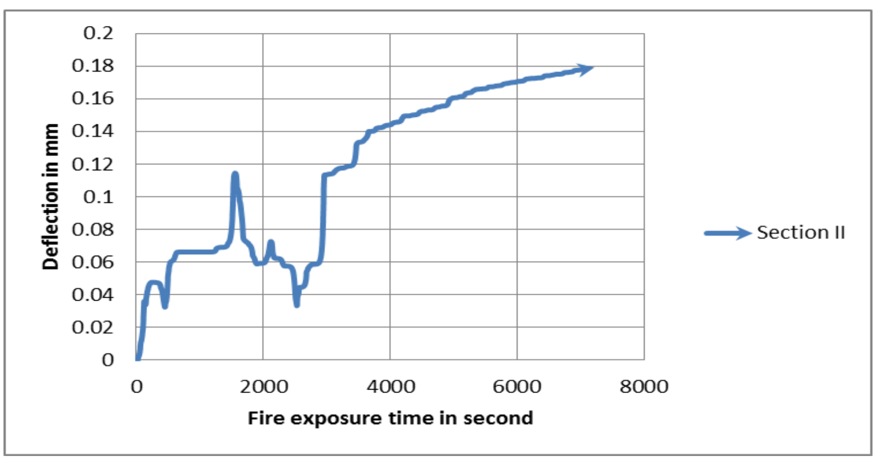


Fig 4-17: Deflection-Time exposure of composite column for section II

As shown above in Figure 4-17 the deflection of the composite column has increased as temperature increased.at 120 minute the deflection is maximum at 0-30 minute the deflection is linearly proportional after this the deflection if almost constant up to 120 minute.in section II the steel ratio is 0.035 the maximum deflection has been taken that is 0.18mm.fire duration at 30 minute the deflection is maximum that is 0.12mm.

Stress verses width at section III

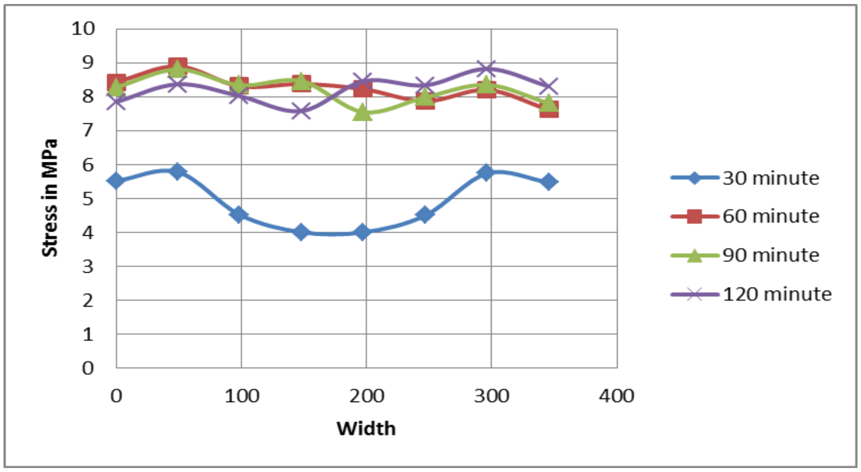


Fig 4-18 Stress misses distribution along the width of x-section for section III

From the above figure 4-18 shows the stress distribution almost similar along the width of the column cross-section at 30 minute time exposures the stress distribution has been minimum and at 120 minute fire duration the stress distribution is maximum.

Stress verses width at section III

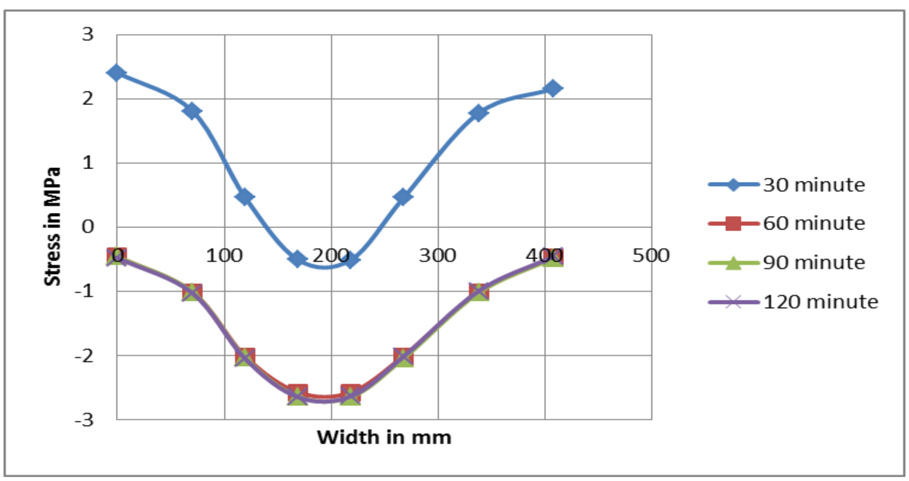


Fig 4-19: Stress misses distribution along width section III

From the above figure 4-19 shows the stress distribution of the column is maximum around the side of the column and minimum at the interior part of the column cross-section. The fire duration at 30 and 60 minute the stress distribution is almost similar and also the stress at 90 and 120 also similar because of the steel section is small compare to section 1 and section 2.

Load verses width of column cross section at section III

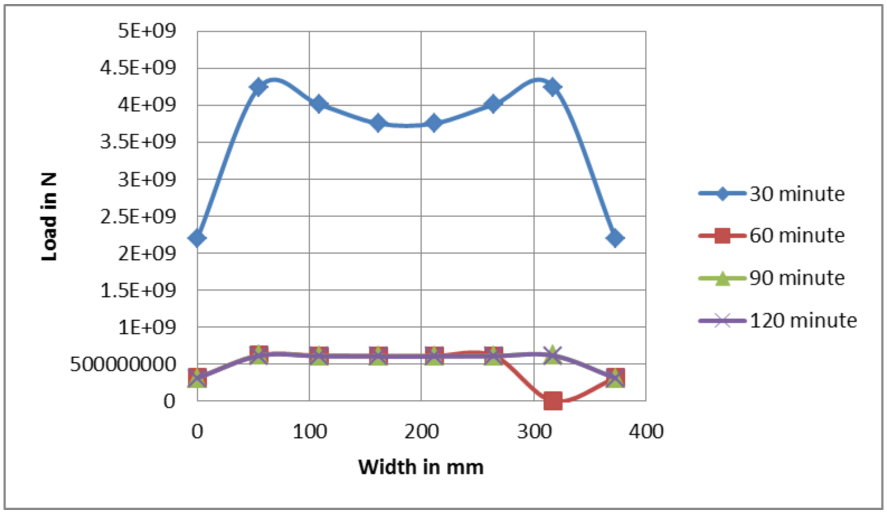


Fig 4-20: load-width of composite column for section III

From the above figure 4-20 shows, The load distribution of the column member has maximum at 30 minute time exposure in addition this the fire duration from 60-120 minute the load distribution along the width is decrease and the variation along the width is almost linear.

Stress verses width of steel flange at section III

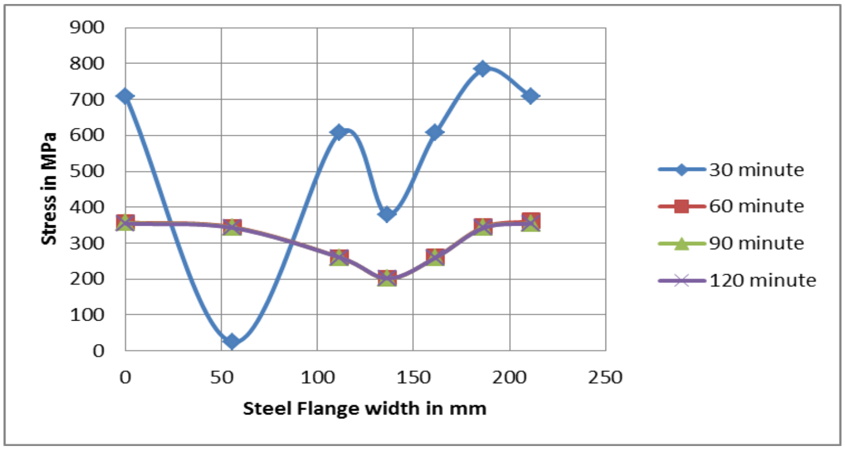


Fig 4-21: Stress misses distribution along width for section III

From the above figure 4-21 shows, the stress distribution at the side of the flange maximum for 30 minute time exposure and from 60-120 minute time exposure the stress distribution curve is overlap because of the steel section is small.

Deflection verses time exposure at section III

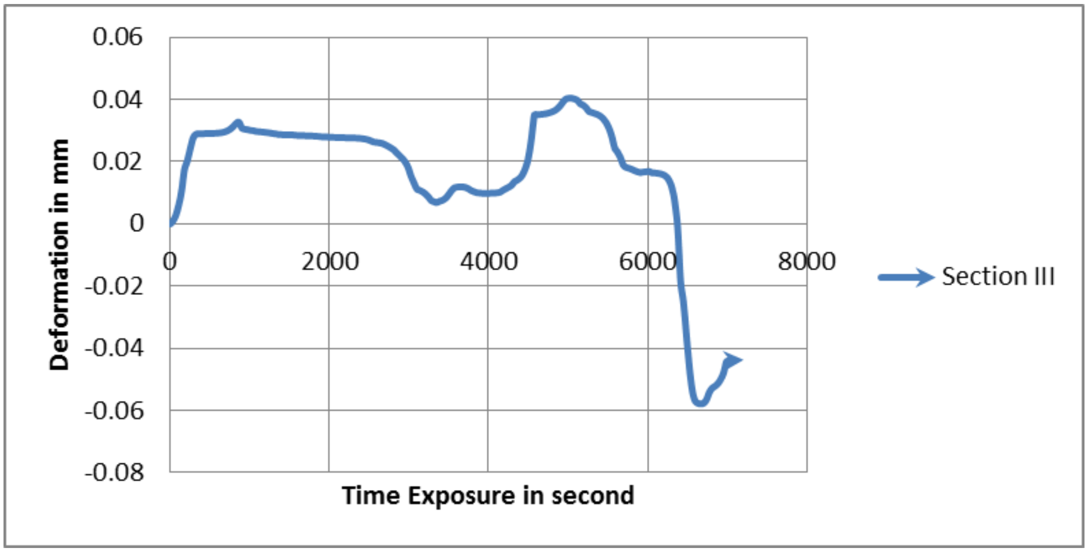


Fig 4-22: Deflection-Time exposure of composite column for section III

As shown above in Figure 4-22 the deflection of the composite column has increased as temperature increased. The deflection is 0.03mm at 30 minute time exposure.at 60 minute time exposure the deflection is 0.04mm. 90 - 120 minute time exposure the deformation result has been decreased.

The above all figure are put on the table below

Table 4-2 : The stress distribution in different steel ratio and Section, at 30 minute time exposure

Time	Steel Ratio	Stress misses	S11	deformation	Flange stress	Section
30	0.124	22	-91	0.024	100	I
	0.035	5	-1	0.12	200	II
	0.024	4	-0.5	0.3	400	III

At 30 minute time exposure the steel ratio decrease the stress distribution also decreases but the deformation at the mid-point has been increase.

Table 4-3 : The stress distribution in different steel ratio and Section, at 60 minute time exposure

Time	Steel Ratio	Stress misses	S11	Deformation	Flange Stress	Section
60	0.124	11	-82	0.15	250	I
	0.035	7	-1.4	0.14	205	II
	0.024	8.5	-2.8	0.01	200	III

At 60 minute time exposure the steel ratio decrease the stress distribution also decreases but the deformation at the mid-point has been decrease.

Table 4-4 : The stress distribution in different steel ratio and Section, at 90 minute time exposure

Time	Steel Ratio	Stress misses	S11	Deformation	Flange Stress	Section
90	0.124	9	-79	0.15	275	I
	0.035	17	-0.75	0.16	100	II
	0.024	8.5	-2.8	0.02	200	III

At 90 minute time exposure the steel ratio decrease the stress distribution also decreases but the deformation at the mid-point has been changed.

Table 4-5: The stress distribution in different steel ratio and Section, at 120 minute time exposure

Time	Steel Ratio	Stress misses	S11	Deformation	Flange Stress	Section
120	0.124	30	-67	0.15	200	I
	0.035	8	-1.6	0.18	200	II
	0.024	7.5	-2.8	0.04	200	III

At 120 minute time exposure the steel ratio decrease the stress distribution also decreases but the deformation at the mid-point has been increased.

Table 4-6 : The stress distribution in different time exposure and steel ratio

Section	Stress misses		S11		deformation	Stress at the flange	Steel ratio	Time
	Center	Side	Center	Side	Mid -point	Top Width	(%)	minute
I	22	2	-91	-10	0.024	100	0.124	30
	11	2	-82	-10	0.15	250	0.124	60
	9	2	-79	-10	0.15	275	0.124	90
	30	15	-67	-10	0.15	200	0.124	120
II	5	2	-1	-0.75	0.12	200	0.035	30
	7	2	-1.4	0	0.14	205	0.035	60
	17	5	-0.75	0.6	0.16	100	0.035	90
	8	2	-1.6	-0.25	0.18	200	0.035	120
III	4	5.5	-0.5	2.5	0.03	400	0.024	30
	8.5	8.5	-2.8	-0.5	0.01	200	0.024	60
	8.5	8.2	-2.8	-0.5	0.02	200	0.024	90
	7.5	8	-2.8	-0.5	0.04	200	0.024	120

Generally, the fire exposure increase the deformation of the column structure has been increase and the steel ratio also decreases.

CHAPTER FIVE
CONCLUSION AND RECOMMENDATION

Conclusion

This study aims at presenting the Finite element analysis of concrete encased steel I-section exposed to fire by using 3D finite element software. Different steps of modeling has been conducted, such as geometric definition, material properties, mesh generation and element selection creating boundary condition and steps of analysis. Both thermal and mechanical properties of materials are defined according to Eurocode and previous researchs as discused under chapter three.

Based on this research the following conclusions are drawn.

- Based on the thermal analysis test it has been found that the nodal temperature is getting maximum at the outer side of the column member; whereas the nodal temperature is getting minimum in the inner part of the column. Moreover, the fire duration always increases while the nodal temperature becoming high.
- In case of load distribution perpendicular to the x-section at the inner part of the column increases, the load at outer part of the column has decreased.
- 3d finite element sequentially fully coupled thermal stress analysis simulation is capable of determining the response of concrete column exposed to fire.
- As the Stress distribution of the column being dependent on the steel ratio and fire duration. The finding attests that the stress distribution of the column section has decreased; however, when the steel ratio decreases the fire duration has differently increased. In addition an increase in duration of fire exposure of the column, the compressive strength of concrete has decreased.
- Furthermore, it is important to note that when there is an increase in fire duration the analysis shown that both the deformation and the steel ratio of the column member have been decreased.

