EXPERIMENTAL AND PROBABILISTIC ASSESSMENT OF CONCRETE INCORPORATING EXPANDED POLYSTYRENE (EPS) WASTE AT ELEVATED TEMPERATURES

BY

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DECEMBER, 2016.

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ZARIA, NIGERIA

DECEMBER, 2016.

DECLARATION

I hereby declare that the work in this dissertation entitled "**Experimental and Probabilistic Assessment of Concrete Incorporating Expanded Polystyrene (EPS) Waste at Elevated Temperatures"** was carried out by me in the Department of Civil Engineering, Ahmadu Bello University, Zaria. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this work has been presented for another degree at any institution.

Kudirat Oziohu YUSUF

(Name of Student)	(Signature)	Date

CERTIFICATION

This dissertation entitled "**Experimental and Probabilistic Assessment of Concrete Incorporating Expanded Polystyrene (EPS) Waste at Elevated Temperatures**" by **Kudirat Oziohu YUSUF** meets the regulation governing the award of Master of Science (MSc.) degree in Civil Engineering of the Ahmadu Bello University, zaria and is approved for its contribution to knowledge and literary presentation.

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ABBREVIATIONS AND NOTATIONS

G_k = Dead load

Q_k = Live load

α = Load ratio

A = Area

ACI = American Concrete Institute

As = Area of Steel

b = width of beam

BS = British Standard

C = weight of cement

C-S-H = Calcium Silicate Hydrate

d = depth of beam

EN = European Standard

EPS = Expanded Polystyrene

EUMEPS = European Manufacturer of Expanded Polystyrene

FORM = First Order Reliability Method

G(x) = Performance function

L= length between two supports

LWC = Lightweight Concrete

M_A = Applied Moment

M_D = Design Moment

M_R = Moment of Resistance

P = Applied load

P_f = Probability of failure

R = Reliability

RC = Reinforced Concrete

RT = Room Temperature

SORM = Second Order Reliability Method

SPS = Stabilised Polystyrene

UPV = Ultra Pulse Velocity

V_C = Volume fraction of cement

$V_{C.A}$ = Volume fraction of coarse aggregate

$V_{F.A}$ = Volume fraction of fine aggregate

V_W = Volume fraction of water

Wt. = weight

Υg = Partial safety factor live load

Υq = Partial safety factor dead load

β = safety index

f_b = flexural strength of concrete beam

$f ck$ = Cube Characteristic strength

f_{cu} = Compressive Strength of concrete cube

$f y$ = Steel strength

= mean

ABSTRACT

This study is to investigate the effects of Expanded Polystyrene (EPS) as a partial replacement for coarse aggregates at 0%, 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, and 50% at elevated temperatures of Room Temperature (28^0C), 200℃, 400℃, 600℃, and 800℃ for the duration of 2 hrs each. Compressive strength and flexural strength were carried out on concrete cubes of size 150mm × 150mm × 150mm and concrete beams of size 150mm × 150mm × 750mm respectively. The experimental results shows that the increase in EPS content as well as the increase in temperature causes decrease in the strength of concrete at room temperature, while inclusion of EPS from 5% to 15% increased the resistance of concrete to heat better than the control at a maximum temperature of 400^0C. This implied that the trapped air within the closed cells of EPS reduces the flow of heat, thereby reducing loss of moisture from the concrete but the optimum performance of EPS in concrete lies at 10% EPS content at a temperature of 400^0C, where the target Compressive strength of 25N/mm^2 was still achievable. Maximum flexural strength was achieved at 200^0C at 25% EPS content. The mathematical model relating compressive strength of concrete cubes with Expanded Polystyrene was predicted using least regression analysis from the experimental data obtained and it was found to have coefficient of correlation values (R^2) of 0.984, 0.934, 0.856, 0.947 and 0.952 respectively for 28^0C, 200^0C, 400^0C, 600^0C and 800^0C. These were incorporated in the Probabilistic assessment of a designed simply supported reinforced concrete beam exposed to elevated temperatures. Flexural limit state function was developed and evaluated using First Order Reliability Method (FORM) which was implemented through a developed program using MATLAB. From the reliability analysis, safety index is higher at load ratio (dead load to live load) of 1.0 (Q_k = 7.8kN/m), while for a reinforced concrete beams to be considered safe in bending considering 800^0C, the maximum EPS content must be 20% coarse aggregate replacement which gives a safety index of 3.98 as above the targeted safety of 3.8 as recommended in JCSS (2001).

CHAPTER ONE

INTRODUCTION

1.1 Background

The high demand for construction materials most especially aggregates of concrete which are sometimes derived from natural resources through quarrying of rocks or dredging of seas causing the depletion of this natural resources, thereby making them to becoming scarce day by day. At this point researchers and engineers who have foresight to keep developmental activities abreast and curtail the cost factor have started looking for alternative building materials (Thomas, *et al.*, 2014).

For sustainability and reusability, so many wastes have been used to replace aggregates of concrete, ranging from agricultural wastes to industrial waste products. With greater knowledge and insulation concerns, more material were also used including expanded clay, expanded glass, Polypropylene and expanded polystyrene (EPS) (Kuhail and Shihada, 2003).

EPS is a light weight cellular plastics material comprising of 98% air and 2% (polystyrene). It has a closed cell structure and cannot absorb water. Therefore, it has a good sound and thermal insulation characteristics as well as impact resistance (Bello, 2011).

As a result of its light weight nature and also its thermal and sound insulating effects, it has been proven by so many researcher works as an alternative in building material. In using any material as building components, getting to know the material properties only is not enough to determine how safe the material will be during its service life. During the service life of a structure, such as building and bridges which has reinforced concrete beam as its major members, it is expected to transfer load safely to the foundation. There are three types of load that affect structures (Kigha, 2014); they are primary loads which are loads which permanently or very often affect the structure, these could be dead load, live load etc, Secondary loads which are loads that affects the structure less often, such as wind loads, snow

loads etc and thirdly Special loads, which are loads which rarely affects the structure, for example, earthquake loads, critical accident loads, fire loads etc.

Since it is well established that the mechanical properties of concrete in general are adversely affected by thermal exposure (Phan, 1996) and human safety in case of fire is one major consideration in the design of buildings, it is extremely necessary to have a complete knowledge about the behaviour of all construction materials before using them in structural elements (Morsy, *et al*. 2010). Therefore, the knowledge of concrete structural members when used in buildings has to satisfy appropriate fire safety requirements specified in building codes (EN 1991-1-2; EN 1992-1-2).

The motivation for this research is to create awareness to the use Expanded Polystyrene waste for affordable and less expensive structures in the case of elevated temperature such as fire. Structural design has moved towards a more rational and probability – based approach which is referred to as limit state design; such design which takes into account more information than the deterministic methods in designing structural components (Melchers, 1999). Kohler (2007) reported that the most straight forward method of structural reliability analysis is Monte Carlo Simulation while the most efficient are First Order Reliability Method (FORM) and Second Order Reliability Method (SORM). Thus, the safety levels of reinforced concrete beams under various elevated temperatures, considering the percentage replacement of EPS for coarse aggregate was evaluated through an experimental assessment and probabilistic formulation approach using FORM.

1.2 Statement of Problem

Solid waste as defined by Babayemi and Dauda, (2009), is a non-liquid and non-gaseous products of human activities regarded as being unwanted or useless. After the original use of EPS as packaging materials, its goes back to the dumpsites as solid wastes and it's remain there as long as eternity due to its non-biodegradable nature. Since elevated temperature is

one extreme condition to which concrete structure could be exposed to either accidentally or industrial means. The need to have new knowledge and structural performance on this expanded polystyrene as construction materials at elevated temperatures becomes necessary since Expanded Polystyrene (EPS) building product has been predominantly used in Nigerian building industry in urban areas like Abuja and Akure (Anthony *et al*., 2014).

1.3 Justification of Study

In most developed nations of the world, it has been verified that the conventional building materials are inadequate towards meeting the housing needs of the growing population, which has led to futuristic researches towards the development of new alternative building materials through advance plastics materials as building materials that will meets the safety standards and the dweller's comfort requirements, which must also be thermally insulating, lightweight and inexpensive (Lee, *et al*. 2006).

For a developing nation like Nigeria, utilising expanded polystyrene waste in concrete production will not only solves the problem of disposing this ultra-light (up to 98% air) solid waste but also helps to preserve natural resources.(Herki, *et al*. 2013) and also ascertain the safety of this material in concrete after being exposed to extreme conditions such as fire.

1.4 Aim and Objectives

1.4.1 Aim

The aim of the study is to investigate the properties of concrete incorporating Expanded Polystyrene (EPS) waste at Elevated temperatures using experimental and probabilistic approaches.

1.4.2 Objectives

The Specific Objectives include:

i. To investigate the properties of materials used such as cement, fine aggregates, coarse aggregates and Expanded Polystyrene (EPS).

ii. To investigate the compressive strength and flexural strength on Concrete (cubes and beams) containing various percentages of EPS at elevated temperatures.

iii. To established the relationship between the compressive strength of concrete and EPS at various temperatures.

iv. To assessed the reliability or safety of reinforced concrete beams containing EPS at elevated temperatures.

v. To assessed different load ratio on the safety of the beam containing EPS under elevated temperatures.

1.5 SCOPE AND LIMITATIONS

1.5.1 Scope of Research

The Scope of this research covers the Compressive strength, Flexural Strength test and the Reliability analysis of the structural performance of a designed simply supported reinforced concrete beam containing Expanded Polystyrene (EPS) at various temperatures exposure in its flexural capacity, which was evaluated using First Order Reliability Method (FORM) and implemented through a developed program using MATLAB toolkit.

1.5.2 Limitations of Study

i. The reinforced concrete beam containing Expanded Polystyrene (EPS) was analyzed in flexure only, using MATLAB.

ii. The designed simply supported reinforced concrete beam was obtained from literature.

iii. The strength properties used was obtained from the experimental study carried out in this work.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

The high consumption of concrete in construction industry has lead to increase in demands for construction materials such as aggregates, cement and water. The high rate of consumption of these raw materials in the construction industry most especially aggregates which are derived from resources such as rocks and dredging of rivers causes the depletion of natural and mineral resources(Mehta, 1999). For sustainable growth, so many wastes have been used to replace aggregate of concrete ranging agricultural waste products as well; as industrial waste (Kuhail and Shihada, 2003).

After the September 11th attack on the World Trade Center, U.S.A, interest in the design of structures for fire has greatly increased, since fire is one hazard that may result in death, injury or property damage. The extensive use of concrete as a structural material for nuclear power reactors, pressure vessels, storage tank for hot crude oil, etc has increased the risk of exposure of concrete to high temperatures (Balakrishnaiah *et al*., 2013). Building codes specified that concrete structural members when used in building have to satisfy appropriate fire safety requirements, with the objective of protecting life and properties (Kacianauskas, *et al*., 2014). The Knowledge of strength and deformation properties of concrete at elevated temperatures is essential in estimating the behaviour and the load-bearing capacity of concrete structures when subjected to fire since the fire performance of structural members depends on the properties of the constituent materials, knowledge of high-temperature properties of concrete is critical for fire resistance assessment under performance-based codes (Kodur *et al.*, 2008). The need to determine the fire performance of the constituent material used in structural members through experimental and probabilistic method is of paramount importance, since the uncertainties in structural parameters such as material properties,

external loads; etc has caused serious attentions to reliability in structural design (Ghasemi and Yousefi, 2011).

2.2 Polystyrene

Polystyrene is a synthetic resin produced by the polymerization of styrene, while styrene is obtained by reacting ethylene with benzene in the presence of aluminium chloride to yield ethylbenzene. There are two widely used forms of polystyrene, they are; Extruded Polystrene (XPS) which is produced by moulding sprayed styrene resin polymerization under pressure and Expanded Polystyrene (EPS) which is produced by subjecting the small expandable beads to steam which causes the thermoplastic polystyrene to soften.

2.2.1 Expanded Polystyrene (EPS)

Expanded Polystyrene Foam (EPS) is a foam-like-closed-pored thermoplastic material, typically in white colour, obtained from polymerization of styrene monomer as shown in Plate I. It is a lightweight cellular plastics material consisting of closed cell structured fine spherical shaped particles which are comprised of about 98% air and 2% polystyrene.

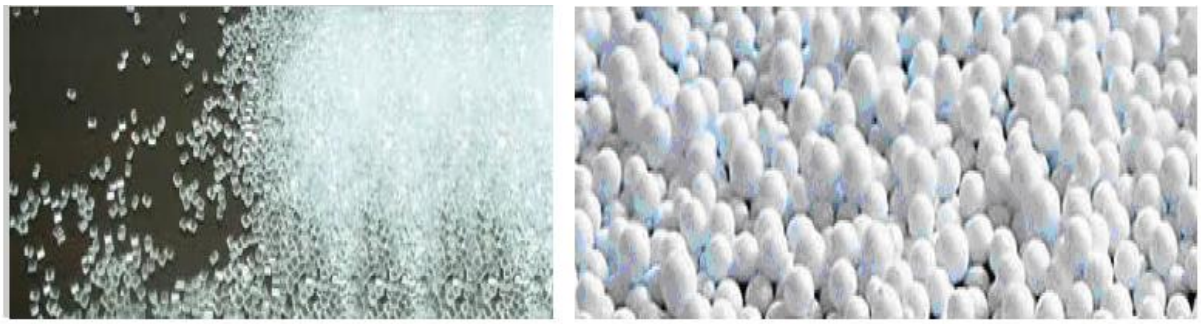


Plate I: Polystyrene and expanded polystyrene (Kaya and Kar (2014)

Expanded polystyrene has very wide range of applications. These applications can be classified into three main categories, which are;

i. Packaging
ii. Construction
iii. Other applications.

i. Packaging: EPS is the best packaging option for high value heavy product and also food packaging. Owing to its shock absorbing properties, it can completely protect and safe industrial products such as fragile pharmaceutical products to electronic components from risk in transporting and handling,

ii. Construction: EPS is used in many aspects of building work including large structures. Its major uses as insulating material due to its low value of thermal conductivity, its low cost of installation, its resistance to moisture, etc has been emphasized by Gnip *et al*., (2008) and Doroudiani and Omidian, (2010).

iii. Other applications: Polystyrene can be used for other applications, such as coffee cups, plastic chairs, videocassette cases and office equipment (Maharana *et al*.,2007).

2.2.2 Applications as a Construction Material

The following properties of EPS that made it important to be used as construction materials are;

i. Low thermal conductivity – due to its closed air-filled cell structure that inhibits the passage of heat or cold, a high capacity for thermal insulation is achieved.

ii. Low weight – its low density allows for light and safe construction works.

iii. Low water absorption – EPS does not absorb moisture and its thermal and mechanical properties are unaffected by damp, humidity or moisture.

iv. Ease of handling and installation – the low weight of EPS makes it easy to handle and to transport to site.

v. Chemical resistance – EPS is completely compatible with other materials used in construction including cements, water and so on (EUMEPS).

2.3 Incorporating EPS in Concrete

Sadrmomtazi *et al*. (2007) investigated the effect of using polypropylene fibers and different cementitious materials on mechanical properties of EPS concrete and concluded that the

compressive strength of EPS concretes appears to increase linearly with an increase in concrete density, or with a decrease in the EPS volume while the results of flexural behaviour test showed that, the flexural strength decreased with an increase in the volume of EPS in mixes.

Kaya and Kar (2014), researched on thermal and Mechanical properties of concrete with EPS waste by using hot wire method for measuring the thermal conductivity of the sample having magnitude and sensitivity of 0.02 – 10 $Wm^{-1}K^{-1}$ and $\pm$5% on its scale respectively. The result shows that as EPS increases, thermal conductivity, water absorbtion, density of the samples and tensile strength values decreases. And they recommended the following uses of EPS; (i) production of earthquake-proof low-intensity concrete, (ii) as insulation-purpose construction material, (iii) decoration.

Thomas *et al.,* (2014) researched on the partial replacement of coarse aggregates by expanded polystyrene beads in concrete using 5%, 10%, 15%, 20%, 25% and 30% by volume of coarse aggregates replacement and concluded that the increase in the EPS beads content in concrete mixes reduces the compressive and tensile strength of concrete. Which was attributed to increased in voids in the mix due to the increased in EPS volume and as well as the low specific gravity of EPS which causes overall reduction of density of the concrete.

Idawati, *et al*., (2003) reports the results of an experimental investigation into the properties of hardened concrete bricks containing expanded polystyrene beads. The beads were used as part of sand replacement in the mixes. It was found that polystyrene concrete has low compressive strength. The results indicated that polystyrene concrete mix with certain portion of the beads may provide as a suitable alternative material in the construction industry.

Le Roy *et al*. (2005) investigated the mix design and mechanical properties of very lightweight concrete (LWC) made of expanded polystyrene spheres (EPS). Their research

shows that the lower the inclusion size, the higher the compressive strength of the hardened concrete.

From Miled *et al.*, (2007) investigation, It was also observed that the lower the EPS bead size, the greater the concrete compressive strength.

Babu, *et al*. (2003) investigated the behaviour of lightweight expanded polystyrene concrete containing silica fume and found that the strength of EPS concrete marginally increased as EPS bead size decreased and increased as the natural coarse aggregate size in concrete increased.

Bello (2011) carried out a research work on the suitability of polystyrene beads waste materials for lightweight concrete and concluded that the compressive strength which corresponds to the specified requirement for structural lightweight concrete was achieved with 30% and 50% coarse aggregate replacement by volume.

Kuhail and Shihada (2003) studied the Mechanical properties of polystyrene-lightweight concrete and in their studies, factors which affect the compressive strength of polystyrene-lightweight concrete such as water-cement ratio, polystyrene/cement ratio, cement content, curing time, maturity, compaction, fire and admixtures were examined and also establishing a relation between the tensile and compressive strength and procedure for designing polystyrene-lightweight concrete mixes were set out. It shows that the compressive strength increases as the water cement decreases, as the amount of aggregates increases, and as the cement content increases. The compressive strength of polystyrene-lightweight concrete is much lower than normal weight concrete due to the weak bond between the polystyrene beads and the cement paste, and weakness of the beads themselves. Likewise the tensile strength of polystyrene-lightweight concrete increases as the cement content or the amount of aggregate is increased, they attributed this substantial reduction in tensile strength to the weaker bond

between the aggregates and cement paste and to the weakness of the polystyrene beads in tension.

Momtazi *et al*. (2010) investigated the durability of lightweight concrete containing EPS in salty exposure condition and concluded that after 210 days, the concrete specimen containing EPS show positive effects which can safe keep the reinforcing steel bars from corrosion. Likewise, Bandala *et al*. (2015) who also investigated the electrochemical and mechanical properties of lightweight concrete blocks with expanded polystyrene foam by replacing gravel with thermally modified expanded polystyrene (MEPS) to the levels of 0%, 25%, 50%, 75% and 100% in volume. It was observed from the study that with 75% and 100% replacement the concrete block lightened and when submerged in the solution of 3.5% sodium chloride (NaCl) they showed a better corrosion protection.

According to the European Manufacturer of EPS (EUMEPS), If EPS is exposed to temperatures above 100°C, it begins to soften, to contract and finally to melt.

Anthony *et al*. (2014) studied the performance perception of expanded polystyrene building product by the clients and the end users, in which a building estate in Abuja was used as a case study. Questionnaires were distributed among the clients (Citec International Estates Limited) and the residents of the building estate (Mount Pleasant Estates, Abuja) and statistical tools were used to analyse the data collected and they concluded that there is a great satisfaction in the application of expanded polystyrene building product in Nigerian building industry. Plate II shows the building in Citec International Estates, Abuja which was constructed using EPS.

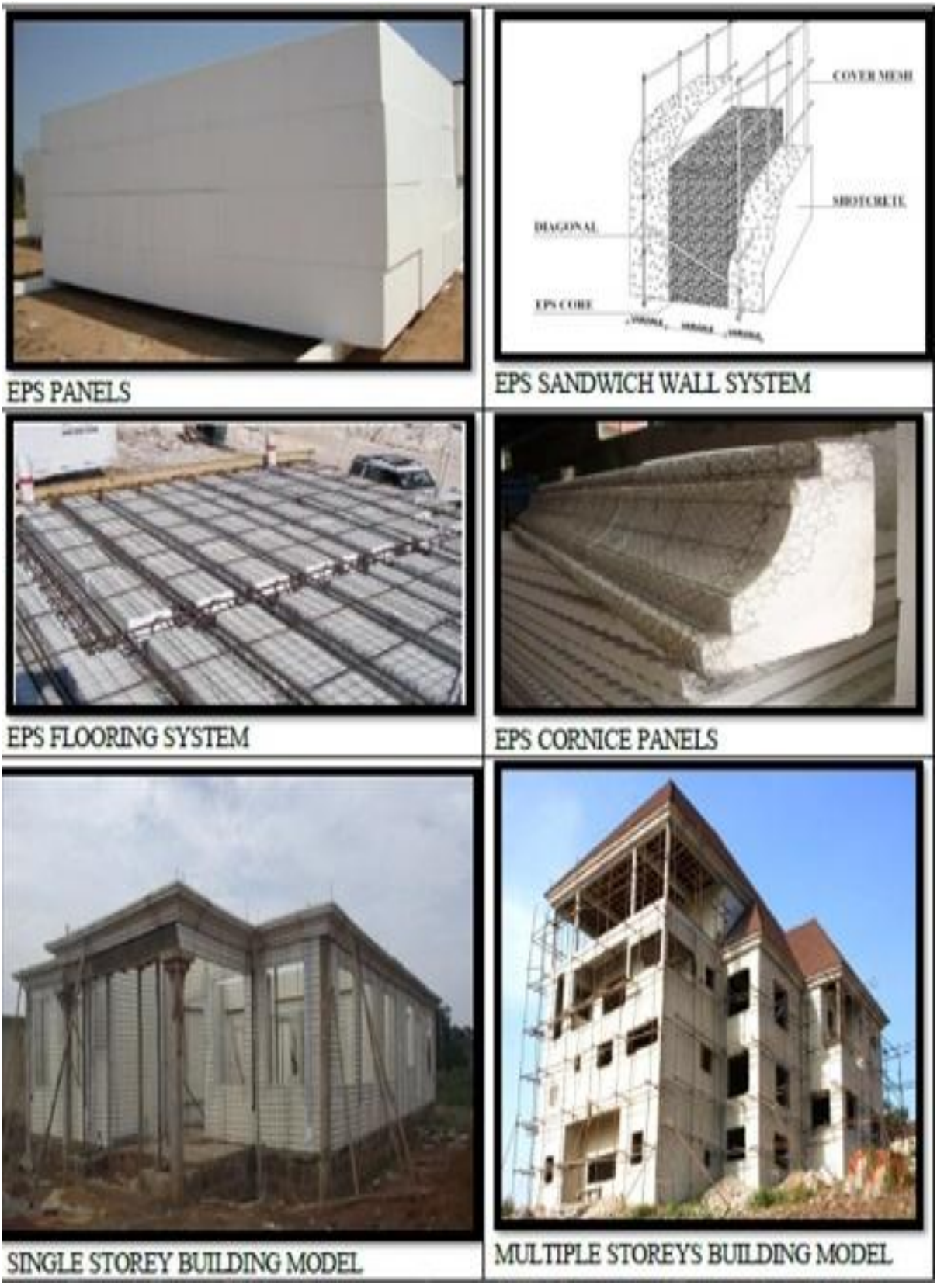


Plate II: A Typical EPS building System in Abuja; Source: Anthony *et al*. (2014)

2.4 Lightweight Aggregate Concrete

Due to ultra lightweight properties of EPS, its inclusion in concrete will makes a lightweight concrete which has so many advantages, such as lighter loads during construction, reduced self-weight in structures, and increased thermal resistance. Lightweight concrete is generally accepted as concrete having density of about 1800kg/m^3 or less (Thomat *et al*., 2014).

Lightweight concretes can be produced by replacing the normal aggregates in concrete either partially or fully, depending upon the requirements of density and strength (Ganesh 2003). Lightweight concrete is used for both structural and non-structural applications.. Structural lightweight concrete (LWC) has an in place density (unit weight) of 1440 to 1840 kg/m^3 compared to normal weight concrete with a density in the range of 2240 to 2400 kg/m^3. For structural applications the concrete strength should be greater than (17.0 MPa) (ACI 213 2003)

2.5 Material Properties of Concrete at High Temperature

When hardened concrete is heated gradually, the loss of weight appears to take place in the following three stages. In the first stage, called drying stage, evaporation of water from large capillaries and void will take place. At the second stage called dehydration stage, which occurs between 100 and 600^{0}C, loss of non –evaporable water from gel pores and small capillary pores will take place. This stage is accompanied with substantial shrinkage of concrete. At the final stage, decomposition stage, several changes will occur in the concrete system. At the temperature above 1000^{0}C, the combined water form hardened paste will be released. This will cause the hardened paste to lose its cementing property and thus significantly reducing the hardened concrete properties. This process will be accompanied with significant shrinkage of cement paste as well as the loss in strength (Kigha, 2014).

According to Handoo *et al*., (2002), subjecting concrete to high temperatures leads to transformations and reactions that cause progressive breakdown of cement gel structure and consequent loss in load-bearing capacity. In addition, several factors have been identified for the deterioration of concrete due to high temperature. These include decomposition of the calcium hydroxide with time and water, expansion of lime on re-hydration, destruction of gel structure, phase transformation in some types of aggregate, and development of micro-cracks due to thermal incompatibility between cement paste matrix and aggregate phase (Mohammad *et al.*, (2009).

