DESIGN OF LIGHTER WEIGHT CONCRETE ELECTRICITY POLES AS AN ALTERNATIVE FOR POWER DISTRIBUTION IN SUPPORT OF GHANA'S NUCLEAR POWER PLANT PROGRAMME

CATHERINE LADZE BOYETEY

DEPARTMENT OF NUCLEAR ENGINEERING

SCHOOL OF NUCLEAR AND ALLIED SCIENCES

UNIVERSITY OF GHANA

MPHIL

2021

DESIGN OF LIGHTER WEIGHT CONCRETE ELECTRICITY POLES AS AN ALTERNATIVE FOR POWER DISTRIBUTION IN SUPPORT OF GHANA'S NUCLEAR POWER PLANT PROGRAMME

A thesis submitted to the:

DEPARTMENT OF NUCLEAR ENGINEERING

SCHOOL OF NUCLEAR AND ALLIED SCIENCES

UNIVERSITY OF GHANA

By

BOYETEY CATHERINE LADZE

(10705310)

In partial fulfilment of the requirements for the degree of

MASTER OF PHILOSOPHY

In

NUCLEAR ENGINEERING

JULY 2021

DECLARATION

I hereby declare that with the exception of references to other people's work which have been duly acknowledged, this compilation is the result of my own research work and no part of it has been presented for another degree in this University or elsewhere.

…………………………………… **Date**…………………………….

CATHERINE LADZE BOYETEY

(Candidate)

I hereby declare that the preparation of this project was supervised in accordance with the guidelines of the supervision of Thesis work laid down by University of Ghana.

…………………………………………… ……………………………………...

Dr NII K. ALLOTEY **Dr E.K. BOAFO**

(PRINCIPAL SUPERVISOR) (Co-SUPERVISOR)

Date…………………… Date……………………

ABSTRACT

Electricity is an essential commodity or utility for individuals and nations alike. With the advancement of technology, access to electrical power is paramount to the economic development of a country. The World Bank ranked electricity as the second most important constraint to business activities in the country. It estimated that Ghana lost about 1.8 per cent of GDP during the 2007 power crisis. Key elements of the electricity distribution network in Ghana are the electricity poles, conductors, transformers and insulators. The primary materials used for the construction of poles are timber, concrete and steel with timber being the most common due to its relatively low cost and availability. Timber, however, is plagued by varied agents of destruction which include termite and fungal action, as well as destruction by outbreaks of fire. Concrete poles though unaffected by these destructive elements, tend to be quite heavy. This poses a unique problem for the transport and management of such poles. This study is focused on improving the design of the concrete poles such that they are lighter than the previously used concrete poles while ensuring strength and stability. A proposed model of a tapered pole with a rectangular cross-section was designed according to guidelines stated in the EUROCODES design manual and analysed in ETABS 2016. From the analysis results, the pole design was found to have successfully passed all design requirements with a weight of 450kg and 575kg for the 9 meter and 11-meter pole respectively. Though these pole designs are not as light as timber poles, they are about half the weight of previously used concrete poles. This study could enhance the electricity distribution infrastructure in Ghana. In anticipation of the introduction of nuclear power into the energy generation mix of the country, the lighter

weight reinforced concrete poles designed in this study could be utilised to increase the accessibility of electricity to the end-user.

ACKNOWLEDGEMENT

First, I will like to thank God Almighty for the grace and mercy shown me in this degree's pursuance. I thank my parents and sisters for the unending support they have given me over the years that brought me this far.

My profound gratitude goes to my supervisors, Dr Nii Kwashie Allotey and Dr Emmanuel Boafo, for their patience, guidance, and support, which made this thesis a success. I would also like to appreciate the following people for their assistance in various forms towards the completion of this study: Dr Seth K. Debrah, Dr. Emmanuel Maurice Aurthur, Dr. Ameyaw Ing. Brownson Ateko, Kojo Asare Amankrah, Kwaku Amoa Buahin, David Diop Frimpong, Ethna Adzokpa and Caleb Wiredu.

Finally, I would like to thank all my friends and loved ones. I couldn't have done it without you.

TABLE OF CONTENTS

DECLARATION i

ABSTRACT ii

ACKNOWLEDGEMENT iv

Table of Contents v

List of Figures viii

List of Tables x

1 CHAPTER ONE: INTRODUCTION 1

1.1 Background and Context 1

1.1.1 The current state of the distribution network in Ghana 3

1.2 Problem Statement 4

1.3 Research Objectives 5

1.4 Relevance and Importance of the Research 6

1.5 Outline of the Thesis 8

2 CHAPTER TWO: LITERATURE REVIEW 9

2.1 Introduction 9

2.1.1 Electrical Power Distribution 9

2.1.2 History and Evolution of Electricity Poles 9

2.2 Types of Electricity Distribution Poles 10

2.2.1 Wooden Electric Pole 11

2.2.2 Concrete poles 16

2.3 Structural Design 17

2.3.1 Limit State Design 18

2.3.2 Analysis and design 19

2.3.3 Load Considerations 21

2.3.4 Material Design 22

2.3.5 Finite Element Method 26

2.3.6 Computational Modelling Using Finite Element Method 27

3 CHAPTER THREE: METHODOLOGY 30

3.1 Introduction 30

3.2 Collection of Data and Acquisition of Design Tools and standards 31

3.3 Modelling and Simulation 32

3.3.1 Initial Pole Design Proposal 33

3.3.2 Model Creation 34

3.3.3 Boundary conditions 36

3.3.4 Load Definition and Calculation 36

3.4 Post-processing 45

4 CHAPTER FOUR: RESULTS AND DISCUSSION 46

4.1 Moment Distribution 46

4.2 Pole Structure Displacement 48

4.3 Interaction Diagram for Pole Structure 50

4.4 Design Summary 53

5 CHAPTER FIVE: CONCLUSION AND RECOMMENDATION 55

5.1 Conclusion 55

5.2 Recommendation 56

REFERENCES 57

APPENDIX A 63

APPENDIX B 80

List of Figures

Figure 1.1: Electric-Power-Generation-Transmission-and-Distribution-Network-in-Ghana (Nunoo & Attachie, 2011) 1

Figure 1.2:High tension pole with mounted transformer 4

Figure 2.1: types of trees considered for the production of timber poles 12

Figure 2.2: Deterioration of timber pole due to ant and termite infestation 14

Figure 2.3: Mix proportion relationships 22

Figure 2.4: Strength gain curve of concrete 23

Figure 2.5: Cover to reinforcement 26

Figure 2.6: Complete procedure for finite element method (Kolgiri, 2009) 27

Figure 3.1: flow chart of how the study was carried out 30

Figure 3.2: Initial pole designs proposed 33

Figure 3.3: Free body diagram for tapered pole design drawn in AutoCAD 35

Figure 3.4: Material definition for concrete and steel in ETABS 2016 35

Figure 3.5: Wind velocity at 10m height for Ghana (Badger et al., n.d.) 38

Figure 3.6: Wind forces on conductors – General case (*En 50341-1 – Overhead Electrical Lines Exceeding AC 1 KV – Part 1: General Requirements – Common Specifications*, 2012) 43

Figure 4.1: a. Moment distribution for 9meter pole with pinned support 46

Figure 4.2 a. Moment distribution for 11meter pole with pinned support 47

Figure 4.3: a. Un-guyed displacement graph, 9meter pole b. Un-guyed displacement graph, 11meter pole 48

Figure 4.4: a. Guyed displacement graph – 9meter pole b. Guyed displacement graph – 11meter pole 49

Figure 4.5: Axially loaded column with both uniaxial and biaxial loading...................... 50

Figure 4.6 Interaction diagram for combined bending and axial load 51

Figure 4.7: PMM interaction diagram for 9meter pole provided by ETABS 2016.......... 52

Figure 4.8: PMM interaction diagram for 9meter pole provided by ETABS 2016.......... 52

Figure B.1: Terrain images for Terrain types 0, III and IV 82

LIST OF TABLES

Table 2-1: Concrete strength classes for C20/25 to C35/45 (British Standards Institution, 2008) 24

Table 3-1: Initial electricity pole design dimensions 34

Table 3-2: Wind load calculation output 40

Table 3-3: Values of wind force action on tapered and circular pole as well as on conductors 44

Table 4-1: Final Pole design dimensions 53

Table 4-2: Comparison between previously used concrete poles and the lighter weight concrete pole design 54

Table 4-3: 54

Table A-0-1: Wind force action on conductors for 9meter poles at Terrain IV 64

Table A-0-2: Wind force action on conductors for 9meter poles at Terrain III 66

Table A-0-3: Wind force action on conductors for 9meter poles at Terrain 0 67

Table A-0-4: Wind force action on conductors for 11meter poles at Terrain IV 68

Table 0-5: Wind force action on conductors for 11meter poles at Terrain III 69

TableA-0-6: Wind force action on conductors for 11meter poles at Terrain 0 70

Table 0-7: Wind force action on poles for 9meter poles at Terrain IV 71

TableA-0-8: Wind force action on poles for 9meter poles at Terrain III 72

Table A-0-9: Wind force action on poles for 9meter poles at Terrain 0 73

Table A-0-10: Wind force action on poles for 11meter poles at Terrain IV 75

Table 0-11: Wind force action on poles for 11meter poles at Terrain III 76

Table A-0-12: Wind force action on poles for 11meter poles at Terrain 0 77

Table B-1: Terrain type description 81

Table B-3:Exposure classes related to environmental conditions in accordance with EN 206-1(British Standards Institution, 2008) 84

Table B-4: Minimum concrete cover(British Standards Institution, 2008) 88

1 CHAPTER ONE: INTRODUCTION

1.1 BACKGROUND AND CONTEXT

Electricity is an essential commodity or utility for individuals and nations alike. With the advancement of technology, access to electrical power is paramount to the economic development of a country. The World Bank ranked electricity as the second most important constraint to business activities in the country. It estimated that Ghana lost about 1.8 per cent of GDP during the 2007 power crisis (Mathrani et al., 2013). An added advantage of a reliable power supply system is that the comfort of individuals is ensured.