Recommendation

- Exposure to fire or elevated temperature of structural member is an extreme condition that leads to change of structural behavior ;consequently, change in overall in behavior of the whole structure .So there should be the building rule and regulation of allowance for fire resistance rating and methods of determining fire resistance rating of structural elements and whole structure of different types of structure, i.e. Reinforced concrete ,composite structure, steel structure and timber structure.
- Analysis the reinforced concrete, steel structure and composite column member as one side, two side and three side fire exposures are studies.

Reference

[1].Lie T.T ,“ Fire temperature time Relation .”Hdbk Fire protection Eng;g,3rd .ed SFPE,Bethesda,MD 2002.

[2]. António J.P. Moura Correia, João Paulo C. Rodrigues, “Fire resistance of partially encased steel columns with restrained thermal elongation”, 4 December 2010

[3]. M. B. Dwaikat and V. K. R. Kodur, “Hydrothermal model for predicting fire-induced spalling in concrete structural systems,” Fire Safety Journal, vol. 44, no. 3, pp. 425–434, 2009

[4].ACI Committee 2161, “Standard Method for Structural Fire Protection” .Reston,VA: American Society of Civil Engineers:1999.

[5]. Steel-Concrete Composite Column-I

[6]. V. K. R. Kodur and L. Phan, “Critical factors governing the fire performance of high strength concrete systems,” Fire Safety Journal, vol. 42, no. 6-7, pp. 482–488, 2007.

[8].James Milke, “overview of fire protection in buildings"

[9]. X. Yu, X. Zha, and Z. Huang, “The influence of spalling on the fire resistance of RC structures,” Advanced Materials Research, vol. 255–260, pp. 519–523, 2011.

[10].Lane B, “Performance Based Design for Fire Resistance”, Modern Steel Construction, December 2000.

[11]. Carmen Ibáñez Usach: “Fire response analysis of circular concrete filled tubular columns and the effects of axial and rotational restraints”, Valencia (Spain), October 2015

[12].Anderberg,Y.; Thelandersson,S.: “Stress and deformation characteristics of concrete at high temperatures”, Lund Institute of Technology,Lund,Sweden,1996

[13]. V. K. R. Kodur and M. Dwaikat, “Effect of fire induced spalling on the response of reinforced concrete beams,” International Journal of Concrete Structures and Materials, vol. 2, no. 2, pp. 71–82, 2008.

[14]. Chao Zhang1,Guang-Yong Wang, Su-Duo Xue1, and Hong-Xia Yu, “Experimental Research on the Behavior of Eccentrically loaded SRC Columns Subjected to the ISO-834 Standard Fire Including a Cooling Phase”, International Journal of Steel Structures 16(2): 425-439 (2016)

[15].Khoury,G.A.;Grainger,B.N.;Sullivan,P.J.E: “Transient thermal strain of concrete” :literature review, condition within specimen and behavior of individual constituents, in magazine of

concrete research, cement and concrete Association, Waxhaw Springs,Slough,Vol.37,No.132,pp.131-144,1985

[16].Bazant,Z.P.;Kaplan,M.F, "Concrete at High Temperature Material properties and mathematical models", Longman Group Ltd.,Essex,England,1996

[17] Cvetkovska, M.: "Nonlinear stress strain behavior of RC elements and RC frames exposed to fire", PhD thesis, University "St. Cyril and Methodius", Civil Engineering Faculty-Skopje, 2002.

[18]. Dat duthinh, structural design for fire: survey of building code and standards.

[19].malholtra,H.L: "Design of fire resisting structure ,surrey university press",London,1982

[20].Eurocode 1:Action on structure-Part 1-2:General Action-Action on structures exposed to fire,November 2002

[21].Euro code 2: Design of concrete structure .EN 1992-1-2 part 1.2:General rules-structural fire design, European Committee for Standardization,Brussels,2002

[22].Eurocode 2: Design of concrete structure .ENV 1992-1-2 part 1.2; General rules structural fire design, European committee for standardization, Brussels, 1995

[23].Eurocode 1:Design of concrete structures.ENV 1992-1-2 part 1.2:General Rules Structural fire design,European Committee for standardization,Brussels,1995

[24].Fletches,I.,Borg,A.,Hitchen,N.,Welch,S., "Performance of concrete in fire": a review of the state of the art ,with a case study of the Windsor tower fire, in proceeding of the fourth international workshop structure in fire,2006;Aveiro,p.779-790

[25]. Gu,X.;Jin,X.;Zhou,Y. "Basic principle of concrete structure",2016

[26].Schneider,U.:Verhalten von Betonbeihohen Temperature,DAfStb Heft 337,Ernst and Sohn,Berlin,1982

[27] ABAQUS-Computer program, University of Liege, Belgium, 2014

[28]. ISO 834, "Fire resistance tests elements of building construction", International Organization for standardization: 1975

[29].Buchanan,A.H,: "structural design for fire safety", Jone Wiley & Sons,West Sussex,2001

[30].The building standard law of japan august, 2011

[31].Elghazouli,A.Y,Izzuddin,B.A, "Analytical assessment of the structural performance of composite floors subject to compartment fires", 2001

[32].Eurocode 3, “Design of steel structures- Part 1-2: General rules - structural fire design,” BS EN 1993-1-2:2005 also DIN EN 1993-1-2:2010-12, CEN, Brussels, Belgium, 2005

[33].Martin Gillie: “Fire Resistance of Structures, School of Engineering and Electronics”, The University of Edinburgh

[34].Buchanan,A.H ,”Structural Design for Fire safety”, John Wiley & Sons, New York, USA, 2002

[35].Ehab Ellobody , Ben Young, Dennis Lam, “Eccentrically loaded concrete encased steel composite columns”, 13 August 2010

[36].Fire design of concrete structure –structure behavior and assessment, federation international du beton, 209 pp.

[37].European committee for standardization, Design of concrete structure;General rules:structural fire design,EN 1992-1-2,Eurocode 2 part 1-2:Brussels,2004.

[38].Fletcher,I.A,Welch,S.,Torero,J.L.,Carvel,R.O.,Usmani,A.,The Behavior of concrete structures in fire. Journal of Thermal Science .2007.11(2):P.37-52

[39].Marechal JC.Variations of the modulus of elasticity and poisson’s ratio with temperature Concrete for Nuclear Reactors.Detroit,MI:American Concrete Institute;1972

Appendix

Appendix A Thermal properties of materials used as input.

A.1 thermal properties of concrete

Table A-1-1 thermal conductivity of concrete

Thermal conductivity of concrete (W/mk)	Temperature (^{o}C)
1.95	20
1.76	100
1.55	200
1.36	300
1.19	400
1.04	500
0.91	600
0.8	700
0.72	800
0.66	900
0.62	1000
0.59	1100
0.59	1200

Table A-1-2 Specific heat of concrete

specific heat capacity(J/kg k)	Temperature(^{o}C)
900	20
900	100
1000	200
1100	300
1100	400
1150	500
1200	600
1100	700
1100	800
1100	900
1100	1000
1100	1100
1100	1200

A-2 Thermal properties of steel

Table A-2-1 thermal conductivity of steel

thermal conductivity of steel(W/m k)	Temperature(^{o} C)
53.33	20
50.67	100
47.34	200
44.01	300
44.01	400
40.68	500
34.02	600
30.69	700
27.36	800
27.3	900
27.3	1000
27.3	1100
27.3	1200

Table A-2-2 Specific heat of steel

Specific heat capacity(J/kg k)	Temperature(^{o} C)
439.8	20
487.62	100
529.76	200
567.74	300
605.88	400
666.5	500
759.92	600
1008.16	700
5000	800
803.26	900
650.44	1000
650	1100
650	1200

A-3 General properties of materials

Table A-3-1 density of concrete

Density (kg/m^3)	Temperature(^{o}C)
2400	All temperature

Table A -3-2 Density of steel

Density (kg/m^3)	Temperature (^{o}C)
7850	All temperature

APPENDIX B Mechanical properties of materials used as input

B-1 Material properties of Concrete

Table B 1-1 concrete damage Plasticity Parameter

Dilation angle	31
Flow potential eccentricity e	0.1
Ratio of initial equibiaxial compressive yield stress to initial uniaxial compressive yield stress σ_{bo}/σ_{co}	1.16
Ratio of the second stress invariant on the tensile meridian.Kc	0.667
Viscosity Parameter	0

Table B-1-2 young's modulus of concrete (Mpa)

young modulus elasticity (Mpa)	Poission's ratio	Temperature(^{o} C)
32000	0.2	20
32000	0.2	100
22956.8	0.2	200
18531.2	0.2	300
14406.4	0.2	400
10640	0.2	500
7289.6	0.2	600
4412.8	0.2	700
2067.2	0.2	800
310.4	0.2	900

Table B-1-3 expansion coeffient of concrete

expansion coefficients of concrete, (/^{o}C)	Temperature(^{o}C)
0	20
9.29E-06	100
1.00E-05	200
1.12E-05	300
1.29E-05	400
1.50E-05	500

1.76E-05	600
2.06E-05	700
1.79E-05	800
1.59E-05	900
1.43E-05	1000
1.30E-05	1100
1.19E-05	1200

Table B-1-4 compression hardening of concrete

Yield stress(Mpa)	Inelastic strain	Temperature	Yield Stress	inelastic Stress	Temperature
8.964143426	0	20	13.35654086	0.0181	600
12.46320387	0.0002	20	13.40920607	0.0186	600
14.16787356	0.0003	20	13.44952137	0.0191	600
15.8307014	0.0004	20	13.47783645	0.0196	600
17.44186047	0.0005	20	13.49452875	0.0201	600
24.36823105	0.001	20	13.5	0.0206	600
28.66242038	0.0015	20	13.49467269	0.0211	600
30	0.002	20	13.47898661	0.0216	600
28.96995708	0.0025	20	13.45339541	0.0221	600
26.55986509	0.003	20	13.41836334	0.0226	600
23.62204724	0.0035	20	13.37436205	0.0231	600
20.68437181	0.004	20	13.3218676	0.0236	600
18	0.0045	20	13.2613576	0.0241	600
15.65464896	0.005	20	13.19330865	0.0246	600
13.65015167	0.0055	20	13.11819386	0.0251	600
11.95341234	0.006	20	13.03648069	0.0256	600
10.52104208	0.0065	20	12.94862898	0.0261	600
9.310344828	0.007	20	12.8550892	0.0266	600
8.283479061	0.0075	20	12.75630091	0.0271	600
7.40848344	0.008	20	12.65269143	0.0276	600
6.658993752	0.0085	20	12.54467477	0.0281	600
6.013504009	0.009	20	12.43265066	0.0286	600
5.454545455	0.0095	20	12.31700387	0.0291	600
4.967931868	0.01	20	12.19810358	0.0296	600
4.54211782	0.0105	20	12.07630305	0.0301	600
4.167673351	0.011	20	11.95193929	0.0306	600
3.836862299	0.0115	20	2.689243028	0	700
3.543307087	0.012	20	2.954271459	0.0005	700
3.281723325	0.0125	20	3.217758851	0.001	700

3.047709828	0.013	20	3.479422832	0.0015	700
2.8375822	0.0135	20	3.738961162	0.002	700
2.648240594	0.014	20	3.996053281	0.0025	700
2.47706422	0.0145	20	4.250362068	0.003	700
2.321826837	0.015	20	4.501535818	0.0035	700
2.180628748	0.0155	20	4.749210419	0.004	700
2.051841822	0.016	20	4.99301173	0.0045	700
1.934064823	0.0165	20	5.23255814	0.005	700
1.826086957	0.017	20	5.46746329	0.0055	700
1.726857971	0.0175	20	5.69733894	0.006	700
1.635463529	0.018	20	5.921797938	0.0065	700
1.551104822	0.0185	20	6.140457275	0.007	700
1.473081636	0.019	20	6.352941176	0.0075	700
1.40077821	0.0195	20	6.558884205	0.008	700
8.964143426	0	100	6.757934315	0.0085	700
10.06766152	0.0001	100	6.949755839	0.009	700
11.1627907	0.0002	100	7.134032341	0.0095	700
16.4414843	0.0007	100	7.310469314	0.01	700
21.17647059	0.0012	100	7.478796673	0.0105	700
25.06527415	0.0017	100	7.638771007	0.011	700
27.87096774	0.0022	100	7.790177557	0.0115	700
29.49524506	0.0027	100	7.9328319	0.012	700
30	0.0032	100	8.066581306	0.0125	700
29.57216201	0.0037	100	8.191305755	0.013	700
28.45849802	0.0042	100	8.306918607	0.0135	700
26.9044586	0.0047	100	8.413366921	0.014	700
25.11627907	0.0052	100	8.510631419	0.0145	700
23.24743868	0.0057	100	8.598726115	0.015	700
21.40127389	0.0062	100	8.677697612	0.0155	700
19.64082746	0.0067	100	8.747624102	0.016	700
18	0.0072	100	8.808614081	0.0165	700
16.49317837	0.0077	100	8.860804812	0.017	700
15.12252042	0.0082	100	8.904360572	0.0175	700
13.88303945	0.0087	100	8.939470714	0.018	700
12.76595745	0.0092	100	8.966347581	0.0185	700
11.76081672	0.0097	100	8.985224298	0.019	700
10.8567512	0.0102	100	8.996352499	0.0195	700
10.04321128	0.0107	100	9	0.02	700
9.310344828	0.0112	100	8.996448461	0.0205	700
8.649168118	0.0117	100	8.98599107	0.021	700
8.051612903	0.0122	100	8.968930272	0.0215	700
7.510503694	0.0127	100	8.94557556	0.022	700