2.5.1 Physical and Chemical Response of Concrete to High Temperatures

High temperatures cause chemical and micro structural changes, such as water migration (diffusion, drying), increased dehydration, interfacial thermal incompatibility, and chemical decomposition of hardened cement paste and aggregates. According to Zhang *et al*., (2000), these changes cause decrease in both the strength and stiffness of concrete and lead to irrecoverable deformation of structural components. Furthermore, the effect of elevated temperatures at varying heating scenarios on the strength of plain concrete has been investigated by many researchers such as Phan *et al*., (2001); Xiao and Falkner, (2006); Jianzhuang and Konig, (2004); Kigha (2014); Dahiru (2014) etc.

According to Gruz, (1966), Chew, (1993) during fire event, concrete elements (beams, columns, slabs, walls and sometimes foundations) are exposed to different heating scenarios (temperatures) which considerably changes the strength, stiffness as well as the physical properties of concrete.

According to Ian *et al*., (2005); Khoury, (2004), when the temperature reaches 400^0C, the calcium hydroxide in the cement will begin to dehydrate, generating more water vapour which consequently brings significant reduction in the physical strength of the concrete.

Anand and Arulraj, (2011) presented a research based on experimental studies on the performance of concrete when exposed to higher temperature, and concluded that some important factors such as Strength of concrete, type of cement, type of aggregate, water cement ratio, density of concrete, percentage of reinforcement and cover to the reinforcement, affects the performance of concrete at elevated temperature.

Dahiru, (2014) Investigated the behaviour of concrete subjected to various elevated temperatures using combined aggregates and single aggregate size to determine the fire resistance of concrete cubes and concrete prisms at five different temperatures level of 100^0C, 300^0C, 500^0C, 700^0C and 900^0C for four different exposure time ranging from 30min up to 120min. He observed that above exposure time of 1hour, high temperature have significant effect on the residual compressive strength of concrete and the flexural strength was found to be more sensitive to high temperature exposure than compressive strength. The result also shows that there is higher deflection for concrete with high concrete cover at exposure time of 2hours.

Concrete is well known for its capacity to endure high temperatures and fires, owing to its low thermal conductivity and high specific heat (Arioz, 2007). However, it does not mean that fire as well as higher temperatures does not affect the concrete. Characteristics such as colour, compressive strength, elasticity, concrete density and surface appearance are affected by high temperature (Morsy, *et al*. 2010). Sha and Pereira, (2001) pointed out that the behaviour of concrete subjected to high temperatures is as a result of many factors such as heating rate, peak temperatures, dehydration of C-S-H gel, phase transformations, and thermal incompatibility between aggregates and cement paste.

2.6 Properties Influencing Fire Resistance

The fire response of reinforced concrete members as explained by Kaccianauskas *et al*., (2014), is influenced by the characteristics of constituent materials namely, concrete and

reinforcing steel. These include (a) thermal properties, (b) mechanical properties, (c) deformation properties, and (d) material specific characteristics such as spalling in concrete. The thermal properties determine the extent of heat transfer to the structural member, whereas the mechanical properties of constituent materials determine the extent of strength loss and stiffness deterioration of the member. The deformation properties in conjunction with mechanical properties, determine the extent of deformations and strains in the structural member.

2.6.1 Thermal Properties

The thermal properties that influence temperature rise and distribution in a concrete structural member are thermal conductivity, specific heat, thermal diffusivity and mass loss.

2.6.1.1 Thermal Conductivity

Thermal conductivity is the property of a material to conduct heat. Concrete contains moisture in different forms, and the type and the amount of moisture have a significant influence on thermal conductivity. On average, the thermal conductivity of conventional normal strength concrete, at room temperature, ranges between 1.4 and 3.6 W/m^0C.

2.6.1.2 Specific heat

This is the amount of heat per unit mass, required to change the temperature of a material by one degree and is often expressed in terms of thermal (heat) capacity which is the product of specific heat and density. Specific heat is highly influenced by moisture content, aggregate type and density of concrete

2.6.1.3 Thermal diffusivity

The thermal diffusivity of a material is defined as the ratio of thermal conductivity to the volumetric specific heat of the material. It measures the rate of heat transfer from an exposed surface of a material to inner layers.

2.6.1.4 Mass loss

Depending on the density, concrete are usually subdivided into two major groups: (1) normal-weight concretes with densities in 2240 to 2400kg/m^3 range; and (2) lightweight concretes with densities between 1440 and 1840 kg/m^3. The density or mass of concrete decreases with increasing temperature due to loss of moisture, in which the type of aggregate has high influence in the retention in mass of concrete at elevated temperatures.

2.6.2 Mechanical Properties

The mechanical properties that are of primary interest in fire resistance design are compressive strength, tensile strength, elastic modulus, and stress-strain response in compression. Mechanical properties of concrete at elevated temperatures have been studied extensively in the literature in comparison to thermal properties (Kodur and Harmathy, 2008; Khoury, 2008; Tang, and Lo, 2009; Noumowe, 2005; Li, *et al*., 2004)

2.6.3 Deformation Properties

Deformation properties that include thermal expansion, creep strain, and transient strain are highly dependent on the chemical composition, the type of aggregate, and the chemical and physical reactions that occur in concrete during heating (Schneider, 1988).

2.6.4 Spalling

In addition to thermal, mechanical, and deformation properties, another factor that has a significant influence on the fire performance of a concrete structural member is spalling

(Dwaikat and Kodur, 2009). Spalling can occur after exposure to rapid heating and can be accompanied by violent explosions or it may happen during later stages 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 exposure of deeper layers of concrete to fire temperatures, thereby increasing the rate of transmission of heat to the reinforcement.

2.7 Reliability

Reliability is the probability that unsatisfactory performance or failure will not occur or Probability that a system will perform its intended function for a specific period of time under a given set of conditions.

$$R = 1 - P_f \tag{2.2}$$

Where P_f is the probability of failure.

The uncertainties in structural parameters such as material properties, external loads, geometry, etc., have caused serious attentions to reliability in structural design and analysis (Ghasemi and Yousefi, 2011). Thus, reliability theory, as a branch of theory of probability, provides a firm framework which can introduce a proper factor of safety when required (Faber and Sorensen, 2002). Thus, any system made of a satisfied reliability index, may be referred to as safe. According to Uche and Afolayan (2008), it was reported that the design of any structure must ensure safety at worst loading condition and the deformation of the members during normal working condition must be accepted from durability performance and appearance of the structure

2.7.1 Limit State Functions

A limit state function gives a descriptive assessment of the state of the structure as being "Unsafe" or "Safe". It is obtained from the traditional deterministic analysis but uncertain parameters are treated statistically. Generally, limit state function is given as:

$$G(\mathcal{X}) = R - S \tag{2.3}$$

Where R is a function of material property and S is a function of applied loads, densities and dimensions of the members under consideration. The limit state function is usually expressed in terms of the basic random variables X which affect the structural performance.

$\mathcal{X}_{\mathrm{i}} = (\mathcal{X}_1, \mathcal{X}_2, \mathcal{X}_3, \ldots\ldots\ldots \mathcal{X}_n)$, and

$$G(\mathcal{X}) = f(\mathcal{X}) = f(\mathcal{X}_1, \mathcal{X}_2, \mathcal{X}_3, \ldots\ldots\ldots \mathcal{X}_n) \tag{2.4}$$

Where $G(\mathcal{X})$ is the performance function (safety margin)

The limit state equation is represented as;

$G(\mathcal{X}) < 0$, corresponds to failure in the structure.

$G(\mathcal{X}) = 0$, correspond to interface between safety and failure.

$G(\mathcal{X}) > 0$, corresponds to safety of the structure.

Therefore, the probability of failure is given as $P[G(\mathcal{X}) < 0]$

2.7.2 First Order Reliability Method (FORM)

First Order Reliability Method (FORM), a very powerful, robust and accurate for computing of failure probabilities is used in the evaluation of structures in the context of non-linear analysis, which yields accurate prediction of structural behaviour in the context of probability analysis (Mohammed and Karim, 2015).

The probability of failure (P_f) used to express structural safety is typically represented by the reliability index, β. This is the shortest distance from the origin of the Cartesians point to the approximated failure surface as shown in Fig. 2.1. The failure surface is known as the limit state surface, g (x) evaluated at the undesired level. In this study, this β is when the design moment, M_D exceeds the Resistance moment of the section, M_R as in equation 2.5.

$$G(\mathcal{X}) = G(\mathcal{X}_1, \mathcal{X}_2, \mathcal{X}_3, \ldots\ldots\ldots \mathcal{X}_n) = M_R - M_D \quad (2.5)$$

Where, $\mathcal{X}_i$ represents the basic random variables in the load and strength domains.

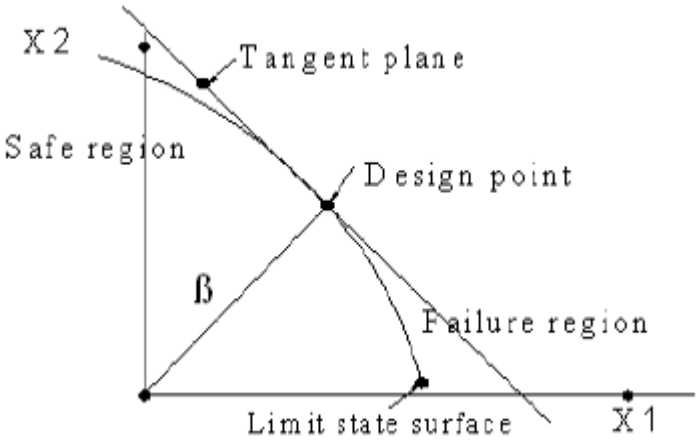


Fig. 2.1: Typical FORM approximation surface (Mohammed and Karim, 2015).

CHAPTER THREE

MATERIALS AND METHODS

3.1 PREAMBLE

The test involved the constituent materials, fresh and the hardened concrete. All the tests were carried out in the department of Civil Engineering, Ahmadu Bello University, Zaria with the exception of specimens heating which was carried out at Industrial Development Center, (IDC) Samaru, Zaria.

3.2 Materials

3.2.1 Cement

A Dangote brand of cement was used as the binder for the concrete production. Physical properties test were carried out on the Cement in accordance with BS 4550-3:1978.

3.2.1.1 Consistency Test (%): The test was carried out in accordance with BS 4550-3:1978, Using Vicat apparatus with plunger. Cement paste of standard consistence has a specified resistance to penetration by standard plunger. The water required for such a paste is determined by trial penetrations of pastes with different water contents. Content of water was expressed as percentage by mass of the cement. Appendix I-a shows the detailed result.

3.2.1.2 Setting Time Test: The test was conducted in accordance with BS 4550-3:1978 Using Vicat apparatus with steel needle, the Initial and the final setting time was determined by observing the needle penetration into the cement paste of standard consistence inside the mould until it reaches a specified value. Appendix I-b and I-c shows the detailed result.

3.2.1.3 Soundness Test: The purpose of this test is to observe the expansion of cement paste. This reveals the ability of hardened cement to retain its volume after setting. This was carried out in accordance with BS 4550-3:1978 Appendix I-d shows the result.

3.2.1.4 Specific Gravity Test (g/cm^3): This is the physical properties of the material which is defined by mass of a unit volume of a material substance, expressed as grams per cubic centimetre (g/cm^3). The test was conducted in accordance with BS 4550-3:1978, using the density bottle (Pycnometer method). Appendix I-e shows the specific gravity of cement.

3.2.2 Aggregates (Fine and Coarse)

The fine aggregate and the coarse aggregate were obtained in Samaru area in Zaria, located within latitude 11^0 17′N and longitude 7^0 63′E.. The tests carried out includes, particle size distribution analysis, specific gravity and bulk density.

3.2.2.1 Sieve Analysis (grading): Sieve analysis was conducted on the aggregates sample (fine and coarse aggregates) with various sieve sizes in accordance with BS 812: Part 103; 1985 as shown in Appendix I-f and I-j for fine and coarse aggregates respectively.

3.2.2.2 Specific gravity Test: The specific gravity test was carried out on fine and Coarse aggregate. This was done in accordance with BS 812 part 2; 1995. Appendix I-g and I-k shows the result.

3.2.2.3 Bulk density (kg/m^3): The test was conducted in accordance with BS 812 part 2; 1995 using the density cylinder and water. Appendix I-h and I-l shows the result obtained.

3.2.2.4 Moisture Content of Sand (%): The moisture content test was conducted on the fine aggregate in accordance with BS 812 part 109; 1990. Appendix I-i and I-o shows the result.

3.2.2.5 Aggregate Crushing Value (%): This test was conducted on the coarse aggregate in accordance with BS 812 part 110; 1990 and the results is presented in Appendix I-n

3.2.2.6 Aggregate Impact Value (%): This test was conducted on the coarse aggregate in accordance with BS 812 part 112; 1990 and the results is presented in Appendix I-m

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3.2.3 Expanded Polystyrene (EPS) waste

Expanded polystyrene (EPS) is a white, lightweight material that is being used in packaging industry Manufacturers rely on EPS packaging because of its ability to prevent or minimize product damage during transit and its excellent insulation properties. Plate III shows the EPS as a solid waste in dumpites within Ahmadu Bello University, Zaria, Main campus, while Plate IV shows the EPS after Shredding. The detailed results on the bulk density and specific gravity of EPS are presented in Appendix I-p and I-q.



Plate III: A waste form of EPS



Plate IV: Shredded EPS

3.3 Mix Design for Concrete

The mix design used for preparing the concrete was based on an absolute volume method given by Neville (2003). A mix ratio of 1:2:4, water-cement ratio of 0.5 and characteristic strength of 25N/mm^2 (Grade 25 concrete) was used for the concrete mix design. The mix proportion for each specimen is presented in Table 3.1.

$$V_W + V_C + V_{F.A} + V_{C.A} = 1m^3 \quad (3.1)$$

Where V_W, V_C, $V_{F.A}$, $V_{C.A}$ are volumes fraction of water, cement, fine aggregate and coarse aggregate respectively. With the mix ratio 1:2:4 and water-cement ratio of 0.5 by weight.

Where:

$$V_X = \frac{\text{mass of sample X}}{\text{Specific gravity of sample } (P_X) \times \text{Density of water } (1000\text{kg/m}^3)} \quad (3.2)$$

Then eqn. (3.1) becomes:

$$\frac{W}{(P_W * 1000)} + \frac{C}{(P_C * 1000)} + \frac{F.A}{(P_{F.A} * 1000)} + \frac{C.A}{(P_{C.A} * 1000)} = 1 \quad (3.3)$$

Where:

W = weight of water, C = weight of cement, F.A = weight of fine aggregate, C.A = weight of coarse aggregate

$\frac{W}{C} = 0.5$, therefore the weight of water W then becomes $W = 0.5C$

$$\frac{0.5C}{(1 * 1000)} + \frac{C}{(3.15 * 1000)} + \frac{2C}{(2.52 * 1000)} + \frac{4C}{(2.70 * 1000)} = 1 \quad (3.4)$$

Where C denotes the weight of cement and the value of specific gravity of materials are determined from the experiment.

Which implies that C = 323kg/m^3

Therefore, the concrete will have the following batch quantities for the control specimen, in which all other parameters are kept constant and coarse aggregate varies with different EPS percentage. Batch by weight was used except for the EPS which was batched by volume.

Water = 162 kg/m^3

Cement = 323 kg/m^3

Fine aggregate = 646 kg/m^3

Coarse aggregate = 1292 kg/m^3

Table 3.1: Mix Proportion per Specimen

Mix / EPS (%)	Water (kg/m^3)	Cement (kg/m^3)	Sand (kg/m^3)	Granite (kg/m^3)	EPS (kg/m^3)	EPS (m^3/ m^3)
Control	162	323	646	1292	0	0
5	162	323	646	1227	64.6	0.065
10	162	323	646	1163	129.2	0.13
15	162	323	646	1098	193.8	0.19
20	162	323	646	1034	258.4	0.26
25	162	323	646	969	323	0.32
30	162	323	646	904	387.6	0.39
35	162	323	646	840	452.2	0.45
40	162	323	646	775	516.8	0.52
45	162	323	646	710.6	581.4	0.58
50	162	323	646	646	646	0.65

3.4 Mixing of Specimen

Expanded polystyrene were obtained from dumpsite within samara campus, ABU Zaria, shredded into Sizes of 5-6mm with a perforated metal sheet having a diameter of 6mm as shown in plate III and IV. The shredded EPS were weighed by volume as shown in plate V. Other materials used in the concrete mix such as cement, fine aggregates, coarse aggregates and water were also weighed as shown in plate VI, which were weighed accordingly and accurately following the calculation mentioned in Table 3.1. Hand mixing was adopted throughout the mixing process of the experimental work as shown plate VII. Plate VIII, plate IX, and plate X shows the process of compaction with tamping rod, process of curing and the specimen after curing respectively.



Plate V: Batching of EPS by Volume



Plate VI: Weighing of other Materials



Plate VII: Hand mixing of Aggregates



Plate VIII: Compaction with Tamping Rod



Plate IX: Curing of Specimen



Plate X: Specimen after Curing

A total numbers of 198 concrete cubes of 150×150×150mm in dimension and 165 numbers of beams of size 150×150×750mm were produced for the compressive strength and flexural strength testing considering various EPS percentage and also different temperature ranges. Plate XI shows the process of loading the specimen in the furnace.



Plate XI: Loading of Specimen into Furnace

3.5 Workability Test on fresh concrete

3.5.1 Slump

This test is to determine the degree of consistency in wet concrete. The test was conducted to assess the properties of freshly mixed concrete (control mixes) and those with coarse aggregate partially replaced with EPS at 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, 50%. This was carried out in accordance with BS 1881 part 102; 1983. Plate XII shows the process of carrying out the slump test. The detailed result is presented in Appendix I-r.



Plate XII: Slump Test

3. 6 Casting of Concrete Cubes and Beams

After slump test, concrete cubes/beams were cast. The inner surface of concrete moulds 150×150×150mm for cubes and 150×150×750mm for beams was oiled and the wet concrete poured. The concrete was placed in three layers with each layer compacted using steel rods of 25 mm square size, with minimum of 35 blows per layer and the surface was levelled using a hand trowel. Each concrete specimen was marked by number and manufacturing date for identification. After 24 hours, the concrete cubes were demoulded and cured in a water tank for 28 days.

3.7 Cube Compression Test

After curing for 28 days, the cubes were removed from curing tank, left to air dry then weighed and taken for heat test in the furnace before crushing. The crushing was performed using a Universal compression machine in accordance with BS 1881-116:1983. The load was applied until the specimen failed as shown in plate XIII. The failure load was recorded and the compressive strength was calculated using equation 3.5. The detailed result is presented in Appendix II-a to II-e.

$$f_{cu} = {}^{P}/_{A} \text{ (N/mm}^2\text{)} \quad (3.5)$$

Where, P is the failure load and A is the cross sectional Area of the cube



Plate XIII: Compression Test

3.8 Flexural Strength Test

Flexural strength test were carried out on the beams of size 150×150×750mm using a three point bending test as set-up in Fig. 3.1, the specimen was simply supported on the two rollers of the machine as shown in plate XIV, which were 600mm apart in accordance with BS 1881-118: 1983, the bending strength was calculated using the formula in equation 3.6. The detailed result is presented in Appendix III-a to III-e.

$$f_b = {}^{Pl}/_{bd^2} \quad (3.6)$$

Where, p is the ultimate failure load, l is the length between the supports, b is the width and d is the depth in mm

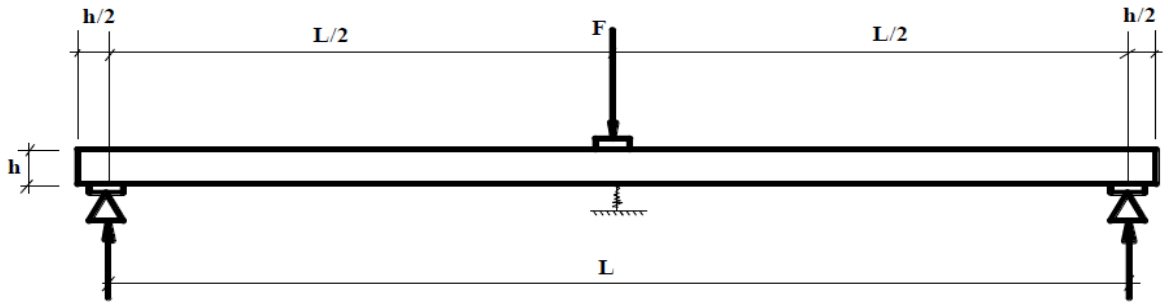


Fig. 3.1: Three-point bending test set-up (Mohammed, 2014)



Plate XIV: Flexural Strength Test

3.9 PROBABILISTIC METHOD

3. 9.1 Reliability Analysis

A Simply Supported reinforced concrete beam of width 300mm and a height of 600mm of 6m length was investigated having the following properties as presented in Table 3.2 under bending modes of failure in order to achieve the following objectives;

- Develop structural configuration of the beam under investigation.
- Develop the resistance model for failure under bending with reference to Euro-code 2 (2004).
- Develop load action models for the structural analysis.
- Develop limit state function

- Develop stochastic model of all basic variables for the performance function
- Develop First Order Reliability Algorithm in order to evaluate the performance function.
- Develop MATLAB- based program to implement the objective function
- Obtain safety indices by varying the load ratio in order to study the effects of EPS content on the safety of the beam under elevated temperatures.

Table 3.2: Beams properties (Chanakya, 2009)

Length of beam (m)	6	Width(b) (mm)	300
Depth (h) (mm)	600	Effective depth (d) (mm)	552
Concrete grade (N/mm^2)	25	Design load (w) = $1.35G_k + 1.5Q_k$ (kN/m)	25.61
Dead load from beam (kN/m)	7.8	Steel Strength fy ($N/mm^{2)}$	500
Self – weight of beam (kN/m)	4.5	Design Moment $M_{Ed} = wl^2/8$ (kNm)	115.245
Total dead load (kN/m)	12.3	Ultimate Moment $M_{Rd} = 0.167f_{cu}bd^2$	381.6
Imposed load on beam (kN/m)	6	Area of Steel (mm^2)	1542

3.9.2 Structural Configuration of the beam

The section of the simply supported beam as well as its cross-section is as presented in fig. 3.2

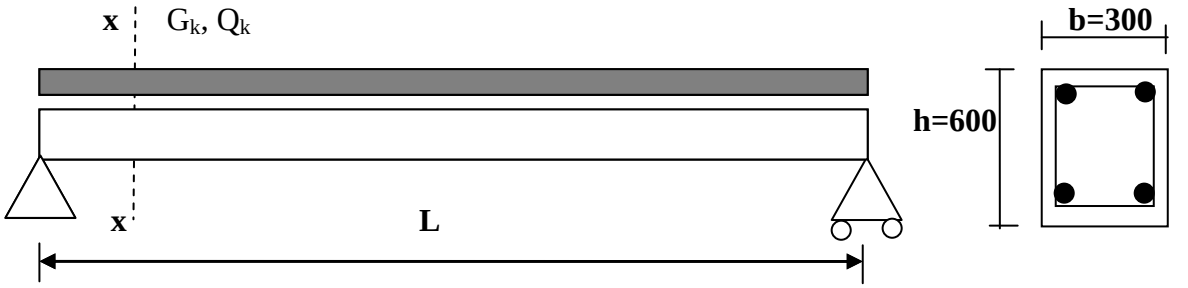


Fig 3.2: Structural configuration of a simply supported beam Section x-x

3.9.3 Load action Model for Beams under Bending

Applied Moment $M_A = wl^2/8$ (3.7)

Where, $w = \gamma_g G_k + \gamma_q Q_k$ (3.8)

Divide both sides by Q_k

$\frac{w}{Q_k} = \gamma_g \alpha + \gamma_q$

Where:

$\alpha = \frac{G_k}{Q_k}$

$w = Q_k(\gamma_g \alpha + \gamma_q)$ (3.9)

Substituting for w in equation 3.6, Applied moment M_A then becomes

$M_A = \frac{Q_k(\gamma_g \alpha + \gamma_q)L^2}{8}$

$M_A = 0.125 Q_k(\gamma_g \alpha + \gamma_q)L^2$ (3.10)

3.9.4 Resistance Model for Beams under bending

The resistance model for beams due to bending is generated in accordance with Euro-code 2.