Generally, electricity goes through a three-step process before it arrives at the end-user for consumption. First, power is produced from generators. Second, the electric power is transported over the transmission network to the bulk load distribution substations. Finally, power is delivered to the individual customer sites using distribution lines.

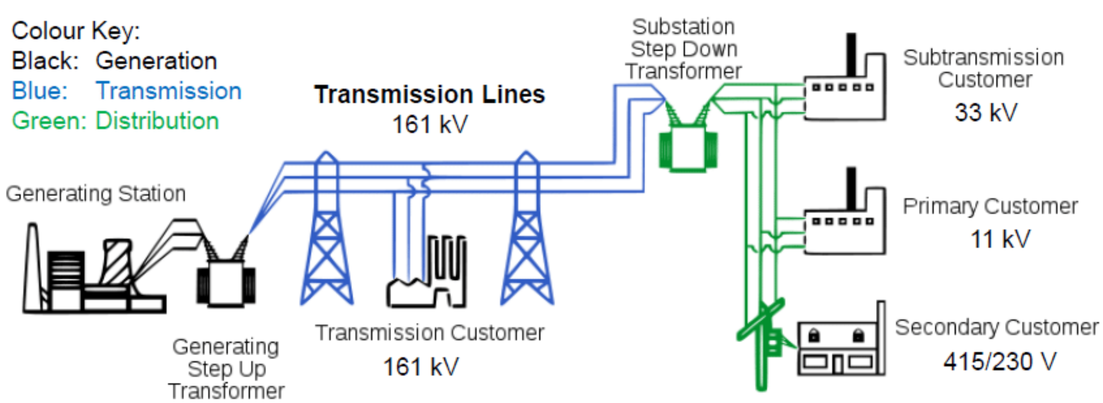


Figure 1.1: Electric-Power-Generation-Transmission-and-Distribution-Network-in-Ghana (Nunoo & Attachie, 2011)

Presently, electrical power in Ghana is generated through Hydro and thermal power plants. Over the past decade, Ghana's power sector has been plagued with power supply challenges, resulting in a considerable impact on the country's economic situation. To offset the power crisis, policies have been made to harness nuclear energy. Nuclear energy will serve as a base-load power supply to offset energy crises experienced recently in the country (Bokpe, 2019).

A system of electrical wires and cables transmit electrical power from the source of generation to consumers. These lines may be overhead as used in Ghana or sometimes laid underground, as is the case in most European countries (House et al., 2003).

There are two stages of transporting electricity:

- The transmission of electricity from the source/power plant to a substation.
- The distribution of electricity - transports power from the substation to consumers.

The transmission and distribution lines network make up what is commonly referred to as "the grid."

Ghana has an extensive transmission system that covers all the regions of the country. High-voltage transmission network connects generation sites in Akosombo, Aboadze, Takoradi, Kpong and Tema to various load centres around the country. The network features over 4,000 km of high-voltage electric transmission lines that connect to over 40 substations. Substations on the transmission system receive power at higher voltages and lower them to lesser volts to feed the distribution systems. (Kuenyehia et al., 2019)

The distribution system is a network of low-voltage distribution lines generally considered to begin at the bulk power distribution substation. GRIDCo then delivers electricity to wholesale power buyers and then to the retail consumer's meter. At key locations, voltage is lowered by transformers to meet consumer needs. The distribution network consists of electric poles, transformers, conductors and insulators. Timber, concrete as well as metal (steel) are materials used for electric poles with timber being the most common. Timber is the material of choice because of its low cost of production as well as availability.

1.1.1 The current state of the distribution network in Ghana

The distribution network in Ghana currently, predominantly makes use of timber poles with a few sightings of concrete and steel poles. The Electricity Company of Ghana (ECG) is venturing into the use of other materials apart from timber as the mainstay for the distribution poles. The Northern Electricity Distribution Company (NEDCO) has also given out a contract for the production of concrete poles. This presupposes that timber as the preferred material used for the production of distribution poles may be phasing out. The conductors of choice are120 mm^2 All Aluminium Alloy Conductors (AAAC). The distribution network is grouped into two categories, the high-tension poles and the low-tension poles.

The high-tension poles are characterised by longer and thicker poles, usually 11meter poles with three conductors attached at the pole, as shown in Figure 1.2. The longest span between high tension poles are 100 meters, and the shortest is 80 meters. There are some assemblies of high-tension poles that have a transformer mounted on the pole while others have a transformer placed close by.

Low tension poles are comparatively shorter and thinner, usually 9meter in length and have four conductors attached to it. The distance between low tension poles may span up to 50 meters.

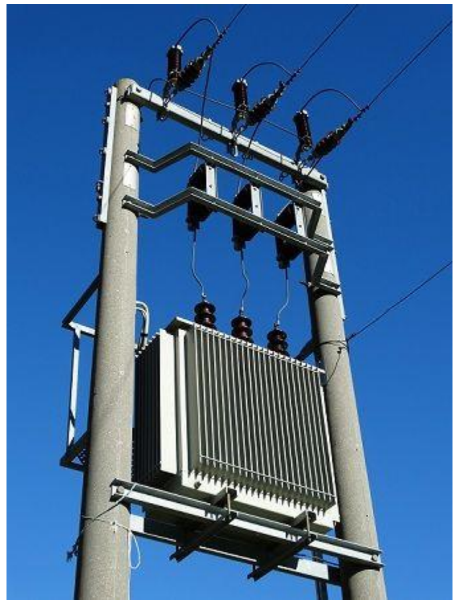


Figure 1.2:High tension pole with mounted transformer

1.2 PROBLEM STATEMENT

A study undertaken by the Governments of Ghana and the United States concluded that "inadequate and unreliable" power supply is one of three major constraints to future economic growth. The Institute of Statistical, Social and Economic Research (ISSER) at the University of Ghana estimated in a 2014 study that Ghana, on the average, lost production worth about US $2.1 million per day (2% of GDP) through the power crisis("Institute of Statistical, Social and Ecconomical Research (ISSER) Annual Report," 2015).

There are a host of challenges faced in the generation, transmission and distribution of power. This research deals with some of the challenges with the distribution network, specifically, the challenges associated with electric distribution poles. As stated early on, Ghana makes use of three materials for electric distribution poles, timber, concrete and metal, timber being the most common.

Timber is treated to prevent deterioration by natural elements. However, despite treatments, the timber still is subject to deterioration and decay at varying levels due to fungal and termite attacks. (Yang Yu, Jianchun Li, Ning Yan, Ulrike Dackermann, Bijan Samali, 2016). Another issue that has plagued the use of timber electric poles is how easily it burns. In Ghana, bush burning is a common practice for farmers at the turn of planting seasons and has quickly become the bane of timber poles. According to two news articles from 2017 and February 2019, a total of 228 high-tension poles and 48 low-tension poles have been lost to bush fires, which cost the government of Ghana over 200,000 Ghana cedis to replace (Asiedu-Addo, 2017; Saeed, 2019). Also, a pole fire can be ignited by sparks that may occur as a result of damaged or faulty wires or insulators that allow leakage of current into the wooden pole. (Lunuwilage, 2013)

Timber has been the material of choice for electric poles due to low cost of production as well as availability. However, in recent times, there has been a decline in the Ghana timber industry. Hence, there is a need to import timber to replace destroyed poles and erect new ones to achieve 100 per cent power access in Ghana (Adaam, 2014). Importing timber to be used for poles considerably increases the cost of production.

This research focuses on improving the design of concrete poles such that the inherent strength and stability of the pole is equal to or better than the timber poles while eradicating the problem of using timber.

1.3 RESEARCH OBJECTIVES

The overall objective of this study is to design a lighter weight reinforced concrete distribution pole as an alternative to existing timber electric poles in Ghana. This would result in the improvement of the electricity distribution infrastructure in Ghana. The following tasks aided in achieving this goal.