7.019498607	0.0132	100	8.916241369	0.0225	700
6.573013812	0.0137	100	8.881245066	0.023	700
6.166143306	0.0142	100	8.84090507	0.0235	700
5.794580561	0.0147	100	8.7955391	0.024	700
5.454545455	0.0152	100	8.745462571	0.0245	700
5.142718	0.0157	100	8.690987124	0.025	700
4.856179329	0.0162	100	8.632419321	0.0255	700
4.592359735	0.0167	100	8.570059468	0.026	700
4.348993289	0.0172	100	8.504200605	0.0265	700
4.12407841	0.0177	100	8.43512762	0.027	700
3.91584371	0.0182	100	8.363116512	0.0275	700
3.722718459	0.0187	100	8.288433774	0.028	700
3.543307087	0.0192	100	8.21133591	0.0285	700
3.376367146	0.0197	100	8.132069053	0.029	700
3.220790287	0.0202	100	8.050868699	0.0295	700
3.075585799	0.0207	100	7.967959528	0.03	700
2.93986637	0.0212	100	7.883555323	0.0305	700
2.812835733	0.0217	100	7.797858958	0.031	700
8.515936255	0	200	7.71106246	0.0315	700
11.54202306	0.0004	200	7.62334713	0.032	700
15.18048423	0.0009	200	7.534883721	0.0325	700
18.56027987	0.0014	200	1.344621514	0	800
21.56810285	0.0019	200	1.477135729	0.0055	800
24.09933444	0.0024	200	1.608879425	0.006	800
26.07561437	0.0029	200	1.739711416	0.0065	800
27.45782955	0.0034	200	1.869480581	0.007	800
28.25095576	0.0039	200	1.99802664	0.0075	800
28.5	0.0044	200	2.125181034	0.008	800
28.27927107	0.0049	200	2.250767909	0.0085	800
27.67884338	0.0054	200	2.37460521	0.009	800
26.79189789	0.0059	200	2.496505865	0.0095	800
25.70523439	0.0064	200	2.61627907	0.01	800
24.49363717	0.0069	200	2.733731645	0.0105	800
23.21762376	0.0074	200	2.84866947	0.011	800
21.92359312	0.0079	200	2.960898969	0.0115	800
20.64536288	0.0084	200	3.070228637	0.012	800
19.40630276	0.0089	200	3.176470588	0.0125	800
18.22154659	0.0094	200	3.279442102	0.013	800
17.1	0.0099	200	3.378967158	0.0135	800
16.04602468	0.0104	200	3.47487792	0.014	800
15.06077884	0.0109	200	3.56701617	0.0145	800
14.14324383	0.0114	200	3.655234657	0.015	800

13.29098725	0.0119	200	3.739398337	0.0155	800
12.50071604	0.0124	200	3.819385503	0.016	800
11.76866824	0.0129	200	3.895088778	0.0165	800
11.09088389	0.0134	200	3.96641595	0.017	800
10.4633875	0.0139	200	4.033290653	0.0175	800
9.88230672	0.0144	200	4.095652877	0.018	800
9.343945809	0.0149	200	4.153459304	0.0185	800
8.844827586	0.0154	200	4.206683461	0.019	800
8.381713768	0.0159	200	4.25531571	0.0195	800
7.951610778	0.0164	200	4.299363057	0.02	800
7.551766089	0.0169	200	4.338848806	0.0205	800
7.179658633	0.0174	200	4.373812051	0.021	800
6.832985713	0.0179	200	4.404307041	0.0215	800
6.509648118	0.0184	200	4.430402406	0.022	800
6.207734541	0.0189	200	4.452180286	0.0225	800
5.925506056	0.0194	200	4.469735357	0.023	800
5.661381107	0.0199	200	4.48317379	0.0235	800
5.413921309	0.0204	200	4.492612149	0.024	800
5.181818182	0.0209	200	4.49817625	0.0245	800
4.963880922	0.0214	200	4.5	0.025	800
4.759025181	0.0219	200	4.49822423	0.0255	800
4.566262854	0.0224	200	4.492995535	0.026	800
4.384692814	0.0229	200	4.484465136	0.0265	800
4.213492532	0.0234	200	4.47278778	0.027	800
4.051910514	0.0239	200	4.458120684	0.0275	800
7.619521912	0	300	4.440622533	0.028	800
8.156300997	0.0001	300	4.420452535	0.0285	800
10.80259366	0.0006	300	4.39776955	0.029	800
13.35649385	0.0011	300	4.372731285	0.0295	800
15.77208976	0.0016	300	4.345493562	0.03	800
18	0.0021	300	4.31620966	0.0305	800
19.992	0.0026	300	4.285029734	0.031	800
21.70596751	0.0031	300	4.252100303	0.0315	800
23.11035758	0.0036	300	4.21756381	0.032	800
24.18741751	0.0041	300	4.181558256	0.0325	800
24.9345898	0.0046	300	4.144216887	0.033	800
25.36395576	0.0051	300	4.105667955	0.0335	800
25.5	0.0056	300	4.066034527	0.034	800
25.37628343	0.0061	300	4.025434349	0.0345	800
25.03171953	0.0066	300	3.983979764	0.035	800
24.50706663	0.0071	300	3.941777662	0.0355	800
23.84204947	0.0076	300	3.898929479	0.036	800

23.07329716	0.0081	300	3.85553123	0.0365	800
22.23309609	0.0086	300	3.811673565	0.037	800
21.34883721	0.0091	300	3.76744186	0.0375	800
20.44298463	0.0096	300	3.722916328	0.038	800
19.53338997	0.0101	300	3.678172145	0.0385	800
18.63380282	0.0106	300	3.633279599	0.039	800
17.75446407	0.0111	300	3.588304248	0.0395	800
16.90270552	0.0116	300	3.543307087	0.04	800
16.0835088	0.0121	300	0.717131474	0	900
15.3	0.0126	300	0.787805722	0.0005	900
14.55387087	0.0131	300	0.858069027	0.001	900
13.84572765	0.0136	300	0.927846089	0.0015	900
13.17537345	0.0141	300	0.99705631	0.002	900
12.54203262	0.0146	300	1.065614208	0.0025	900
11.94452625	0.0151	300	1.133429885	0.003	900
11.38140739	0.0156	300	1.200409551	0.0035	900
10.85106383	0.0161	300	1.266456112	0.004	900
10.35179503	0.0166	300	1.331469795	0.0045	900
9.881868866	0.0171	300	1.395348837	0.005	900
9.439562624	0.0176	300	1.457990211	0.0055	900
9.023191939	0.0181	300	1.519290384	0.006	900
8.631130555	0.0186	300	1.579146117	0.0065	900
8.261823167	0.0191	300	1.637455273	0.007	900
7.913793103	0.0196	300	1.694117647	0.0075	900
7.585646214	0.0201	300	1.749035788	0.008	900
7.276071996	0.0206	300	1.802115817	0.0085	900
6.983842754	0.0211	300	1.853268224	0.009	900
6.707811406	0.0216	300	1.902408624	0.0095	900
6.446908362	0.0221	300	1.949458484	0.01	900
6.200137836	0.0226	300	1.99434578	0.0105	900
5.966573816	0.0231	300	2.037005602	0.011	900
5.745355895	0.0236	300	2.077380682	0.0115	900
5.535685071	0.0241	300	2.11542184	0.012	900
5.336819625	0.0246	300	2.151088348	0.0125	900
5.14807113	0.0251	300	2.184348201	0.013	900
4.968800628	0.0256	300	2.215178295	0.0135	900
4.798415017	0.0261	300	2.243564512	0.014	900
6.72310757	0	400	2.269501712	0.0145	900
8.372093023	0.0005	400	2.292993631	0.015	900
9.990133202	0.001	400	2.314052696	0.0155	900
11.56458423	0.0015	400	2.332699761	0.016	900
13.08139535	0.002	400	2.348963755	0.0165	900

14.52567398	0.0025	400	2.362881283	0.017	900
15.88235294	0.003	400	2.374496152	0.0175	900
17.13692228	0.0035	400	2.383858857	0.018	900
18.27617329	0.004	400	2.391026021	0.0185	900
19.28889377	0.0045	400	2.396059813	0.019	900
20.16645327	0.005	400	2.399027333	0.0195	900
20.90322581	0.0055	400	2.4	0.02	900
21.49681529	0.006	400	2.399052923	0.0205	900
21.94807058	0.0065	400	2.396264285	0.021	900
22.26090143	0.007	400	2.391714739	0.0215	900
22.44192659	0.0075	400	2.385486816	0.022	900
22.5	0.008	400	2.377664365	0.0225	900
22.44566723	0.0085	400	2.368332018	0.023	900
22.29060342	0.009	400	2.357574685	0.0235	900
22.04707637	0.0095	400	2.345477093	0.024	900
21.72746781	0.01	400	2.332123352	0.0245	900
21.34387352	0.0105	400	2.317596567	0.025	900
20.90779128	0.011	400	2.301978486	0.0255	900
20.42989659	0.0115	400	2.285349192	0.026	900
19.91989882	0.012	400	2.267786828	0.0265	900
19.38646661	0.0125	400	2.249367365	0.027	900
18.8372093	0.013	400	2.230164403	0.0275	900
18.27870105	0.0135	400	2.210249007	0.028	900
17.71653543	0.014	400	2.189689576	0.0285	900
17.15539981	0.0145	400	2.168551748	0.029	900
16.599161	0.015	400	2.14689832	0.0295	900
16.05095541	0.0155	400	2.124789207	0.03	900
15.51327886	0.016	400	2.102281419	0.0305	900
14.98807255	0.0165	400	2.079429056	0.031	900
14.47680325	0.017	400	2.056283323	0.0315	900
13.98053612	0.0175	400	2.032892568	0.032	900
13.5	0.018	400	2.009302326	0.0325	900
13.03564489	0.0185	400	1.985555375	0.033	900
12.58769203	0.019	400	1.961691811	0.0335	900
12.15617703	0.0195	400	1.937749119	0.034	900
11.74098672	0.02	400	1.913762266	0.0345	900
11.34189032	0.0205	400	1.88976378	0.035	900
10.95856568	0.021	400	1.865783853	0.0355	900
10.59062117	0.0215	400	1.841850436	0.036	900
10.23761375	0.022	400	1.817989333	0.0365	900
9.899063966	0.0225	400	1.794224307	0.037	900
9.574468085	0.023	400	1.770577173	0.0375	900

9.263308017	0.0235	400	0.358565737	0	1000
8.965059256	0.024	400	0.393902861	0.0055	1000
8.67919722	0.0245	400	0.429034513	0.006	1000
8.405202232	0.025	400	0.463923044	0.0065	1000
8.1425634	0.0255	400	0.498528155	0.007	1000
7.890781563	0.026	400	0.532807104	0.0075	1000
7.649371499	0.0265	400	0.566714942	0.008	1000
7.417863504	0.027	400	0.600204776	0.0085	1000
7.19580448	0.0275	400	0.633228056	0.009	1000
6.982758621	0.028	400	0.665734897	0.0095	1000
5.73217306	0	500	0.697674419	0.01	1000
6.260235909	0.0003	500	0.728995105	0.0105	1000
7.132374523	0.0008	500	0.759645192	0.011	1000
7.992106561	0.0013	500	0.789573058	0.0115	1000
8.836363636	0.0018	500	0.818727637	0.012	1000
9.661853211	0.0023	500	0.847058824	0.0125	1000
10.46511628	0.0028	500	0.874517894	0.013	1000
11.24259302	0.0033	500	0.901057909	0.0135	1000
11.99069505	0.0038	500	0.926634112	0.014	1000
12.70588235	0.0043	500	0.951204312	0.0145	1000
13.3847425	0.0048	500	0.974729242	0.015	1000
14.02406939	0.0053	500	0.99717289	0.0155	1000
14.62093863	0.0058	500	1.018502801	0.016	1000
15.17277642	0.0063	500	1.038690341	0.0165	1000
15.67741935	0.0068	500	1.05771092	0.017	1000
16.13316261	0.0073	500	1.075544174	0.0175	1000
16.5387947	0.0078	500	1.092174101	0.018	1000
16.89361766	0.0083	500	1.107589148	0.0185	1000
17.19745223	0.0088	500	1.121782256	0.019	1000
17.45062837	0.0093	500	1.134750856	0.0195	1000
17.65396222	0.0098	500	1.146496815	0.02	1000
17.80872114	0.0103	500	1.157026348	0.0205	1000
17.91657889	0.0108	500	1.16634988	0.021	1000
17.97956346	0.0113	500	1.174481877	0.0215	1000
18	0.0118	500	1.181440642	0.022	1000
17.98045136	0.0123	500	1.187248076	0.0225	1000
17.92365849	0.0128	500	1.191929429	0.023	1000
17.83248274	0.0133	500	1.195513011	0.0235	1000
17.70985167	0.0138	500	1.198029906	0.024	1000
17.55870968	0.0143	500	1.199513667	0.0245	1000
17.38197425	0.0148	500	1.2	0.025	1000
17.18249835	0.0153	500	1.199526461	0.0255	1000

16.96303917	0.0158	500	1.198132143	0.026	1000
16.72623302	0.0163	500	1.19585737	0.0265	1000
16.47457627	0.0168	500	1.192743408	0.027	1000
16.21041157	0.0173	500	1.188832183	0.0275	1000
15.93591906	0.0178	500	1.184166009	0.028	1000
15.65311182	0.0183	500	1.178787343	0.0285	1000
15.36383492	0.0188	500	1.172738547	0.029	1000
15.06976744	0.0193	500	1.166061676	0.0295	1000
14.77242692	0.0198	500	1.158798283	0.03	1000
14.47317565	0.0203	500	1.150989243	0.0305	1000
14.17322835	0.0208	500	1.142674596	0.031	1000
13.87366078	0.0213	500	1.133893414	0.0315	1000
13.57541899	0.0218	500	1.124683683	0.032	1000
13.2793288	0.0223	500	1.115082202	0.0325	1000
12.9861054	0.0228	500	1.105124503	0.033	1000
12.69636282	0.0233	500	1.094844788	0.0335	1000
12.41062308	0.0238	500	1.084275874	0.034	1000
12.12932501	0.0243	500	1.07344916	0.0345	1000
11.85283256	0.0248	500	1.062394604	0.035	1000
11.5814426	0.0253	500	1.05114071	0.0355	1000
11.31539227	0.0258	500	1.039714528	0.036	1000
11.05486566	0.0263	500	1.028141661	0.0365	1000
10.8	0.0268	500	1.016446284	0.037	1000
10.55089134	0.0273	500	1.004651163	0.0375	1000
10.30759968	0.0278	500	0.992777687	0.038	1000
10.07015363	0.0283	500	0.980845905	0.0385	1000
9.838554583	0.0288	500	0.96887456	0.039	1000
9.612780525	0.0293	500	0.956881133	0.0395	1000
4.033864542	0	600	0.94488189	0.04	1000
4.431407188	0.0011	600	0.932891927	0.0405	1000
4.826638276	0.0016	600	0.920925218	0.041	1000
5.219134248	0.0021	600	0.908994667	0.0415	1000
5.608441743	0.0026	600	0.897112153	0.042	1000
5.994079921	0.0031	600	0.885288587	0.0425	1000
6.375543102	0.0036	600	0.873533953	0.043	1000
6.752303727	0.0041	600	0.861857363	0.0435	1000
7.123815629	0.0046	600	0.850267104	0.044	1000
7.489517595	0.0051	600	0.838770683	0.0445	1000
7.848837209	0.0056	600	0.827374872	0.045	1000
8.201194935	0.0061	600	0.345119522	0	1005.988
8.54600841	0.0066	600	0.412945719	0.006	1005.988
8.882696907	0.0071	600	0.479833349	0.007	1005.988