The Moment of resistance M_R may be evaluated as presented by equation 3.11

$M_R = A_S f_y \left(d - \frac{0.5 A_S f_y}{b f_{cu}}\right)$ (3.11)

Where f_{cu} is obtained from the prediction model generated from the experimental data obtained from the linear square regression analysis in the form of straight line equation in equation 3.12.

$$y = mx + c \quad (3.12)$$

Thus, the value for f_{cu} was deduced from equation 3.12

$$f_{cu} = Cons1 * epsc + Cons2 \quad (3.13)$$

Where:

f_{cu} = Compressive strength of concrete cube representing “y”

Cons1 = gradient from the plot of Strength against EPS representing “m”

Epsc = Corresponding EPS content representing "x”

Cons2 = Intercept from the plot of Strength against EPS representing “c”

3.9.5 Limit State Function

The limit state functions for failure due to bending is presented as follows

$$G(X) = M_R - M_A$$

$$G(X) = \left[A_S f_y \left(d - \frac{0.5 A_S f_y}{b f_{cu}} \right) \right] - [0.125 Q_k (\gamma_g \alpha + \gamma_q) L^2 \times 10^6] \quad (3.14)$$

Where terms in equations (3.7 to 3.14) are defined as; M_A is the Applied moment, w is the ultimate design load, L is the Length of beam, γ_g is the dead load factor, γ_q is the Live load factor, G_k is the Dead load, Q_k is the Live load, α is the Load Action, M_R is Ultimate Moment of Resistance of the beam, A_S is Area of Steel, f_y is the Yield Strength of Steel, d is the Depth, b is the Width of beam, f_{cu} is the Concrete Strength, $G(X)$ is the limit state function due to failure due to bending,

3.9.6 Stochastic Models

The statistical model for all the basic variables for each limit state function is then presented in Table 3.3;

Table 3.3; Statistical models of the basic design variables (JCSS 2001)

S/N	Basic Variable	Distribution Model	Unit	Mean	COV	Standard deviation
1	Imposed load, Q_K	Gumbel	kN/m	6	0.40	8.0
2	Dead load factor, Υ_g	Deterministic	-	1.35	-	-
3	Live load factor, Υ_q	Deterministic	-	1.5	-	-
4	Load action, α	Deterministic	-	1.3	-	-
5	Length of beam, L	Deterministic	M	6	-	-
6	Area of Steel, A_S	Normal	mm^2	1542	0.10	77.10
7	Yield Strength, f_y	Lognormal	N/mm^2	500	0.05	25.32
8	Depth of beam, d	Normal	Mm	552	0.025	13.80
9	Concrete Strength, f_{cu}	Lognormal	N/mm^2	25	0.17	4.25
10	Width of beam, b	Normal	Mm	300	0.025	7.50

3.9.7 First Order Reliability Method (FORM) Algorithm

The Algorithm for the First Order Reliability Method was developed by;

i. Obtaining the partial derivatives of failure mode due to bending.

ii. Isolating the Mean values and as well as the standard deviation from Table 3.3

3.9.7.1 Partial derivation of Failure mode due to Bending

The partial derivatives with respect to bending were obtained as;

$$\frac{\partial G(X)}{\partial Q_K} = -0.125(\gamma_g \alpha + \gamma_q)L^2 \times 10^6 \quad (3.15)$$

$$\frac{\partial G(X)}{\partial A_S} = f_y d - \frac{A_S {f_y}^2}{b f_{cu}} \quad (3.16)$$

$$\frac{\partial G(X)}{\partial f_y} = A_S d - \frac{{A_S}^2 f_y}{b f_{cu}} \quad (3.17)$$

$$\frac{\partial G(X)}{\partial d} = A_S f_y \quad (3.18)$$

$$\frac{\partial G(X)}{\partial b} = \frac{0.5{A_S}^2 {f_y}^2}{b^2 f_{cu}} \quad (3.19)$$

$$\frac{\partial G(X)}{\partial f_{cu}} = \frac{0.5{A_S}^2 {f_y}^2}{b {f_{cu}}^2} \quad (3.20)$$

3.9.7.2 Mean values and Standard Deviation for failure mode due to bending

The mean ($\mu G(X)$) and standard deviation ($\sigma G(X)$) for the failure mode due to bending with their respective derivatives can be obtained as;

$$\mu G(X) = \mu A_S \,.\, \mu f_y \,.\, \mu d - [\frac{0.5\mu {A_s}^2 .\ \mu {f_y}^2}{\mu b \,.\, \mu f_{cu}}] - [0.125 \mu Q_{k \,\cdot\, \mu(\gamma_g \alpha + \gamma_q)} L^2 \times 10^6] \quad (3.21)$$

$$\boldsymbol{\sigma G(X)} = \sqrt{(\frac{\partial \boldsymbol{G(X)}}{\partial \boldsymbol{A_s}})^2 \cdot (\boldsymbol{\sigma A_S})^2 + (\frac{\partial \boldsymbol{G(X)}}{\partial \boldsymbol{f_y}})^2 \cdot (\boldsymbol{\sigma f_y})^2 + (\frac{\partial \boldsymbol{G(X)}}{\partial \boldsymbol{d}})^2 \cdot (\boldsymbol{\sigma d})^2 + (\frac{\partial \boldsymbol{G(X)}}{\partial \boldsymbol{b}})^2 \cdot (\boldsymbol{\sigma b})^2 + (\frac{\partial \boldsymbol{G(X)}}{\partial \boldsymbol{f_{cu}}})^2 \cdot (\boldsymbol{\sigma f_{cu}})^2 + (\frac{\partial \boldsymbol{G(X)}}{\partial \boldsymbol{Q_K}})^2 \cdot (\boldsymbol{\sigma Q_K})^2} \quad (3.22)$$

Safety Index (β) is computed as presented in equation 3.23 as shown

$$\beta = \frac{\mu G(X)}{\sigma G(X)} \quad (3.23)$$

The flow chart for the computation of β can be represented as shown in Fig 3.3

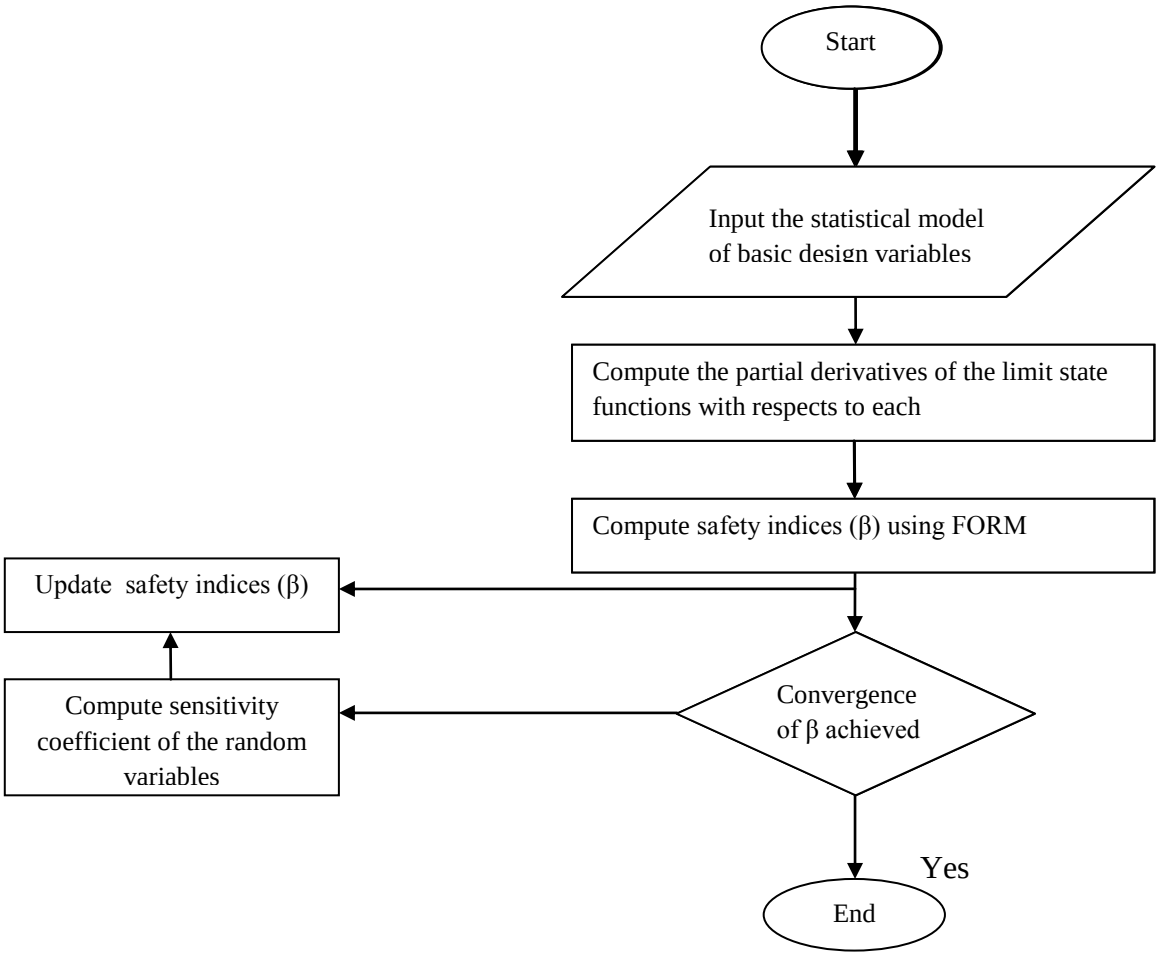


Fig. 3.3; Program Flowchart representation for the computation of β (Hassan, 2016))

3.10 Results from Laboratory Experiments

The summarized results obtained from the laboratory experiments for both the compressive strength test of the cubes and flexural strength of beams are presented in Table 3.4 and 3.5, while the detailed results are presented in Appendix II-a to II-e and IIIa to IIIe respectively. While the results of safety indices obtained from the reliability analysis of reinforced concrete beam are presented in Table 3.6 to 3.11.

Table 3.4; Mean Compressive Strength of Cubes at 28 days in N/mm^2

Temp ^0C	EPS CONTENT (%)										
	0	5	10	15	20	25	30	35	40	45	50
28(RT)	26.01	25.26	24.00	21.30	17.85	16.59	15.19	13.67	11.78	10.67	9.19
200	24.00	25.75	25.19	24.59	21.56	18.59	17.69	13.94	12.74	10.95	10.00
400	20.00	25.41	25.01	22.45	20.07	18.01	16.83	13.16	12.55	10.74	9.33
600	12.30	11.70	11.11	10.37	10.07	6.22	4.44	3.96	2.89	2.67	1.63
800	10.96	10.22	7.26	6.52	5.19	4.44	3.11	2.67	2.33	1.19	0.74

Table 3.5; Mean Flexural Strength of Beams at 28 days in N/mm^2

Temp ^0C	EPS CONTENT (%)										
	0	5	10	15	20	25	30	35	40	45	50
28(RT)	1.78	1.51	1.24	1.16	1.07	1.07	0.98	0.89	0.80	0.80	0.80
200	1.42	1.42	1.42	1.51	1.60	1.96	1.69	1.24	1.07	0.89	0.89
400	0.89	0.89	0.89	0.98	1.07	1.33	1.16	0.98	0.71	0.71	0.71
600	0.44	0.40	0.44	0.49	0.53	0.71	0.62	0.53	0.36	0.36	0.36
800	0.18	0.18	0.18	0.22	0.27	0.36	0.31	0.18	0.13	0.09	0.09

Table 3.6; Safety Indices for a Reinforced Concrete Beam at various Load ratio and EPS content at 28^0C (RT)

EPS% α	**1.0**	**1.1**	**1.2**	**1.3**	**1.4**	**1.5**
1.0	6.10	5.91	5.73	5.55	5.38	5.21
5.0	6.10	5.91	5.72	5.54	5.37	5.20
10	6.08	5.90	5.71	5.53	5.35	5.18
20	6.06	5.86	5.67	5.48	5.30	5.12
30	6.00	5.79	5.59	5.40	5.21	5.02
40	5.83	5.62	5.41	5.20	5.00	4.81
50	5.28	5.06	4.84	4.63	4.43	4.23

Table 3.7; Safety Indices for a Reinforced Concrete Beam at various Load ratio and EPS content at 200^0C

EPS% α	1.0	1.1	1.2	1.3	1.4	1.5
1.0	6.10	5.92	5.74	5.56	5.39	5.22
5.0	6.10	5.91	5.73	5.55	5.38	5.21
10	6.09	5.90	5.72	5.54	5.36	5.19
20	6.07	5.88	5.67	5.50	5.32	5.14
30	6.03	5.83	5.63	5.44	5.25	5.07
40	5.92	5.71	5.50	5.30	5.10	4.91
50	5.61	5.38	5.17	4.96	4.75	4.55

Table 3.8; Safety Indices for a Reinforced Concrete Beam at various Load ratio and EPS content at 400^0C

EPS% α	1.0	1.1	1.2	1.3	1.4	1.5
1.0	6.10	5.91	5.73	5.55	5.37	5.20
5.0	6.09	5.90	5.72	5.54	5.36	5.19
10	6.08	5.89	5.71	5.52	5.34	5.17
20	6.06	5.86	5.67	5.48	5.30	5.12
30	6.00	5.80	5.60	5.41	5.22	5.04
40	5.89	5.68	5.47	5.27	5.07	4.88
50	5.59	5.36	5.15	4.94	4.73	4.54

Table 3.9; Safety Indices for a Reinforced Concrete Beam at various Load ratio and EPS content at 600^0C

EPS% α	1.0	1.1	1.2	1.3	1.4	1.5
1.0	5.89	5.67	5.46	5.26	5.06	4.87
5.0	5.82	5.60	5.39	5.18	4.99	4.79
10	5.70	5.48	5.26	5.06	4.85	4.66
20	5.21	4.99	4.77	4.56	4.36	4.17
30	3.84	3.65	3.47	3.29	3.12	2.96
40	0.51	0.43	0.36	0.28	0.20	0.13
50	-2.94	-2.96	-2.97	-2.99	-3.00	-3.02

Table 3.10; Safety Indices for a Reinforced Concrete Beam at various Load ratio and EPS content at 800^0C

EPS% α	1.0	1.1	1.2	1.3	1.4	1.5
1.0	5.59	5.36	5.15	4.94	4.73	4.54
5.0	5.43	5.20	4.99	4.78	4.57	4.38
10	5.14	4.92	4.70	4.49	4.29	4.10
20	3.98	3.79	3.60	3.42	3.24	3.08
30	1.41	1.31	1.21	1.10	1.01	0.91
40	-1.84	-1.88	-1.91	-1.94	-1.98	-2.01
50	-3.81	-3.83	-3.85	-3.86	-3..88	-3.90

Table 3.11; Safety Indices for Reinforced Concrete Beam at various Temperatures and EPS content at Load ratio (α) of 1.0

EPS% Tempt℃	1.0	5.0	10	20	30	40	50
RT	6.10	6.09	6.08	6.06	6.00	5.84	5.28
200	6.10	6.09	6.09	6.07	6.03	5.92	5.61
400	6.09	6.09	6.08	6.06	6.01	5.89	5.59
600	5.89	5.82	5.70	5.21	3.84	0.51	-2.94
800	5.59	5.43	5.14	3.98	1.41	-1.84	-3.81

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Properties of Constituent Materials

The properties of constituent materials used which includes Cement, fine aggregates, coarse aggregates and EPS as compared with their standard requirement as per codes specification are presented below.

4.1.1 Properties of Cement (Dangote cement)

The test results for the properties of cement as compared with standard specifications are presented in Table 4.1. It shows that the cement samples satisfies the provision of code of practice in term of consistency, Initial and final setting time, specific gravity and soundness. Therefore, the dangote cement used satisfied the code specifications for ordinary Portland cement.

Table 4.1: Summary of Physical Properties of Cement

Physical Property	**Results Obtained**	**Codes Specification**
Normal Consistency (%)	30.5	26-33
Initial Setting time (min)	121	Min 45
Final Setting time (min)	286	Max 600
Specific gravity	3.15	3.15
Soundness (mm)	0	Max 10

4.1.2 Properties of Aggregates

4.1.2.1 Physical Properties of Aggregates

The results obtained for the physical properties of Aggregates and their comparisons to codes are presented in Table 4.2. From the value obtained, it shows that the materials meet specification requirements for quality aggregates.

Table 4.2: Summary of Physical Properties of Aggregate

Description of Test	**Average result obtained**	**Codes specification**
Specific gravity of fine aggregate	2.52	2.50 – 2.75
Bulk density of fine aggregate	1522	1500-2000
Moisture content (%) of fine aggregate	2.00	Max 2
Aggregate Impact Value (%)	19	Max 25
Aggregate Crushing Value (%)	20	Max 25
Specific gravity of coarse aggregate	2.70	2.50 – 2.75
Bulk density of coarse aggregate	1700	1500-2000
Moisture content (%) of coarse aggregate	1.52	Max 2

4.1.2.2 Particles Size distribution of fine and coarse aggregates

The particle size distribution curve for fine aggregates are presented in Fig. 4.1 and it shows that the curve falls within Zone II envelopes, which indicates that the sand is good in making concrete..

Fig. 4.2 shows the particle size distribution for coarse aggregates and it was observe that the size of aggregates with a greater percentage passing is at 19mm, which indicates that the nominal size for the coarse aggregates used is 19mm.

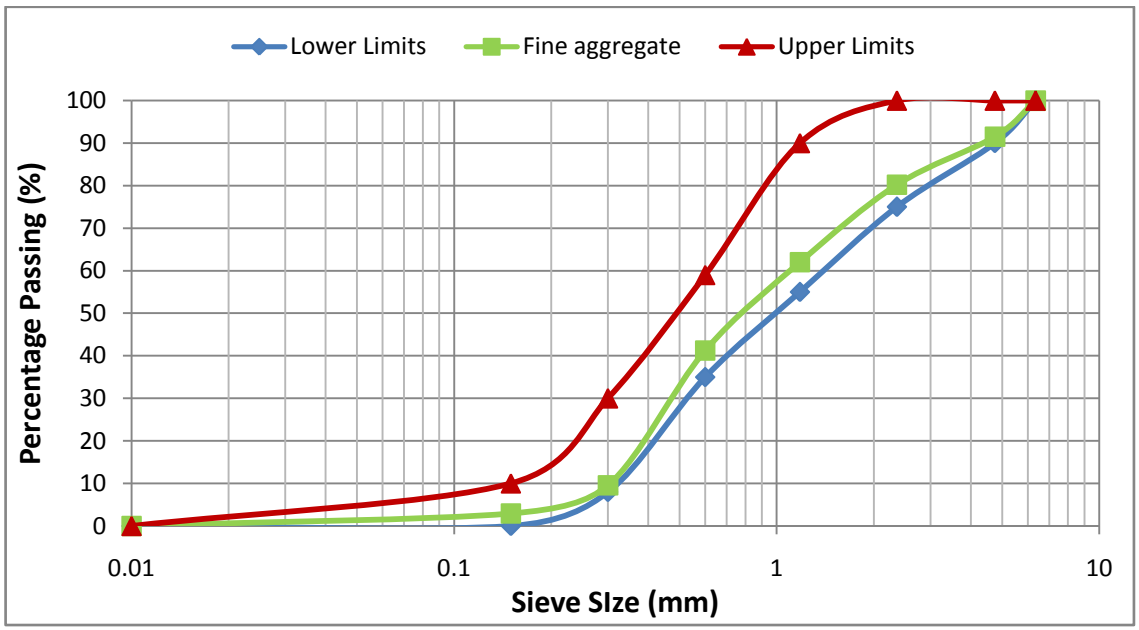


Fig 4.1; Grain Size distribution curve for fine aggregate

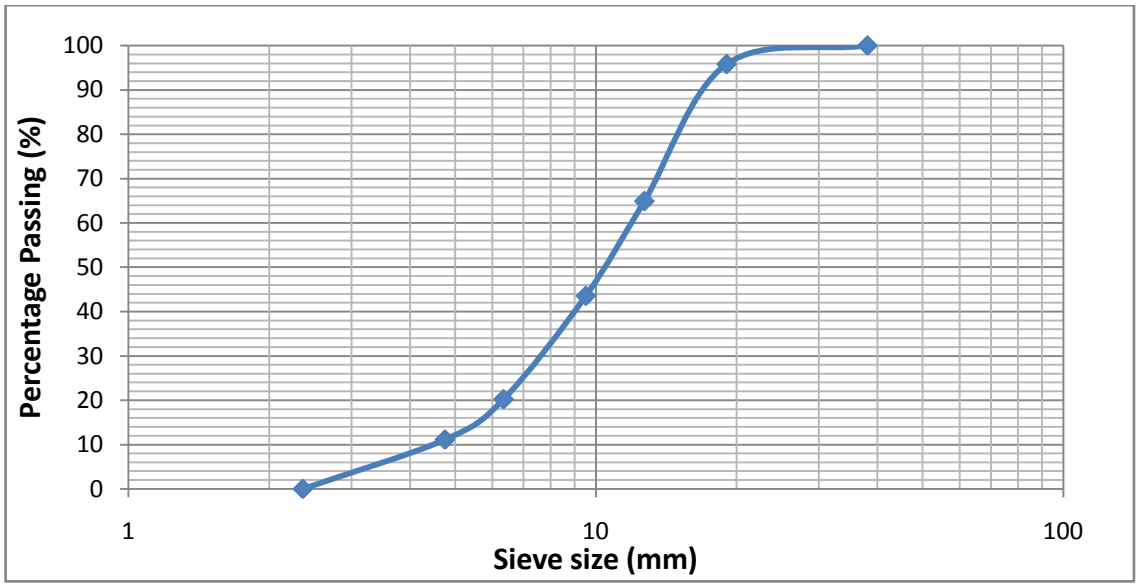


Fig. 4.2; Grain Size distribution curve for coarse aggregate

4.1.3 Properties of EPS

The results obtained for the properties of Expanded Polystyrene is presented in Table 4.3 and from the results of the specific gravity which is 0.069 and the bulk density which is 12.15, its indicates that EPS is a lightweight materials.

Table 4.3: Properties of Expanded Polystyrene

Description of Test	**Results obtained**
Specific gravity	0.069
Bulk density (kg/m^3)	12.15
Particle size (mm)	5-6

4.2 Variation in Slump

The difference in slump with varying EPS content in the mix is presented in Table 4.4 and it was observed that the slump increases as the EPS content increases in the mix. This might be as a result of inability of EPS to absorb water, leaving the remaining aggregates in the mix to take up the available water.

Table 4.4: Variation in Slump

EPS Replacement (%)	0	5	10	15	20	25	30	35	40	45	50
Slump (mm)	5	5	10	15	20	30	40	45	50	55	65

4.3 Results of Compressive Strength Test

A graph of the cube compressive strength against Temperature is presented in Fig. 4.3, while that of the cube compressive strength against the percentage of EPS is presented in Fig. 4.4.

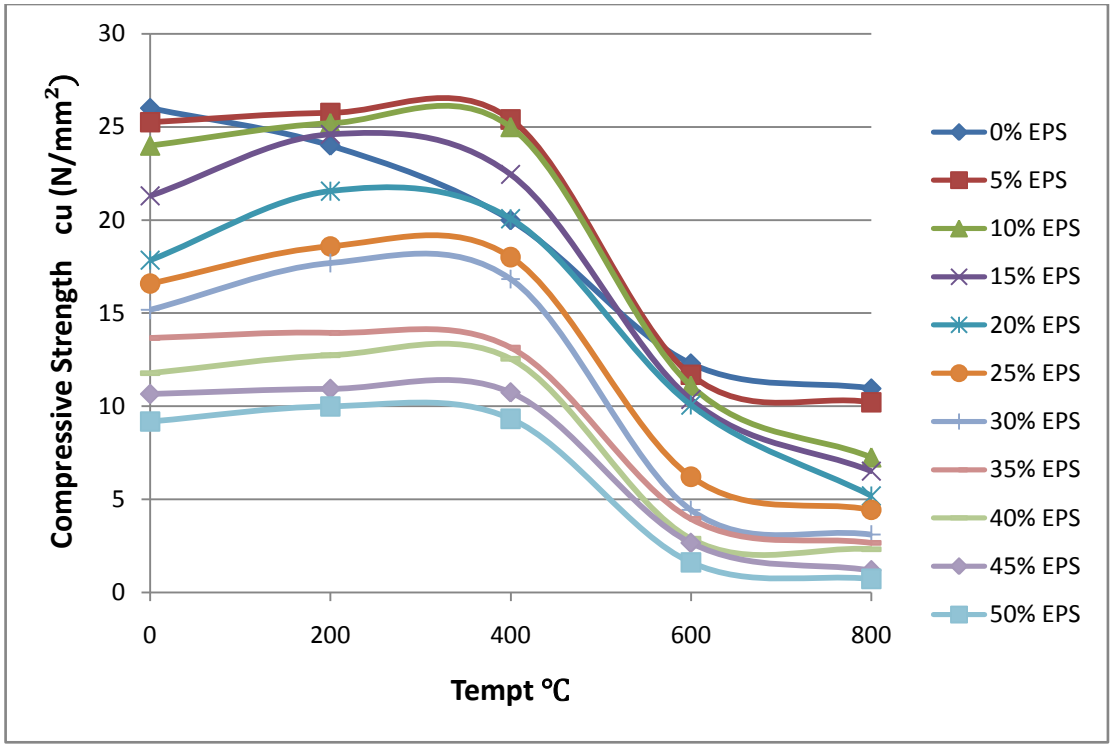


Fig 4.3: Cube compressive strength against Temperature

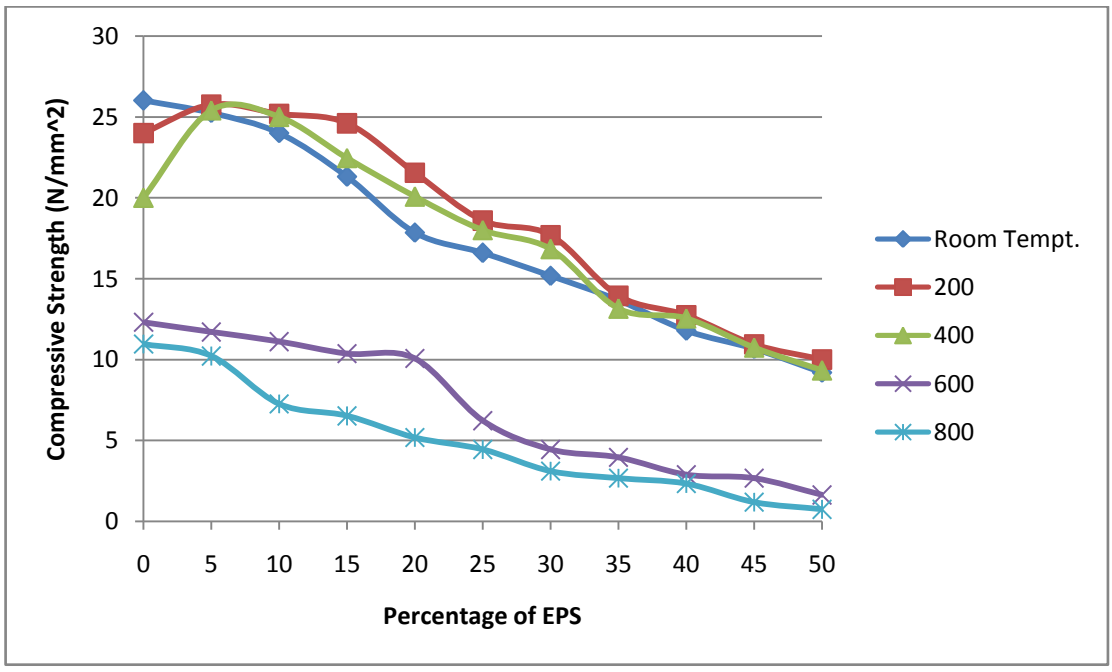


Fig 4.4: Cube compressive strength against percentage of EPS

Fig. 4.3 shows the relationship between the Cubes Compressive strength of concrete at different temperatures and at various EPS content. It was observed that the compressive strengths of the cubes at room temperature decreases as the EPS percentage increases. This might be as a result of large voids created in the mix by EPS due to its low specific gravity and also its low bulk density.