- Determine the overall wind force applied to the distribution pole.
- Model and simulate an FE model of the proposed concrete pole with the use of a mechanical tool.
- Determine the capacity of the proposed pole structure.
- Assess the stability of the proposed pole structure
- Based on the moment distribution, select the type of support system.

1.4 Relevance and Importance of the Research

Electricity is one of the essential utilities in a country and a major determinant of the economic prosperity of the country. It plays a significant role in industries such as healthcare, education, just to mention a few. On an individual level as well, the use of electrical gadgets have made the execution of daily tasks easier and hence improves the quality of life(Kumi, 2017).

As of the year 2018, Ghana could boast of an 82.3% electricity access, one of the highest in Sub-Saharan Africa (*Ghana Energy Situation - Energypedia.Info*, n.d.) with plans to make it a hundred per cent by the year 2020. To achieve this, it is required that generation, transmission and distribution of power are reliable and stable.

Generation of electricity in Ghana is achieved primarily from the hydropower plant at Akosombo as well as from thermal power plants. The overall installed capacity of all generation plants add up to 4399 MW; however, 2400 MW of electric power is produced. Changing hydrological conditions, inadequate fuel supply, as well as run-down infrastructure, have caused the plants to generate below their capacity. (Africa & Support, 2016). In view of this, there is a national policy for Ghana to include nuclear power in her energy generation mix. Nuclear power has proven to be a more reliable source and can serve as the base-load for electric power generation. With the likely introduction of nuclear power, the reliability and stability desired on the generation leg of power production will be largely dealt with.

However, from the perspective of the end-user, until electricity is accessible, solving the problems associated with generation does not solve their problem. This brings to light the issues associated with the transmission and distribution of power.

Electricity distribution poles are predominantly constructed with timber and a few others with concrete. As mentioned earlier, timber is susceptible to burning and decay while the concrete poles are so old most have deteriorated beyond repair.

If Ghana is to achieve 100 per cent electricity access, and for the end user to enjoy the full benefits of a stable and reliable power generation, investigations should be conducted into the use of other materials for electricity pole construction thereby making this study relevant.

The outcome of the research will be the development of a more stable alternative to the timber poles, made of lighter weight concrete. This will be designed to have a longer life span and strength as well as eradicate the problem of decay and burning associated with timber and hence generally improve the electricity distribution infrastructure in Ghana.

The key contribution of this study is the design of normal weight concrete to produce relatively light electricity poles in Ghana. Over the years, there have been numerous research studies as well as experimental work conducted in the use of alternative materials for the construction of electricity poles. In this study, the choice of material investigated was informed by the ease of production of normal weight concrete in Ghana without the need for specialised skills. Also, materials for reinforced normal weight concrete are locally available and comparatively cheaper than other materials.

1.5 Outline of the Thesis

The thesis is divided into five chapters and is organised as per the detail given below:

Chapter 1: Presents a brief introduction to the topic of study.

Chapter 2: Presents a review of literature on topics relevant to this study.

Chapter 3: Presents the method employed to achieve the objective of this study.

Chapter 4: Presents a discussion on the results obtained.

Chapter 5: Presents conclusions of the study and recommendations for future studies.

2 CHAPTER TWO: LITERATURE REVIEW

2.1 INTRODUCTION

This chapter presents a brief overview of the current distribution network in Ghana. It outlines the types of electricity poles and focuses on the design of concrete poles.

2.1.1 Electrical Power Distribution

Electric power distribution is the delivery of electricity from high-voltage transmission circuits to the end-user. Primary distribution lines are “medium-voltage” circuits, normally thought of as 600 V to 35 kV. At a distribution substation, a transformer takes the incoming transmission-level voltage (35 to 230 kV) and steps it down to several distribution primary circuits, which fan out from the substation. Close to each end user, a distribution transformer takes the primary-distribution voltage and steps it down to a low-voltage secondary circuit (commonly 120/240 V; other utilisation voltages are used as well). From the distribution transformer, the secondary distribution circuits connect to the end user where the connection is made at the service entrance.

The distribution network can be underground or mounted on poles. Over the years due to technological advancement, different material such as steel, timber, concrete and fibreglass have been investigated and used for poles.

2.1.2 History and Evolution of Electricity Poles

The first of utility poles were erected in the 19th century to carry telegraph wires. In 1843, Samuel Morse wanted to connect Baltimore, Maryland and Washington DC with a telegraph line. He had perfected the telegraph, a technology in which the government showed interest and awarded him the contract to construct the telegraph line. He initially buried the line underground but found so many problems with the line and was forced to dig it up. With time running out and funds running low, he with his team came up with a plan to hang the line on posts, to be exact, chestnut posts 20 to 30 feet in height. This plan worked successfully and in I844, the first telegraph was transmitted. Though the wooden poles were used because of time and financial constraints, however, they quickly caught on because it was cheaper and chestnut was abundant. By the turn of the 20th century, the chestnut poles carried telegraph, telephone and electrical lines. The poles were outfitted with insulators so they could safely carry electrical lines.

Overtime, the use of chestnut wood phased out and other species of wood were introduced. (Mulqueen, 2017; *Utility Poles - Aged Woods, Inc.*, 2017)

Due to technological advancements, materials such as steel fibreglass and concrete have been introduced to be used as electrical/utility poles. Timber poles however continue to dominate mainly because of the low cost of production.(Adaam, 2014)

2.2 Types of Electricity Distribution Poles

There are various types of poles being used today. The type of pole is selected based on a combination of factors, the most common of which are the:

- mechanical strength
- weight – preferably, the pole should be lighter weight without having an impact on its mechanical strength
- Cost impact of such construction, including the maintenance cost

In the world today, there are different types of materials being used for the construction of poles. The most common materials in use are:

1. Wooden Electric Pole
2. Concrete Electric Pole
3. Steel Tubular Electric Pole

Recently, studies are being conducted on the use of composite materials as well as other materials such as fibre glass for electricity distribution poles but this research will concentrate on normal weight concrete as the material of choice.

2.2.1 Wooden Electric Pole

As stated earlier, wood was the material to be used for the first poles. In the beginning, these wooden poles were used for 400- and 200-volts low tension lines, 11 kilovolt high tension lines and on occasion 33 kilovolt lines.

Wood selected for use as electric poles should meet the necessary strength requirements. With these requirements of utility poles in mind, trees selected for use should possess the following.

The main trunk of the tree should be:

- 30 to 60 feet high and be string-line straight (Figure 2.1), however in some cases, it may be impossible to get straight wood for such lengths hence a small degree of curvature is acceptable. Alternatively, two short length poles can be joint together to achieve the length requirements.
- free of major stem defects (cankers, cat-faces, rot)
- have minimal taper
- be largely free of branch knots
- have a small juvenile core

- Meet specific height and diameter requirements.

Figure 2.1: types of trees considered for the production of timber poles

Based on the above stated requirements, there are some species of wood that are deemed acceptable for use as distribution poles. Initially, species such as chestnut and cedar were used because they are naturally resistant to rot and decay. However, with the decline of cedar and the fungal problems associated with chestnut, other species of wood have been introduced. Some common ones include:

- Southern Yellow Pine
- Douglas Fir
- Western Larch
- Lodgepole pine
- Western Red Cedar
- Ponderosa Pine
- Jack Pine

2.2.1.1 Causes of Deterioration

Wood poles are continually exposed to biotic and abiotic factors. (Gezer et al., 2015) Examples of abiotic factors are weathering and burning. Weathering is the erosion of wood surface due to the combined action of wind, rain, changing temperatures and exposure to sunlight.(Graham, 1960; Shupe et al., 2008) This causes roughening of the surface, checking, splitting and wood cell erosion. In some areas where bush fires are rampant, there are issues of wood poles being burnt. The biotic factors include attack by plants, insects, and animals that utilise wood both for food and for shelter, some of which are:

- Decay fungi: Decay utilise starches, cellulose, and lignin of complex plants, in this case the cell walls in wood to produce food causing changes in appearance, that is colour and luster, as well as compromising the strength.(Graham, 1960)
- Termites: Termites feed on cellulose which is abundant in wood material. (Graham, 1960)
- Carpenter Ants: Carpenter ants bore holes in wood material to be used as places for shelter and nesting purposes, (Shupe et al., 2008)
- Beetles: They feed on the wood when they hatch, creating tunnels in the process. Once the larvae have developed into adults, they emerge from the wood leaving behind holes in the wood surface.(Shupe et al., 2008; *Wood Boring Insects and Beetles | Western Exterminator*, n.d.)