9.210685912	0.0076	600	0.545463132	0.008	1005.988
9.529411765	0.0081	600	0.609482004	0.009	1005.988
9.838326307	0.0086	600	0.671511628	0.01	1005.988
10.13690147	0.0091	600	1.103503185	0.02	1005.988
10.42463376	0.0096	600	1.155	0.025	1005.988
10.70104851	0.0101	600	1.115343348	0.03	1005.988
10.96570397	0.0106	600	0.909448819	0.04	1005.988
11.21819501	0.0111	600	0.793622029	0.045125	1005.988
11.45815651	0.0116	600			
11.68526633	0.0121	600			
11.89924785	0.0126	600			
12.09987196	0.0131	600			
12.28695863	0.0136	600			
12.46037791	0.0141	600			
12.62005038	0.0146	600			
12.76594713	0.0151	600			
12.89808917	0.0156	600			
13.01654642	0.0161	600			
13.12143615	0.0166	600			
13.21292112	0.0171	600			
13.29120722	0.0176	600			

Table B-1-5 compression damage properties of concrete

Compresion damage	Inelastic strain	Tempreture	Compresion damage	Inelastic strain	Tempreture
0	0	20	0.176703657	0.0146	600
0.006900437	0.0002	20	0.188539978	0.0151	600
0.012184545	0.0003	20	0.200636934	0.0156	600
0.018887567	0.0004	20	0.212971229	0.0161	600
0.027131954	0.0005	20	0.225518987	0.0166	600
0.093862975	0.001	20	0.238255932	0.0171	600
0.200637083	0.0015	20	0.251157565	0.0176	600
0.330666784	0.002	20	0.264199333	0.0181	600
0.461373485	0.0025	20	0.277356788	0.0186	600
0.576728573	0.003	20	0.290605747	0.0191	600
0.670603732	0.0035	20	0.303922431	0.0196	600
0.74361598	0.004	20	0.317283598	0.0201	600
0.799200035	0.0045	20	0.33066666	0.0206	600
0.84123975	0.005	20	0.344049793	0.0211	600
0.873104168	0.0055	20	0.357412028	0.0216	600
0.897425437	0.006	20	0.370733327	0.0221	600

0.916165679	0.0065	20	0.383994653	0.0226	600
0.930758633	0.007	20	0.397178018	0.0231	600
0.942245753	0.0075	20	0.410266525	0.0236	600
0.951384862	0.008	20	0.423244394	0.0241	600
0.958730688	0.0085	20	0.436096976	0.0246	600
0.964692649	0.009	20	0.448810765	0.0251	600
0.969575763	0.0095	20	0.461373385	0.0256	600
0.973609509	0.01	20	0.473773583	0.0261	600
0.976968255	0.0105	20	0.486001207	0.0266	600
0.979785781	0.011	20	0.498047178	0.0271	600
0.982165699	0.0115	20	0.50990346	0.0276	600
0.984188979	0.012	20	0.521563016	0.0281	600
0.985919446	0.0125	20	0.533019776	0.0286	600
0.987407818	0.013	20	0.544268583	0.0291	600
0.988694714	0.0135	20	0.555305152	0.0296	600
0.9898129	0.014	20	0.566126019	0.0301	600
0.990788992	0.0145	20	0.576728495	0.0306	600
0.991644754	0.015	20	0	0	700
0.992398087	0.0155	20	0.001316978	0.0005	700
0.993063809	0.016	20	0.002892	0.001	700
0.993654246	0.0165	20	0.004746279	0.0015	700
0.994179711	0.017	20	0.006900252	0.002	700
0.994648873	0.0175	20	0.009373448	0.0025	700
0.995069054	0.018	20	0.012184361	0.003	700
0.995446465	0.0185	20	0.015350325	0.0035	700
0.9957864	0.019	20	0.018887385	0.004	700
0.996093386	0.0195	20	0.02281017	0.0045	700
0	0	100	0.027131773	0.005	700
0.001685776	0.0001	100	0.031863633	0.0055	700
0.003783009	0.0002	100	0.037015428	0.006	700
0.021792641	0.0007	100	0.042594977	0.0065	700
0.055058884	0.0012	100	0.048608153	0.007	700
0.105225471	0.0017	100	0.055058814	0.0075	700
0.170890376	0.0022	100	0.061948745	0.008	700
0.247918117	0.0027	100	0.069277624	0.0085	700
0.33066671	0.0032	100	0.077042998	0.009	700
0.413522	0.0037	100	0.085240288	0.0095	700
0.492047463	0.0042	100	0.093862806	0.01	700
0.563441217	0.0047	100	0.1029018	0.0105	700
0.626418629	0.0052	100	0.112346508	0.011	700
0.680814674	0.0057	100	0.122184248	0.0115	700
0.727150761	0.0062	100	0.132400511	0.012	700

0.766288717	0.0067	100	0.142979078	0.0125	700
0.799200013	0.0072	100	0.153902154	0.013	700
0.826832418	0.0077	100	0.165150514	0.0135	700
0.85004435	0.0082	100	0.176703657	0.014	700
0.869580625	0.0087	100	0.188539978	0.0145	700
0.886070929	0.0092	100	0.200636934	0.015	700
0.900039287	0.0097	100	0.212971229	0.0155	700
0.911917758	0.0102	100	0.225518987	0.016	700
0.922060804	0.0107	100	0.238255932	0.0165	700
0.930758625	0.0112	100	0.251157565	0.017	700
0.938248788	0.0117	100	0.264199333	0.0175	700
0.944726025	0.0122	100	0.277356788	0.018	700
0.950350319	0.0127	100	0.290605747	0.0185	700
0.955253485	0.0132	100	0.303922431	0.019	700
0.959544488	0.0137	100	0.317283598	0.0195	700
0.963313733	0.0142	100	0.33066666	0.02	700
0.96663651	0.0147	100	0.344049793	0.0205	700
0.96957576	0.0152	100	0.357412028	0.021	700
0.972184304	0.0157	100	0.370733327	0.0215	700
0.974506647	0.0162	100	0.383994653	0.022	700
0.976580425	0.0167	100	0.397178018	0.0225	700
0.978437585	0.0172	100	0.410266525	0.023	700
0.980105348	0.0177	100	0.423244394	0.0235	700
0.981606986	0.0182	100	0.436096976	0.024	700
0.982962466	0.0187	100	0.448810765	0.0245	700
0.984188977	0.0192	100	0.461373385	0.025	700
0.985301366	0.0197	100	0.473773583	0.0255	700
0.986312494	0.0202	100	0.486001207	0.026	700
0.987233538	0.0207	100	0.498047178	0.0265	700
0.98807424	0.0212	100	0.50990346	0.027	700
0.988843113	0.0217	100	0.521563016	0.0275	700
0	0	200	0.533019776	0.028	700
0.006081041	0.0004	200	0.544268583	0.0285	700
0.019571504	0.0009	200	0.555305152	0.029	700
0.04103047	0.0014	200	0.566126019	0.0295	700
0.0713523	0.0019	200	0.576728495	0.03	700
0.110599641	0.0024	200	0.587110609	0.0305	700
0.157955866	0.0029	200	0.597271066	0.031	700
0.211840731	0.0034	200	0.607209194	0.0315	700
0.2701671	0.0039	200	0.616924895	0.032	700
0.330666647	0.0044	200	0.626418601	0.0325	700
0.391196337	0.0049	200	0	0	800

0.449959234	0.0054	200	0.001316978	0.0055	800
0.505614488	0.0059	200	0.002892	0.006	800
0.557288706	0.0064	200	0.004746279	0.0065	800
0.604520852	0.0069	200	0.006900252	0.007	800
0.647175171	0.0074	200	0.009373448	0.0075	800
0.685348707	0.0079	200	0.012184361	0.008	800
0.719289142	0.0084	200	0.015350325	0.0085	800
0.749329574	0.0089	200	0.018887385	0.009	800
0.775840973	0.0094	200	0.02281017	0.0095	800
0.799199994	0.0099	200	0.027131773	0.01	800
0.819768826	0.0104	200	0.031863633	0.0105	800
0.837883775	0.0109	200	0.037015428	0.011	800
0.853849834	0.0114	200	0.042594977	0.0115	800
0.86793912	0.0119	200	0.048608153	0.012	800
0.880391672	0.0124	200	0.055058814	0.0125	800
0.891417564	0.0129	200	0.061948745	0.013	800
0.901199657	0.0134	200	0.069277624	0.0135	800
0.909896565	0.0139	200	0.077042998	0.014	800
0.917645577	0.0144	200	0.085240288	0.0145	800
0.924565394	0.0149	200	0.093862806	0.015	800
0.930758619	0.0154	200	0.1029018	0.0155	800
0.936313967	0.0159	200	0.112346508	0.016	800
0.941308209	0.0164	200	0.122184248	0.0165	800
0.945807858	0.0169	200	0.132400511	0.017	800
0.949870617	0.0174	200	0.142979078	0.0175	800
0.953546632	0.0179	200	0.153902154	0.018	800
0.956879559	0.0184	200	0.165150514	0.0185	800
0.959907472	0.0189	200	0.176703657	0.019	800
0.962663648	0.0194	200	0.188539978	0.0195	800
0.965177224	0.0199	200	0.200636934	0.02	800
0.967473767	0.0204	200	0.212971229	0.0205	800
0.969575757	0.0209	200	0.225518987	0.021	800
0.971503001	0.0214	200	0.238255932	0.0215	800
0.973272985	0.0219	200	0.251157565	0.022	800
0.974901178	0.0224	200	0.264199333	0.0225	800
0.976401292	0.0229	200	0.277356788	0.023	800
0.977785505	0.0234	200	0.290605747	0.0235	800
0.979064654	0.0239	200	0.303922431	0.024	800
0	0	300	0.317283598	0.0245	800
0.000915386	0.0001	300	0.33066666	0.025	800
0.007573551	0.0006	300	0.344049793	0.0255	800
0.018358873	0.0011	300	0.357412028	0.026	800

0.034019697	0.0016	300	0.370733327	0.0265	800
0.055058884	0.0021	300	0.383994653	0.027	800
0.081674725	0.0026	300	0.397178018	0.0275	800
0.113728221	0.0031	300	0.410266525	0.028	800
0.15074728	0.0036	300	0.423244394	0.0285	800
0.191970722	0.0041	300	0.436096976	0.029	800
0.236425769	0.0046	300	0.448810765	0.0295	800
0.28302516	0.0051	300	0.461373385	0.03	800
0.33066671	0.0056	300	0.473773583	0.0305	800
0.378319796	0.0061	300	0.486001207	0.031	800
0.425088518	0.0066	300	0.498047178	0.0315	800
0.470247895	0.0071	300	0.50990346	0.032	800
0.513255155	0.0076	300	0.521563016	0.0325	800
0.553741666	0.0081	300	0.533019776	0.033	800
0.591492316	0.0086	300	0.544268583	0.0335	800
0.626418629	0.0091	300	0.555305152	0.034	800
0.658530513	0.0096	300	0.566126019	0.0345	800
0.687909847	0.0101	300	0.576728495	0.035	800
0.714687674	0.0106	300	0.587110609	0.0355	800
0.739025641	0.0111	300	0.597271066	0.036	800
0.761101646	0.0116	300	0.607209194	0.0365	800
0.781099215	0.0121	300	0.616924895	0.037	800
0.799200013	0.0126	300	0.626418601	0.0375	800
0.815578818	0.0131	300	0.635691225	0.038	800
0.830400405	0.0136	300	0.64474412	0.0385	800
0.843817805	0.0141	300	0.653579036	0.039	800
0.855971569	0.0146	300	0.662198078	0.0395	800
0.866989701	0.0151	300	0.670603671	0.04	800
0.876988041	0.0156	300	0	0	900
0.886070929	0.0161	300	0.001317024	0.0005	900
0.89433201	0.0166	300	0.002892046	0.001	900
0.901855121	0.0171	300	0.004746326	0.0015	900
0.908715181	0.0176	300	0.006900299	0.002	900
0.914979066	0.0181	300	0.009373494	0.0025	900
0.920706429	0.0186	300	0.012184407	0.003	900
0.925950468	0.0191	300	0.015350371	0.0035	900
0.930758625	0.0196	300	0.01888743	0.004	900
0.935173226	0.0201	300	0.022810215	0.0045	900
0.939232049	0.0206	300	0.027131818	0.005	900
0.942968838	0.0211	300	0.031863678	0.0055	900
0.946413759	0.0216	300	0.037015473	0.006	900
0.949593804	0.0221	300	0.042595022	0.0065	900

0.952533153	0.0226	300	0.048608197	0.007	900
0.955253485	0.0231	300	0.055058858	0.0075	900
0.957774265	0.0236	300	0.061948789	0.008	900
0.96011299	0.0241	300	0.069277667	0.0085	900
0.962285404	0.0246	300	0.077043041	0.009	900
0.964305693	0.0251	300	0.085240331	0.0095	900
0.966186658	0.0256	300	0.093862849	0.01	900
0.967939861	0.0261	300	0.102901841	0.0105	900
0	0	400	0.112346549	0.011	900
0.003783009	0.0005	400	0.122184289	0.0115	900
0.009373522	0.001	400	0.132400551	0.012	900
0.017071592	0.0015	400	0.142979118	0.0125	900
0.027131845	0.002	400	0.153902193	0.013	900
0.039751391	0.0025	400	0.165150553	0.0135	900
0.055058884	0.003	400	0.176703696	0.014	900
0.073106054	0.0035	400	0.188540016	0.0145	900
0.093862874	0.004	400	0.200636972	0.015	900
0.11721718	0.0045	400	0.212971266	0.0155	900
0.142979141	0.005	400	0.225519023	0.016	900
0.170890376	0.0055	400	0.238255967	0.0165	900
0.200636994	0.006	400	0.2511576	0.017	900
0.231865396	0.0065	400	0.264199367	0.0175	900
0.264199388	0.007	400	0.277356822	0.018	900
0.297257143	0.0075	400	0.29060578	0.0185	900
0.33066671	0.008	400	0.303922464	0.019	900
0.364079056	0.0085	400	0.317283629	0.0195	900
0.397178063	0.009	400	0.330666691	0.02	900
0.429687259	0.0095	400	0.344049824	0.0205	900
0.461373425	0.01	400	0.357412058	0.021	900
0.492047463	0.0105	400	0.370733357	0.0215	900
0.521563052	0.011	400	0.383994682	0.022	900
0.549813666	0.0115	400	0.397178046	0.0225	900
0.576728526	0.012	400	0.410266553	0.023	900
0.60226797	0.0125	400	0.42324442	0.0235	900
0.626418629	0.013	400	0.436097003	0.024	900
0.649188728	0.0135	400	0.448810791	0.0245	900
0.670603696	0.014	400	0.46137341	0.025	900
0.690702217	0.0145	400	0.473773607	0.0255	900
0.709532783	0.015	400	0.486001231	0.026	900
0.727150761	0.0155	400	0.498047202	0.0265	900
0.743615951	0.016	400	0.509903482	0.027	900
0.758990608	0.0165	400	0.521563038	0.0275	900