At 200^0C and 400^0C, an increased in compressive strength was observed for (5, 10, 15)% EPS content respectively as compared to 0% EPS content. The increment at this percentage inclusion of EPS might be as a result of low movement of heat in air in the closed cells structure of EPS which reduces moisture loss and also the lesser voids spaces created by EPS.

At 600^0C and 800^0C, a drastic decreased in the compressive strength was observed for EPS content of (5, 10, 15, 20, 25, 30, 35, 40, 45, 50) % as compared to 0% EPS. This implies that EPS has negative effect in concrete been exposed to temperatures above 400^0C. This might be as a result of high exposure of heat on the Concrete, which melts off the EPS, since according to European manufacturer of EPS (EUMEPS), EPS starts to melts at 100^0C. It can be concluded that at this point the heat inside the concrete is above 100^0C which the EPS could no longer withstand.

Fig. 4.4 shows the relationship between the Cubes Compressive strength of concrete at different EPS content and at various temperatures. It was observed that the compressive strength at 0% EPS content decreases as the temperatures increases. These shows the adverse effect of high temperature has on normal aggregates concrete due to moisture loss.

An increment in strength was observable for concrete containing EPS which was exposed to temperature from 200℃ to 400℃ as compared to those at room temperature. This implies that the presence of EPS in the mix at this stated temperatures helps to reduce the transfer of heat in its closed cells structures which contains 98% of air and 2% polystyrene.

However, it was observed that the designed target strength of 25N/mm^2 for the EPS concrete was still achievable at 400^{0}C temperature at 10% EPS content.

4.4 Results of Flexural Strength Test

The plots of Flexural strength against EPS content is as shown in Fig. 4.5

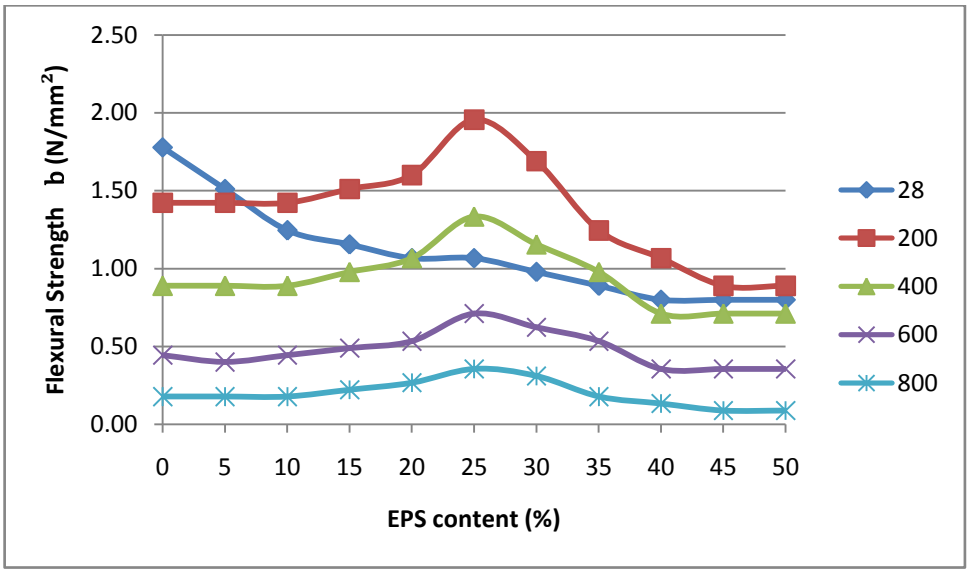


Fig. 4.5: Flexural strength against EPS content

Fig. 4.5 shows the relationship between flexural strength and EPS content at various temperatures. It was observed that at room temperature (28^{0}C), the flexural strength decreases slightly as the EPS content increases as compared to 0% EPS.

At 200^{0}C to 800^{0}C, it was observed that there was no change in the strength up to 10% EPS content. But from 15% EPS to 25% EPS, a slight increased in strength was noticed where further addition of EPS content above 25% causes the strength to decreased slightly. At 25% EPS content, it can be seen that the flexural strength was maximum at 200^{0}C temperature.

4.5 Physical Properties of Concrete at Elevated Temperatures

The following were the physical properties observed after exposure;

Colour change – the colour of the concrete cubes went from being grey at ordinary room temperature and 200^0C to clayish brown at 400^0C to darkish grey at 600^0C and above as shown in Plate XV



Plate XV: Colour difference after exposure to temperatures

Emergence of small honeycomb- after exposure to temperature of 600^0C and above were observed around the concrete cube which signifies the original space being occupied by the EPS around the concrete before being melts off. This is as shown in Plate XVI



Plate XVI: Specimen after exposure to high temperature

4.6 Regression Analysis of Compressive Strength and EPS Content

Linear regression analysis was conducted on the cube compressive strength in order to investigate the correlation between compressive strength and percentage of EPS content in the concrete mix. Least square regression model was generated for various temperature values as shown in Fig 4.6 to 4.10 using Microsoft Excel 2007, in which the compressive strength is the dependent variable while EPS percentages is the independent variable. The least square regression model is given by:

f_{cuRT} = -0.358EPS_{RT} + 26.36 (4.1)

f_{cu200} = -0.348EPS_{200} + 27.35 (4.2)

f_{cu400} = -0.307EPS_{400} + 25.19 (4.3)

f_{cu600} = -0.241EPS_{600} + 13.05 (4.4)

f_{cu800} = -0.203EPS_{800} + 10.04 (4.5)

Where, f_{cuRT} is the compressive strength of concrete cubes at 24^0C (room temperature), EPS_{RT} is corresponding Expanded Polystyrene waste content at room temperature, f_{cu200} is the compressive strength of concrete cubes at 200^0C, EPS_{200} is corresponding Expanded Polystyrene waste content at 200^0C, f_{cu400} is the compressive strength of concrete cubes at 400^0C, EPS_{400} is corresponding Expanded Polystyrene waste content at 400^0C, f_{cu600} is the compressive strength of concrete cubes at 600^0C, EPS_{400} is corresponding Expanded Polystyrene waste content at 600^0C, f_{cu800} is the compressive strength of concrete cubes at 800^0C, EPS_{400} is corresponding Expanded Polystyrene waste content at 800^0C.

Fig. 4.6, 47, 4.8, 4.9 and 4.10 shows the Least Square Regression Plot of Cubes Compressive Strength and Percentage of EPS at Room Temperature, 200^0C, 400^0C, 600^0C, 800^0C respectively, having the correlation (R^2) of 0.984, 0.934, 0.856, and 0.947. Since these values

of R^2 are closer to 1, It means the relationship between cube strength and EPS content at various temperatures are highly correlated.

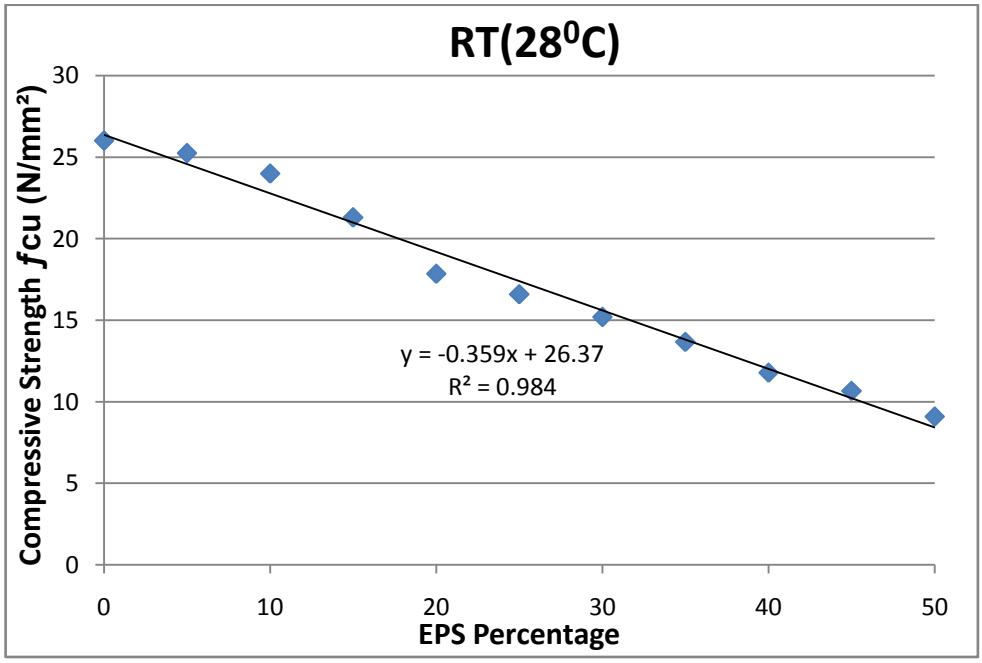


Fig 4.6; Least Square Regression Plot of cube Compressive Strength and EPS content at RT

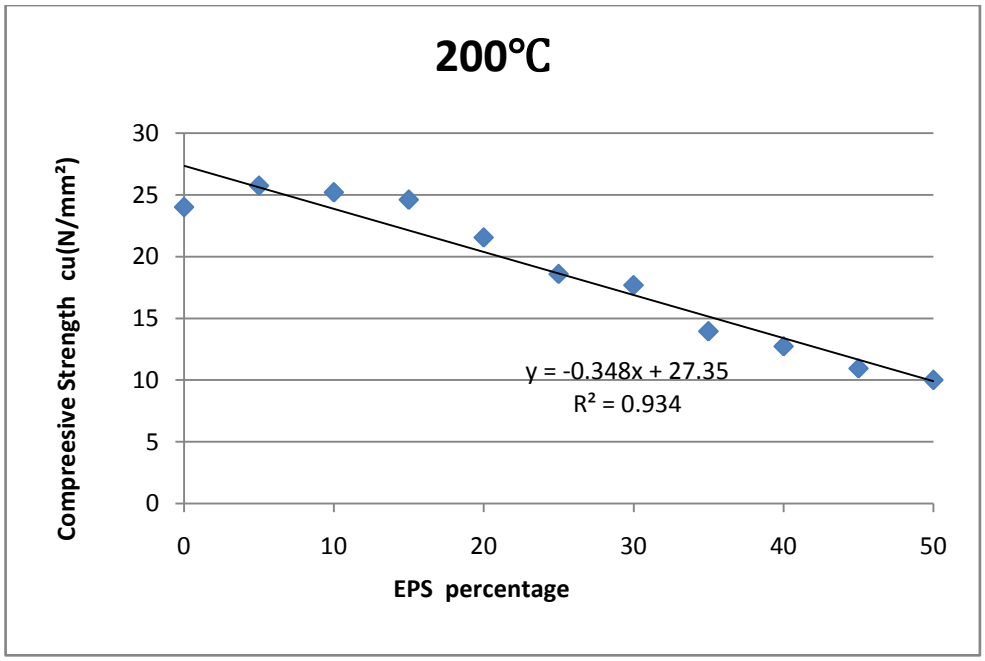


Fig 4.7; Least Square Regression Plot of cube Compressive Strength and EPS content at 200^0C

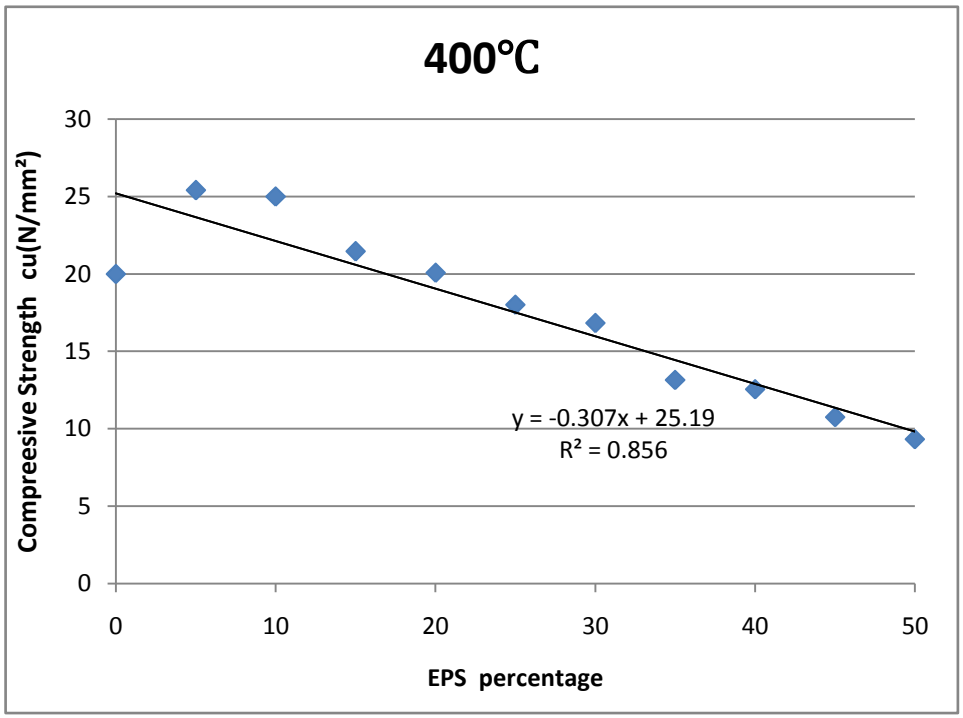


Fig 4.8; Least Square Regression Plot of cube Compressive Strength and EPS content at 400^0C

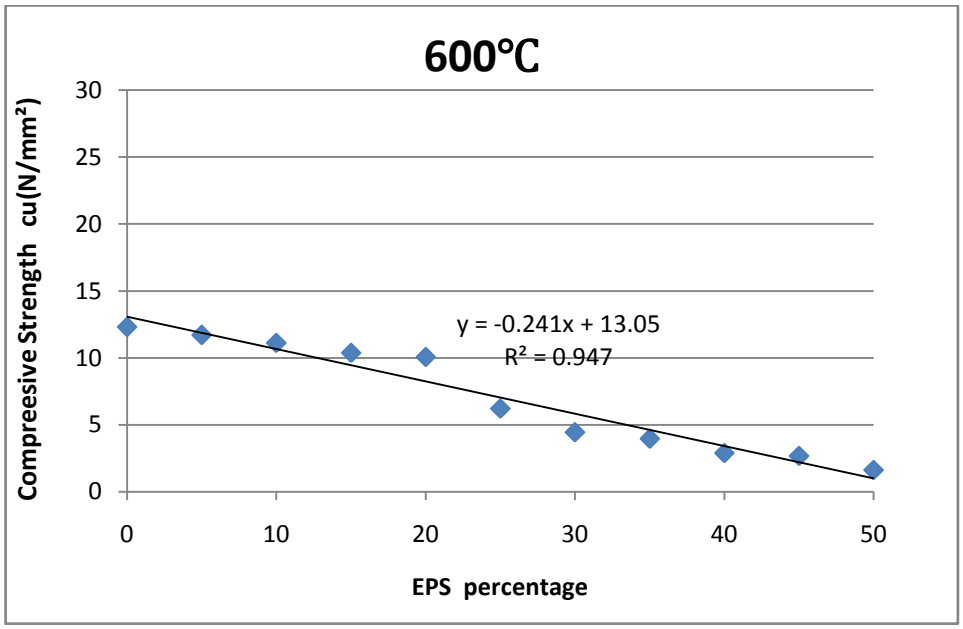


Fig 4.9; Least Square Regression Plot of cube Compressive Strength and EPS content at 600^0C

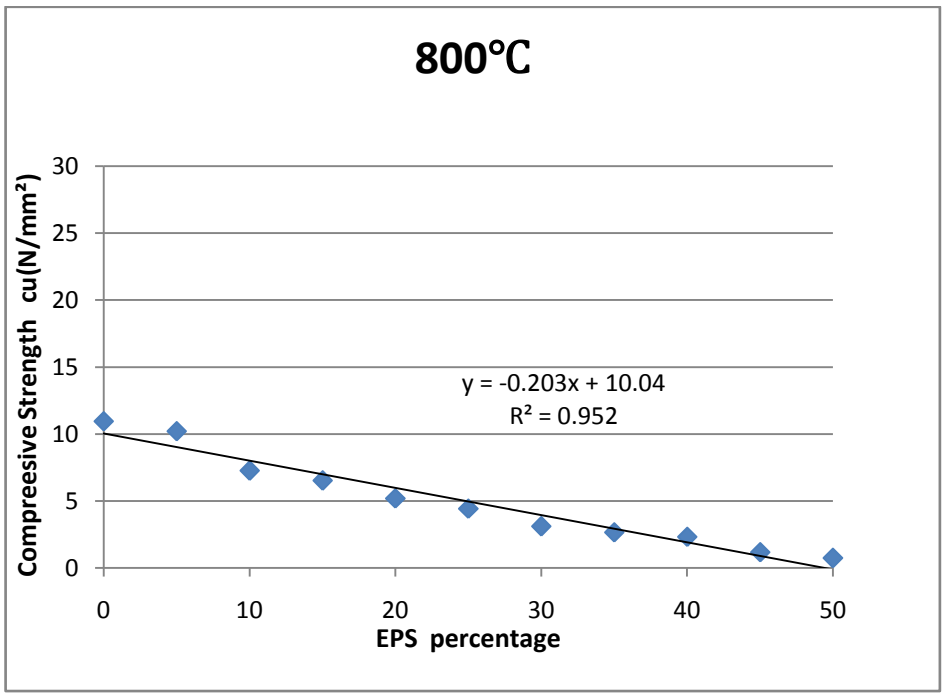


Fig.4.10; Least Square Regression Plot of cube Compressive Strength and EPS content at 800^0C

4.7 Computation of Safety Indices

To compute the safety Indices at various temperatures, the limit state equation for the Bending mode of failure used according to Eurocode 2, 2004, is as follows;

$$G(X) = \left[A_S f_y \left(d - \frac{0.5 A_S f_y}{b f_{cu}} \right) \right] - \left[0.125 Q_k (\gamma_g \alpha + \gamma_q) L^2 \times 10^6 \right] \quad (4.6)$$

Where f_{cu} for various temperatures is obtained in equation (4.1) to (4.5), this implies that the value of f_{cu} in equation (4.6) can be replaced by equation (4.1) to (4.5) in the limit state equation for the reliability analysis depending on the temperature being considered. MATLAB programming language used to develop the computer program for the reliability analysis is presented in Appendix IV.

The safety indices generated with respect to the MATLAB program are as presented in the graphs in Figs. 4.11 to 4.16

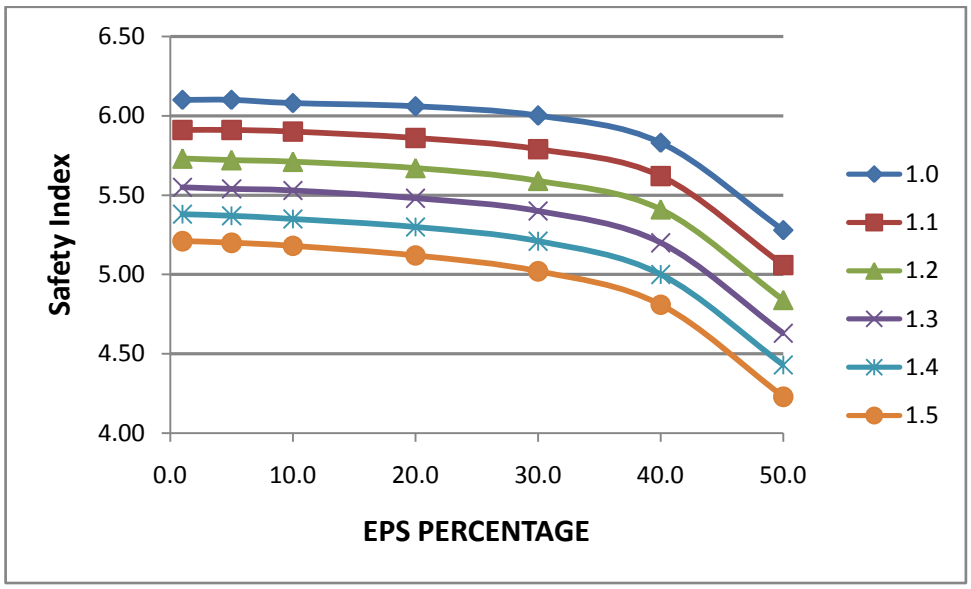


Fig.4.11; Relationship between Safety Index and EPS content at RT at various load ratios

Fig.4.11 shows the plot of safety index at varying EPS content and varying load ratio under room temperature. It was observed that there is a slight decreased in their safety index at different load ratio as the EPS content increased. But drastic decreased were noticed at EPS content greater than 40%. For instance, the safety index for failure due to bending decreases from a value **6.10** (1.0% EPS) to **5.28** (50% EPS) for 1.0 load ratio, while 1.5 load ratio gives **5.21** (1.0% EPS) to **4.23** (50% EPS). This implies that for the range of values of load ratio considered, the beam can be considered to be safe for the bending mode of failure.

The same trend was observed in Figs. 4.12 and 4.13, which shows the relationship between safety indices and EPS content at 200^0C and 400^0C. But tend to have higher safety index as compared to room temperature. For instance, the safety index at 200^0C decreases from **6.10** (1.0% EPS) to **5.61** (50% EPS) for load ratio 1.0, while 1.5 load ratio was **5.22** (1.0% EPS) to **4.55** (50% EPS). Likewise the safety index at 400^0C decreases from **6.10** (1.0% EPS) to **5.59** (50% EPS) for load ratio of 1.0, while load ratio of 1.5 was **5.20** (1.0% EPS) to **4.54** (50% EPS).