Figure 2.2: Deterioration of timber pole due to ant and termite infestation

Deterioration can however be retarded by treating the wood with preservatives, hence increasing the life expectancy of the wood pole. Initially 15 to 20 years of service was expected, today wood poles have been seen to last up to 50 years. (Graham, 1960)

2.2.1.2 Wood Preservation

Wood preservation is the injection of chemicals into wood through the process of pressure or thermal impregnation to provide effective long-term resistance to attack by fungi, bacteria, insects, and marine borers. (Neulicht & Shular, 1999)

A few trees like cedar, chestnut and redwood have a heartwood with naturally occurring chemicals that make them resistant to rot and decay and organisms that destroy the wood, but other species of wood have to be injected with chemicals to achieve that resilience to rot and decay. These chemicals also serve to protect against weathering and fire damage. (Graham, 1960)

Preservatives are mainly classified into two groups, the tar oil/ oil-soluble preservatives and the water-soluble preservatives. (Shupe et al., 2008) There are others such as organic solvent-borne preservatives and emulsions/micro-emulsions (Mai & Militz, 2007), however the above mentioned are the widely used.

Oil-soluble preservatives such as creosote and pentachlorophenol are the most common for the treatment of wood for poles. An additional benefit is that these preservatives provide protection against weathering and hence dimensional stability by reducing water absorption. (Graham, 1960)

2.2.1.3 Durability of Wooden Poles

According to Gezer et al.,(2015), on their research work on inspection of wooden poles in Artvin, Turkey, they found that, the reasons for the short service life of utility poles were

1. the decay due to fungi,
2. insect infestation,
3. inadequate impregnation,
4. insufficient preservative penetration depth,
5. the deep cracks and splits,
6. poor quality control,
7. no inspection and lack of remedial treatments.

The above led them to conclude on the importance of increasing the service life of wood poles because of:

1. the costs associated with their replacement
2. environmental concerns, out of service poles are considered hazardous wastes which must be adequately disposed of or recycled.

Taking a cue from this research, instead of looking at prolonging the service life of the wood pole, this research thesis, explores the idea of using an alternative material, specifically normal weight concrete to achieve the same goal.

2.2.2 Concrete poles

Concrete is a composite material that is comprised of water, fine and coarse aggregates and cementitious material. Chemical additives may be added to achieve desired properties of the concrete mix for a specific use.

Concrete has been found to have high compressive strength however has a low tensile strength equivalent to about 10% of its compressive strength and hence considered a quasi-brittle material. To rectify this problem, concrete structures are designed with steel bars which serve as a reinforcement of tensile strength and protection against a brittle failure.(Słowik, 2019)

Concrete is one of the most widely used materials in the construction industry across the world due to the economy of its use, durability as well as the ease of manufacturing. Concrete having the ability to be cast into any desired form or shape is also an added advantage of concrete as a construction material. (Durocrete Engineering Services Pvt. Ltd, 2000).

Concrete poles have been in use since the early 1900s, but gained popularity when the use of creosote (the most common wood preservative) proved to have negative effects on the environment(“A Wide Creosote Ban Is Proposed by E.P.A.,” 1984; Angeling, 2017). Studies have shown that concrete poles are durable, require low maintenance and have a life span of more than 80 years (Angeling, 2017). The initial cost of erecting concrete poles are higher than wooden pole, however the long term cost effect is lower due to lower maintenance cost.

Normal concrete is a relatively heavy material weighing between 2240 to 2450 kg/m^3. This increases the cost of transportation and hence the overall cost of production of concrete poles. During the twentieth century, numerous experiments have been conducted to reduce the weight of concrete whilst retaining the other properties. The result of these experiments was lightweight concrete with a density of 300–2000 kg/m3, with a practical range of 500–1850 kg/m3 (Guo, 2014; Hedjazi, 2016). It has been found that the use of lightweight concrete reduces the overall weight of the structure by 20 to 40%.(Guo, 2014).

2.3 Structural Design

According to Mrema, 2011, "Structural design is the methodical investigation of the stability, strength and rigidity of structures." The objective in structural analysis and design is to produce a structure, in this case the electricity pole, which can resist applied loads without failure during its intended life. The principal purpose of a structure is to transmit or support loads. If actual loads applied exceed the design specifications, the structure will probably fail to perform its intended function, with possible serious consequences.

Electricity distribution poles are designed to withstand loads generated from weather-related events, construction and maintenance events and must provide failure containment to minimise damage from catastrophic events. The characteristic design loads depend on the structure location, that is, the geography, topography and elevation of the location.(Dagher, 2006)

2.3.1 Limit State Design

Designing an engineering structure should ensure that:

- under the worst loadings the structure will be safe
- during normal working conditions, deformation of the members do not diminish the appearance, durability or performance of the structure.

Three basic methods using factors of safety are used to achieve safe, workable structures have been developed;

- The permissible stress method: ultimate strengths of the materials are divided by a factor of safety to provide design stresses usually within the elastic range.
- The load factor method: working loads are multiplied by a factor of safety.
- The limit state method: working loads are multiplied by partial factors of safety. Also the materials' ultimate strengths are divided partial factors of safety.

Though the permissible stress method has proved to be a simple and useful method, it does have some serious inconsistencies. It is based on an elastic stress distribution hence cannot be applied to semi-plastic materials like concrete. Neither is it suited to non-proportional load deformations as in slender columns.(Mosley et al., 2012)

Ultimate strength of the materials are used in the load factor method calculations. The method does not apply factors of safety to material stresses, and does not take into account the variability of the materials. Also, it cannot be used for deflections calculations or cracking at working loads.

The limit state method of design overcomes the disadvantages of the previous methods by the application of partial factors of safety, both to the loads and to the material strengths.

The magnitude of the factors is varied so they may be used either with the plastic conditions in the ultimate state or with the more elastic stress range at working loads.

The two types of limit state are the ultimate limit state and the serviceability limit state.

1. **Ultimate Limit State (ULS):** This limit state is concerned with the safety of the people and of the structure. This requires that the whole structure or its elements should not collapse, overturn or buckle when subjected to the design loads.
2. **Serviceability Limit State (SLS)**: This limit state is concerned with:
   - Comfort of the occupants
   - Appearance of the structure. The structure should not become unfit for use due to excessive deflection or cracking.

The normal practice is to design for the ultimate limit state for reinforced concrete structures is to check for serviceability and take all necessary precautions to ensure durability.(Bhatt et al., 2017; Mosley et al., 2012)

2.3.2 Analysis and design

The complete analysis of a load-carrying structural member by the method of equilibrium involves consideration of three conditions relating to specific laws of forces. The laws of material deformation, and geometric compatibility. These basic principles of analysis are as follows:

1. Equilibrium Conditions: Equations of the equilibrium of forces must be satisfied throughout the structural member.
2. Material Behavior: The stress–strain otherwise force-deformation relations (for example, Hooke's law) must apply.

3. Geometry of Deformation: Compatibility conditions of deformations must be satisfied, that is, the deformed portion of each member must fit together

An alternative to the equilibrium methods is the use of energy methods. The aspect of both the equilibrium and the energy approaches is twofold. These methods can provide solutions of acceptable accuracy

The process by which science and engineering techniques are applied to a structure or system to allow its realization is engineering design. The objective of a structural design includes finding suitable materials, dimensions, and shapes of the members of a structure in order to support prescribed loads without failure.

A good design satisfies the following requirements;

- Performance
- Cost
- safety requirements.

For a design problem with numerous choices, the designer may make decisions on the basis of experience. Design decisions, like the choice of the values of safety factors and material properties, are significant in the preliminary design process.

The following is the design procedure for a structural member:

1. Evaluate the most likely modes of failure of the member.
2. Determine the expressions relating applied loading, eg. to stress, strain.
3. Determine the maximum usable value of stress, strain, or energy

4. Select a design factor of safety. This is to account for uncertainties in a number of aspects of the design.

The factor of safety is expressed as:

$$n = \frac{\text{maximum usable stress}}{\text{allowable stress}}$$

The factor of safety should be greater than 1.0 for failure to be circumvented. The value 1.5 or greater is usually selected as a factor of safety, based on the experience and judgment of the designer.(Ugural & Fenster, 2016)

2.3.3 Load Considerations

In structural design, forces and moments applied to a structure is termed loads. These may be applied externally (surface loads), or within the structure (body loads). Loads are described as either static or dynamic. Static loads are of constant magnitude, direction, and location, independent of time. Dynamic loads however change with time, some examples are:

- Live loads'' from occupant activity,
- wind loads,
- seismic (earthquake)

Dynamic loads are grouped into two categories:(Jenkins & Khanna, 2005)

1. Steady-state loads - loads that maintain the same character (frequency, amplitude, etc.)

over the long term.