0.773337863	0.017	400	0.533019797	0.028	900
0.786720496	0.0175	400	0.544268604	0.0285	900
0.799200013	0.018	400	0.555305172	0.029	900
0.810835966	0.0185	400	0.56612604	0.0295	900
0.821685475	0.019	400	0.576728514	0.03	900
0.831802915	0.0195	400	0.587110628	0.0305	900
0.841239732	0.02	400	0.597271085	0.031	900
0.85004435	0.0205	400	0.607209212	0.0315	900
0.858262168	0.021	400	0.616924913	0.032	900
0.865935597	0.0215	400	0.626418618	0.0325	900
0.873104154	0.022	400	0.635691242	0.033	900
0.87980457	0.0225	400	0.644744137	0.0335	900
0.886070929	0.023	400	0.653579052	0.034	900
0.891934807	0.0235	400	0.662198093	0.0345	900
0.897425425	0.024	400	0.670603686	0.035	900
0.902569801	0.0245	400	0.678798539	0.0355	900
0.907392894	0.025	400	0.686785608	0.036	900
0.911917758	0.0255	400	0.694568068	0.0365	900
0.91616567	0.026	400	0.702149283	0.037	900
0.920156273	0.0265	400	0.709532775	0.0375	900
0.923907694	0.027	400	0	0	1000
0.927436663	0.0275	400	0.001317024	0.0055	1000
0.930758625	0.028	400	0.002892046	0.006	1000
0	0	500	0.004746326	0.0065	1000
0.001487837	0.0003	500	0.006900299	0.007	1000
0.004583459	0.0008	500	0.009373494	0.0075	1000
0.008530277	0.0013	500	0.012184407	0.008	1000
0.013415519	0.0018	500	0.015350371	0.0085	1000
0.019317445	0.0023	500	0.01888743	0.009	1000
0.026303717	0.0028	500	0.022810215	0.0095	1000
0.034429837	0.0033	500	0.027131818	0.01	1000
0.043737726	0.0038	500	0.031863678	0.0105	1000
0.054254528	0.0043	500	0.037015473	0.011	1000
0.065991695	0.0048	500	0.042595022	0.0115	1000
0.078944436	0.0053	500	0.048608197	0.012	1000
0.093091549	0.0058	500	0.055058858	0.0125	1000
0.108395694	0.0063	500	0.061948789	0.013	1000
0.124804089	0.0068	500	0.069277667	0.0135	1000
0.142249625	0.0073	500	0.077043041	0.014	1000
0.160652356	0.0078	500	0.085240331	0.0145	1000
0.179921313	0.0083	500	0.093862849	0.015	1000
0.199956557	0.0088	500	0.102901841	0.0155	1000

0.220651397	0.0093	500	0.112346549	0.016	1000
0.241894679	0.0098	500	0.122184289	0.0165	1000
0.263573057	0.0103	500	0.132400551	0.017	1000
0.285573172	0.0108	500	0.142979118	0.0175	1000
0.307783663	0.0113	500	0.153902193	0.018	1000
0.330096957	0.0118	500	0.165150553	0.0185	1000
0.352410802	0.0123	500	0.176703696	0.019	1000
0.374629513	0.0128	500	0.188540016	0.0195	1000
0.396664927	0.0133	500	0.200636972	0.02	1000
0.418437082	0.0138	500	0.212971266	0.0205	1000
0.439874617	0.0143	500	0.225519023	0.021	1000
0.460914933	0.0148	500	0.238255967	0.0215	1000
0.481504147	0.0153	500	0.2511576	0.022	1000
0.501596862	0.0158	500	0.264199367	0.0225	1000
0.521155795	0.0163	500	0.277356822	0.023	1000
0.540151301	0.0168	500	0.29060578	0.0235	1000
0.558560812	0.0173	500	0.303922464	0.024	1000
0.576368228	0.0178	500	0.317283629	0.0245	1000
0.593563285	0.0183	500	0.330666691	0.025	1000
0.610140918	0.0188	500	0.344049824	0.0255	1000
0.626100627	0.0193	500	0.357412058	0.026	1000
0.641445879	0.0198	500	0.370733357	0.0265	1000
0.656183532	0.0203	500	0.383994682	0.027	1000
0.670323306	0.0208	500	0.397178046	0.0275	1000
0.683877293	0.0213	500	0.410266553	0.028	1000
0.696859517	0.0218	500	0.42324442	0.0285	1000
0.70928553	0.0223	500	0.436097003	0.029	1000
0.721172067	0.0228	500	0.448810791	0.0295	1000
0.732536727	0.0233	500	0.46137341	0.03	1000
0.743397711	0.0238	500	0.473773607	0.0305	1000
0.753773584	0.0243	500	0.486001231	0.031	1000
0.763683078	0.0248	500	0.498047202	0.0315	1000
0.773144923	0.0253	500	0.509903482	0.032	1000
0.782177709	0.0258	500	0.521563038	0.0325	1000
0.79079977	0.0263	500	0.533019797	0.033	1000
0.799029087	0.0268	500	0.544268604	0.0335	1000
0.806883218	0.0273	500	0.555305172	0.034	1000
0.814379237	0.0278	500	0.56612604	0.0345	1000
0.821533689	0.0283	500	0.576728514	0.035	1000
0.828362561	0.0288	500	0.587110628	0.0355	1000
0.834881258	0.0293	500	0.597271085	0.036	1000
0	0	600	0.607209212	0.0365	1000

0.001316978	0.0011	600	0.616924913	0.037	1000
0.002892	0.0016	600	0.626418618	0.0375	1000
0.004746279	0.0021	600	0.635691242	0.038	1000
0.006900252	0.0026	600	0.644744137	0.0385	1000
0.009373448	0.0031	600	0.653579052	0.039	1000
0.012184361	0.0036	600	0.662198093	0.0395	1000
0.015350325	0.0041	600	0.670603686	0.04	1000
0.018887385	0.0046	600	0.678798539	0.0405	1000
0.02281017	0.0051	600	0.686785608	0.041	1000
0.027131773	0.0056	600	0.694568068	0.0415	1000
0.031863633	0.0061	600	0.702149283	0.042	1000
0.037015428	0.0066	600	0.709532775	0.0425	1000
0.042594977	0.0071	600	0.716722204	0.043	1000
0.048608153	0.0076	600	0.723721341	0.0435	1000
0.055058814	0.0081	600	0.730534046	0.044	1000
0.061948745	0.0086	600	0.737164253	0.0445	1000
0.069277624	0.0091	600	0.743615944	0.045	1000
0.077042998	0.0096	600	0	0	1005.988
0.085240288	0.0101	600	0.002891947	0.006	1005.988
0.093862806	0.0106	600	0.0069002	0.007	1005.988
0.1029018	0.0111	600	0.012184309	0.008	1005.988
0.112346508	0.0116	600	0.018887333	0.009	1005.988
0.122184248	0.0121	600	0.027131721	0.01	1005.988
0.132400511	0.0126	600	0.200636892	0.02	1005.988
0.142979078	0.0131	600	0.330666624	0.025	1005.988
0.153902154	0.0136	600	0.461373356	0.03	1005.988
0.165150514	0.0141	600	0.670603654	0.04	1005.988
0.176703657	0.0146	600	0.745201419	0.045125	1005.988

Mechanical properties of steel

Table B-2-1 young's modulus of steel

young modulus of steel(Es)	poisson ratio(v)	Temperature(^oC)
210000	0.3	20
210000	0.3	100
182700	0.3	200
151200	0.3	300
117600	0.3	400
84000	0.3	500
50400	0.3	600
16800	0.3	700

12600	0.3	800
10500	0.3	900
6300	0.3	1000
4200	0.3	1100

Table B-2-2 Expansion Coefficient of steel

Expansion coefficient,a(1/^{o}C)	Temperature(^{o}C)
0	20
1.25E-05	100
1.29E-05	200
1.33E-05	300
1.37E-05	400
1.41E-05	500
1.45E-05	600
1.51E-05	700
1.31E-05	800
1.34E-05	900
1.41E-05	1000
1.46E-05	1100
1.51E-05	1200

Table B-2-3 Compression hardening of steel

yield stress (MPa)	plastic strain	Temperature(^{o}C)
1466.205	0	20
1518.75	0.000481	20
1573.441	0.001481	20
1609.257	0.002481	20
1725	0.012481	20
996.9687	0	100
1121.22	0.000783	100
1237.099	0.001783	100
1327.258	0.002783	100
1400.86	0.003783	100
1462.348	0.004783	100
1707.75	0.014783	100
747.7874	0	200
885.3922	0.000907	200
998.0007	0.001907	200
1087.692	0.002907	200
1162.029	0.003907	200

1224.903	0.004907	200
1278.628	0.005907	200
1500.75	0.015907	200
469.1544	0	300
512.2501	0.000266	300
642.7159	0.001266	300
743.3284	0.002266	300
825.7578	0.003266	300
895.3262	0.004266	300
954.9971	0.005266	300
1006.62	0.006266	300
1051.438	0.007266	300
1242	0.017266	300
190.6141	0	400
289.5309	0.000793	400
376.5285	0.001793	400
443.7021	0.002793	400
498.8763	0.003793	400
545.6014	0.004793	400
585.8497	0.005793	400
620.8514	0.006793	400
651.4327	0.007793	400
678.1785	0.008793	400
793.5	0.018793	400
102.6375	0	500
105.2345	2.53E-05	500
167.6834	0.001025	500
205.1599	0.002025	500
233.6267	0.003025	500
256.8337	0.004025	500
276.4022	0.005025	500
293.2114	0.006025	500
307.8009	0.007025	500
320.5299	0.008025	500
331.6505	0.009025	500
379.5	0.019025	500
73.31255	0	600
78.2746	8.30E-05	600
101.9851	0.001083	600
114.7776	0.002083	600
124.3277	0.003083	600
132.0549	0.004083	600

138.5431	0.005083	600
144.1015	0.006083	600
148.917	0.007083	600
153.1127	0.008083	600
156.7746	0.009083	600
172.5	0.019083	600
43.98752	0	700
56.74176	0.000744	700
70.19137	0.001744	700
81.07108	0.002744	700
90.20529	0.003744	700
98.02973	0.004744	700
104.808	0.005744	700
110.7137	0.006744	700
115.8677	0.007744	700
138	0.017744	700
29.325	0	800
38.85383	0.002083	800
47.01821	0.003083	800
53.46635	0.004083	800
58.81147	0.005083	800
63.35418	0.006083	800
67.26856	0.007083	800
70.66599	0.008083	800
73.62259	0.009083	800
86.25	0.019083	800
14.6625	0	900
17.43081	0.000494	900
22.41217	0.001494	900
26.7216	0.002494	900
30.49355	0.003494	900
33.81753	0.004494	900
36.75655	0.005494	900
39.35677	0.006494	900
41.65306	0.007494	900
51.75	0.017494	900
0.733125	0	995
0.87154	0.000494	995
1.120609	0.001494	995
1.33608	0.002494	995
1.524677	0.003494	995
1.690877	0.004494	995

1.837827	0.005494	995
1.967838	0.006494	995
2.082653	0.007494	995
2.5875	0.017494	995

Appendix C Output from FE for thermal analysis of concrete column

Table C-1-1 Result from thermal analysis, nodal temperature at four node and temperature distribution along width.

30 minute

node 1		node 2089		node 2090		node 2109	
Time	temp.	time	temp.	time	temp.	time	temp.
0	0	0	0	0	0	0	0
0.2	53.5402	0.2	45.1588	0.2	20.0546	0.2	20.0256
0.4	61.0783	0.4	50.8154	0.4	20.0676	0.4	20.0331
0.6	69.8177	0.6	57.3745	0.6	20.0814	0.6	20.0399
1	91.3818	1	73.569	1	20.1148	1	20.0562
1.8	154.318	1.8	121.017	1.8	20.2033	1.8	20.0987
3	309.538	3	241.709	3	20.3727	3	20.1765
4.8	631.893	4.8	538.579	4.8	20.5968	4.8	20.2702
7.5	1058.64	7.5	1000.47	7.5	20.8297	7.5	20.3549
11.55	1581.49	11.55	1551.91	11.55	21.1445	11.55	20.4511
17.625	2290.75	17.625	2276.11	17.625	21.5901	17.625	20.58
26.7375	3312.93	26.7375	3305.83	26.7375	22.2973	26.7375	20.7595
39.4808	4722.02	39.4808	4718.51	39.4808	23.2814	39.4808	20.9942
52.224	6124.69	52.224	6122.6	52.224	24.2591	52.224	21.2513
64.9673	7137.43	64.9673	7135.89	64.9673	24.9631	64.9673	21.4592
77.7106	7542.69	77.7106	7541.31	77.7106	25.2447	77.7106	21.5426
90.4538	7947.87	90.4538	7946.63	90.4538	25.526	90.4538	21.6257
115.94	8758.08	115.94	8757.05	115.94	26.0882	115.94	21.792
161.226	9681.66	161.226	9680.82	161.226	26.7285	161.226	21.9816
206.512	10411.2	206.512	10410.5	206.512	27.2338	206.512	22.1314
251.798	11003.7	251.798	11003	251.798	27.6439	251.798	22.253
319.726	11702.1	319.726	11701.5	319.726	28.1271	319.726	22.3965
421.619	12524.7	421.619	12524.2	421.619	28.6956	421.619	22.5654
574.458	13434.6	574.458	13434.1	574.458	29.324	574.458	22.7524
727.298	14136.4	727.298	14136	727.298	29.8082	727.298	22.8966
956.557	14951	956.557	14950.7	956.557	30.3699	956.557	23.064
1185.82	15590	1185.82	15589.7	1185.82	30.8101	1185.82	23.1953
1529.7	16349.1	1529.7	16348.8	1529.7	31.3327	1529.7	23.3513