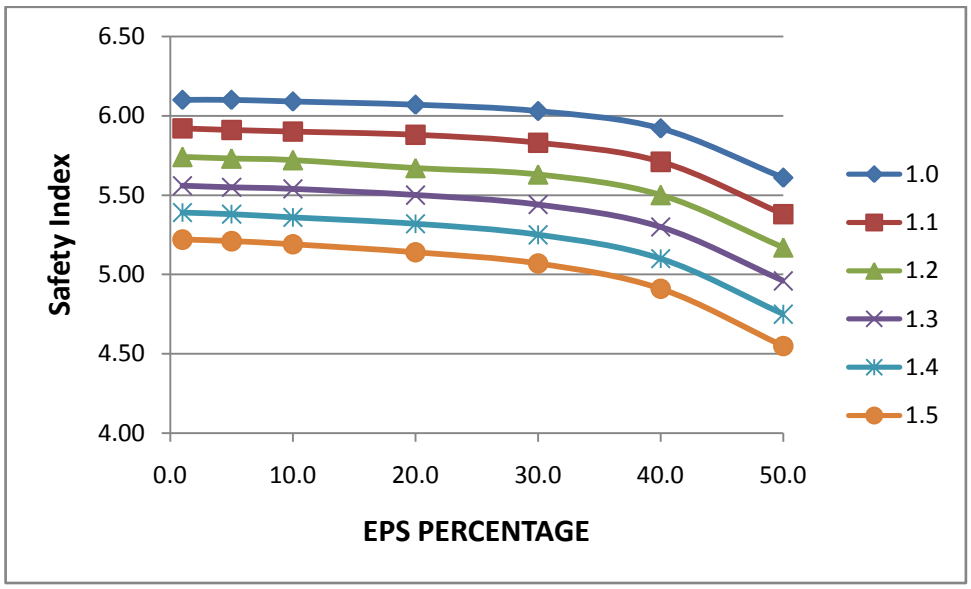


Fig 4.12; Relationship between Safety Index and EPS content at 200^0C at various load ratios

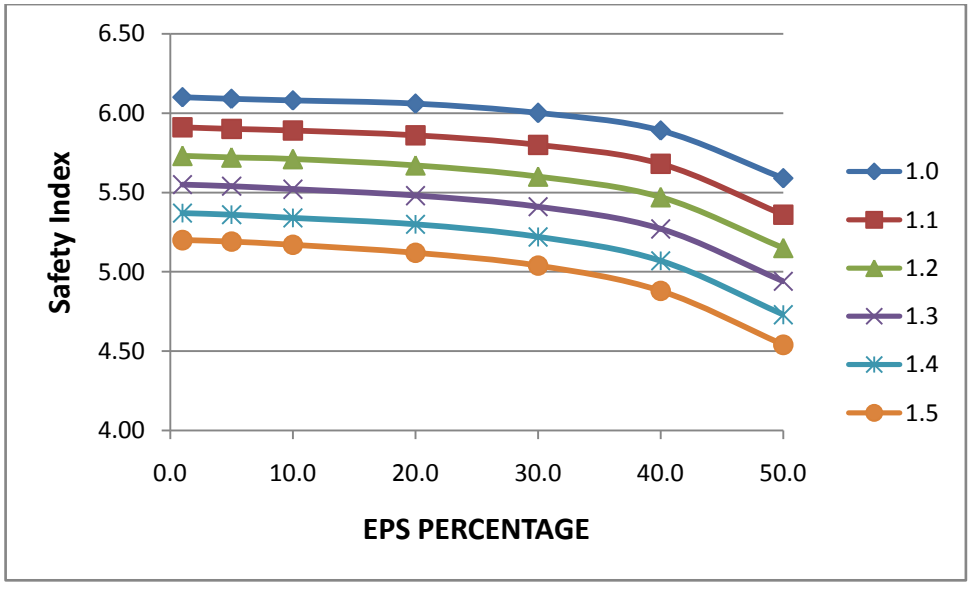


Fig. 4.13; Relationship between Safety Index and EPS content at 400^0C at various load ratios

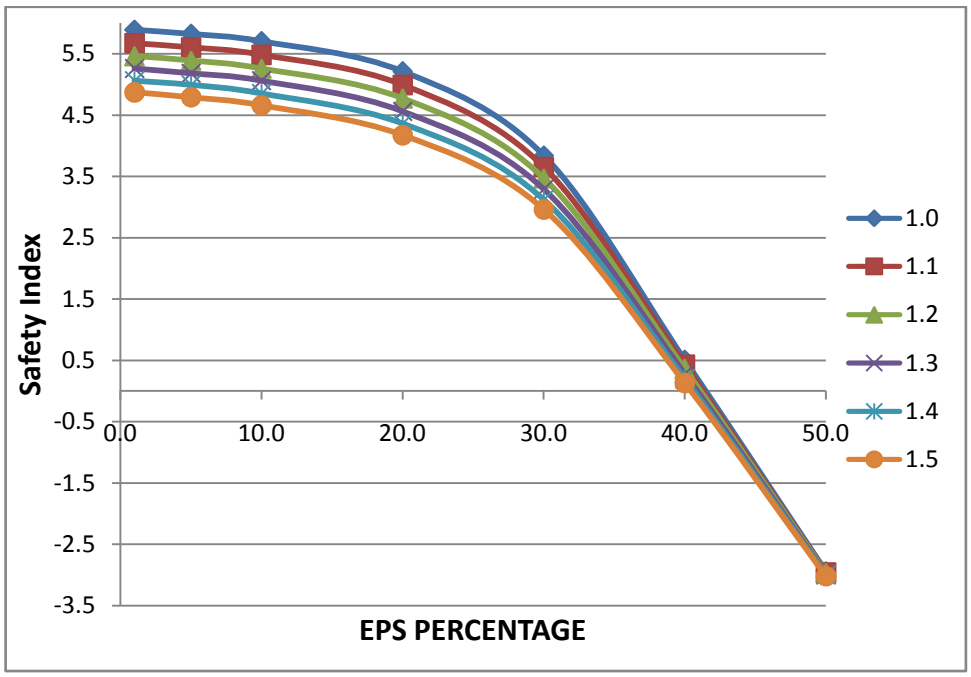


Fig. 4.14; Relationship between Safety Index and EPS content at 600^0C for various load ratios

Fig. 4.14 shows the relationship between safety index and EPS content at 600^0C for various load ratios. From the plots, it was observed that the safety index value at 1.0 load ratio decreases from **5.89** (1.0 % of EPS) to **3.84** (30% of EPS), while at 40% of EPS its value was **0.51** and 50% EPS gives a negative safety index of **-2.94**. Likewise at 1.5 load ratio, the safety indices decreases from **4.87** (1.0% of EPS) to **2.96** (30% of EPS), **0.13** for 40% EPS and a negative safety index of **-3.02** for 50% EPS. This negative value for safety indices signifies that the beam has failed, thus to guide against negative safety index and to also accommodate all the load ratios considered, the EPS content should be between 25% to 30% at this temperature, considering 3.8 as the level of safety.

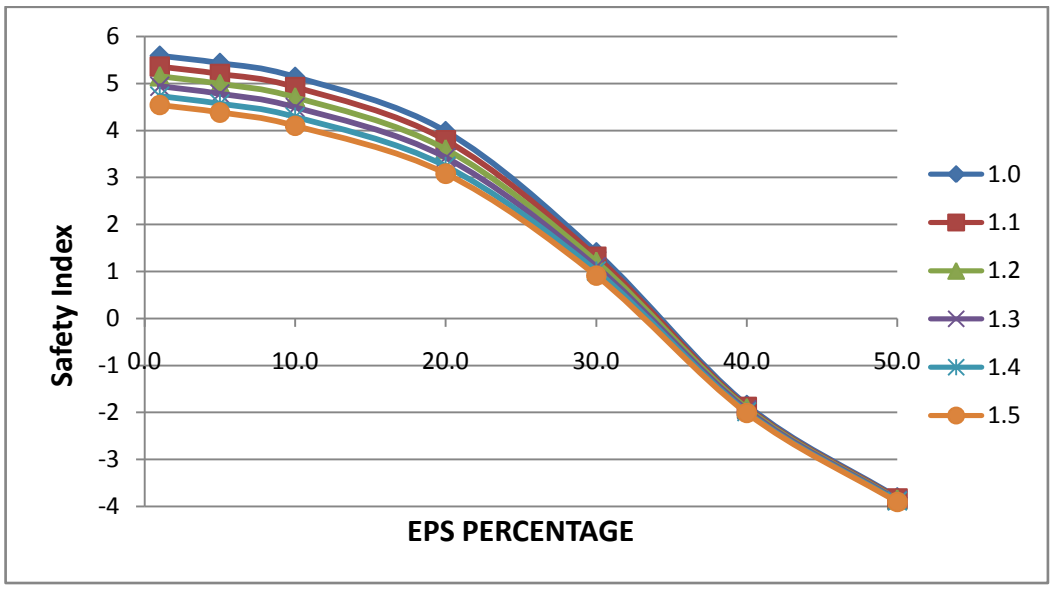


Fig. 4.15; Relationship between Safety Index and EPS content at 800^0C for various load ratios

Fig. 4.15 shows the relationship between safety Index and EPS content at 800^0C for various load ratios. It was observed from the plot that the values of safety index decreases from **5.59** (1.0% of EPS) to **1.41** (30% of EPS) at 1.0 load ratio, while 40% and 50% gives a negative safety indices of **-1.84** and **–3.81** respectively and also from **4.54** (1.0% of EPS) to **0.91** (30% of EPS) for 1.5 load ratio, while 40% and 50% gives a negative indices of **-2.00** and **-3.90** respectively. This implies that the beam is considered less safe as the EPS content increases and to also accommodate for all the load ratios been considered, the EPS content should be between 15% to 20% at this temperature.

The convergence of safety indices observed at fig 4.14 and fig 4.15 at 30% EPS content and above for temperatures at 600℃ and 800℃ implies that variation in load ratio has no significant effects on the beam.

Generally, it can be deduced that maximum safety indices was observed at a load ratio of 1.0 considering Fig. 4.11 to 4.15.

Thus, the summarized safety indices for each temperature range and EPS content for a load ratio of 1.0 is then presented in Fig. 4.16.

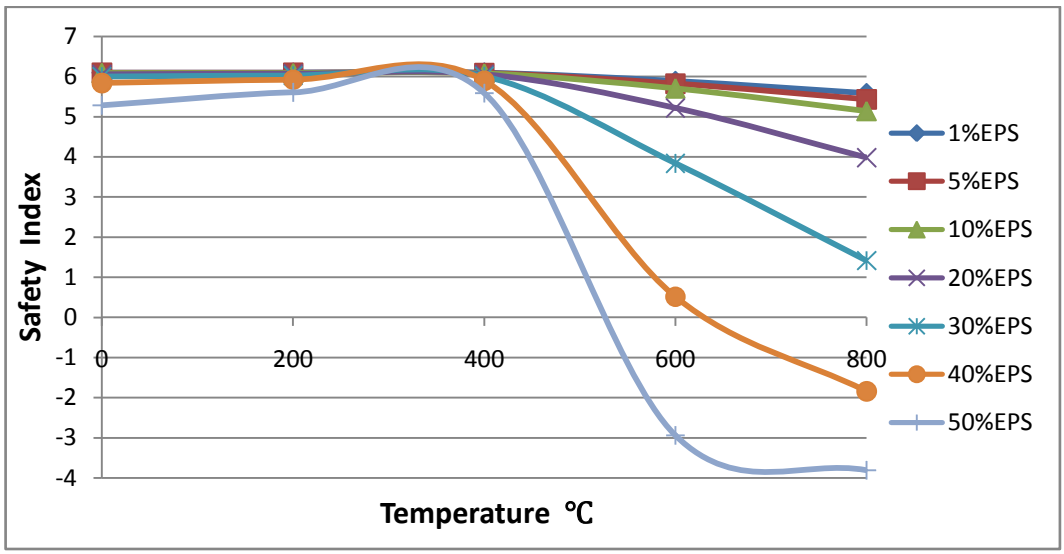


Fig. 4.16; Relationship between Safety Index and Temperature at load ratio of 1.0

From Fig. 4.16, it can be observed that there is high safety index for all percentage of EPS up to a temperature of 400^0C, while above 400^0C, the beam is considered safe at a maximum EPS content of 20% at 800^0C considering the safety level of 3.8.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

1) From the preliminary test on the materials used, the cement used was an ordinary Portland cement, the river sands used conformed to Zone II, which makes it good for concrete work, the coarse aggregate has a nominal size of 19mm, the EPS is a light weight material, while the slump test to check the workability of the mix indicates that EPS does not absorbed water.

2) The inclusion of EPS in concrete mix at ordinary room temperature causes reduction in the compressive strength, while inclusion of EPS between 5% and 15% in concrete increased the resistance of concrete to heat better than the control at a maximum temperature of 400℃. The target compressive strength of 25 N/mm^2 was achievable at 10% EPS content when exposed to temperature of about 400℃, while at temperatures up to 400^{0}C, concrete containing EPS content not exceeding 30% can still produced a concrete strength for structural application which must not be less than 17 Mpa as being specified by American Concrete Institute. The flexural strength of plain concrete beam at elevated temperatures was maximum at 25% EPS content, while the beam achieved its maximum flexural strength at 25% EPS content at a temperature of 200^{0}C.

3) From the regression analysis, mathematical models predicting the compressive strength of EPS concrete exposed to high temperatures for 28 days cube, gives a high correlation value (R^2).

4) The safety of reinforced concrete beam due to bending decreases as EPS content increases and as load ratio increases.

5) From reliability analysis, Load ratio of 1.0 (Q_k= 7.8kN/m) gives the highest safety indices and it was considered safe up to temperature of 400^{0}C for load ratios up to 1.5 and EPS content of 50%, while above 400^{0}C, the safety of the beam tends to be between

20% and 30% EPS content considering 3.8 as the target safety index as recommended by JCSS (2001).

5.2 Recommendation

1) From the experimental point of view, it could be recommended that 30% EPS content in concrete and temperature exposure not beyond 400^0C can be used effectively for structural applications. While above this EPS content, the concrete becomes light weight concrete which is still useful for non load bearing structural components.
2) The inclusion of EPS content up to 15% will resist temperature better than normal aggregate concrete at a maximum temperature of 400^0C.
3) Plain concrete beam achieved maximum flexural strength at 25% EPS content under a temperature exposure of 200^0C.
4) From the reliability approach it could be recommended that with EPS content of 20%, a reinforced concrete beam can withstand failure due to bending with a load ratio of 1.0 (Q_k= 7.8kN/m) at a temperature up to 800^0C, provided EPS is encapsulated inside the concrete. This shows that it can be use as alternative building materials at elevated temperature thereby giving enough time for rescue team to safe life and properties.

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APPENDIX I: Preliminary Test carried on Constituent Materials

I-a: Consistency of Cement samples

Cement	Water Content %	Needle penetration(mm)	Water-Cement Ratio
Sample I	30.5	6.00	0.31
Sample II	30.6	6.30	0.32
Sample III	30.4	5.70	0.30
Average	30.5	6.00	0.31

I-b: Initial Setting Time of Cement samples

Cement	Starting time	Finishing time	Initial Setting Time (min)
Sample I	10:20am	12.22pm	122
Sample II	10:25am	12.25pm	120
Sample III	10:30am	12:31pm	121
Average	10:25am	12:26pm	121

I-c: Final Setting Time of Cement samples

Cement	Starting time	Finishing time	Final Setting Time (min)
Sample I	10:20am	03:05pm	285
Sample II	10:25am	03:14pm	289
Sample III	10:30am	03:14pm	284
Average	10:25am	03:11pm	286

I-d: Soundness of Cement samples

Cement	Initial Measurement (mm)	Final Measurement (mm)	Expansion (mm)
Sample I	5	5	0
Sample II	5	5	0
Sample III	5	5	0
Average	5	5	0

I-e: Specific Gravity of Cement

Serial No.	Observation	Trial	
		1	**2**
1.	Weight of Specific gravity bottle, W_1 (g)	28.5	28.5
2.	Weight of Specific gravity bottle and dry sample W_2 (g)	54.8	55.3
3.	Weight of Specific gravity bottle + Cement Samples + Kerosene W_3 (g)	87.07	87.57
4	Weight of Specific gravity bottle and Kerosene W_4 (g)	69.2	69.2
5	Weight of Cement Samples only A (g) = $W_2 - W_1$	26.3	26.8
6	Weight of Kerosene used B (g) = $W_3 - W_2$	32.27	32.27
7	Weight of Kerosene only C (g) = $W_4 - W_1$	40.7	40.7
8	Specific gravity of the Cement Sample = A/(C-B)	3.12	3.18
9	Average Specific gravity	3.15	

I-f: Sieve Analysis of Fine aggregate

Weight of Sample = 1200g

SIEVE SIZE (mm)	WEIGHT RETAINED (g)	PERCENTAGE RETAINED (%)	PERCENTAGE CUMULATIVE RETAINED (%)	PERCENTAGE PASSING (%)
6.35	0	0	0	100
4.75	102	8.5	8.5	91.5
2.36	135	11.25	19.75	80.25
1.18	219	18.25	38	62
0.60	249	20.75	58.75	41.25
0.30	380	31.67	90.42	9.58
0.15	79.6	6.63	97.05	2.95
Pan	35.4	2.95	100	0

I-g: Specific gravity of fine aggregates

Total Weight of the sample = 500g

	TRIAL		
SPECIMEN	**I**	**II**	**III**
Wt of pycnometer + water (P)	1280	1280	1280
Wt of Sand + pycnometer + water (P_s)	1580	1584	1580
Wt of Sand (B)	500g	500	500
Specific gravity = $\frac{B}{P + B - P_s}$	2.50	2.55	2.50
Average Specific gravity	2.52		

I-h: Bulk density of fine aggregates

Description	**TRIAL**		
	I	**II**	**III**
Wt of empty cylinder W_1 (kg)	1.4	1.4	1.4
Wt of cylinder filled with water W_2 (kg)	4.1	4.1	4.1
Wt of cylinder + Sample W_3 (kg)	5.51	5.57	5.45
Wt of water W = ($W_2 – W_1$) (kg)	2.7	2.7	2.7
Density of water □ (kg/m^3)	1000	1000	1000
Volume of water V = W/ □ (m^3)	0.0027	0.0027	0.0027
Wt of Sample M = $W_3 – W_1$ (kg)	4.11	4.17	4.05
Bulk density = M/V	1522	1544	1500
Average bulk density	1522		

I-i: Moisture content of sand (%)

Test Description	**Result**
Wt of Sample A (g)	500
Wt of Oven dry sample B (g)	490.2
Moisture content w (%) = 100 × (A –B)/B	2.00

I-j: Sieve Analysis of Coarse aggregate

Weight of Sample = 3000g

SIEVE SIZE (mm)	WEIGHT RETAINED (g)	PERCENTAGE RETAINED (%)	PERCENTAGE CUMULATIVE RETAINED (%)	PERCENTAGE PASSING (%)
38.1	0	0	0	100
19.05	126	4.2	4.2	95.8
12.7	928	30.93	35.13	64.87
9.52	640	21.33	56.46	43.54
6.35	700	23.33	79.79	20.21
4.76	272	9.07	88.86	11.14
Pan	334	11.14	100	0.00

I-k: Specific gravity of coarse aggregate

Total Weight of the sample = 1000g

	TRIAL		
SPECIMEN	**I**	**II**	**III**
Wt of glass jar + water (P)	2520	2520	2520
Wt of Sample +glass jar + water (P_s)	3150	3142	3156
Wt of Sand (B)	1000g	1000	500
Specific gravity = $\frac{B}{P + B - P_s}$	2.70	2.65	2.75
Average Specific gravity	2.70		

I-l: Bulk density of Coarse aggregates

Using 0.01m^3 capacity of cylinder

Test Description	**TRIAL**		
	I	**II**	**III**
Wt of cylinder W_1 (kg)	1.4	1.4	1.4
Wt of cylinder + Sample W_2 (kg)	17.9	19.3	18
Wt of Sample (M) = $W_2 - W_1$ (kg)	16.5	17.9	16.6
Volume of Cylinder V (m^3)	0.01	0.01	0.01
Bulk density = M/V (kg/m^3)	1650	1790	1660
Average bulk density (kg/m^3)	1700		

I-m: Aggregate impact value Test

Specimen	**I**	**II**
Wt of Sample A (g)	500	500
Wt of samples remaining after weighing B (g)	138	144
Wt of sample passing sieve 2.36mm C (g)	71	64
AIV = $\frac{C}{(A-B)} \times 100$ (%)	19.6	18.0
Average AIV (%)	**19**	

I-n: Aggregate crushing value Test

Specimen	**I**	**II**
Wt of Sample A (g)	5000	5000
Wt of left over sample B (g)	1180	1300
Wt of sample passing sieve 2.36mm C (g)	759	754
ACV = $\frac{C}{(A-B)} \times 100$ (%)	19.9	20.4
Average ACV (%)	20	

I-o: Moisture content of Granite (%)

Test Description	**Result**
Wt of Sample A (g)	2000
Wt of Oven dry sample B (g)	1970
Moisture content w (%) = 100 × (A –B)/B	1.52

I-p: Bulk Density of EPS

Test Description	**Trial**	
	I	**II**
Wt of empty cylinder W_1 (kg)	1.4	1.4
Wt of cylinder filled with water W_2 (kg)	4.1	4.1
Wt of cylinder + Sample W_3 (kg)	1.4324	1.43321
Wt of water W = (W_2 –W_1) (kg)	2.7	2.7
Density of water □ (kg/m^3)	1000	1000
Volume of water V = W/ □ (m^3)	0.0027	0.0027
Wt of Sample M = W_3 – W_1 (kg)	0.0324	0.03321
Bulk density = M/V	12.0	12.3
Average bulk density	12.15	

I-q: Specific Gravity of EPS

Serial No.	Observation	Trial	
		1	II
1.	Weight of glass jar, W_1 (g)	875	875
2.	Weight of glass jar and EPS sample W_2 (g)	907.7	904.1
3.	Weight of glass jar + EPS Samples + Water, W_3 (g)	1735.1	1731.5
4	Weight of glass jar and Water, W_4 (g)	2150	2150
5	Weight of EPS Samples only A (g) = $W_2 - W_1$	32.7	29.1
6	Weight of Water used B (g) = $W_3 - W_2$	827.4	827.4
7	Weight of Water only C (g) = $W_4 - W_1$	1275	1275
8	Specific gravity of the Cement Sample = A/(C-B)	0.073	0.065
9	Average Specific gravity	0.069	

I-r: Variation in slump with EPS (%)

S/No.	EPS Replacement (%)	Height of Cone A (mm)	Height of Concrete B (mm)	Slump A-B (mm)
1	0	300	295	5
2	5	300	295	5
3	10	300	290	10
4	15	300	285	15
5	20	300	280	20
6	25	300	270	30
7	30	300	260	40
8	35	300	255	45
9	40	300	250	50
10	45	300	245	55
11	50	300	235	65

APPENDIX II: Experimental Data Obtained for the Compressive Strength of Cubes (150×150×150)mm

II-a: Compressive Strength at Room Temperature (RT)

Spec. Mark	EPS %	Date Cast	Wt. before heating	Wt. After heating	Tempt ^{0}C	Unit Wt. Kg/m^3	Failure Load (kN)	Comp. Strength (N/mm^2)	Mean Strength
CI	0	26/05/2015	8.10		ROOM TEMPERATURE	2444	600	26.67	26.01
CII			8.30				570	25.33	
CIII			8.35				585	26.04	
5I	5	27/05/2015	8.20			2436	555	24.67	25.26
5II			8.20				550	24.44	
5III			8.25				600	26.67	
10I	10	01/06/2015	8.30			2406	550	24.44	24.00
10II			7.95				500	22.22	
10III			8.10				570	25.33	
15I	15	02/06/2015	8.00			2356	470	20.89	21.30
15II			7.80				470	20.80	
15III			8.05				500	22.22	
20I	20	03/06/2015	8.05			2350	360	16.00	17.85
20II			7.80				400	17.78	
20III			7.95				445	19.78	
25I	25	04/06/2015	7.60			2258	380	16.89	16.59
25II			7.60				340	15.11	
25III			7.65				400	17.78	
30I	30	08/06/2015	7.10			2187	375	16.67	15.19
30II			7.40				350	15.56	
30III			7.65				300	13.33	
35I	35	09/06/2015	7.00			2089	288	12.80	13.67
35II			7.05				340	15.11	
35III			7.10				295	13.11	
40I	40	10/06/2015	6.90			2053	230	10.22	11.78
40II			6.90				265	11.78	
40III			7.00				300	13.33	
45I	45	11/06/2015	6.85			2044	230	10.22	10.67
45II			6.90				250	11.11	
45III			6.95				240	10.67	
50I	50	12/06/2015	6.90			2039	200	8.89	9.19
50II			6.80				210	9.33	
50III			6.95				210	9.33	

II-b: Compressive Strength at 200^{0}C Temperature

Spec. Mark	EPS %	Date Cast	Wt. b/4 heating	Wt. After heating	Tempt ^{0}C	Unit Wght Kg/m^3	Failure Load (kN)	Comp. Strength (N/mm^2)	Mean Strength
CI2	0	26/05/	8.00	7.90	200^{0}C	2364	540	24.00	24.00
CII2		2015	8.05	8.00			510	22.7	
CIII2			8.10	8.05			570	25.33	
5I2	5	27/05/	8.30	8.40		2444	590	26.22	25.75
5II2		2015	8.10	8.10			550	24.44	
5III2			8.40	8.40			598	26.58	
10I2	10	01/06/	8.45	8.20		2421	600	26.67	25.19
10II2		2015	8.25	8.00			500	22.22	
10III2			8.45	8.30			600	26.67	
15I2	15	02/06/	8.00	8.00		2385	580	25.78	24.59
15II2		2015	8.05	8.05			480	21.33	
15III2			8.10	8.10			600	26.67	
20I2	20	03/06/	7.60	8.00		2364	510	22.67	21.56
20II2		2015	8.05	7.65			455	20.22	
20III2			8.30	8.20			490	21.78	
25I2	25	04/06/	7.60	7.70		2281	350	15.56	18.59
25II2		2015	7.70	7.65			430	19.11	
25III2			7.75	7.75			475	21.11	
30I2	30	08/06/	7.40	7.35		2193	450	20.00	17.69
30II2		2015	7.40	7.40			385	17.11	
30III2			7.45	7.45			359	15.96	
35I2	35	09/06/	7.30	7.20		2148	301	13.38	13.94
35II2		2015	7.30	7.25			290	12.89	
35III2			7.50	7.30			350	15.56	
40I2	40	10/06/	7.50	7.35		2124	300	13.33	12.74
40II2		2015	7.00	6.95			270	12.00	
40III2			7.30	7.20			290	12.89	
45I2	45	11/06/	7.25	7.10		2104	250	11.11	10.95
45II2		2015	7.05	6.90			199	8.84	
45III2			7.35	7.30			290	12.89	
50I2	50	12/06/	7.15	7.00		2074	200	8.89	10.00
50II2		2015	6.85	6.70			225	10.00	
50III2			7.50	7.30			250	11.11	