2. Transient loads are loads that change their character (e.g., they may decay) with time.

2.3.4 Material Design

There are numerous properties of concrete such as durability, porosity among others which are considered very important. However, the strength of the concrete is usually considered to be the most valuable property. The strength of concrete is directly related to the structure of the cement paste (water: cement ratio) and hence gives an overall image of the concrete quality.(Neville & Brooks, 2010)

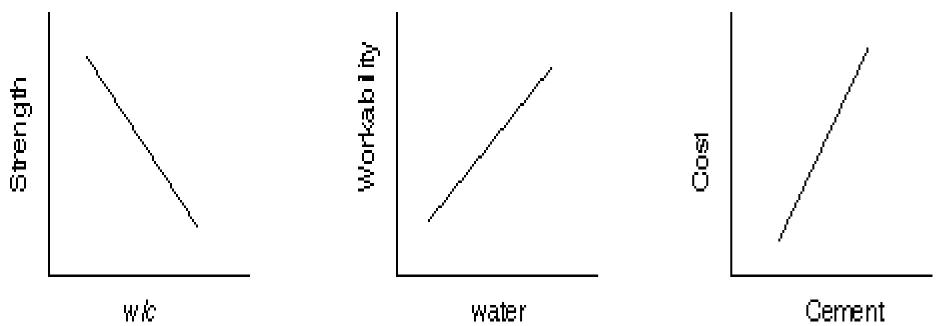


Figure 2.3: Mix proportion relationships

The strength of concrete may be defined as the compressive strength of hardened concrete at an age of 28 days. As can be seen in Figure 2.3 beyond 28 days there are very small increments in the strength and does not change much from what is recorded on day 28.

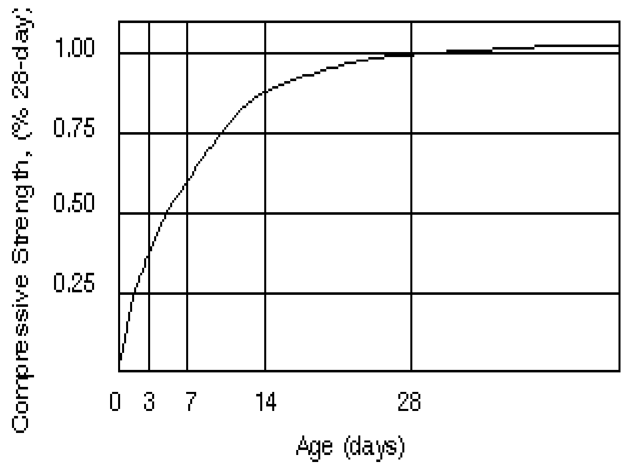


Figure 2.4: Strength gain curve of concrete

The compressive strength of concrete is categorised into different strength classes, which are based on the characteristic (5%) cylinder strength or the characteristic cube strength. The highest recommended value for the compressive strength of concrete is C90/105. From Figure 2.4, it can be seen that as compressive strength increases, the water cement ratio (*wcr*) decreases hence affecting other properties of concrete. (Angeling, 2017)

Strength and strain properties for strength concrete classes C20/25 – C35/45 (normal strength concrete), according to EN 1992 (British Standards Institution, 2008), can be found in Table 2-1

Table 2-1: Concrete strength classes for C20/25 to C35/45 (British Standards Institution, 2008)

Stregnth Class/ Property	$f_{ck,}$ MPa	$f_{ck,cube}$MPa	f_{cm} Mpa	f_{ctm} Mpa	$f_{ctk,0.05}$ Mpa	$f_{ctk,0.95}$ Mpa	E_{cm} GPa
C20/25	20	25	28	2.2	1.5	2.9	30
C25/30	25	30	33	2.6	1.8	3.3	31
C30/37	30	37	38	2.9	2.0	3.8	33
C35/45	35	45	43	3.2	2.2	4.2	34

f_{ck}: the cylindrical compression strength

$f_{ck.cube}$: cubical compression strength. Other values given in the table are the

f_{cm}: mean value for cylindrical compression strength,

$f_{ctk0.05}$: the lower characteristic tensile strength

$f_{ctk0.95}$: an upper characteristic tensile strength

f_{tm}: the mean tensile strength

f_{cm}: at maximum stress;

E_{cm}: mean value for the modulus of elasticity

Concrete as a material has a significantly low tensile strength. Reinforced cement concrete (RCC), a composite material was introduced to overcome the low tensile strength of concrete. The reinforcement which are steel bars transfer tensile forces after cracking in the tensile areas. (Angeling, 2017)

Reinforcement or steel bars are categorised as high yield bars and mild steel bars. Both types of bars are ribbed to enhance the bond between the bar and the concrete.

Reinforcement bars are susceptible to corrosion when exposed to the atmosphere. To cater for this, a distance between the surface of the reinforcement bar (including links and stirrups and surface reinforcement where relevant) and the surface the concrete is provided. This is called concrete cover or cover to reinforcement.(British Standards Institution, 2008)

The cover provided is defined in EUROCODE 2 as a minimum cover, c_{min} plus an allowance in design for deviation, Δc_{dev}.

$$c_{nom} = c_{min} + \Delta c_{dev}$$

The minimum cover specified is dependent on the exposure conditions and environmental factors. EUROCODE 2 defines different exposure conditions and the minimum cover to be provided. See Tables B-2 and B-3 in Appendix B

Besides corrosion protection, minimum concrete cover is provided in order to ensure:

- the safe transmission of bond forces

- an adequate fire resistance (British Standards Institution, 2008)

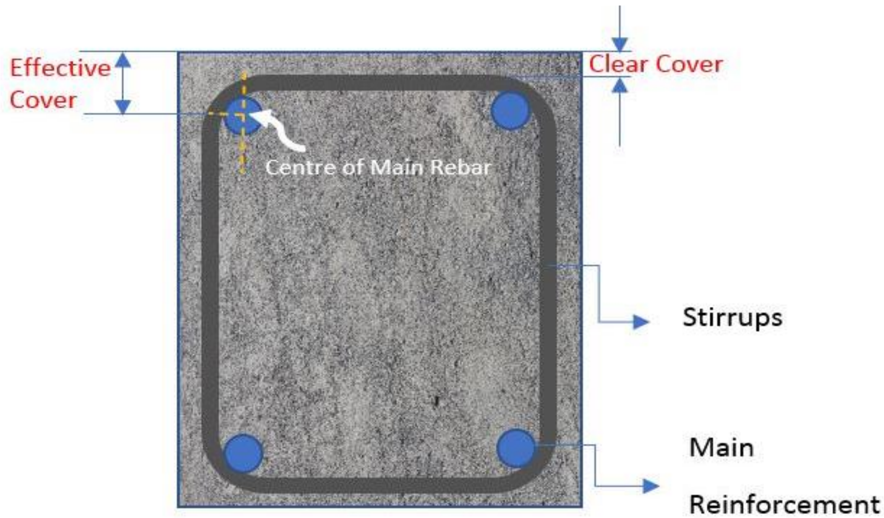


Figure 2.5: Cover to reinforcement

2.3.5 Finite Element Method

Engineering problems are generally physical representations of mathematical models. These mathematical models are sets of differential equations derived from applying fundamental laws of nature to a system(Moaveni, 1999). There are numerous methods for solving these mathematical models of which the finite element method is one.

Finite Element Method (FEM) is a computational technique used to obtain approximate solutions of boundary value problems in engineering (Hutton, 2004). Simply, it is a method used to solve a complicated problem by replacing it with a simple problem. (Rao, 2011). The method is based on dividing the problem domain into several small elements known as domain discretisation, which are analysed by applying known physical laws to each of them.(Amankrah, 2015; Liu & Quek, 2013)

The behaviour of each sub-domain, shaped by nodes and elements, is approached by using piecewise linear functions to represent the continuous function of an unknown field variable. The unknown represents discrete values of the field variable at the nodes.

Appropriate principles are then used to develop equations for the elements which are then combined in a system of linear algebraic simultaneous equations which represent the system. These equations are solved to return the necessary field variable (Liu & Quek, 2013). Figure 2-6 below shows the finite element process.

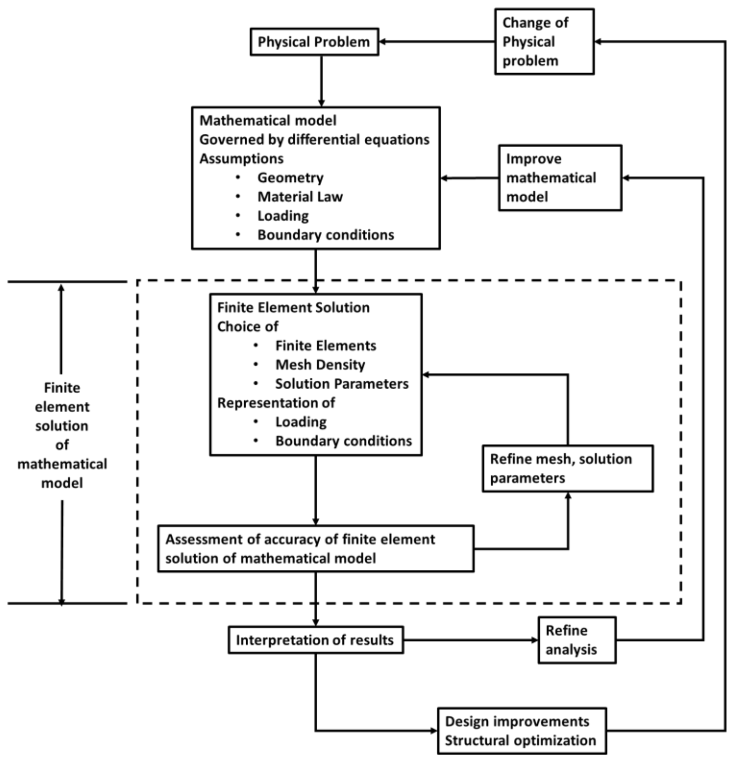


Figure 2.6: Complete procedure for finite element method (Kolgiri, 2009)

2.3.6 Computational Modelling Using Finite Element Method

The behaviour of a physical phenomenon in a system depends upon the geometry of the system, the material properties and the initial and boundary conditions.