1800	16835.1	1800	16834.8	1800	31.6671	1800	23.4513

60 minute

node 1		node 2089		node 2090		node 2109	
Time	temp.	time	temp	time	temp	time	temp
0	0	0	0	0	0	0	0
0.2	53.5402	0.2	45.1588	0.2	20.0546	0.2	20.0256
0.4	61.0783	0.4	50.8154	0.4	20.0676	0.4	20.0331
0.6	69.8177	0.6	57.3745	0.6	20.0814	0.6	20.0399
1	91.3818	1	73.569	1	20.1148	1	20.0562
1.8	154.318	1.8	121.017	1.8	20.2033	1.8	20.0987
3	309.538	3	241.709	3	20.3727	3	20.1765
4.8	631.893	4.8	538.579	4.8	20.5968	4.8	20.2702
7.5	1058.64	7.5	1000.47	7.5	20.8297	7.5	20.3549
11.55	1581.49	11.55	1551.91	11.55	21.1445	11.55	20.4511
17.625	2290.75	17.625	2276.11	17.625	21.5901	17.625	20.58
26.7375	3312.93	26.7375	3305.83	26.7375	22.2973	26.7375	20.7595
40.4063	4824.02	40.4063	4820.65	40.4063	23.3525	40.4063	21.0114
60.9094	7008.37	60.9094	7006.77	60.9094	24.8734	60.9094	21.4326
87.9203	7867.32	87.9203	7866.05	87.9203	25.4701	87.9203	21.6092
114.931	8726	114.931	8724.97	114.931	26.066	114.931	21.7854
141.942	9310.02	141.942	9309.11	141.942	26.4709	141.942	21.9053
182.458	10077.6	182.458	10076.8	182.458	27.0028	182.458	22.0629
243.233	10910.8	243.233	10910.2	243.233	27.5797	243.233	22.234
334.395	11832.7	334.395	11832.2	334.395	28.2174	334.395	22.4233
471.138	12849.5	471.138	12849.1	471.138	28.92	471.138	22.6322
676.252	13919.4	676.252	13919	676.252	29.6586	676.252	22.852
983.923	15033.9	983.923	15033.6	983.923	30.427	983.923	23.081
1445.43	16180.5	1445.43	16180.2	1445.43	31.2166	1445.43	23.3167
2137.69	17348.1	2137.69	17347.9	2137.69	32.0199	2137.69	23.5567
3176.08	18531.5	3176.08	18531.2	3176.08	32.8329	3176.08	23.8001
3600	18906.1	3600	18905.9	3600	33.0901	3600	23.8772

90 minute

node 1		node 2089		node 2090		node 2109	
time	temp.	time	temp	time	temp	time	temp
0	0	0	0	0	0	0	0
0.2	53.5402	0.2	45.1588	0.2	20.0546	0.2	20.0256
0.4	61.0783	0.4	50.8154	0.4	20.0676	0.4	20.0331
0.6	69.8177	0.6	57.3745	0.6	20.0814	0.6	20.0399
1	91.3818	1	73.569	1	20.1148	1	20.0562
1.8	154.318	1.8	121.017	1.8	20.2033	1.8	20.0987
3	309.538	3	241.709	3	20.3727	3	20.1765
4.8	631.893	4.8	538.579	4.8	20.5968	4.8	20.2702
7.5	1058.64	7.5	1000.47	7.5	20.8297	7.5	20.3549
11.55	1581.49	11.55	1551.91	11.55	21.1445	11.55	20.4511
17.625	2290.75	17.625	2276.11	17.625	21.5901	17.625	20.58
26.7375	3312.93	26.7375	3305.83	26.7375	22.2973	26.7375	20.7595
40.4063	4824.02	40.4063	4820.65	40.4063	23.3525	40.4063	21.0114
60.9094	7008.37	60.9094	7006.77	60.9094	24.8734	60.9094	21.4326
91.6641	7986.35	91.6641	7985.12	91.6641	25.5528	91.6641	21.6336
137.796	9230.11	137.796	9229.19	137.796	26.4155	137.796	21.8889
183.928	10097.9	183.928	10097.2	183.928	27.0169	183.928	22.067
253.126	11018.1	253.126	11017.5	253.126	27.6539	253.126	22.256
356.923	12033.3	356.923	12032.8	356.923	28.3561	356.923	22.4645
512.619	13096.8	512.619	13096.4	512.619	29.0908	512.619	22.683
746.162	14211.1	746.162	14210.7	746.162	29.8597	746.162	22.9119
1096.48	15356.6	1096.48	15356.3	1096.48	30.6493	1096.48	23.1473
1621.95	16524.2	1621.95	16523.9	1621.95	31.4532	1621.95	23.3873
2410.16	17706.6	2410.16	17706.4	2410.16	32.2663	2410.16	23.6305
3592.47	18899.8	3592.47	18899.6	3592.47	33.0858	3592.47	23.8759
5365.94	20100.2	5365.94	20100	5365.94	33.9092	5365.94	24.1228
5400	20119.2	5400	20119	5400	33.9222	5400	24.1267

120 minute

node 1		node 2089		node 2090		node 2109	
time	temp.	time	temp	time	temp	time	temp
0	0	0	0	0	0	0	0
0.2	53.5402	0.2	45.1588	0.2	20.0546	0.2	20.0256
0.4	61.0783	0.4	50.8154	0.4	20.0676	0.4	20.0331
0.6	69.8177	0.6	57.3745	0.6	20.0814	0.6	20.0399
1	91.3818	1	73.569	1	20.1148	1	20.0562

1.8	154.318	1.8	121.017	1.8	20.2033	1.8	20.0987
3	309.538	3	241.709	3	20.3727	3	20.1765
4.8	631.893	4.8	538.579	4.8	20.5968	4.8	20.2702
7.5	1058.64	7.5	1000.47	7.5	20.8297	7.5	20.3549
11.55	1581.49	11.55	1551.91	11.55	21.1445	11.55	20.4511
17.625	2290.75	17.625	2276.11	17.625	21.5901	17.625	20.58
26.7375	3312.93	26.7375	3305.83	26.7375	22.2973	26.7375	20.7595
40.4063	4824.02	40.4063	4820.65	40.4063	23.3525	40.4063	21.0114
60.9094	7008.37	60.9094	7006.77	60.9094	24.8734	60.9094	21.4326
91.6641	7986.35	91.6641	7985.12	91.6641	25.5528	91.6641	21.6336
137.796	9230.11	137.796	9229.19	137.796	26.4155	137.796	21.8889
206.994	10417.9	206.994	10417.2	206.994	27.2385	206.994	22.1327
310.791	11622.5	310.791	11621.9	310.791	28.072	310.791	22.3801
466.487	12819	466.487	12818.5	466.487	28.8989	466.487	22.6259
700.03	14021.7	700.03	14021.3	700.03	29.7291	700.03	22.873
1050.35	15228.4	1050.35	15228	1050.35	30.561	1050.35	23.121
1575.82	16437.8	1575.82	16437.5	1575.82	31.3937	1575.82	23.3696
2364.03	17648.8	2364.03	17648.5	2364.03	32.2265	2364.03	23.6186
3546.34	18861.2	3546.34	18861	3546.34	33.0592	3546.34	23.8679
5319.81	20074.4	5319.81	20074.2	5319.81	33.8914	5319.81	24.1175
7200	20980.3	7200	20980.1	7200	34.5122	7200	24.3039

Appendix D output of stress misses, S11 , load and stress at the flange section 1

Table D-1-1 Results of Stress misses

width (mm)	30 minute	60 minute	90 minute	120 minute
0	1.36223	1.77188	2.49435	15.5341
51.8724	4.12304	1.72488	2.3713	10.9804
103.166	10.0396	2.912	2.68338	8.94434
154.278	20.3858	9.83343	9.00116	28.1517
204.142	20.9447	9.99734	9.14094	28.5511
255.18	10.7092	3.12588	2.88037	9.3412
306.483	4.24338	1.7643	2.4228	10.9826
350	1.3817	1.75078	2.48292	15.5436

Table D-1-2 Results of S11

Width(mm)	30 minute	60 minute	90 minute	120 minute
0	-11.4645	-9.85291	-10.3614	-8.98773
49.1414	-30.1366	-24.1721	-24.138	-22.2098
99.1556	-65.0594	-54.7397	-52.4641	-47.2551
148.92	-88.735	-79.0598	-76.1942	-65.3559
198.582	-89.5389	-79.8467	-77.0847	-65.4139
248.346	-66.1999	-55.8727	-54.0255	-47.3612
298.347	-30.4766	-24.6289	-25.0693	-22.8395
347.503	-11.4715	-10.0743	-10.8823	-8.99234

Table D-1-3 Results of Steel Flange stress

top flange(mm)	30 minute	60 minute	90 minute	120 minute
0	159.427	212.773	224.145	413.931
25.94	205.997	261.094	277.808	299.059
51.8844	241.913	309.8	329.231	192.733
77.879	262.978	318.569	338.333	237.183
103.88	205.844	291.226	317.497	233.955
129.9	110.855	246.447	274.524	194.114
155.92	201.796	287.834	314.113	233.093
181.922	258.468	314.86	334.668	236.231
207.917	239.881	308.005	327.443	192.17
233.863	202.715	258.621	275.969	298.2
250	154.839	209.549	222.248	412.897

Table D-1-4 Results of load

Width(mm)	30 minute	60 minute	90 minute	120 minute
0	6.79E+08	8.55E+08	1.36E+09	2.98E+08
51.8724	1.35E+09	1.68E+09	2.67E+09	5.93E+08
103.166	1.33E+09	1.65E+09	2.62E+09	5.89E+08
154.278	1.31E+09	1.62E+09	2.57E+09	5.85E+08
204.142	1.30E+09	1.62E+09	2.57E+09	5.85E+08
255.18	1.33E+09	1.65E+09	2.62E+09	5.89E+08
306.483	1.35E+09	1.68E+09	2.67E+09	5.93E+08
350	6.79E+08	8.54E+08	1.36E+09	2.98E+08

Table D-1-5 Result for section II stress misses

width	30 minute	60 minute	90 minute	120 minute
0	1.58762	1.80698	4.79659	2.22565
52.9657	2.64073	2.38586	3.84554	2.63265
104.723	2.94687	2.85485	3.08201	3.21453
156.828	5.2744	6.75173	15.8727	7.53652
206.701	4.94018	6.63457	16.5655	7.23561
258.293	3.35911	3.13765	3.06916	3.56422
309.89	3.32445	2.68005	2.89586	2.96352
350	1.46214	1.59545	4.30865	1.78564

Table D-1-6 Result for section II load

width	30 minute	60 minute	90 minute	120 minute
0	1.10E+09	1.40E+09	4.19E+08	1.40E+09
52.9657	2.15E+09	2.71E+09	8.25E+08	2.72E+09
104.723	2.09E+09	2.62E+09	8.10E+08	2.61E+09
156.828	2.03E+09	2.55E+09	7.97E+08	2.51E+09
206.701	2.03E+09	2.60E+09	7.95E+08	2.51E+09
258.293	2.09E+09	2.61E+09	8.08E+08	2.61E+09
309.89	2.15E+09	2.72E+09	6.08E+08	2.72E+09
362.753	1.10E+09	1.40E+09	4.20E+08	1.40E+09

Table D-1-7 Result for section II Flange steel stress output

width	30 minute	60 minute	90 minute	120 minute
0	205.629	308.625	303.443	309.82
25.3909	374.19	484.269	319.243	485.411
50.8086	549.718	652.703	329.068	654.144

76.2299	370.519	427.842	221.197	429.034
101.605	182.862	209.14	101.496	209.657
126.976	246.728	290.707	163.122	291.544
152.403	394.013	504.728	245.072	505.846
177.833	331.678	438.544	272.115	439.354
203.258	210.673	161.811	274.31	277.876

Table D-1-8 Result for section III stress misses out put

width	30 minute	60 minute	90 minute	120 minute
0	5.51663	8.429	8.2777	7.84539
49.1821	5.78055	8.89831	8.8064	8.36848
98.4869	4.52336	8.31015	8.34187	8.02176
148.058	4.00638	8.37494	8.45975	7.57843
197.396	4.00483	8.22619	7.5456	8.46036
246.967	4.50251	7.86919	7.98431	8.33775
296.271	5.74095	8.19891	8.34872	8.8228
345.466	5.47602	7.61462	7.80469	8.30383

Table D-1-9 Result for section III S11 output

width	30 minute	60 minute	90 minute	120 minute
0	2.40465	-0.46024	-0.46222	-0.47928
70.1162	1.80818	-1.01169	-1.01264	-1.02751
119.421	0.465133	-2.01536	-2.03716	-2.05029
168.992	-0.50953	-2.57566	-2.64216	-2.6507
218.33	-0.51153	-2.57627	-2.64882	-2.63739
267.901	0.456761	-2.01077	-2.04461	-2.01703
338.16	1.77418	-1.01532	-1.02302	-0.99691
408.322	2.15642	-0.47791	-0.48138	-0.45798

Table D-1-10 Result for section III Load out put

width	30 minute	60 minute	90 minute	120 minute
0	2.19E+09	3.12E+08	3.10E+08	3.09E+08
55.4077	4.24E+09	6.20E+08	6.16E+08	6.14E+08
108.741	4.01E+09	6.14E+08	6.09E+08	6.07E+08
161.669	3.75E+09	6.10E+08	6.06E+08	6.04E+08
211.156	3.75E+09	6.10E+08	6.06E+08	6.04E+08
264.086	4.01E+09	6.13E+08	6.09E+08	6.07E+08

317.413	4.24E+09	0	6.16E+08	6.14E+08
372.814	2.19E+09	3.12E+08	3.10E+08	3.09E+08

Table D-1-11 Result for section III Steel Flange stress

width	30 minute	60 minute	90 minute	120 minute
0	708.296	357.717	355.862	354.494
55.7797	24.3554	344.739	343.168	342.509
111.591	607.265	260.367	259.902	259.933
136.581	379.3	201.168	201.419	201.867
161.572	607.248	260.487	259.926	259.86
186.5	783.267	344.997	343.152	342.401
211.429	708.255	361.273	355.211	354.904

Appendix E output of deflection with different section

Table E-1-1 Result for deflection for section I

Time	Deflection	Time	Deflection	Time	Deflection	Time	Deflection
0	0	1800	0.021334	3600	0.0131929	5400	0.013135
15	0.00080279	1815	0.02109	3615	0.0131925	5415	0.013135
30	0.00226243	1830	0.020865	3630	0.013192	5430	0.013135
45	0.0052072	1845	0.0207	3645	0.0131913	5445	0.013134
60	0.00845424	1860	0.0204	3660	0.0131902	5460	0.013134
75	0.0114397	1875	0.017841	3675	0.0131897	5475	0.013133
90	0.0153369	1890	0.014456	3690	0.0131891	5490	0.013133
105	0.0168352	1905	0.01219	3705	0.0131889	5505	0.013133
120	0.0174025	1920	0.011345	3720	0.0131885	5520	0.013133
135	0.018262	1935	0.012222	3735	0.013188	5535	0.013133
150	0.0191626	1950	0.0124	3750	0.0131872	5550	0.013133
165	0.020029	1965	0.012523	3765	0.013186	5565	0.013133
180	0.0212473	1980	0.013262	3780	0.0131843	5580	0.013133
195	0.0223666	1995	0.014213	3795	0.0131841	5595	0.013133
210	0.0226168	2010	0.015442	3810	0.0131838	5610	0.013133
225	0.0228477	2025	0.015813	3825	0.0131835	5625	0.013133
240	0.0230247	2040	0.016002	3840	0.0131829	5640	0.013132
255	0.0231894	2055	0.016125	3855	0.0131821	5655	0.013132
270	0.0233368	2070	0.016043	3870	0.0131808	5670	0.013131
285	0.0233815	2085	0.01598	3885	0.0131804	5685	0.013131
300	0.023416	2100	0.015952	3900	0.0131796	5700	0.013131
315	0.023447	2115	0.015918	3915	0.0131786	5715	0.013131
330	0.0234856	2130	0.01585	3930	0.013177	5730	0.013131
345	0.0235216	2145	0.015436	3945	0.0131747	5745	0.013131
360	0.0235152	2160	0.015059	3960	0.0131738	5760	0.01313
375	0.0233748	2175	0.015106	3975	0.013173	5775	0.01313
390	0.0233092	2190	0.015313	3990	0.0131721	5790	0.01313
405	0.0231993	2205	0.015588	4005	0.0131712	5805	0.01313
420	0.0230511	2220	0.015663	4020	0.01317	5820	0.01313
435	0.0230011	2235	0.015776	4035	0.0131681	5835	0.01313
450	0.0229118	2250	0.015952	4050	0.0131679	5850	0.013129
465	0.0227368	2265	0.016117	4065	0.0131676	5865	0.013129
480	0.0227342	2280	0.016276	4080	0.0131675	5880	0.013128
495	0.0227282	2295	0.016483	4095	0.0131674	5895	0.013128
510	0.0227265	2310	0.016749	4110	0.0131671	5910	0.013128
525	0.0227246	2325	0.016831	4125	0.0131668	5925	0.013128
540	0.0227241	2340	0.016951	4140	0.0131663	5940	0.013128
555	0.0227236	2355	0.016999	4155	0.0131656	5955	0.013128