II-c: Compressive Strength at 400^{0}C Temperature

Spec. Mark	EPS %	Date Cast	Wt. before heating	Wt. After heating	Tempt ^{0}C	Unit Wt. Kg/m^3	Failure Load (kN)	Comp. Strength (N/mm^2)	Mean Strength
CI4	0	26/05/2015	8.05	7.80	400^{0}C	2317	450	20.00	20.00
CII4			8.00	7.60			400	17.78	
CIII4			8.10	8.05			500	22.22	
5I4	5	27/05/2015	7.95	8.25		2439	565	25.11	25.41
5II4			8.10	8.20			570	25.33	
5III4			8.10	8.25			580	25.78	
10I4	10	01/06/2015	8.00	8.25		2412	550	24.44	25.01
10II4			8.10	8.05			555	24.67	
10III4			8.20	8.15			583	25.91	
15I4	15	02/06/2015	8.10	8.00		2367	500	22.22	22.45
15II4			8.25	7.95			535	23.89	
15III4			8.50	8.05			478	21.24	
20I4	20	03/06/2015	8.10	8.05		2356	450	20.00	20.07
20II4			7.70	7.90			450	20.00	
20III4			7.65	7.90			455	20.22	
25I4	25	04/06/2015	7.75	7.80		2281	406	18.04	18.01
25II4			7.45	7.50			400	17.78	
25III4			7.80	7.80			410	18.22	
30I4	30	08/06/2015	7.30	7.35		2190	335	14.89	16.83
30II4			7.10	7.40			341	15.16	
30III4			7.50	7.45			460	20.44	
35I4	35	09/06/2015	7.10	7.05		2104	335	11.02	13.16
35II4			7.00	7.05			341	13.33	
35III4			7.20	7.20			460	15.11	
40I4	40	10/06/2015	7.10	6.95		2056	280	12.44	12.55
40II4			6.70	6.90			267	11.87	
40III4			6.90	7.00			300	13.33	
45I4	45	11/06/2015	7.00	6.95		2047	225	10.00	10.74
45II4			7.00	6.90			290	12.89	
45III4			7.15	6.90			210	9.33	
50I4	50	12/06/2015	7.00	6.80		2041	130	5.78	9.33
50II4			7.05	6.90			240	10.67	
50III4			7.15	6.95			260	11.56	

II-d: Compressive Strength at 600^{0}C Temperature

Spec. Mark	EPS %	Date Cast	Wt. before heating	Wt. After heating	Tempt ^{0}C	Unit Wt. Kg/m^3	Failure Load (kN)	Comp. Strength (N/mm^2)	Mean Strength
CI6 CII6 CIII6	0	26/05/ 2015	7.95 8.10 8.20	7.60 7.50 8.00	600^{0}C	2281	290 220 320	12.89 9.78 14.22	12.30
5I6 5II6 5III6	5	27/05/ 2015	7.90 7.95 8.00	7.50 7.80 7.65		2279	160 330 300	7.11 14.67 13.33	11.70
10I6 10II6 10III6	10	01/06/ 2015	7.90 7.90 8.00	7.80 7.00 7.60		2213	180 270 300	8.00 12.00 13.33	11.11
15I6 15II6 15III6	15	02/06/ 2015	8.30 8.10 8.30	7.40 7.40 7.60		2213	180 240 280	8.00 10.67 12.44	10.37
20I6 20II6 20III6	20	03/06/ 2015	8.30 7.65 8.25	7.35 7.40 7.50		2199	310 90 280	13.78 4.00 12.44	10.07
25I6 25II6 25III6	25	04/06/ 2015	7.55 7.90 8.05	7.00 7.30 7.50		2154	140 120 160	6.22 5.33 7.11	6.22
30I6 30II6 30III6	30	08/06/ 2015	7.25 7.25 7.40	6.70 6.70 7.00		2015	120 80 100	5.33 3.56 4.44	4.44
35I6 35II6 35III6	35	09/06/ 2015	7.10 7.00 7.20	6.45 6.40 7.00		1961	90 77 100	4.00 3.42 4.44	3.96
40I6 40II6 40III6	40	10/06/ 2015	6.15 6.95 7.00	6.00 6.35 6.90		1902	70 65 60	3.11 2.89 2.67	2.89
45I6 45II6 45III6	45	11/06/ 2015	6.80 6.85 6.90	6.40 6.30 6.40		1887	70 65 45	3.11 2.89 2.00	2.67
50I6 50II6 50III6	50	12/06/ 2015	6.80 7.00 6.90	6.40 6.00 6.50		1867	20 40 50	0.89 1.78 2.22	1.63

II-e: Compressive Strength at 800^{0}C Temperature

Spec. Mark	EPS %	Date Cast	Wt. before heating	Wt. After heating	Tempt ^{0}C	Unit Wt. Kg/m^3	Failure Load (kN)	Comp. Strength (N/mm^2)	Mean Strength
CI8	0	26/05/2015	8.05	7.50	800^{0}C	2237	260	11.56	10.96
CII8			7.90	7.60			210	9.33	
CIII8			8.10	7.55			270	12.00	
5I8	5	27/05/2015	8.60	7.60		2252	270	12.00	10.22
5II8			8.25	7.55			190	8.44	
5III8			8.00	7.65			230	10.22	
10I8	10	01/06/2015	7.95	7.60		2193	160	7.11	7.26
10II8			8.00	7.10			140	6.22	
10III8			7.90	7.50			190	8.44	
15I8	15	02/06/2015	8.20	7.35		2169	160	7.11	6.52
15II8			8.05	7.20			80	3.56	
15III8			8.10	7.40			200	8.89	
20I8	20	03/06/2015	8.15	7.40		2154	100	4.44	5.19
20II8			7.70	7.00			100	4.44	
20III8			8.00	7.40			150	6.67	
25I8	25	04/06/2015	7.60	7.05		2080	90	4.00	4.44
25II8			7.60	6.90			90	4.00	
25III8			7.90	7.10			120	5.33	
30I8	30	08/06/2015	7.30	6.60		2006	80	3.56	3.11
30II8			7.10	6.70			30	1.33	
30III8			7.20	7.00			100	4.44	
35I8	35	09/06/2015	7.00	6.50		1941	60	2.67	2.67
35II8			7.20	6.50			40	1.78	
35III8			7.10	6.65			80	3.56	
40I8	40	10/06/2015	7.20	6.05		1873	57	2.53	2.33
40II8			6.80	6.45			40	1.78	
40III8			7.00	6.45			60	2.67	
45I8	45	11/06/2015	7.20	6.30		1846	30	1.33	1.19
45II8			7.10	6.25			20	0.89	
45III8			7.20	6.15			30	1.33	
50I8	50	12/06/2015	7.20	6.20		1831	10	0.44	0.74
50II8			7.20	6.10			20	0.89	
50III8			7.30	6.25			20	0.89	

APPENDIX III: Experimental Data Obtained for the Flexural Strength of Beams

(150×150×750) mm

III-a: Flexural Strength of Beams at Room Temperature (RT)

Spec. Mark	Wt. before heating(kg)	Wt. After Heating(kg)	Ultimate Failure Load (kN)	Tempt ^{0}C	Flexural Strength (N/mm^2)	Mean flexural Strength
CI	41.20		10.00	ROOM TEMPERATURE	1.78	1.78
CII	41.10		9.50		1.69	
CIII	41.30		10.50		1.87	
5I	40.30		8.50		1.51	1.51
5II	40.30		9.00		1.60	
5III	40.30		8.00		1.42	
10I	40.70		7.00		1.24	1.24
10II	40.90		6.00		1.07	
10III	40.50		8.00		1.42	
15I	42.80		6.50		1.16	1.16
15II	42.90		7.00		1.24	
15III	42.70		6.00		1.07	
20I	39.80		6.00		1.07	1.07
20II	39.90		6.50		1.16	
20III	39.70		5.50		0.98	
25I	36.60		7.00		1.24	1.07
25II	36.50		6.00		1.07	
25III	36.70		6.00		0.89	
30I	35.10		5.50		0.98	0.98
30II	35.20		6.50		1.16	
30III	35.00		4.50		0.80	
35I	35.80		5.00		0.89	0.89
35II	35.60		5.00		0.89	
35III	36.00		5.00		0.89	
40I	36.40		4.50		0.80	0.80
40II	36.50		5.00		0.89	
40III	36.30		4.00		0.71	
45I	35.30		4.50		0.80	0.80
45II	35.50		4.50		0.80	
45III	35.10		4.50		0.80	
50I	34.10		4.50		0.80	0.80
50II	34.00		5.50		0.98	
50III	34.20		3.50		0.62	

III-b: Flexural Strength of Beams at 200^{0}C Temperature

`Spec. Mark	Wt. before heating(kg)	Wt. After Heating(kg)	Ultimate Failure Load (kN)	Tempt ^{0}C	Flexural Strength (N/mm^2)	Mean flexural Strength
CI	41.20	40.90	8.00		1.42	1.42
CII	41.10	40.80	9.00		1.60	
CIII	41.20	40.90	7.00		1.24	
5I	42.20	38.50	9.00		1.60	1.42
5II	42.15	38.50	6.00		1.07	
5III	42.10	40.90	9.00		1.60	
10I	41.20	40.90	8.00		1.42	1.42
10II	41.05	40.60	8.00		1.42	
10III	41.25	40.80	8.00		1.42	
15I	40.10	39.90	8.00		1.42	1.51
15II	40.00	39.90	8.50		1.51	
15III	40.05	39.80	9.00		1.60	
20I	39.60	38.80	9.00		1.60	1.60
20II	39.55	38.90	9.00		1.60	
20III	39.60	38.80	9.00		1.60	
25I	39.20	38.50	11.00		1.96	1.96
25II	39.05	38.45	12.00		2.13	
25III	39.15	38.45	10.00		1.78	
30I	36.00	35.70	9.50		1.69	1.69
30II	36.00	35.50	9.00		1.60	
30III	36.10	35.80	10.00		1.78	
35I	35.20	34.90	7.00		1.24	1.24
35II	35.10	34.90	8.00		1.42	
35III	35.20	34.80	6.00		1.07	
40I	34.40	34.00	7.00		1.24	1.07
40II	34.40	34.00	5.00		0.89	
40III	34.40	33.90	6.00		1.07	
45I	34.55	34.05	5.00		0.89	0.89
45II	34.50	34.00	5.00		0.89	
45III	34.50	34.10	5.00		0.89	
50I	34.70	34.10	6.00		1.07	0.89
50II	34.50	34.05	5.00		0.89	
50III	34.90	34.00	4.00		0.71	

200^{0}C

III-c: Flexural Strength of Beams at 400^0C Temperature

Spec. Mark	Wt. before heating(kg)	Wt. After Heating(kg)	Ultimate Failure Load (kN)	Tempt ^{0}C	Flexural Strength (N/mm^2)	Mean flexural Strength
CI	39.70	38.00	5.00		0.89	0.89
CII	39.70	38.90	5.50		0.98	
CIII	39.60	38.00	4.50		0.80	
5I	40.10	38.90	5.00		0.89	0.89
5II	40.00	38.90	5.00		0.89	
5III	40.00	38.70	5.00		0.89	
10I	40.60	39.80	6.00		1.07	0.89
10II	40.50	39.70	4.00		0.71	
10III	40.60	39.80	5.00		0.89	
15I	41.20	38.20	6.00		1.07	0.98
15II	41.10	38.30	5.50		0.98	
15III	41.20	38.10	5.00		0.89	
20I	38.20	36.50	6.00		1.07	1.07
20II	38.20	36.40	6.00		1.07	
20III	38.00	36.50	6.00		1.07	
25I	38.90	37.00	7.50	400^0C	1.33	1.33
25II	38.80	37.00	6.50		1.16	
25III	38.80	37.10	8.50		1.51	
30I	36.50	36.60	6.00		1.07	1.16
30II	36.50	36.60	6.50		1.16	
30III	36.50	36.50	7.00		1.24	
35I	37.30	35.40	5.50		0.98	0.98
35II	37.10	35.10	6.00		1.07	
35III	37.30	35.10	5.00		0.89	
40I	38.00	35.80	3.50		0.62	0.71
40II	38.10	35.80	4.50		0.80	
40III	38.05	35.70	4.00		0.71	
45I	35.05	33.15	4.00		0.71	0.71
45II	35.00	33.20	3.00		0.53	
45III	35.10	33.15	5.00		0.89	
50I	32.10	30.50	4.00		0.71	0.71
50II	32.10	30.50	4.00		0.71	
50III	32.10	30.70	4.00		0.71	

III-d: Flexural Strength of Beams at 600^{0}C Temperature

Spec. Mark	Wt. before heating(kg)	Wt. After Heating(kg)	Ultimate Failure Load (kN)	Tempt ^{0}C	Flexural Strength (N/mm^2)	Mean flexural Strength
CI	41.90	39.90	2.50		0.44	0.44
CII	41.90	39.80	3.00		0.53	
CIII	41.50	39.90	2.00		0.36	
5I	41.10	39.00	2.50		0.44	0.40
5II	41.10	39.10	2.25		0.40	
5III	41.20	39.05	2.00		0.36	
10I	39.20	36.80	2.50		0.44	0.44
10II	39.15	36.80	2.50		0.44	
10III	39.25	36.80	2.50		0.44	
15I	40.00	37.70	2.50		0.44	0.49
15II	40.05	37.80	2.75		0.49	
15III	40.10	37.80	3.00		0.53	
20I	38.40	36.30	3.00		0.53	0.53
20II	38.20	36.30	3.00		0.53	
20III	38.40	36.20	3.00		0.53	
25I	38.30	36.10	4.50		0.80	0.71
25II	38.30	36.30	4.00	600^{0}C	0.71	
25III	38.50	36.30	3.50		0.62	
30I	36.80	35.90	3.50		0.62	0.62
30II	36.80	35.90	4.00		0.71	
30III	36.80	35.85	3.00		0.53	
35I	34.50	33.05	2.50		0.44	0.53
35II	34.30	33.10	3.50		0.62	
35III	34.50	33.20	3.00		0.53	
40I	32.20	30.20	2.00		0.36	0.36
40II	32.10	30.20	2.00		0.36	
40III	32.05	30.20	2.00		0.36	
45I	33.40	31.30	2.25		0.40	0.36
45II	33.45	31.25	2.25		0.40	
45III	33.40	31.30	1.50		0.27	
50I	34.60	32.40	2.50		0.44	0.36
50II	34.60	32.30	2.00		0.36	
50III	34.50	32.50	1.50		0.27	

III-e: Flexural Strength of Beams at 800^{0}C Temperature

Spec. Mark	Wt. before heating(kg)	Wt. After Heating(kg)	Ultimate Failure Load (kN)	Tempt ^{0}C	Flexural Strength (N/mm^2)	Mean flexural Strength
CI	41.20	38.20	1.00		0.18	0.18
CII	41.20	38.10	1.00		0.18	
CIII	41.30	38.10	1.00		0.18	
5I	38.80	35.70	1.00		0.18	0.18
5II	38.50	35.70	1.00		0.18	
5III	38.90	35.60	1.00		0.18	
10I	40.90	37.10	1.00		0.18	0.18
10II	40.90	37.10	1.00		0.18	
10III	40.80	37.05	1.00		0.18	
15I	40.20	36.40	1.25		0.22	0.22
15II	40.10	36.40	1.00		0.18	
15III	40.30	36.40	1.50		0.27	
20I	39.70	36.30	1.50		0.27	0.27
20II	39.60	36.10	1.25		0.22	
20III	40.00	36.20	1.75		0.31	
25I	38.50	34.70	2.00	800^{0}C	0.36	0.36
25II	38.50	34.60	1.50		0.27	
25III	38.30	34.70	2.50		0.44	
30I	36.10	33.00	1.50		0.27	0.31
30II	36.00	33.00	1.50		0.27	
30III	36.10	33.10	2.25		0.40	
35I	36.70	33.55	1.00		0.18	0.18
35II	36.80	33.60	1.25		0.22	
35III	36.75	33.50	0.75		0.13	
40I	37.30	34.10	0.50		0.09	0.13
40II	37.30	34.10	1.25		0.22	
40III	37.30	34.00	0.50		0.09	
45I	36.40	33.10	0.50		0.09	0.09
45II	36.35	33.20	0.50		0.09	
45III	36.40	33.10	0.50		0.09	
50I	35.50	32.10	0.50		0.09	0.09
50II	35.50	32.20	0.50		0.09	
50III	35.55	32.10	0.50		0.09	

APPENDIX IV: RELIABILITY CODE FOR REINFORCED CONCRETE BEAM IN BENDING

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%
%
%  THIS IS A MATLAB PROGRAM FORB THE STRUCTURAL RELIABILITY
%ANALYSIS OF SIMPLY SUPPORTED REINFORCED CONCRETE BEAM WITH
%EXPANDED POLYSTYRENE WASTE AS PARTIAL REPLACEMENT FOR COARSE
%AGGREGATE AT ELEVATED TEMPERATURES
%
%
%  NAME: KUDIRAT OZIOHU YUSUF
%  REG. NO: P13EGCV8042
%
%  MAJOR SUPERVISOR: Dr. Y. D. AMARTEY
%  MINOR SUPERVISOR: Dr. A. OCHOLI
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%
%
%  ROUTINE FOR DATA INPUT
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%
disp('   ')
clc
[cov1,cov2,cov3,cov4,cov5]...
    = covariance1;
disp('    ')
cons1 = input(' INPUT THE GRADIENT FOR THE FC PREDICTION MODEL
');
disp('  ')
cons2 = input(' INPUT THE INTERCEPT FOR THE FC PREDICTION
MODEL   ');
disp('  ')
epsc = input(' INPUT PERCENTAGE EPS CONTENT   ');
FCK = cons1*epsc + cons2;
disp('  ')
QK = input(' INPUT THE IMPOSED LOAD ON BEAM IN kN/m   ');
disp('    ')
L = input(' INPUT THE LENGTH OF BEAM IN m   ');
disp('    ')
B = input('   INPUT THE WIDTH OF THE BEAM IN mm   ');
disp('    ')
ALPHA = input('   Input dead to live load ratio   ');
disp('    ')
```

```
AS = input('   INPUT AREA OF REINFORCING STEEL IN mm^2   ');
disp('    ')
gammag = 1.35; gammaq = 1.5;
FY = input('   INPUT STEEL YIELD STRENGTH IN N/mm^2   ');
disp('    ')
D = input('   INPUT EFFECTIVE DEPTH OF THE CONCRETE IN mm
');
disp('    ')
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%
%
% ROUTINE FOR THE FIRST ORDER RELIABILITY ANALYSIS
% THE RELIABILITY ANALYSIS IS EXECUTED THROUGH A SPECIAL
% MATLAB FUNCTION CALLED 'kudi_flexural.m'
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%
beta_mode_1 =
kudi_flexural(QK,gammag,ALPHA,gammaq,L,AS,FY,D,FCK,B,...
      cov1,cov2,cov3,cov4,cov5);
pf = probability_of_failure(beta_mode_1);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%
%
disp('The safety index')
disp('   ')
disp(beta_mode_1)
disp('   ')
disp('The probability of failure')
disp('   ')
disp(pf)
```

```
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%
%
function [cov1,cov2,cov3,cov4,cov5]...
    = covariance1
%
cov1  = 0.40;
cov2  = 0.10;
cov3  = 0.05;
cov4  = 0.025;
cov5  = 0.17;
end
```

```
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%
%
%       TRANSFORMATION OF NON-NORMAL DISTRIBUTION
%       TO EQUIVALENT NORMAL DISTRIBUTION
%
%        RACKWITZ FIESSLER TRANSFORMATION
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%
%
function [DISTYPE1,DISTYPE2,DISTYPE3,DISTYPE4,DISTYPE5]...
          = distribution_mode1
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%
%
% INCLUDED DISTRIBUTION MODELS
%
% TYPE 1 FOR: Normal DISTRIBUTION
% TYPE 2 FOR: LOGNORMAL DISTRIBUTION
% TYPE 3 FOR: GUMBEL DISTRIBUTION
% TYPE 4 FOR: WEIBUL DISTRIBUTION
% TYPE 5 FOR: FRECHET DISTRIBUTION
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%
%
DISTYPE1 = 3; DISTYPE2 = 1;
DISTYPE3 = 2; DISTYPE4 = 1;
DISTYPE5 = 2;
```

```
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%
function beta_mode_1 = ...

kudi_flexural(QK,gammag,ALPHA,gammaq,L,AS,FY,D,FCK,B,...
               cov1,cov2,cov3,cov4,cov5)
%
[DISTYPE1,DISTYPE2,DISTYPE3,DISTYPE4,DISTYPE5] =
distribution_mode1;
cv(1) = cov1; cv(2) = cov2; cv(3) = cov3; cv(4) = cov4;
cv(5) = cov5;
%
rfmu(1)   = QK;     rmfx1  = QK*cv(1);
rfmu(2)   = AS;     rmfx2  = AS*cv(2);
rfmu(3)   = FY;     rmfx3  = FY*cv(3);
rfmu(4)   = D;      rmfx4  = D*cv(4);
rfmu(5)   = FCK;    rmfx5  = FCK*cv(5);
%
if(DISTYPE1 == 1)
    %
    % DOING NORMAL
    %
    mean(1) = rfmu(1);
    sd(1) = rmfx1;
elseif(DISTYPE1 == 2)
    %
    % DOING LOGNORMAL TRANSFORMATION
    %
 [mean(1) sd(1)] = lognormal(rfmu(1),rmfx1);
elseif(DISTYPE1 == 3)
    %
    % DOING GUMBEL TRANSFORMATION
    %
 [mean(1) sd(1)] = gumbel(rfmu(1),rmfx1);
elseif(DISTYPE1 == 4)
    %
    % DOING WEIBULL TRANSFORMATION
    %
 [mean(1) sd(1)] = weibull(rfmu(1),rmfx1);
elseif(DISTYPE1 == 5)
    %
    % DOING FRECHET TRANSFORMATION
    %
 [mean(1) sd(1)] = frechet(rfmu(1),rmfx1);
end
```

```
if(DISTYPE2 == 1)
    %
    % DOING NORMAL
    %
    mean(2) = rfmu(2);
    sd(2) = rmfx2;
elseif(DISTYPE2 == 2)
    %
    % DOING LOGNORMAL TRANSFORMATION
    %
 [mean(2) sd(2)] = lognormal(rfmu(2),rmfx2);
elseif(DISTYPE2 == 3)
    %
    % DOING GUMBEL TRANSFORMATION
    %
 [mean(2) sd(2)] = gumbel(rfmu(2),rmfx2);
elseif(DISTYPE2 == 4)
    %
    % DOING WEIBULL TRANSFORMATION
    %
 [mean(2) sd(2)] = weibull(rfmu(2),rmfx2);
elseif(DISTYPE2 == 5)
    %
    % DOING FRECHET TRANSFORMATION
    %
 [mean(2) sd(2)] = frechet(rfmu(2),rmfx2);
end
if(DISTYPE3 == 1)
    %
    % DOING NORMAL
    %
    mean(3) = rfmu(3);
    sd(3) = rmfx3;
elseif(DISTYPE3 == 2)
    %
    % DOING LOGNORMAL TRANSFORMATION
    %
 [mean(3) sd(3)] = lognormal(rfmu(3),rmfx3);
elseif(DISTYPE3 == 3)
    %
    % DOING GUMBEL TRANSFORMATION
    %
 [mean(3) sd(3)] = gumbel(rfmu(3),rmfx3);
elseif(DISTYPE3 == 4)
    %
    % DOING WEIBULL TRANSFORMATION
```

```
    %
 [mean(3) sd(3)] = weibull(rfmu(3),rmfx3);
elseif(DISTYPE3 == 5)
    %
    % DOING FRECHET TRANSFORMATION
    %
 [mean(3) sd(3)] = frechet(rfmu(3),rmfx3);
end
if(DISTYPE4 == 1)
    %
    % DOING NORMAL
    %
    mean(4) = rfmu(4);
    sd(4) = rmfx4;
elseif(DISTYPE4 == 2)
    %
    % DOING LOGNORMAL TRANSFORMATION
    %
 [mean(4) sd(4)] = lognormal(rfmu(4),rmfx4);
elseif(DISTYPE4 == 3)
    %
    % DOING GUMBEL TRANSFORMATION
    %
 [mean(4) sd(4)] = gumbel(rfmu(4),rmfx4);
elseif(DISTYPE4 == 4)
    %
    % DOING WEIBULL TRANSFORMATION
    %
 [mean(4) sd(4)] = weibull(rfmu(4),rmfx4);
elseif(DISTYPE4 == 5)
    %
    % DOING FRECHET TRANSFORMATION
    %
 [mean(4) sd(4)] = frechet(rfmu(4),rmfx4);
end
%
if(DISTYPE5 == 1)
    %
    % DOING NORMAL
    %
    mean(5) = rfmu(5);
    sd(5) = rmfx5;
elseif(DISTYPE5 == 2)
    %
    % DOING LOGNORMAL TRANSFORMATION
    %
```

```
 [mean(5) sd(5)] = lognormal(rfmu(5),rmfx5);
elseif(DISTYPE5 == 3)
    %
    % DOING GUMBEL TRANSFORMATION
    %
 [mean(5) sd(5)] = gumbel(rfmu(5),rmfx5);
 elseif(DISTYPE5 == 4)
    %
    % DOING WEIBULL TRANSFORMATION[
    %
 [mean(5) sd(5)] = weibull(rfmu(5),rmfx5);
elseif(DISTYPE5 == 5)
    %
    % DOING FRECHET TRANSFORMATION
    %
 [mean(5) sd(5)] = frechet(rfmu(5),rmfx5);
end
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%
sev1 = sd(1); sev2 = sd(2); sev3 = sd(3); sev4 = sd(4);
sev5 = sd(5);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%
dev1 = mean(1); dev2 = mean(2); dev3 = mean(3); dev4 =
mean(4);
dev5 = mean(5);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%
ALL1     = 1;
ALL2     = 1;
ALL3     = 1;
ALL4     = 1;
ALL5     = 1;
if (ALL1 == 1)
part1 = -0.125*((gammag*ALPHA) + gammaq)*(L^2)*1000000.0;
else part1 = 0;
end
```