The procedure of computational modelling using FEM broadly consists of four steps:

• Modelling of the geometry

• Meshing (discretisation)

• Specification of material property

• Specification of boundary and loading conditions

2.3.6.1 Modelling of the geometry

There are numerous ways to model a geometry in in an analysis software or a simulator. Many simulators are coded with the option of modelling the geometry in the software. Otherwise, provision is made to import the geometry file from Computer Aided Design software like AutoCAD and SOLIDWORKS.

2.3.6.2 Meshing

The process of discretising the geometry into small units called elements is referred to as meshing.

Scientific theories are needed to discretise the geometry. The theories differ for every problem and provide the equations that govern the analysis to be run by the simulator.

Mesh generation is an important task in pre-processing and can be tricky to produce a credible mesh especially for complex problems. The geometry and the displacement distribution of a real structure varies continuously. When using finite element to model the structure, the discretised structure cannot be fully matched with real model which causes errors. These errors can be reduced using smaller element or what is referred to a finer mesh (Neupane, 2014). For a mesh to be considered credible, the domain should be properly divided into elements of specific shapes. Triangles and quadrilaterals are used in 2D geometries while tetrahedrons and hexahedrons in 3D geometries. (Liu & Quek, 2013)

2.3.6.3 Material properties

Engineering systems usually consist of multiple components. Each of these components may be of the same material or different materials. In some situations, there may be multiple materials within a single component as is the case of a composite material. Properties of materials can be defined for a group of elements or individual elements if required. The FEM can therefore work conveniently for systems with multiple materials, which is a significant advantage. For different phenomena or physics to be simulated, different sets of material properties are required, for instance, Young's modulus and shear modulus are material properties that need to be specified for the stress analysis of solids and structures. (Liu & Quek, 2013)

2.3.6.4 Boundary, initial, and loading conditions

Boundary, initial, and loading conditions play a decisive role in the simulation. Conditions can be specified either to the geometrical identities (points, lines or curves, surfaces, and solids) or to the mesh identities (nodes, elements, element edges, element surfaces). The boundary, initial, and loading conditions differ for each problem (Liu & Quek, 2013).

3 CHAPTER THREE: METHODOLOGY

3.1 INTRODUCTION

The method applied in the design and analysis of the distribution pole is presented in Figure 3.1.

A description of the various components of the methodology is provided in sections of this chapter.

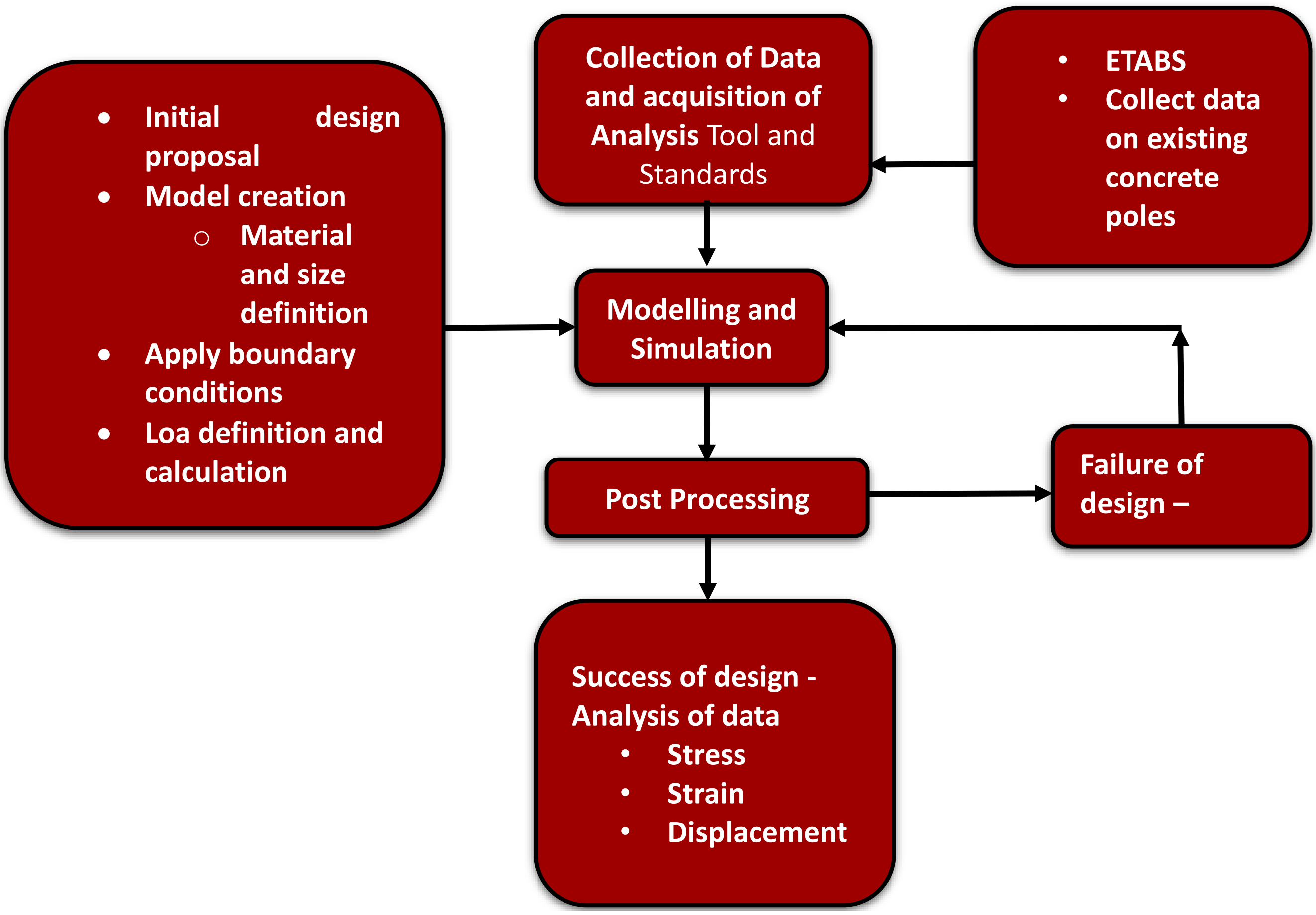


Figure 3.1: flow chart of how the study was carried out

3.2 Collection of Data and Acquisition of Design Tools and standards

Relevant data were collected from some institutions throughout the course of the study.

Electricity Company of Ghana (E.C.G.)

The Electricity Company of Ghana provided information on the design specifications they use for the existing timber poles. E.C.G. also provided information on the costs and problems associated with the use of timber poles. Data provided include structural design report of steel concrete and timber poles, which captured input parameters such as cross-sectional dimensions and material specifications.

African Concrete Products (A.C.P.), CK Engineering and Construction Limited

Design reports of the concrete poles previously used in Ghana were obtained from A.C.P. CK Engineering and Construction Limited also provided reports on prestressed spun concrete poles. The information provided included material specification as well as pole dimensions.

Bye Ways Company Limited

An interview was conducted with the production manager of the company. The production process involved in the production of timber poles, from the procurement of the wood, through the preparation and preservation of the pole

Acquisition of design tools and standards

ETABS 2016 from CSI was obtained and utilised for modelling and simulation of the pole structure. EUROCODE design manuals were also used as a guide for the pole design.

- EN 50341-1 : Overhead electrical lines exceeding AC 1 kV - Part 1: General requirements - Common specifications (*En 50341-1 - Overhead Electrical Lines Exceeding AC 1 KV - Part 1: General Requirements - Common Specifications*, 2012)
- BS EN1991-1-4: Actions on structures — Part 1-4: General actions — Wind actions (BSI, 2010)
- BS EN 019921-1: Design of concrete structures —Part 1-1: General rules and rules for buildings(British Standards Institution, 2008)
- BS EN 13369:2004 : Common rules for precast concrete products (British Standards Institution, 2007)
- BS EN 12843:2004 : Precast concrete products – Masts and Poles (British Standards Institution, 2004)

3.3 MODELLING AND SIMULATION

This portion of the work was completed using ETABS 2016 from CSI. To accomplish the design in ETABS, the following steps were required:

- Initial design proposal
    - Model creation
- Material and size definition
- Apply boundary conditions
- Load definition and calculation
- Solve the problem

The pole structure in this study was designed assuming the worst-case scenario. Hence a pole located at either the beginning or the end of a line network was considered.