570	0.0227231	2370	0.017103	4170	0.0131644	5970	0.013128
585	0.0227222	2385	0.017271	4185	0.0131628	5985	0.013128
600	0.0227219	2400	0.017565	4200	0.0131627	6000	0.013127
615	0.0227216	2415	0.017831	4215	0.0131624	6015	0.013127
630	0.0227212	2430	0.017911	4230	0.0131623	6030	0.013127
645	0.0227207	2445	0.018007	4245	0.0131622	6045	0.013127
660	0.0227198	2460	0.018144	4260	0.013162	6060	0.013126
675	0.0227197	2475	0.018388	4275	0.0131617	6075	0.013126
690	0.0227197	2490	0.018477	4290	0.0131613	6090	0.013125
705	0.0227197	2505	0.018549	4305	0.0131607	6105	0.013125
720	0.0227197	2520	0.01856	4320	0.0131597	6120	0.013125
735	0.0227196	2535	0.018514	4335	0.0131583	6135	0.013125
750	0.0227195	2550	0.018277	4350	0.0131582	6150	0.013124
765	0.0227194	2565	0.017416	4365	0.013158	6165	0.013124
780	0.0227192	2580	0.016579	4380	0.0131577	6180	0.013123
795	0.0227189	2595	0.016321	4395	0.0131574	6195	0.013123
810	0.0227185	2610	0.016306	4410	0.0131571	6210	0.013123
825	0.022718	2625	0.016343	4425	0.0131567	6225	0.013122
840	0.0227174	2640	0.016558	4440	0.0131561	6240	0.013122
855	0.0227168	2655	0.017365	4455	0.0131551	6255	0.013122
870	0.0227161	2670	0.017569	4470	0.0131548	6270	0.013122
885	0.0227147	2685	0.017736	4485	0.0131542	6285	0.013122
900	0.0227149	2700	0.017854	4500	0.0131541	6300	0.013122
915	0.022715	2715	0.017698	4515	0.013154	6315	0.013122
930	0.0227151	2730	0.017359	4530	0.0131539	6330	0.013122
945	0.0227152	2745	0.017184	4545	0.0131537	6345	0.013122
960	0.0227153	2760	0.017303	4560	0.0131535	6360	0.013121
975	0.0227154	2775	0.017493	4575	0.0131531	6375	0.01312
990	0.0227155	2790	0.017616	4590	0.0131526	6390	0.013119
1005	0.0227156	2805	0.017626	4605	0.0131518	6405	0.013119
1020	0.0227156	2820	0.017493	4620	0.0131515	6420	0.013119
1035	0.0227156	2835	0.017387	4635	0.013151	6435	0.013119
1050	0.0227156	2850	0.016689	4650	0.0131509	6450	0.013119
1065	0.0227156	2865	0.01479	4665	0.0131508	6465	0.013119
1080	0.0227156	2880	0.013997	4680	0.0131507	6480	0.013119
1095	0.0227155	2895	0.013921	4695	0.0131506	6495	0.013119
1110	0.0227155	2910	0.013792	4710	0.0131504	6510	0.013119
1125	0.0227154	2925	0.013741	4725	0.0131501	6525	0.013118
1140	0.0227152	2940	0.01366	4740	0.0131496	6540	0.013118
1155	0.022715	2955	0.013527	4755	0.0131489	6555	0.013117
1170	0.0227148	2970	0.013477	4770	0.013148	6570	0.013117
1185	0.0227145	2985	0.0134	4785	0.0131476	6585	0.013116

1200	0.0227139	3000	0.013371	4800	0.0131475	6600	0.013116
1215	0.0227131	3015	0.013327	4815	0.0131473	6615	0.013116
1230	0.0227115	3030	0.013311	4830	0.0131471	6630	0.013116
1245	0.0227092	3045	0.013305	4845	0.0131469	6645	0.013116
1260	0.0227064	3060	0.013296	4860	0.0131467	6660	0.013116
1275	0.0227034	3075	0.013282	4875	0.0131464	6675	0.013116
1290	0.0226992	3090	0.013277	4890	0.013146	6690	0.013116
1305	0.0226915	3105	0.013269	4905	0.0131453	6705	0.013116
1320	0.0226757	3120	0.013266	4920	0.0131444	6720	0.013116
1335	0.0226477	3135	0.013262	4935	0.0131441	6735	0.013115
1350	0.0226045	3150	0.013255	4950	0.0131436	6750	0.013115
1365	0.0225451	3165	0.013246	4965	0.0131431	6765	0.013114
1380	0.0225232	3180	0.013242	4980	0.0131426	6780	0.013113
1395	0.0224916	3195	0.013238	4995	0.0131419	6795	0.013113
1410	0.0224504	3210	0.013235	5010	0.0131408	6810	0.013112
1425	0.0224367	3225	0.013229	5025	0.0131408	6825	0.013112
1440	0.0224321	3240	0.013227	5040	0.0131406	6840	0.013112
1455	0.0224264	3255	0.013224	5055	0.0131406	6855	0.013112
1470	0.0224188	3270	0.013221	5070	0.0131405	6870	0.013112
1485	0.0224058	3285	0.013218	5085	0.0131404	6885	0.013112
1500	0.0224007	3300	0.013217	5100	0.0131402	6900	0.013112
1515	0.0223925	3315	0.013215	5115	0.0131399	6915	0.013112
1530	0.0223807	3330	0.013213	5130	0.0131395	6930	0.013112
1545	0.0223612	3345	0.013209	5145	0.013139	6945	0.013111
1560	0.0223536	3360	0.013207	5160	0.0131381	6960	0.01311
1575	0.022342	3375	0.013207	5175	0.013138	6975	0.01311
1590	0.0223241	3390	0.013206	5190	0.0131379	6990	0.013109
1605	0.0223048	3405	0.013205	5205	0.0131379	7005	0.013109
1620	0.0222796	3420	0.013203	5220	0.0131378	7020	0.013109
1635	0.0221918	3435	0.013201	5235	0.0131377	7035	0.013109
1650	0.0220579	3450	0.0132	5250	0.0131376	7050	0.013109
1665	0.0219471	3465	0.013199	5265	0.0131374	7065	0.013109
1680	0.0219211	3480	0.013199	5280	0.013137	7080	0.013109
1695	0.0218843	3495	0.013198	5295	0.0131366	7095	0.013109
1710	0.0218333	3510	0.013197	5310	0.0131359	7110	0.013108
1725	0.0217655	3525	0.013195	5325	0.0131356	7125	0.013108
1740	0.0216923	3540	0.013194	5340	0.0131355	7140	0.013107
1755	0.0217212	3555	0.013194	5355	0.0131353	7155	0.013106
1770	0.0216686	3570	0.013193	5370	0.0131353	7170	0.013106
1785	0.0215356	3585	0.013193	5385	0.0131352	7185	0.013106
1800	0.0213343	3600	0.013193	5400	0.0131351	7200	0.013106

Table E-1-2 Result for deflection for section II

time	deflection	time	deflection	time	deflection	time	deflection
0	0	1800	0.069268	3600	0.136106	5400	0.166502
8	0.000301	1808	0.068203	3608	0.136546	5408	0.166513
16	0.001946	1816	0.066563	3616	0.136983	5416	0.166528
24	0.002605	1824	0.064374	3624	0.13742	5424	0.16655
32	0.003567	1832	0.063947	3632	0.138072	5432	0.166584
40	0.004983	1840	0.063414	3640	0.139048	5440	0.166635
48	0.007104	1848	0.062824	3648	0.140513	5448	0.166654
56	0.010787	1856	0.061934	3656	0.140548	5456	0.166661
64	0.01195	1864	0.060655	3664	0.14056	5464	0.166672
72	0.013443	1872	0.060196	3672	0.14058	5472	0.166688
80	0.015495	1880	0.05963	3680	0.140609	5480	0.166712
88	0.018315	1888	0.059353	3688	0.140619	5488	0.166749
96	0.021986	1896	0.059412	3696	0.140636	5496	0.166803
104	0.029524	1904	0.05946	3704	0.14066	5504	0.166883
112	0.036455	1912	0.059585	3712	0.140696	5512	0.166999
120	0.035378	1920	0.059638	3720	0.140751	5520	0.167167
128	0.034251	1928	0.059732	3728	0.140833	5528	0.167416
136	0.034497	1936	0.059741	3736	0.140955	5536	0.167793
144	0.038513	1944	0.059754	3744	0.141137	5544	0.167828
152	0.04012	1952	0.059775	3752	0.141409	5552	0.167863
160	0.042381	1960	0.059797	3760	0.141819	5560	0.167899
168	0.043335	1968	0.059818	3768	0.142437	5568	0.167912
176	0.045037	1976	0.059841	3776	0.142592	5576	0.167932
184	0.045707	1984	0.059878	3784	0.14263	5584	0.167961
192	0.046718	1992	0.059937	3792	0.142688	5592	0.167973
200	0.047105	2000	0.060038	3800	0.142775	5600	0.167989
208	0.047581	2008	0.060212	3808	0.142807	5608	0.168015
216	0.047885	2016	0.060508	3816	0.142856	5616	0.168052
224	0.04808	2024	0.060991	3824	0.142874	5624	0.168109
232	0.048142	2032	0.061769	3832	0.142902	5632	0.168195
240	0.048111	2040	0.062926	3840	0.142943	5640	0.168325
248	0.048109	2048	0.063362	3848	0.142984	5648	0.168373
256	0.048106	2056	0.064007	3856	0.143026	5656	0.168446
264	0.048102	2064	0.064915	3864	0.143088	5664	0.168474
272	0.048093	2072	0.066189	3872	0.143181	5672	0.168515
280	0.048082	2080	0.067851	3880	0.14332	5680	0.16853
288	0.04807	2088	0.069935	3888	0.143528	5688	0.168553
296	0.048048	2096	0.071991	3896	0.14384	5696	0.168588
304	0.048007	2104	0.073068	3904	0.143957	5704	0.168601

312	0.04793	2112	0.073164	3912	0.144132	5712	0.16862
320	0.047899	2120	0.072647	3920	0.144198	5720	0.168649
328	0.047847	2128	0.070849	3928	0.144297	5728	0.168691
336	0.047758	2136	0.066808	3936	0.144334	5736	0.16875
344	0.047603	2144	0.065021	3944	0.144389	5744	0.168839
352	0.047328	2152	0.064328	3952	0.14441	5752	0.168978
360	0.046849	2160	0.063198	3960	0.144441	5760	0.169198
368	0.046022	2168	0.063104	3968	0.144488	5768	0.169542
376	0.044617	2176	0.062948	3976	0.144535	5776	0.169672
384	0.044068	2184	0.062888	3984	0.144581	5784	0.169721
392	0.043203	2192	0.062798	3992	0.144652	5792	0.169795
400	0.041834	2200	0.062789	4000	0.144757	5800	0.169822
408	0.039704	2208	0.062777	4008	0.144914	5808	0.169864
416	0.03761	2216	0.062758	4016	0.145151	5816	0.169927
424	0.03564	2224	0.062729	4024	0.145506	5824	0.170021
432	0.033785	2232	0.062686	4032	0.145639	5832	0.170044
440	0.032987	2240	0.062622	4040	0.145839	5840	0.170068
448	0.035176	2248	0.062526	4048	0.145914	5848	0.170103
456	0.03626	2256	0.062382	4056	0.146027	5856	0.170156
464	0.037936	2264	0.062164	4064	0.146069	5864	0.170236
472	0.041137	2272	0.061834	4072	0.146132	5872	0.170357
480	0.045932	2280	0.061332	4080	0.146227	5880	0.170402
488	0.052266	2288	0.060573	4088	0.146263	5888	0.17047
496	0.054424	2296	0.05943	4096	0.146276	5896	0.170496
504	0.057315	2304	0.058993	4104	0.146296	5904	0.170534
512	0.0585	2312	0.058357	4112	0.146326	5912	0.170592
520	0.060037	2320	0.058129	4120	0.146371	5920	0.170613
528	0.060593	2328	0.058123	4128	0.146439	5928	0.170646
536	0.060799	2336	0.058115	4136	0.14654	5936	0.170658
544	0.06111	2344	0.058103	4144	0.146693	5944	0.170676
552	0.061226	2352	0.058099	4152	0.146921	5952	0.170703
560	0.061398	2360	0.058092	4160	0.147263	5960	0.170745
568	0.061658	2368	0.058082	4168	0.147775	5968	0.170806
576	0.062055	2376	0.058066	4176	0.14854	5976	0.170897
584	0.062625	2384	0.058041	4184	0.148827	5984	0.171028
592	0.063398	2392	0.058	4192	0.149256	5992	0.171219
600	0.064337	2400	0.057937	4200	0.1499	6000	0.171237
608	0.065214	2408	0.057844	4208	0.14996	6008	0.171263
616	0.065773	2416	0.05771	4216	0.15002	6016	0.171273
624	0.066483	2424	0.057514	4224	0.150024	6024	0.171288
632	0.066559	2432	0.057222	4232	0.150029	6032	0.171311
640	0.066589	2440	0.056784	4240	0.150038	6040	0.171319