```
    %
    if(ALL2 == 1)
part2 = (dev3*dev4) - ((dev2*(dev3^2))/(B*dev5));
    else
        part2 = 0;
    end
    %
    if(ALL3 == 1);
part3 = (dev2*dev4) - ((dev3*(dev2^2))/(B*dev5));
    else
        part3 = 0;
    end
    %
    if(ALL4 == 1)
part4 = dev2*dev3;
    else
        part4 = 0;
    end
    %
    if(ALL5 == 1)
part5 = 0.5*(((dev3^2)*(dev2^2))/(B*(dev5^2)));
    else
        part5 = 0;
    end
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%
deno = sqrt(((part1^2)*(sev1^2)) + ((part2^2)*(sev2^2)) + ...
    ((part3^2)*(sev3^2)) + ((part4^2)*(sev4^2)) + ...
    ((part5^2)*(sev5^2)));
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%
nume = ((dev2*dev3*dev4) - (0.5*(dev2^2)*(dev3^2))/(B*dev5))
...
        - ((0.125*dev1*((gammag*ALPHA) +
gammaq)*(L^2))*1000000.0);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%
%
if(deno <= 0)
```

```
    beta_mode_1 = 1000;
else
beta_mode_1 = nume/deno;
end
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%
function [mean, std] = frechet(rfmu,rmfx)
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%
%
%
%           SUBROUTINE FOR RACKWITZ FIESSLER TRANSFORMATION
%       TRANSFORMATION OF GUMBEL VARIABLES TO EQUIBVALENT
%NORMAL VARIABLES
%
%
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%
%
mean1 = rfmu;
stan1 = rmfx;
%
X = mean1;
%
AG = 2.33/((stan1/mean1)^(0.6770001));
cooler = 1-(1/AG);
cooler2 = gamma(cooler);
xx = X;
XU = mean1/cooler2;
cdf  = exp(-(XU/xx)^AG);
pdf  = cdf*(AG/XU)*(XU/xx)^(AG+1);
cdfx = cdf;
%
Z    = invnorm(cdfx);
pdfz = exp((-Z^2)/2.0D0)/sqrt(6.2833185307D0);
std = pdfz/pdf;
mean = X-rmfx*Z;
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%
```

```
%
function  xx = gamma(yy)
if(yy<=0)
    xx = 0;
elseif(yy > 0) && (yy < 1.0)
    xx = gmh(yy);
elseif(yy >= 1.0)
    xxx = yy - 1.0;
    xx = gmh(xxx);
end
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%
function xx = gmh(y)
%
xx = 1.0 + y*(-0.577191652D0 + ...
    y*(0.9878205891D0 + y*(-0.897056937D0 +...
    y*(0.918206857D0 + y*(0.765704078D0 +...
    y*(0.482199394D0 + y*(-0.193527818D0 +...
    y*(0.035868343D0)))))));
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%
function [mean, std] = gumbel(rfmu,rmfx)
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%
%                           SUBROUTINE THIRTY FIVE
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%
%
%
%         SUBROUTINE FOR RACKWITZ FIESSLER TRANSFORMATION
%
%     TRANSFORMATION OF GUMBEL VARIABLES TO EQUIBVALENT
NORMAL          %
%                            VARIABLES
%
%
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%
%
mean1 = rfmu;
stan1 = rmfx;
%
X = mean1;
%
AG = 3.14159264/sqrt(6D0)/stan1;
XU = mean1 - 0.57722/AG;
XT = exp(-AG*(X-XU));
cdf  = exp(-XT);
pdf  = AG*XT*cdf;
cdfx = cdf;
%
Z    = invnorm(cdfx);
pdfz = exp((-Z^2)/2.0D0)/sqrt(6.2833185307D0);
std = pdfz/pdf;
mean = X-rmfx*Z;
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%
function Z = invnorm(cdfx)
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%% SUBROUTINE THIRTRY SEVEN
%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%
%
%
%         SUBROUTINE TO EVALUATE INVERSE NORMA CUMMULATIVE
%
%                     DISTRIBUTION FUNCTION (CDF)
%
%
%
% Uses Hasting Polynomial 26.2.23 of 'Handbook of Mathematical
%
% Functions 1972. M. Abramcwitz and T. M. Stegun Ang 55
%
% National Bureau of Standards US Department of Commerce
%
%
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%
if(cdfx<0.5)
    T = sqrt(log(1.0/cdfx^2));
else
    T = sqrt(log(1.0/(1.0-cdfx)^2));
end
Y = (0.001308*T+0.189269)*(T+1.432788)*T+1.0;
Y = Y-((0.010328*T+0.802853)*T+2.515517)/Y;
if(cdfx<0.5)
    Z = -Y;
else
    Z = Y;
end
end
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%
function[mean,std] = lognormal(rfmu,rmfx)
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%% SUBROUTINE THIRTY EIGHT
%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%
%
% SUBROUTINE FOR RACKWITZ FIESSLER TRANSFORMATION OF LOGNORMAL
%       DISTRIBUTION TO EQUIVALENT NORMAL DISTRIBUTION
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%
%
x0 = rfmu-rmfx;
x = rfmu;
om = sqrt(1.0+(rmfx/(rfmu-x0))^2);
std = (x-x0)*sqrt(2.0*log(om));
mean = x+(x-x0)*log((rfmu-x0)/(x-x0)/om);
end
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%
function [mean, std] = weibull(rfmu,rmfx)
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%
%
%
%          SUBROUTINE FOR RACKWITZ FIESSLER TRANSFORMATION
%
%      TRANSFORMATION OF GUMBEL VARIABLES TO EQUIBVALENT
NORMAL          %
%                              VARIABLES
%
%
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%
%
mean1 = rfmu;
stan1 = rmfx;
%
A = ((stan1/mean1)^2)+1;
X = mean1;
XX = X;
%
AG = ((A-1)^(-1/1.835))-0.5;
%
DEL = -0.5;
AG = AG+DEL;
fool1 = 1+(1/AG);
fool11 = gamma(fool1);
ET = mean1/fool11;
TMP = exp(-(XX/ET)^AG);
cdf = 1-TMP;
pdf = (AG/ET)*((XX/ET)^(AG-1))*TMP;
cdfx = cdf;
%
Z    = invnorm(cdfx);
pdfz = exp((-Z^2)/2.0D0)/sqrt(6.2833185307D0);
std = pdfz/pdf;
mean = X-rmfx*Z;
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%
```

```
function pf = probability_of_failure(beta)
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%   REFERENCE: Melchers R. E. Structural Reliability analysis
%              and prediction. 1999. Ellis Horwood Limited
%              John Wlley and Sons. pp 372 to 374
%
% COMPLEMENTARY STANDARD NORMAL ROUTINE
%
%   SUBROUTINE FOUTY ONE
%
if(beta <= 0)
    pf = 1.0;
elseif(beta > 0) && (beta <= 0.01)
    pf = 0.4960;
elseif(beta > 0.01) && (beta <= 0.02)
    pf = 0.4920;
elseif(beta > 0.02) && (beta <= 0.03)
    pf = 0.4880;
elseif(beta > 0.03) && (beta <= 0.04)
    pf = 0.4841;
elseif(beta > 0.04) && (beta <= 0.05)
    pf = 0.4801;
elseif(beta > 0.05) && (beta <= 0.06)
    pf = 0.4761;
elseif(beta > 0.06) && (beta <= 0.07)
    pf = 0.4721;
elseif(beta > 0.07) && (beta <= 0.08)
    pf = 0.4681;
elseif(beta > 0.08) && (beta <= 0.09)
    pf = 0.4642;
elseif(beta > 0.09) && (beta <= 0.10)
    pf = 0.4602;
elseif(beta > 0.10) && (beta <= 0.11)
    pf = 0.4562;
elseif(beta > 0.11) && (beta <= 0.12)
    pf = 0.4522;
elseif(beta > 0.12) && (beta <= 0.13)
    pf = 0.4483;
elseif(beta > 0.13) && (beta <= 0.14)
    pf = 0.4443;
elseif(beta > 0.14) && (beta <= 0.15)
    pf = 0.4404;
elseif(beta > 0.15) && (beta <= 0.16)
    pf = 0.4364;
```

```
elseif(beta > 0.16) && (beta <= 0.17)
    pf = 0.4325;
elseif(beta > 0.17) && (beta <= 0.18)
    pf = 0.4286;
elseif(beta > 0.18) && (beta <= 0.19)
    pf = 0.4247;
elseif(beta > 0.19) && (beta <= 0.20)
    pf = 0.4207;
elseif(beta > 0.20) && (beta <= 0.21)
    pf = 0.4168;
elseif(beta > 0.21) && (beta <= 0.22)
    pf = 0.4129;
elseif(beta > 0.22) && (beta <= 0.23)
    pf = 0.4091;
elseif(beta > 0.23) && (beta <= 0.24)
    pf = 0.4052;
elseif(beta > 0.24) && (beta <= 0.25)
    pf = 0.4013;
elseif(beta > 0.25) && (beta <= 0.26)
    pf = 0.3974;
elseif(beta > 0.26) && (beta <= 0.27)
    pf = 0.3936;
elseif(beta > 0.27) && (beta <= 0.28)
    pf = 0.3897;
elseif(beta > 0.28) && (beta <= 0.29)
    pf = 0.3859;
elseif(beta > 0.29) && (beta <= 0.30)
    pf = 0.3821;
elseif(beta > 0.30) && (beta <= 0.31)
    pf = 0.3783;
elseif(beta > 0.31) && (beta <= 0.32)
    pf = 0.3745;
elseif(beta > 0.32) && (beta <= 0.33)
    pf = 0.3707;
elseif(beta > 0.33) && (beta <= 0.34)
    pf = 0.3669;
elseif(beta > 0.34) && (beta <= 0.35)
    pf = 0.3632;
elseif(beta > 0.35) && (beta <= 0.36)
    pf = 0.3594;
elseif(beta > 0.36) && (beta <= 0.37)
    pf = 0.3557;
elseif(beta > 0.37) && (beta <= 0.38)
    pf = 0.3520;
elseif(beta > 0.38) && (beta <= 0.39)
    pf = 0.3483;
```

```
elseif(beta > 0.39) && (beta <= 0.40)
    pf = 0.3446;
elseif(beta > 0.40) && (beta <= 0.41)
    pf = 0.3409;
elseif(beta > 0.41) && (beta <= 0.42)
    pf = 0.3372;
elseif(beta > 0.42) && (beta <= 0.43)
    pf = 0.3338;
elseif(beta > 0.43) && (beta <= 0.44)
    pf = 0.3300;
elseif(beta > 0.44) && (beta <= 0.45)
    pf = 0.3264;
elseif(beta > 0.45) && (beta <= 0.46)
    pf = 0.3228;
elseif(beta > 0.46) && (beta <= 0.47)
    pf = 0.3192;
elseif(beta > 0.47) && (beta <= 0.48)
    pf = 0.3156;
elseif(beta > 0.48) && (beta <= 0.49)
    pf = 0.3121;
elseif(beta > 0.49) && (beta <= 0.50)
    pf = 0.3085;
elseif(beta > 0.50) && (beta <= 0.51)
    pf = 0.3050;
elseif(beta > 0.51) && (beta <= 0.52)
    pf = 0.3015;
elseif(beta > 0.52) && (beta <= 0.53)
    pf = 0.2981;
elseif(beta > 0.53) && (beta <= 0.54)
    pf = 0.2948;
elseif(beta > 0.54) && (beta <= 0.55)
    pf = 0.2912;
elseif(beta > 0.55) && (beta <= 0.56)
    pf = 0.2877;
elseif(beta > 0.56) && (beta <= 0.57)
    pf = 0.2843;
elseif(beta > 0.57) && (beta <= 0.58)
    pf = 0.2810;
elseif(beta > 0.58) && (beta <= 0.59)
    pf = 0.2776;
elseif(beta > 0.59) && (beta <= 0.60)
    pf = 0.2743;
elseif(beta > 0.60) && (beta <= 0.61)
    pf = 0.2709;
elseif(beta > 0.61) && (beta <= 0.62)
    pf = 0.2676;
```

```
elseif(beta > 0.62) && (beta <= 0.63)
    pf = 0.2644;
elseif(beta > 0.63) && (beta <= 0.64)
    pf = 0.2611;
elseif(beta > 0.64) && (beta <= 0.65)
    pf = 0.2579;
elseif(beta > 0.65) && (beta <= 0.66)
    pf = 0.2546;
elseif(beta > 0.66) && (beta <= 0.67)
    pf = 0.2514;
elseif(beta > 0.67) && (beta <= 0.68)
    pf = 0.2483;
elseif(beta > 0.68) && (beta <= 0.69)
    pf = 0.2451;
elseif(beta > 0.69) && (beta <= 0.70)
    pf = 0.2420;
elseif(beta > 0.70) && (beta <= 0.71)
    pf = 0.2389;
elseif(beta > 0.71) && (beta <= 0.72)
    pf = 0.2358;
elseif(beta > 0.72) && (beta <= 0.73)
    pf = 0.2327;
elseif(beta > 0.73) && (beta <= 0.74)
    pf = 0.2297;
elseif(beta > 0.74) && (beta <= 0.75)
    pf = 0.2266;
elseif(beta > 0.75) && (beta <= 0.76)
    pf = 0.2236;
elseif(beta > 0.76) && (beta <= 0.77)
    pf = 0.2207;
elseif(beta > 0.77) && (beta <= 0.78)
    pf = 0.2177;
elseif(beta > 0.78) && (beta <= 0.79)
    pf = 0.2148;
elseif(beta > 0.79) && (beta <= 0.80)
    pf = 0.2119;
elseif(beta > 0.80) && (beta <= 0.81)
    pf = 0.2090;
elseif(beta > 0.81) && (beta <= 0.82)
    pf = 0.2061;
elseif(beta > 0.82) && (beta <= 0.83)
    pf = 0.2033;
elseif(beta > 0.83) && (beta <= 0.84)
    pf = 0.2005;
elseif(beta > 0.84) && (beta <= 0.85)
    pf = 0.1977;
```

```
elseif(beta > 0.85) && (beta <= 0.86)
    pf = 0.1949;
elseif(beta > 0.86) && (beta <= 0.87)
    pf = 0.1922;
elseif(beta > 0.87) && (beta <= 0.88)
    pf = 0.1894;
elseif(beta > 0.88) && (beta <= 0.89)
    pf = 0.1867;
elseif(beta > 0.89) && (beta <= 0.90)
    pf = 0.1841;
elseif(beta > 0.90) && (beta <= 0.91)
    pf = 0.1814;
elseif(beta > 0.91) && (beta <= 0.92)
    pf = 0.1788;
elseif(beta > 0.92) && (beta <= 0.93)
    pf = 0.1762;
elseif(beta > 0.93) && (beta <= 0.94)
    pf = 0.1736;
elseif(beta > 0.94) && (beta <= 0.95)
    pf = 0.1711;
elseif(beta > 0.95) && (beta <= 0.96)
    pf = 0.1685;
elseif(beta > 0.96) && (beta <= 0.97)
    pf = 0.1660;
elseif(beta > 0.97) && (beta <= 0.98)
    pf = 0.1635;
elseif(beta > 0.98) && (beta <= 0.99)
    pf = 0.1611;
elseif(beta > 0.99) && (beta <= 1.00)
    pf = 0.1587;
elseif(beta > 1.00) && (beta <= 1.01)
    pf = 0.1563;
elseif(beta > 1.01) && (beta <= 1.02)
    pf = 0.1539;
elseif(beta > 1.02) && (beta <= 1.03)
    pf = 0.1515;
elseif(beta > 1.03) && (beta <= 1.04)
    pf = 0.1492;
elseif(beta > 1.04) && (beta <= 1.05)
    pf = 0.1469;
elseif(beta > 1.05) && (beta <= 1.06)
    pf = 0.1446;
elseif(beta > 1.06) && (beta <= 1.07)
    pf = 0.1423;
elseif(beta > 1.07) && (beta <= 1.08)
    pf = 0.1401;
```

```
elseif(beta > 1.08) && (beta <= 1.09)
    pf = 0.1379;
elseif(beta > 1.09) && (beta <= 1.10)
    pf = 0.1357;
elseif(beta > 1.10) && (beta <= 1.11)
    pf = 0.1335;
elseif(beta > 1.11) && (beta <= 1.12)
    pf = 0.1314;
elseif(beta > 1.12) && (beta <= 1.13)
    pf = 0.1292;
elseif(beta > 1.13) && (beta <= 1.14)
    pf = 0.1271;
elseif(beta > 1.14) && (beta <= 1.15)
    pf = 0.1251;
elseif(beta > 1.15) && (beta <= 1.16)
    pf = 0.1230;
elseif(beta > 1.16) && (beta <= 1.17)
    pf = 0.1210;
elseif(beta > 1.17) && (beta <= 1.18)
    pf = 0.1190;
elseif(beta > 1.18) && (beta <= 1.19)
    pf = 0.1170;
elseif(beta > 1.19) && (beta <= 1.20)
    pf = 0.1151;
elseif(beta > 1.20) && (beta <= 1.21)
    pf = 0.1131;
elseif(beta > 1.21) && (beta <= 1.22)
    pf = 0.1112;
elseif(beta > 1.22) && (beta <= 1.23)
    pf = 0.1094;
elseif(beta > 1.23) && (beta <= 1.24)
    pf = 0.1075;
elseif(beta > 1.24) && (beta <= 1.25)
    pf = 0.1057;
elseif(beta > 1.25) && (beta <= 1.26)
    pf = 0.1038;
elseif(beta > 1.26) && (beta <= 1.27)
    pf = 0.1020;
elseif(beta > 1.27) && (beta <= 1.28)
    pf = 0.1003;
elseif(beta > 1.28) && (beta <= 1.29)
    pf = 0.9853e-01;
elseif(beta > 1.29) && (beta <= 1.30)
    pf = 0.968e-01;
elseif(beta > 1.30) && (beta <= 1.31)
    pf = 0.9510e-01;
```

```
elseif(beta > 1.31) && (beta <= 1.32)
    pf = 0.9342e-01;
elseif(beta > 1.32) && (beta <= 1.33)
    pf = 0.9176e-01;
elseif(beta > 1.33) && (beta <= 1.34)
    pf = 0.9013e-01;
elseif(beta > 1.34) && (beta <= 1.35)
    pf = 0.8851e-01;
elseif(beta > 1.35) && (beta <= 1.36)
    pf = 0.8692e-01;
elseif(beta > 1.36) && (beta <= 1.37)
    pf = 0.8535e-01;
elseif(beta > 1.37) && (beta <= 1.38)
    pf = 0.8380e-01;
elseif(beta > 1.38) && (beta <= 1.39)
    pf = 0.8227e-01;
elseif(beta > 1.39) && (beta <= 1.40)
    pf = 0.8076e-01;
elseif(beta > 1.40) && (beta <= 1.41)
    pf = 0.7927e-01;
elseif(beta > 1.41) && (beta <= 1.42)
    pf = 0.7781e-01;
elseif(beta > 1.42) && (beta <= 1.43)
    pf = 0.7636e-01;
elseif(beta > 1.43) && (beta <= 1.44)
    pf = 0.7494e-01;
elseif(beta > 1.44) && (beta <= 1.45)
    pf = 0.7353e-01;
elseif(beta > 1.45) && (beta <= 1.46)
    pf = 0.7216e-01;
elseif(beta > 1.46) && (beta <= 1.47)
    pf = 0.7078e-01;
elseif(beta > 1.47) && (beta <= 1.48)
    pf = 0.6944e-01;
elseif(beta > 1.48) && (beta <= 1.49)
    pf = 0.6811e-01;
elseif(beta > 1.49) && (beta <= 1.50)
    pf = 0.6681e-01;
elseif(beta > 1.50) && (beta <= 1.51)
    pf = 0.6552e-01;
elseif(beta > 1.51) && (beta <= 1.52)
    pf = 0.6426e-01;
elseif(beta > 1.52) && (beta <= 1.53)
    pf = 0.6301e-01;
elseif(beta > 1.53) && (beta <= 1.54)
    pf = 0.6178e-01;
```

```
elseif(beta > 1.54) && (beta <= 1.55)
    pf = 0.6057e-01;
elseif(beta > 1.55) && (beta <= 1.56)
    pf = 0.5938e-01;
elseif(beta > 1.56) && (beta <= 1.57)
    pf = 0.5821e-01;
elseif(beta > 1.57) && (beta <= 1.58)
    pf = 0.5706e-01;
elseif(beta > 1.58) && (beta <= 1.59)
    pf = 0.5592e-01;
elseif(beta > 1.59) && (beta <= 1.60)
    pf = 0.5480e-01;
elseif(beta > 1.60) && (beta <= 1.61)
    pf = 0.5370e-01;
elseif(beta > 1.61) && (beta <= 1.62)
    pf = 0.5282e-01;
elseif(beta > 1.62) && (beta <= 1.63)
    pf = 0.5155e-01;
elseif(beta > 1.63) && (beta <= 1.64)
    pf = 0.5050e-01;
elseif(beta > 1.64) && (beta <= 1.65)
    pf = 0.4947e-01;
elseif(beta > 1.65) && (beta <= 1.66)
    pf = 0.4846e-01;
elseif(beta > 1.66) && (beta <= 1.67)
    pf = 0.4746e-01;
elseif(beta > 1.67) && (beta <= 1.68)
    pf = 0.4648e-01;
elseif(beta > 1.68) && (beta <= 1.69)
    pf = 0.4552e-01;
elseif(beta > 1.69) && (beta <= 1.70)
    pf = 0.4457e-01;
elseif(beta > 1.70) && (beta <= 1.71)
    pf = 0.4363e-01;
elseif(beta > 1.71) && (beta <= 1.72)
    pf = 0.4272e-01;
elseif(beta > 1.72) && (beta <= 1.73)
    pf = 0.4182e-01;
elseif(beta > 1.73) && (beta <= 1.74)
    pf = 0.4093e-01;
elseif(beta > 1.74) && (beta <= 1.75)
    pf = 0.4006e-01;
elseif(beta > 1.75) && (beta <= 1.76)
    pf = 0.3921e-01;
elseif(beta > 1.76) && (beta <= 1.77)
    pf = 0.3836e-01;
```

```
elseif(beta > 1.77) && (beta <= 1.78)
    pf = 0.3754e-01;
elseif(beta > 1.78) && (beta <= 1.79)
    pf = 0.3673e-01;
elseif(beta > 1.79) && (beta <= 1.80)
    pf = 0.3593e-01;
elseif(beta > 1.80) && (beta <= 1.81)
    pf = 0.3515e-01;
elseif(beta > 1.81) && (beta <= 1.82)
    pf = 0.3438e-01;
elseif(beta > 1.82) && (beta <= 1.83)
    pf = 0.3363e-01;
elseif(beta > 1.83) && (beta <= 1.84)
    pf = 0.3289e-01;
elseif(beta > 1.84) && (beta <= 1.85)
    pf = 0.3216e-01;
elseif(beta > 1.85) && (beta <= 1.86)
    pf = 0.3144e-01;
elseif(beta > 1.86) && (beta <= 1.87)
    pf = 0.3074e-01;
elseif(beta > 1.87) && (beta <= 1.88)
    pf = 0.3005e-01;
elseif(beta > 1.88) && (beta <= 1.89)
    pf = 0.2938e-01;
elseif(beta > 1.89) && (beta <= 1.90)
    pf = 0.2872e-01;
elseif(beta > 1.90) && (beta <= 1.91)
    pf = 0.2807e-01;
elseif(beta > 1.91) && (beta <= 1.92)
    pf = 0.2743e-01;
elseif(beta > 1.92) && (beta <= 1.93)
    pf = 0.2680e-01;
elseif(beta > 1.93) && (beta <= 1.94)
    pf = 0.2619e-01;
elseif(beta > 1.94) && (beta <= 1.95)
    pf = 0.2553e-01;
elseif(beta > 1.95) && (beta <= 1.96)
    pf = 0.2500e-01;
elseif(beta > 1.96) && (beta <= 1.97)
    pf = 0.2442e-01;
elseif(beta > 1.97) && (beta <= 1.98)
    pf = 0.2385e-01;
elseif(beta > 1.98) && (beta <= 1.99)
    pf = 0.2330e-01;
elseif(beta > 1.99) && (beta <= 2.00)
    pf = 0.2275e-01;
```