3.3.1 Initial Pole Design Proposal

The proposed designs for the pole structure, as shown in Figure 3.2 were:

- a tapered structure with a rectangular cross-section
- a cylindrical pole

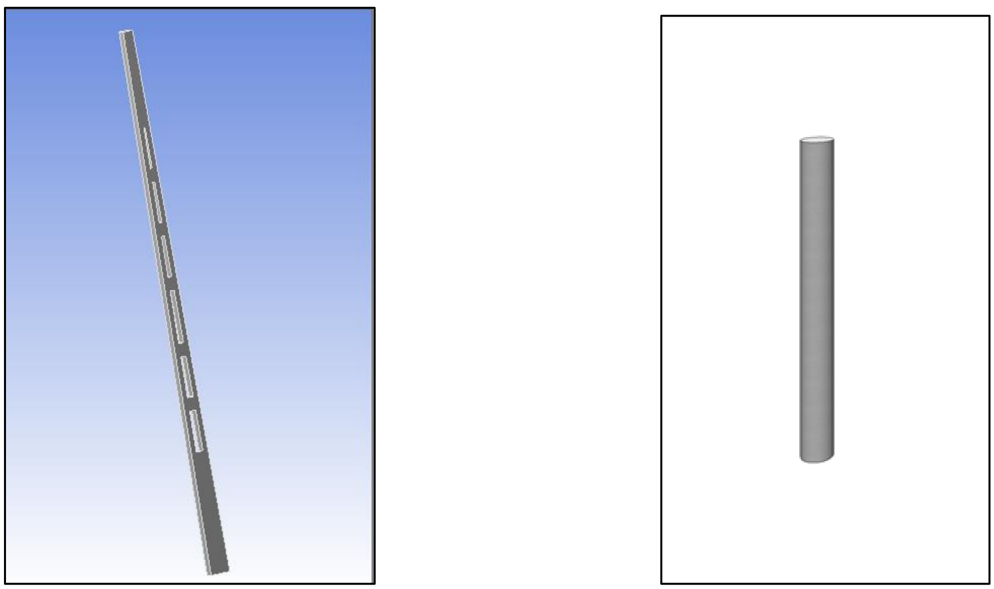


Figure 3.2: Initial pole designs proposed

These designs were proposed based on some considerations. The first consideration was the objective of this study, to design a light concrete pole with normal weight concrete. The size of the pole was reduced as much as possible to achieve a relatively light structure as compared to the previous concrete poles that were being used in Ghana.

The second consideration was the minimum cover to reinforcement that should be provided, as stated by BS EN1992-1-1 and BS EN12843.

Based on the considerations stated above, the dimensions for the initial pole designs proposed were:

Table 3-1: Initial electricity pole design dimensions

	Tapered Pole		Circular Pole	
	9m	11m	9m	11m
Top	150x 150	150 x 150	150	150
Butt	250 x 150	250 x 150	150	150

NB: All dimensions are in millimetres (mm) unless otherwise specified

The weight of the circular pole structure was found to be relatively high (almost the same as the weight of previous concrete poles); hence, only the tapered poles were considered for this study.

3.3.2 Model Creation

A free body diagram (Figure 3.3) for each structure was drawn in AutoCAD and then imported into ETABS 2016 after which the structural and material properties were assigned to the model.

The material used for the pole structure was concrete of strength class C25/30 as specified BS EN 13369 and for the reinforcement bars, high yield steel (f_y = 500). The properties of this material is specified in the software (Figure 3.4) and are be applied as needed during the analysis.

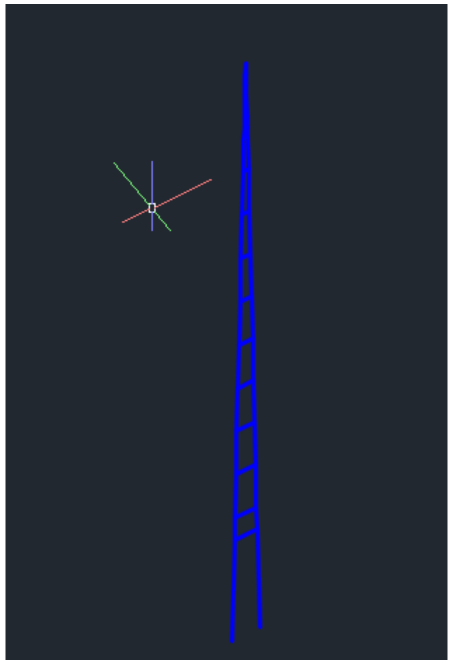


Figure 3.3: Free body diagram for tapered pole design drawn in AutoCAD

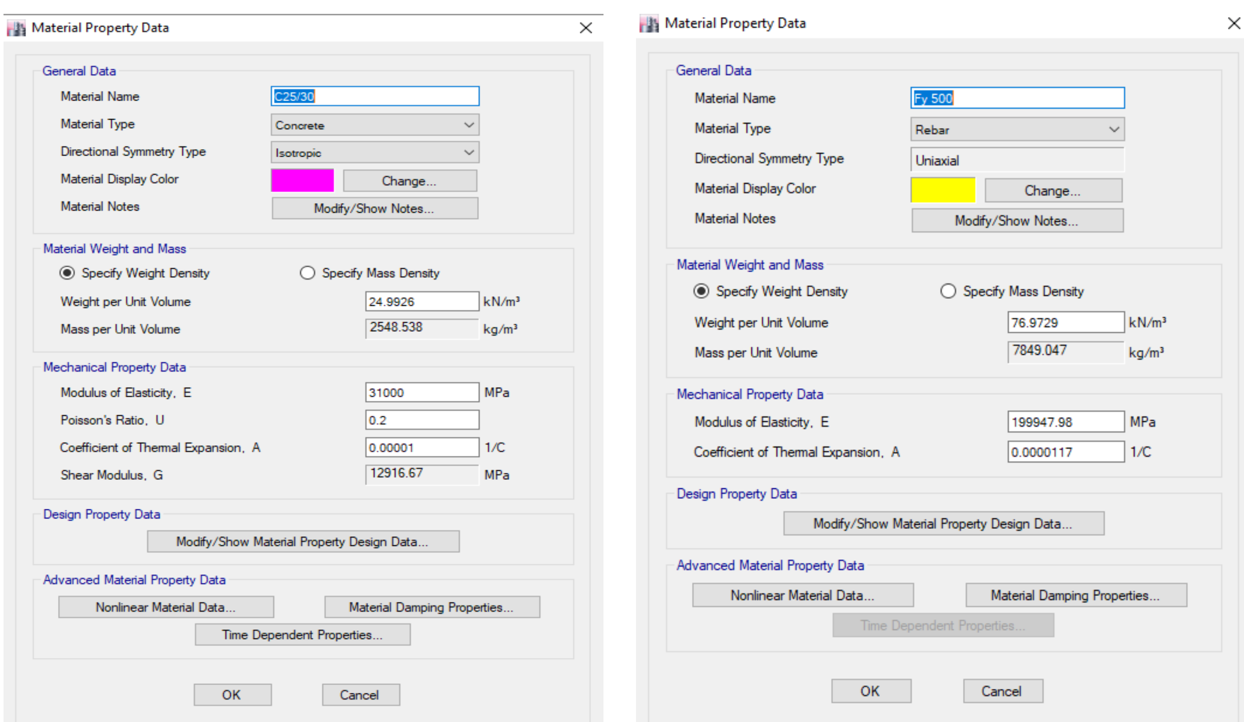


Figure 3.4: Material definition for concrete and steel in ETABS 2016

3.3.3 Boundary conditions

The next step was to apply the boundary conditions, that is, determine the type of supports for the pole structure. Two support scenarios were considered:

- A fixed support
- A pinned support

Pinned supports are able to resist both horizontal and vertical forces but allow rotation. Fixed supports however is rigid and can resist moments as well as vertical and horizontal forces.

3.3.4 Load Definition and Calculation

The final step before simulation was the application of loads cases, as described below, onto the model. With the exception of the self-weight of the pole and maintenance loads, all other loads were applied as lateral point loads at the top pole. The imposed loads were applied to the face of the structure and the wind loads to the side of it. The self-weight of the pole and maintenance loads were applied as axial loads.

The pole is subjected to two types of loading:

- Direct loading which comprises of
    - Dead Loads
    - Maintenance loads, taken to be 0.75 kN/m^2
    - Wind loads
- Imposed Loads - loads generated from the conductors and fixtures attached to the pole.

The dead loads, otherwise called the self-weight of the structure can be calculated by multiplying the volume of the structure and the unit weight of the material used to construct the structure. For this design, however, the self-weight of the pole structure was calculated in the software using the dimensions assigned to the structure and the property of the material assigned.