648	0.066641	2448	0.056129	4248	0.15005	6048	0.171332
656	0.066662	2456	0.055147	4256	0.150069	6056	0.17135
664	0.066697	2464	0.053649	4264	0.150076	6064	0.171379
672	0.066711	2472	0.051408	4272	0.150087	6072	0.171421
680	0.066711	2480	0.048269	4280	0.150103	6080	0.171485
688	0.066711	2488	0.043877	4288	0.150127	6088	0.171581
696	0.066711	2496	0.038728	4296	0.150163	6096	0.171726
704	0.066712	2504	0.037084	4304	0.150216	6104	0.171948
712	0.066712	2512	0.035171	4312	0.150296	6112	0.17229
720	0.066712	2520	0.033929	4320	0.150415	6120	0.172419
728	0.066712	2528	0.039442	4328	0.150459	6128	0.172616
736	0.066713	2536	0.040098	4336	0.150525	6136	0.17269
744	0.066713	2544	0.041366	4344	0.150624	6144	0.172718
752	0.066713	2552	0.043938	4352	0.150661	6152	0.17276
760	0.066713	2560	0.045019	4360	0.150674	6160	0.172822
768	0.066714	2568	0.045044	4368	0.150695	6168	0.172846
776	0.066714	2576	0.045069	4376	0.150726	6176	0.172882
784	0.066714	2584	0.045095	4384	0.150772	6184	0.172935
792	0.066715	2592	0.045134	4392	0.150819	6192	0.172955
800	0.066715	2600	0.045193	4400	0.150865	6200	0.172985
808	0.066715	2608	0.045284	4408	0.150934	6208	0.173031
816	0.066715	2616	0.045423	4416	0.151038	6216	0.173048
824	0.066715	2624	0.045637	4424	0.151194	6224	0.173073
832	0.066715	2632	0.045964	4432	0.151429	6232	0.173083
840	0.066716	2640	0.046471	4440	0.151782	6240	0.173097
848	0.066716	2648	0.047276	4448	0.152317	6248	0.173103
856	0.066716	2656	0.048598	4456	0.152518	6256	0.173111
864	0.066716	2664	0.050818	4464	0.152594	6264	0.173123
872	0.066717	2672	0.054797	4472	0.152707	6272	0.173141
880	0.066717	2680	0.055182	4480	0.152878	6280	0.173169
888	0.066717	2688	0.055806	4488	0.152942	6288	0.17321
896	0.066717	2696	0.056798	4496	0.152966	6296	0.173271
904	0.066718	2704	0.05717	4504	0.153002	6304	0.173294
912	0.066718	2712	0.057723	4512	0.153016	6312	0.173328
920	0.066719	2720	0.05793	4520	0.153036	6320	0.173379
928	0.066719	2728	0.058238	4528	0.153067	6328	0.173398
936	0.06672	2736	0.058699	4536	0.153113	6336	0.173405
944	0.06672	2744	0.058872	4544	0.153182	6344	0.173416
952	0.06672	2752	0.058936	4552	0.153286	6352	0.173431
960	0.06672	2760	0.059033	4560	0.153443	6360	0.173455
968	0.066721	2768	0.05907	4568	0.153502	6368	0.17349
976	0.066721	2776	0.059124	4576	0.15359	6376	0.173542

984	0.066721	2784	0.059145	4584	0.153623	6384	0.173618
992	0.066722	2792	0.059175	4592	0.153635	6392	0.173733
1000	0.066722	2800	0.059221	4600	0.153654	6400	0.173907
1008	0.066722	2808	0.059239	4608	0.153682	6408	0.174173
1016	0.066722	2816	0.059264	4616	0.153692	6416	0.174585
1024	0.066722	2824	0.059303	4624	0.153708	6424	0.174624
1032	0.066723	2832	0.059361	4632	0.153732	6432	0.174639
1040	0.066724	2840	0.059448	4640	0.153767	6440	0.174661
1048	0.066724	2848	0.05958	4648	0.15382	6448	0.174694
1056	0.066724	2856	0.059778	4656	0.1539	6456	0.174706
1064	0.066724	2864	0.060076	4664	0.15402	6464	0.174725
1072	0.066725	2872	0.060522	4672	0.154202	6472	0.174732
1080	0.066725	2880	0.061187	4680	0.154477	6480	0.174742
1088	0.066726	2888	0.062173	4688	0.154893	6488	0.174758
1096	0.066726	2896	0.06364	4696	0.15505	6496	0.174781
1104	0.066727	2904	0.065789	4704	0.155285	6504	0.174817
1112	0.066729	2912	0.068957	4712	0.155373	6512	0.17487
1120	0.066732	2920	0.073685	4720	0.155406	6520	0.174951
1128	0.066736	2928	0.080843	4728	0.155418	6528	0.175072
1136	0.066742	2936	0.091787	4736	0.155437	6536	0.175102
1144	0.066744	2944	0.107986	4744	0.155465	6544	0.175132
1152	0.066747	2952	0.113909	4752	0.155507	6552	0.175176
1160	0.066753	2960	0.113944	4760	0.15557	6560	0.175241
1168	0.066758	2968	0.113996	4768	0.155664	6568	0.175336
1176	0.066763	2976	0.114016	4776	0.155757	6576	0.175371
1184	0.066772	2984	0.114045	4784	0.155848	6584	0.175422
1192	0.066786	2992	0.114089	4792	0.155936	6592	0.175497
1200	0.06681	3000	0.114154	4800	0.156063	6600	0.175605
1208	0.066855	3008	0.114253	4808	0.156075	6608	0.175645
1216	0.066943	3016	0.1144	4816	0.156093	6616	0.17566
1224	0.06711	3024	0.114414	4824	0.15611	6624	0.175665
1232	0.067407	3032	0.114434	4832	0.156128	6632	0.175674
1240	0.067902	3040	0.114465	4840	0.156154	6640	0.175686
1248	0.06869	3048	0.114512	4848	0.156192	6648	0.175691
1256	0.068989	3056	0.114558	4856	0.156248	6656	0.175698
1264	0.069101	3064	0.114604	4864	0.156328	6664	0.175709
1272	0.069271	3072	0.114673	4872	0.156445	6672	0.175725
1280	0.069336	3080	0.114776	4880	0.156619	6680	0.175749
1288	0.069432	3088	0.114931	4888	0.156889	6688	0.175784
1296	0.069469	3096	0.115161	4896	0.157314	6696	0.175837
1304	0.069523	3104	0.115506	4904	0.157992	6704	0.175917
1312	0.069544	3112	0.116023	4912	0.159065	6712	0.176039

1320	0.069575	3120	0.116216	4920	0.159474	6720	0.176235
1328	0.069587	3128	0.116506	4928	0.160099	6728	0.176556
1336	0.069604	3136	0.116942	4936	0.160335	6736	0.176587
1344	0.06963	3144	0.117105	4944	0.160423	6744	0.176633
1352	0.06964	3152	0.11735	4952	0.160556	6752	0.17665
1360	0.069655	3160	0.117442	4960	0.160757	6760	0.176657
1368	0.069678	3168	0.117579	4968	0.161059	6768	0.176667
1376	0.069712	3176	0.117786	4976	0.161135	6776	0.176682
1384	0.069766	3184	0.117864	4984	0.161153	6784	0.176704
1392	0.069852	3192	0.11798	4992	0.161182	6792	0.176738
1400	0.069988	3200	0.118023	5000	0.161192	6800	0.17679
1408	0.070206	3208	0.118089	5008	0.161208	6808	0.176869
1416	0.070553	3216	0.118113	5016	0.161232	6816	0.176899
1424	0.071097	3224	0.11815	5024	0.161256	6824	0.176944
1432	0.071923	3232	0.118164	5032	0.16128	6832	0.176961
1440	0.072232	3240	0.118184	5040	0.161316	6840	0.176986
1448	0.072693	3248	0.118215	5048	0.161369	6848	0.177025
1456	0.073372	3256	0.118262	5056	0.161448	6856	0.177084
1464	0.074355	3264	0.118331	5064	0.161563	6864	0.177173
1472	0.075749	3272	0.118435	5072	0.16173	6872	0.17731
1480	0.077717	3280	0.11859	5080	0.161896	6880	0.177525
1488	0.080475	3288	0.118822	5088	0.161937	6888	0.177868
1496	0.08426	3296	0.118909	5096	0.161978	6896	0.177901
1504	0.090324	3304	0.119038	5104	0.161993	6904	0.17795
1512	0.099035	3312	0.119087	5112	0.162016	6912	0.178024
1520	0.10879	3320	0.11916	5120	0.162051	6920	0.178052
1528	0.113253	3328	0.119269	5128	0.162103	6928	0.178095
1536	0.114442	3336	0.11931	5136	0.162181	6936	0.178111
1544	0.115051	3344	0.119371	5144	0.162299	6944	0.178135
1552	0.11485	3352	0.119394	5152	0.162478	6952	0.178172
1560	0.113857	3360	0.119429	5160	0.162751	6960	0.178208
1568	0.111307	3368	0.119481	5168	0.163168	6968	0.178245
1576	0.105957	3376	0.119558	5176	0.163807	6976	0.178301
1584	0.105447	3384	0.119674	5184	0.163867	6984	0.178385
1592	0.104653	3392	0.119846	5192	0.163958	6992	0.178417
1600	0.103399	3400	0.120103	5200	0.164025	7000	0.178465
1608	0.101385	3408	0.120489	5208	0.164127	7008	0.178484
1616	0.098098	3416	0.121061	5216	0.164166	7016	0.178511
1624	0.096836	3424	0.121916	5224	0.164223	7024	0.178552
1632	0.094888	3432	0.123192	5232	0.164245	7032	0.178567
1640	0.091981	3440	0.125085	5240	0.164277	7040	0.178591
1648	0.089032	3448	0.127885	5248	0.164326	7048	0.1786

1656	0.086106	3456	0.132027	5256	0.164399	7056	0.178613
1664	0.081663	3464	0.133058	5264	0.164509	7064	0.178632
1672	0.075843	3472	0.133315	5272	0.164674	7072	0.178662
1680	0.074514	3480	0.133701	5280	0.164923	7080	0.178707
1688	0.074185	3488	0.133846	5288	0.165298	7088	0.178775
1696	0.073707	3496	0.1339	5296	0.165439	7096	0.178878
1704	0.07353	3504	0.133981	5304	0.16565	7104	0.17904
1712	0.073273	3512	0.134012	5312	0.16573	7112	0.179299
1720	0.072928	3520	0.134058	5320	0.165849	7120	0.179398
1728	0.072701	3528	0.134126	5328	0.166027	7128	0.179436
1736	0.072502	3536	0.134195	5336	0.166294	7136	0.179493
1744	0.072317	3544	0.134263	5344	0.166319	7144	0.17958
1752	0.072044	3552	0.134366	5352	0.166357	7152	0.179613
1760	0.071637	3560	0.134519	5360	0.166413	7160	0.179662
1768	0.071018	3568	0.134751	5368	0.166434	7168	0.179681
1776	0.070789	3576	0.135097	5376	0.166466	7176	0.179709
1784	0.070453	3584	0.135618	5384	0.166478	7184	0.17972
1792	0.069968	3592	0.135813	5392	0.166496	7192	0.179736
1800	0.069268	3600	0.136106	5400	0.166502	7200	0.179759

Table E-1-3 Result for deflection for section III

time	deflection	time	deflection	time	deflection	time	deflection
0	0	1836	0.028306	3636	0.012072	5436	0.0339891
36	0.00108089	1872	0.028221	3672	0.01203	5472	0.0327659
72	0.00283082	1908	0.028115	3708	0.011845	5508	0.0309033
108	0.006145	1944	0.028078	3744	0.011419	5544	0.0282507
144	0.0106411	1980	0.028043	3780	0.01082	5580	0.0245718
180	0.0176163	2016	0.02801	3816	0.010432	5616	0.0232576
216	0.0203315	2052	0.027966	3852	0.010145	5652	0.0214547
252	0.0241952	2088	0.027908	3888	0.010045	5688	0.0190736
288	0.0276629	2124	0.027835	3924	0.009939	5724	0.0182879
324	0.0289509	2160	0.027828	3960	0.00988	5760	0.0180114
360	0.0290768	2196	0.027818	3996	0.009927	5796	0.0176473
396	0.0291071	2232	0.027803	4032	0.010014	5832	0.0172149
432	0.0291435	2268	0.027782	4068	0.010005	5868	0.016852
468	0.0291608	2304	0.027751	4104	0.010148	5904	0.0166327
504	0.0291857	2340	0.02771	4140	0.010304	5940	0.0168028
540	0.029215	2376	0.027645	4176	0.010908	5976	0.0168984
576	0.0292752	2412	0.027538	4212	0.011407	6012	0.0170303
612	0.0293619	2448	0.027411	4248	0.011919	6048	0.0165436

648	0.0294858	2484	0.027195	4284	0.012475	6084	0.0164929
684	0.0296854	2520	0.026819	4320	0.01367	6120	0.0164027
720	0.0300563	2556	0.026431	4356	0.014148	6156	0.0162329
756	0.0305947	2592	0.026324	4392	0.014906	6192	0.0159169
792	0.0313935	2628	0.026189	4428	0.016152	6228	0.0152864
828	0.0324232	2664	0.025999	4464	0.018335	6264	0.0140491
864	0.0328526	2700	0.025597	4500	0.021746	6300	0.0115886
900	0.0309897	2736	0.025101	4536	0.027679	6336	0.0070328
936	0.0305819	2772	0.024536	4572	0.035093	6372	-0.001675
972	0.0304289	2808	0.023924	4608	0.035261	6408	-0.018307
1008	0.0302062	2844	0.022979	4644	0.035324	6444	-0.025173
1044	0.0300923	2880	0.022058	4680	0.035418	6480	-0.035347
1080	0.0298631	2916	0.021177	4716	0.035559	6516	-0.045574
1116	0.0297645	2952	0.01997	4752	0.035768	6552	-0.053058
1152	0.0296961	2988	0.018249	4788	0.036074	6588	-0.056759
1188	0.029592	3024	0.01544	4824	0.036508	6624	-0.057552
1224	0.0294691	3060	0.013365	4860	0.037139	6660	-0.05774
1260	0.0293444	3096	0.011392	4896	0.038114	6696	-0.057567
1296	0.0291811	3132	0.010924	4932	0.039338	6732	-0.056445
1332	0.0290586	3168	0.010474	4968	0.040287	6768	-0.05409
1368	0.0288362	3204	0.009819	5004	0.040504	6804	-0.0527
1404	0.0288148	3240	0.008874	5040	0.040552	6840	-0.052084
1440	0.0287931	3276	0.007672	5076	0.040301	6876	-0.051201
1476	0.0287713	3312	0.00726	5112	0.039844	6912	-0.049827
1512	0.0287385	3348	0.006963	5148	0.038756	6948	-0.047724
1548	0.0286893	3384	0.007419	5184	0.0383	6984	-0.044203
1584	0.028616	3420	0.007706	5220	0.037546	7020	-0.043864
1620	0.0285034	3456	0.008317	5256	0.036295	7056	-0.043736
1656	0.0284929	3492	0.00939	5292	0.035972	7092	-0.043686
1692	0.0284771	3528	0.010677	5328	0.03564	7128	-0.043667
1728	0.0284528	3564	0.011649	5364	0.035302	7164	-0.043638
1764	0.0284188	3600	0.011944	5400	0.034793	7200	-0.043591
1800	0.0283697						