```
elseif(beta > 2.00) && (beta <= 2.01)
    pf = 0.2222e-01;
elseif(beta > 2.01) && (beta <= 2.02)
    pf = 0.2169e-01;
elseif(beta > 2.02) && (beta <= 2.03)
    pf = 0.2118e-01;
elseif(beta > 2.03) && (beta <= 2.04)
    pf = 0.2068e-01;
elseif(beta > 2.04) && (beta <= 2.05)
    pf = 0.2018e-01;
elseif(beta > 2.05) && (beta <= 2.06)
    pf = 0.1970e-01;
elseif(beta > 2.06) && (beta <= 2.07)
    pf = 0.1923e-01;
elseif(beta > 2.07) && (beta <= 2.08)
    pf = 0.1876e-01;
elseif(beta > 2.08) && (beta <= 2.09)
    pf = 0.1831e-01;
elseif(beta > 2.09) && (beta <= 2.10)
    pf = 0.1788e-01;
elseif(beta > 2.10) && (beta <= 2.11)
    pf = 0.1743e-01;
elseif(beta > 2.11) && (beta <= 2.12)
    pf = 0.1700e-01;
elseif(beta > 2.12) && (beta <= 2.13)
    pf = 0.1659e-01;
elseif(beta > 2.13) && (beta <= 2.14)
    pf = 0.1618e-01;
elseif(beta > 2.14) && (beta <= 2.15)
    pf = 0.1578e-01;
elseif(beta > 2.15) && (beta <= 2.16)
    pf = 0.1539e-01;
elseif(beta > 2.16) && (beta <= 2.17)
    pf = 0.1500e-01;
elseif(beta > 2.17) && (beta <= 2.18)
    pf = 0.1483e-01;
elseif(beta > 2.18) && (beta <= 2.19)
    pf = 0.1426e-01;
elseif(beta > 2.19) && (beta <= 2.20)
    pf = 0.1390e-01;
elseif(beta > 2.20) && (beta <= 2.21)
    pf = 0.1355e-01;
elseif(beta > 2.21) && (beta <= 2.22)
    pf = 0.1321e-01;
elseif(beta > 2.22) && (beta <= 2.23)
    pf = 0.1287e-01;
```

```
elseif(beta > 2.23) && (beta <= 2.24)
    pf = 0.1253e-01;
elseif(beta > 2.24) && (beta <= 2.25)
    pf = 0.1222e-01;
elseif(beta > 2.25) && (beta <= 2.26)
    pf = 0.11191e-01;
elseif(beta > 2.26) && (beta <= 2.27)
    pf = 0.1160e-01;
elseif(beta > 2.27) && (beta <= 2.28)
    pf = 0.1130e-01;
elseif(beta > 2.28) && (beta <= 2.29)
    pf = 0.1101e-01;
elseif(beta > 2.29) && (beta <= 2.30)
    pf = 0.1072e-01;
elseif(beta > 2.30) && (beta <= 2.31)
    pf = 0.1044e-01;
elseif(beta > 2.31) && (beta <= 2.32)
    pf = 0.1017e-01;
elseif(beta > 2.32) && (beta <= 2.33)
    pf = 0.9903e-02;
elseif(beta > 2.33) && (beta <= 2.34)
    pf = 0.9642e-02;
elseif(beta > 2.34) && (beta <= 2.35)
    pf = 0.9387e-02;
elseif(beta > 2.35) && (beta <= 2.36)
    pf = 0.9138e-02;
elseif(beta > 2.36) && (beta <= 2.37)
    pf = 0.8894e-02;
elseif(beta > 2.37) && (beta <= 2.38)
    pf = 0.8657e-02;
elseif(beta > 2.38) && (beta <= 2.39)
    pf = 0.8424e-02;
elseif(beta > 2.39) && (beta <= 2.40)
    pf = 0.8198e-02;
elseif(beta > 2.40) && (beta <= 2.41)
    pf = 0.7976e-02;
elseif(beta > 2.41) && (beta <= 2.42)
    pf = 0.7760e-02;
elseif(beta > 2.42) && (beta <= 2.43)
    pf = 0.7550e-02;
elseif(beta > 2.43) && (beta <= 2.44)
    pf = 0.7344e-02;
elseif(beta > 2.44) && (beta <= 2.45)
    pf = 0.7143e-02;
elseif(beta > 2.45) && (beta <= 2.46)
    pf = 0.6947e-02;
```

```
elseif(beta > 2.46) && (beta <= 2.47)
    pf = 0.6758e-02;
elseif(beta > 2.47) && (beta <= 2.48)
    pf = 0.6589e-02;
elseif(beta > 2.48) && (beta <= 2.49)
    pf = 0.6387e-02;
elseif(beta > 2.49) && (beta <= 2.50)
    pf = 0.6210e-02;
elseif(beta > 2.50) && (beta <= 2.51)
    pf = 0.6037e-02;
elseif(beta > 2.51) && (beta <= 2.52)
    pf = 0.5868e-02;
elseif(beta > 2.52) && (beta <= 2.53)
    pf = 0.5703e-02;
elseif(beta > 2.53) && (beta <= 2.54)
    pf = 0.5543e-02;
elseif(beta > 2.54) && (beta <= 2.55)
    pf = 0.5386e-02;
elseif(beta > 2.55) && (beta <= 2.56)
    pf = 0.5234e-02;
elseif(beta > 2.56) && (beta <= 2.57)
    pf = 0.5085e-02;
elseif(beta > 2.57) && (beta <= 2.58)
    pf = 0.4940e-02;
elseif(beta > 2.58) && (beta <= 2.59)
    pf = 0.4799e-02;
elseif(beta > 2.59) && (beta <= 2.60)
    pf = 0.4661e-02;
elseif(beta > 2.60) && (beta <= 2.61)
    pf = 0.4527e-02;
elseif(beta > 2.61) && (beta <= 2.62)
    pf = 0.4397e-02;
elseif(beta > 2.62) && (beta <= 2.63)
    pf = 0.4269e-02;
elseif(beta > 2.63) && (beta <= 2.64)
    pf = 0.4145e-02;
elseif(beta > 2.64) && (beta <= 2.65)
    pf = 0.4025e-02;
elseif(beta > 2.65) && (beta <= 2.66)
    pf = 0.3907e-02;
elseif(beta > 2.66) && (beta <= 2.67)
    pf = 0.3793e-02;
elseif(beta > 2.67) && (beta <= 2.68)
    pf = 0.3681e-02;
elseif(beta > 2.68) && (beta <= 2.69)
    pf = 0.3573e-02;
```

```
elseif(beta > 2.69) && (beta <= 2.70)
    pf = 0.3467e-02;
elseif(beta > 2.70) && (beta <= 2.71)
    pf = 0.3364e-02;
elseif(beta > 2.71) && (beta <= 2.72)
    pf = 0.3264e-02;
elseif(beta > 2.72) && (beta <= 2.73)
    pf = 0.3167e-02;
elseif(beta > 2.73) && (beta <= 2.74)
    pf = 0.3072e-02;
elseif(beta > 2.74) && (beta <= 2.75)
    pf = 0.2980e-02;
elseif(beta > 2.75) && (beta <= 2.76)
    pf = 0.2890e-02;
elseif(beta > 2.76) && (beta <= 2.77)
    pf = 0.2803e-02;
elseif(beta > 2.77) && (beta <= 2.78)
    pf = 0.2718e-02;
elseif(beta > 2.78) && (beta <= 2.79)
    pf = 0.2635e-02;
elseif(beta > 2.79) && (beta <= 2.80)
    pf = 0.2555e-02;
elseif(beta > 2.80) && (beta <= 2.81)
    pf = 0.2477e-02;
elseif(beta > 2.81) && (beta <= 2.82)
    pf = 0.2401e-02;
elseif(beta > 2.82) && (beta <= 2.83)
    pf = 0.2327e-02;
elseif(beta > 2.83) && (beta <= 2.84)
    pf = 0.2256e-02;
elseif(beta > 2.84) && (beta <= 2.85)
    pf = 0.2286e-02;
elseif(beta > 2.85) && (beta <= 2.86)
    pf = 0.2118e-02;
elseif(beta > 2.86) && (beta <= 2.87)
    pf = 0.2052e-02;
elseif(beta > 2.87) && (beta <= 2.88)
    pf = 0.1988e-02;
elseif(beta > 2.88) && (beta <= 2.89)
    pf = 0.1926e-02;
elseif(beta > 2.89) && (beta <= 2.90)
    pf = 0.1866e-02;
elseif(beta > 2.90) && (beta <= 2.91)
    pf = 0.1807e-02;
elseif(beta > 2.91) && (beta <= 2.92)
    pf = 0.1750e-02;
```

```
elseif(beta > 2.92) && (beta <= 2.93)
    pf = 0.1695e-02;
elseif(beta > 2.93) && (beta <= 2.94)
    pf = 0.1641e-02;
elseif(beta > 2.94) && (beta <= 2.95)
    pf = 0.1589e-02;
elseif(beta > 2.95) && (beta <= 2.96)
    pf = 0.1538e-02;
elseif(beta > 2.96) && (beta <= 2.97)
    pf = 0.1489e-02;
elseif(beta > 2.97) && (beta <= 2.98)
    pf = 0.1441e-02;
elseif(beta > 2.98) && (beta <= 2.99)
    pf = 0.1395e-02;
elseif(beta > 2.99) && (beta <= 3.00)
    pf = 0.1350e-02;
elseif(beta > 3.00) && (beta <= 3.01)
    pf = 0.1306e-02;
elseif(beta > 3.01) && (beta <= 3.02)
    pf = 0.14264e-02;
elseif(beta > 3.02) && (beta <= 3.03)
    pf = 0.1223e-02;
elseif(beta > 3.03) && (beta <= 3.04)
    pf = 0.1183e-02;
elseif(beta > 3.04) && (beta <= 3.05)
    pf = 0.1144e-02;
elseif(beta > 3.05) && (beta <= 3.06)
    pf = 0.1107e-02;
elseif(beta > 3.06) && (beta <= 3.07)
    pf = 0.1070e-02;
elseif(beta > 3.07) && (beta <= 3.08)
    pf = 0.1035e-02;
elseif(beta > 3.08) && (beta <= 3.09)
    pf = 0.1001e-02;
elseif(beta > 3.09) && (beta <= 3.10)
    pf = 0.9676e-03;
elseif(beta > 3.10) && (beta <= 3.11)
    pf = 0.9354e-03;
elseif(beta > 3.11) && (beta <= 3.12)
    pf = 0.9042e-03;
elseif(beta > 3.12) && (beta <= 3.13)
    pf = 0.8740e-03;
elseif(beta > 3.13) && (beta <= 3.14)
    pf = 0.8447e-03;
elseif(beta > 3.14) && (beta <= 3.15)
    pf = 0.8163e-03;
```

```
elseif(beta > 3.15) && (beta <= 3.16)
    pf = 0.7888e-03;
elseif(beta > 3.16) && (beta <= 3.17)
    pf = 0.7622e-03;
elseif(beta > 3.17) && (beta <= 3.18)
    pf = 0.7363e-03;
elseif(beta > 3.18) && (beta <= 3.19)
    pf = 0.7113e-03;
elseif(beta > 3.09) && (beta <= 3.20)
    pf = 0.6871e-03;
elseif(beta > 3.20) && (beta <= 3.21)
    pf = 0.6636e-03;
elseif(beta > 3.21) && (beta <= 3.22)
    pf = 0.6409e-03;
elseif(beta > 3.22) && (beta <= 3.23)
    pf = 0.6189e-03;
elseif(beta > 3.23) && (beta <= 3.24)
    pf = 0.5976e-03;
elseif(beta > 3.24) && (beta <= 3.25)
    pf = 0.5770e-03;
elseif(beta > 3.25) && (beta <= 3.26)
    pf = 0.5570e-03;
elseif(beta > 3.26) && (beta <= 3.27)
    pf = 0.5377e-03;
elseif(beta > 3.27) && (beta <= 3.28)
    pf = 0.5190e-03;
elseif(beta > 3.28) && (beta <= 3.29)
    pf = 0.5009e-03;
elseif(beta > 3.29) && (beta <= 3.30)
    pf = 0.4834e-03;
elseif(beta > 3.30) && (beta <= 3.31)
    pf = 0.4664e-03;
elseif(beta > 3.31) && (beta <= 3.32)
    pf = 0.4500e-03;
elseif(beta > 3.32) && (beta <= 3.33)
    pf = 0.4342e-03;
elseif(beta > 3.33) && (beta <= 3.34)
    pf = 0.4189e-03;
elseif(beta > 3.34) && (beta <= 3.35)
    pf = 0.4040e-03;
elseif(beta > 3.35) && (beta <= 3.36)
    pf = 0.3897e-03;
elseif(beta > 3.36) && (beta <= 3.37)
    pf = 0.3758e-03;
elseif(beta > 3.37) && (beta <= 3.38)
    pf = 0.3624e-03;
```

```
elseif(beta > 3.38) && (beta <= 3.39)
    pf = 0.3494e-03;
elseif(beta > 3.39) && (beta <= 3.40)
    pf = 0.3369e-03;
elseif(beta > 3.40) && (beta <= 3.41)
    pf = 0.3248e-03;
elseif(beta > 3.41) && (beta <= 3.42)
    pf = 0.3131e-03;
elseif(beta > 3.42) && (beta <= 3.43)
    pf = 0.3017e-03;
elseif(beta > 3.43) && (beta <= 3.44)
    pf = 0.2908e-03;
elseif(beta > 3.44) && (beta <= 3.45)
    pf = 0.2802e-03;
elseif(beta > 3.45) && (beta <= 3.46)
    pf = 0.2700e-03;
elseif(beta > 3.46) && (beta <= 3.47)
    pf = 0.2602e-03;
elseif(beta > 3.47) && (beta <= 3.48)
    pf = 0.2507e-03;
elseif(beta > 3.48) && (beta <= 3.49)
    pf = 0.2415e-03;
elseif(beta > 3.49) && (beta <= 3.50)
    pf = 0.2326e-03;
elseif(beta > 3.50) && (beta <= 3.51)
    pf = 0.2240e-03;
elseif(beta > 3.51) && (beta <= 3.52)
    pf = 0.2157e-03;
elseif(beta > 3.52) && (beta <= 3.53)
    pf = 0.2077e-03;
elseif(beta > 3.53) && (beta <= 3.54)
    pf = 0.2000e-03;
elseif(beta > 3.54) && (beta <= 3.55)
    pf = 0.1926e-03;
elseif(beta > 3.55) && (beta <= 3.56)
    pf = 0.1854e-03;
elseif(beta > 3.56) && (beta <= 3.57)
    pf = 0.1784e-03;
elseif(beta > 3.57) && (beta <= 3.58)
    pf = 0.1717e-03;
elseif(beta > 3.58) && (beta <= 3.59)
    pf = 0.1653e-03;
elseif(beta > 3.59) && (beta <= 3.60)
    pf = 0.1591e-03;
elseif(beta > 3.60) && (beta <= 3.61)
    pf = 0.1531e-03;
```

```
elseif(beta > 3.61) && (beta <= 3.62)
    pf = 0.1473e-03;
elseif(beta > 3.62) && (beta <= 3.63)
    pf = 0.1417e-03;
elseif(beta > 3.63) && (beta <= 3.64)
    pf = 0.1363e-03;
elseif(beta > 3.64) && (beta <= 3.65)
    pf = 0.1311e-03;
elseif(beta > 3.65) && (beta <= 3.66)
    pf = 0.1261e-03;
elseif(beta > 3.66) && (beta <= 3.67)
    pf = 0.1212e-03;
elseif(beta > 3.67) && (beta <= 3.68)
    pf = 0.1166e-03;
elseif(beta > 3.68) && (beta <= 3.69)
    pf = 0.1121e-03;
elseif(beta > 3.69) && (beta <= 3.70)
    pf = 0.1077e-03;
elseif(beta > 3.70) && (beta <= 3.71)
    pf = 0.1036e-03;
elseif(beta > 3.71) && (beta <= 3.72)
    pf = 0.9956e-04;
elseif(beta > 3.72) && (beta <= 3.73)
    pf = 0.9569e-04;
elseif(beta > 3.73) && (beta <= 3.74)
    pf = 0.9196e-04;
elseif(beta > 3.74) && (beta <= 3.75)
    pf = 0.8837e-04;
elseif(beta > 3.75) && (beta <= 3.76)
    pf = 0.8491e-04;
elseif(beta > 3.76) && (beta <= 3.77)
    pf = 0.8157e-04;
elseif(beta > 3.77) && (beta <= 3.78)
    pf = 0.7836e-04;
elseif(beta > 3.78) && (beta <= 3.79)
    pf = 0.7527e-04;
elseif(beta > 3.79) && (beta <= 3.80)
    pf = 0.7230e-04;
elseif(beta > 3.80) && (beta <= 3.81)
    pf = 0.6943e-04;
elseif(beta > 3.81) && (beta <= 3.82)
    pf = 0.6667e-04;
elseif(beta > 3.82) && (beta <= 3.83)
    pf = 0.6402e-04;
elseif(beta > 3.83) && (beta <= 3.84)
    pf = 0.6147e-04;
```

```
elseif(beta > 3.84) && (beta <= 3.85)
    pf = 0.5901e-04;
elseif(beta > 3.85) && (beta <= 3.86)
    pf = 0.5664e-04;
elseif(beta > 3.86) && (beta <= 3.87)
    pf = 0.5437e-04;
elseif(beta > 3.87) && (beta <= 3.88)
    pf = 0.5218e-04;
elseif(beta > 3.88) && (beta <= 3.89)
    pf = 0.5007e-04;
elseif(beta > 3.89) && (beta <= 3.90)
    pf = 0.4804e-04;
elseif(beta > 3.90) && (beta <= 3.91)
    pf = 0.4610e-04;
elseif(beta > 3.91) && (beta <= 3.92)
    pf = 0.4422e-04;
elseif(beta > 3.92) && (beta <= 3.93)
    pf = 0.4242e-04;
elseif(beta > 3.93) && (beta <= 3.94)
    pf = 0.4069e-04;
elseif(beta > 3.94) && (beta <= 3.95)
    pf = 0.3902e-04;
elseif(beta > 3.95) && (beta <= 3.96)
    pf = 0.3742e-04;
elseif(beta > 3.96) && (beta <= 3.97)
    pf = 0.3588e-04;
elseif(beta > 3.97) && (beta <= 3.98)
    pf = 0.3441e-04;
elseif(beta > 3.98) && (beta <= 3.99)
    pf = 0.3298e-04;
elseif(beta > 3.99) && (beta <= 4.00)
    pf = 0.3162e-04;
elseif(beta > 4.00) && (beta <= 4.05)
    pf = 0.2557e-04;
elseif(beta > 4.05) && (beta <= 4.10)
    pf = 0.2062e-04;
elseif(beta > 4.10) && (beta <= 4.15)
    pf = 0.1659e-04;
elseif(beta > 4.15) && (beta <= 4.20)
    pf = 0.1332e-04;
elseif(beta > 4.20) && (beta <= 4.25)
    pf = 0.1067e-04;
elseif(beta > 4.25) && (beta <= 4.30)
    pf = 0.8524e-05;
elseif(beta > 4.30) && (beta <= 4.35)
    pf = 0.6794e-05;
```

```
elseif(beta > 4.35) && (beta <= 4.40)
    pf = 0.5402e-05;
elseif(beta > 4.40) && (beta <= 4.45)
    pf = 0.4285e-05;
elseif(beta > 4.45) && (beta <= 4.50)
    pf = 0.3391e-05;
elseif(beta > 4.50) && (beta <= 4.55)
    pf = 0.2677e-05;
elseif(beta > 4.55) && (beta <= 4.60)
    pf = 0.2108e-05;
elseif(beta > 4.60) && (beta <= 4.65)
    pf = 0.1656e-05;
elseif(beta > 4.65) && (beta <= 4.70)
    pf = 0.1298e-05;
elseif(beta > 4.70) && (beta <= 4.75)
    pf = 0.1015e-05;
elseif(beta > 4.75) && (beta <= 4.80)
    pf = 0.7914e-06;
elseif(beta > 4.80) && (beta <= 4.85)
    pf = 0.6158e-06;
elseif(beta > 4.85) && (beta <= 4.90)
    pf = 0.4780e-06;
elseif(beta > 4.90) && (beta <= 4.95)
    pf = 0.3701e-06;
elseif(beta > 4.95) && (beta <= 5.00)
    pf = 0.2859e-06;
elseif(beta > 5.00) && (beta <= 5.05)
    pf = 0.2203e-06;
elseif(beta > 5.05) && (beta <= 5.10)
    pf = 0.1694e-06;
elseif(beta > 5.10) && (beta <= 5.15)
    pf = 0.1299e-06;
elseif(beta > 5.15) && (beta <= 5.20)
    pf = 0.9935e-07;
elseif(beta > 5.20) && (beta <= 5.25)
    pf = 0.7582e-07;
elseif(beta > 5.25) && (beta <= 5.30)
    pf = 0.5772e-07;
elseif(beta > 5.30) && (beta <= 5.35)
    pf = 0.4384e-07;
elseif(beta > 5.35) && (beta <= 5.40)
    pf = 0.3321e-07;
elseif(beta > 5.40) && (beta <= 5.45)
    pf = 0.2510e-07;
elseif(beta > 5.45) && (beta <= 5.50)
    pf = 0.1892e-07;
```

```
elseif(beta > 5.50) && (beta <= 5.55)
    pf = 0.1423e-07;
elseif(beta > 5.55) && (beta <= 5.60)
    pf = 0.1067e-07;
elseif(beta > 5.60) && (beta <= 5.65)
    pf = 0.7985e-08;
elseif(beta > 5.65) && (beta <= 5.70)
    pf = 0.5959e-08;
elseif(beta > 5.70) && (beta <= 5.75)
    pf = 0.4436e-08;
elseif(beta > 5.75) && (beta <= 5.80)
    pf = 0.3293e-08;
elseif(beta > 5.80) && (beta <= 5.85)
    pf = 0.2438e-08;
elseif(beta > 5.85) && (beta <= 5.90)
    pf = 0.1800e-08;
elseif(beta > 5.90) && (beta <= 5.95)
    pf = 0.1325e-08;
elseif(beta > 5.95) && (beta <= 6.00)
    pf = 0.9716e-09;
elseif(beta > 6.00) && (beta <= 6.10)
    pf = 0.5220e-09;
elseif(beta > 6.10) && (beta <= 6.20)
    pf = 0.2778e-09;
elseif(beta > 6.20) && (beta <= 6.30)
    pf = 0.1483e-09;
elseif(beta > 6.30) && (beta <= 6.40)
    pf = 0.7636e-10;
elseif(beta > 6.40) && (beta <= 6.50)
    pf = 0.3945e-10;
elseif(beta > 6.50) && (beta <= 6.60)
    pf = 0.2010e-10;
elseif(beta > 6.60) && (beta <= 6.70)
    pf = 0.1023e-10;
elseif(beta > 6.70) && (beta <= 6.80)
    pf = 0.5130e-11;
elseif(beta > 6.80) && (beta <= 6.90)
    pf = 0.2549e-11;
elseif(beta > 6.90) && (beta <= 7.00)
    pf = 0.1254e-11;
elseif(beta > 7.00) && (beta <= 7.10)
    pf = 0.6107e-12;
elseif(beta > 7.10) && (beta <= 7.20)
    pf = 0.2946e-12;
elseif(beta > 7.20) && (beta <= 7.30)
    pf = 0.1407e-12;
```

```
elseif(beta > 7.30) && (beta <= 7.40)
    pf = 0.6654e-13;
elseif(beta > 7.40) && (beta <= 7.50)
    pf = 0.3116e-13;
elseif(beta > 7.50) && (beta <= 7.70)
    pf = 0.1445e-13;
elseif(beta > 7.60) && (beta <= 7.80)
    pf = 0.6636e-14;
elseif(beta > 7.70) && (beta <= 7.80)
    pf = 0.3017e-14
elseif(beta > 7.80) && (beta <= 7.90)
    pf = 0.1359e-14;
elseif(beta > 7.90) && (beta <= 8.00)
    pf = 0.6056e-15;
elseif(beta > 8.00) && (beta <= 8.10)
    pf = 0.2673e-15;
elseif(beta > 8.10) && (beta <= 8.20)
    pf = 0.1169e-15;
elseif(beta > 8.20) && (beta <= 8.30)
    pf = 0.5058e-16;
elseif(beta > 8.30) && (beta <= 8.40)
    pf = 0.2167e-16;
elseif(beta > 8.40) && (beta <= 8.50)
    pf = 0.9197e-17;
elseif(beta > 8.50) && (beta <= 8.60)
    pf = 0.3864e-17;
elseif(beta > 8.60) && (beta <= 8.70)
    pf = 0.1608e-17;
elseif(beta > 8.70) && (beta <= 8.80)
    pf = 0.6623e-18;
elseif(beta > 8.80) && (beta <= 8.90)
    pf = 0.2701e-18;
elseif(beta > 8.90) && (beta <= 9.00)
    pf = 0.1091e-18;
elseif(beta > 9.00) && (beta <= 9.10)
    pf = 0.4363e-19;
elseif(beta > 9.10) && (beta <= 9.20)
    pf = 0.1728e-19;
elseif(beta > 9.20) && (beta <= 9.30)
    pf = 0.6773e-20;
elseif(beta > 9.30) && (beta <= 9.40)
    pf = 0.2629e-20;
elseif(beta > 9.40) && (beta <= 9.50)
    pf = 0.1011e-20;
elseif(beta > 9.50) && (beta <= 9.60)
    pf = 0.3847e-21;
```

```
elseif(beta > 9.60) && (beta <= 9.70)
    pf = 0.1450e-21;
elseif(beta > 9.70) && (beta <= 9.80)
    pf = 0.5408e-22;
elseif(beta > 9.80) && (beta <= 9.90)
    pf = 0.1998e-22;
elseif(beta > 9.90)
    pf = 0.1998e-22;
end
if(pf <= 0)
    pf = 0;
end
```