3.3.4.1 Wind loads

The wind loads were calculated using the guidelines provided by BS EN1991-1-4

Wind Velocity Pressure

Wind actions fluctuate and act directly as pressures on the external surfaces of enclosed structures. Pressures act on areas of the surface of the structure resulting in forces normal to the surface of the structure or of individual cladding components.(BSI, 2010)

The wind loads are calculated based on EUROCODE 1991 – 1- 4 – Actions on Structures. The first step to calculating the wind loads is to obtain the wind velocities. This information was obtained from the Global Wind Atlas based on the previous regional demarcations in Ghana, that is, the ten regions in Ghana. The wind velocities obtained were at an altitude of 10 m as shown in Figure 3.5.

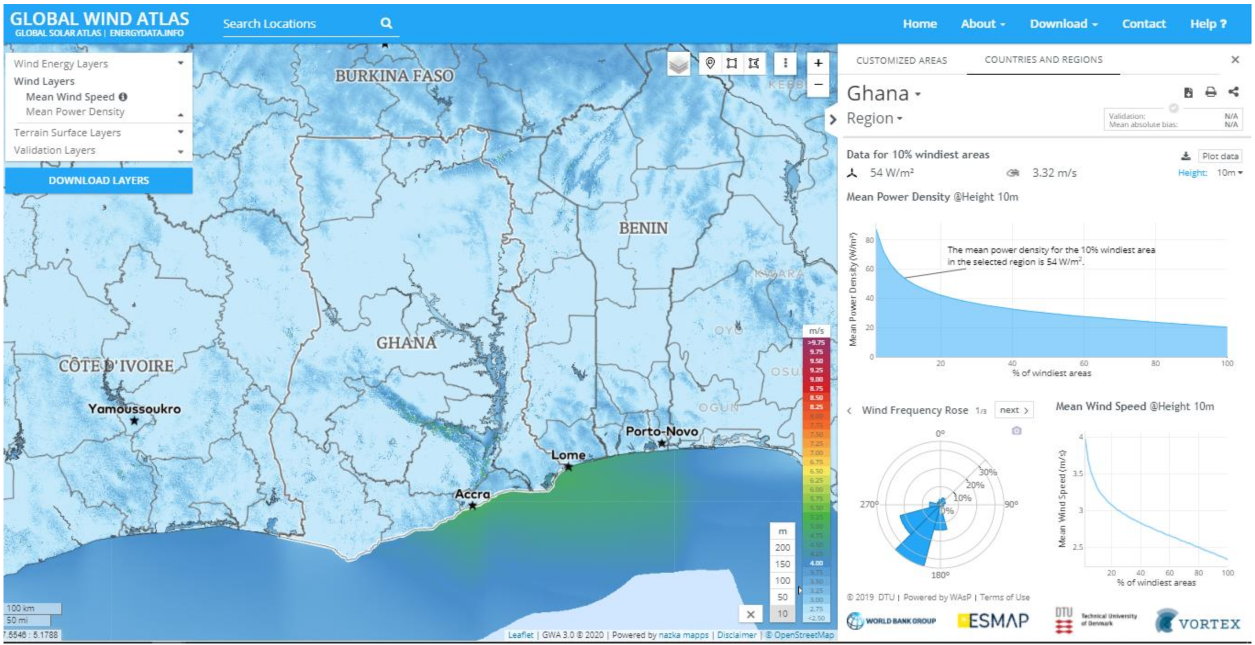


Figure 3.5: Wind velocity at 10m height for Ghana (Badger et al., n.d.)

The wind velocities obtained were corrected using correctional factors as provided by BS EN1991 – 1- 4 – Actions on Structures. The correctional factors are applied using the equations below.

$$v_b = c_{dir} * c_{season} * v_{b,0} \qquad 3.1$$

where:

v_b = basic wind velocity

$v_{b,0}$ = value of the basic wind velocity

c_{dir} = directional factor, taken to be 1.0

c_{season} = season factor, taken to be 1.0

$$v_m(z) = c_r(z) * c_o(z) * v_b \qquad 3.2$$

$v_m(z)$ = mean wind velocity at height z

$c_o(z)$ = orography factor, taken as 1.0

$c_r(z)$ = roughness factor

The Roughness factor $c_r(z)$ is determined by the terrain of the location of the structure. EN BS1991 – 1- 4 – Actions on Structures provides terrain categories and parameters to be used for the wind load calculations. Three terrain categories were used for this study, terrain categories 0, III and IV. See Appendix B for the table and images.

$c_r(z)$ is given by:

$$c_r(z) = k_r * \ln\left(\frac{z}{z_0}\right) \text{ for } z_{min} \leq z \leq z_{max} \qquad 3.3$$

$$c_r(z) = c_r(z_{min}) \text{ for } z \leq z_{min} \qquad 3.4$$

where:

z_0 = roughness length

k_r = terrain factor depending on the roughness length z_0 calculated using:

$$k_r = 0.19 * \left(\frac{z_0}{z_{0,II}}\right)^{0.07} \qquad 3.5$$

where:

$z_{0,II}$ = 0.05 m (terrain category II, Table B-1 Appendix B)

z_{min} is the minimum height

z_{max} is to be taken as 200 m

The next step in the process is to compute the wind velocity pressure ($q_p(z)$), given by the equation:

$$q_p(z) = [1 + 7 * I_v(z)\,] * \frac{1}{2} * \rho * v_m^2(z) \qquad 3.6$$

where:

ρ = air density, to be taken as 1.25 kg/m^3

Iv(z) = wind turbulence intensity calculated using the equation below.

$$I_v(z) = \frac{k_i}{c_0(z) * \ln\left(\frac{z}{z_0}\right)} \text{ for} \qquad 3.7$$

$$I_v(z) = I_v(z_{min}) \text{ for } z \leq z_{min} \qquad 3.8$$

where:

ki = turbulence factor. The recommended value for k_i is 1.0.

Table 3-2: Wind load calculation output

Region	$v_{b,0}$	v_b	v_m	I_v	q_p
Ashanti	3.02	3.0502	1.645772	0.434294	6.839233
Brong Ahafo	3.02	3.0502	1.645772	0.434294	6.839233
Central	3.35	3.3835	1.825608	0.434294	8.415562
Eastern	4.05	4.0905	2.207079	0.434294	12.29996
Greater Accra	4.14	4.1814	2.256125	0.434294	12.85269
Northern	2.93	2.9593	1.596726	0.434294	6.437671
Upper East	3.11	3.1411	1.694818	0.434294	7.252943
Upper West	3.05	3.0805	1.662121	0.434294	6.975787
Volta	3.46	3.4946	1.885554	0.434294	8.977299
Western	2.79	2.8179	1.520432	0.434294	5.837164

Wind Force on Pole

The final step of the wind load calculation is to use the velocity pressure calculated above to compute the wind force (F_W). For this step, the geometry or the shape of the structure to be designed is considered. In some cases, the material to be used is also considered. The equation used to compute the wind force is given by:

$$F_w = c_s c_d * c_f * q_p(z) * A_{ref} \qquad 3.9$$

where:

$c_s c_d$ = structural factor which is taken to be 1.0

A_{ref} = reference area and should be determined by the expression $A_{ref} = l * b$

c_f = force coefficient for structural elements

The force coefficient differs from one structural element to another depending on the geometry of the element. For this research, the structural coefficients considered were structural elements with rectangular sections and cylindrical structural elements.

Structural elements with rectangular cross-sections

The force coefficient c_f for rectangular cross-sections is given by:

$$c_f = c_{f,0} * \psi_r * \psi_\lambda \qquad 3.10$$

and that of cylindrical elements is given by:

$$c_f = c_{f,0} * \psi_\lambda \qquad 3.11$$

where:

$c_{f,0}$ = force coefficient of rectangular sections with sharp corners and cylinders without free-end flow

ψ_r = reduction factor for square sections with rounded corners. $\psi_r = 1$

ψ_λ = end-effect factor for elements with free-end flow

The end factor is a function of the slenderness ratio λ. The value of λ is determined from Figure B-2 in Appendix B. The end factor is subsequently read from the graphs provided in BS EN1991 – 1- 4 – Actions on Structures as shown in Figures B-3 in Appendix B.

Imposed loads

The imposed loads considered for this design were the loads generated from the conductors and fixtures attached to the pole. Fixtures, such as insulators and cross-arms were assumed to generate a force of 1.0kN as provided by BS EN50341

For the conductors, two load cases were considered, that is:

- The self-weight of the conductor
- The force generated due to wind action on the conductor

In Ghana, 120mm^2 All Aluminium Alloy Conductors (AAAC) are used for electricity distribution. The conductor spans a distance of up to 100 meters for high tension distribution and up to 50 meters for low tension distribution. The dimensions of the conductor provided in BS EN50183 are as follows

Area = 118.9 mm^2

Diameter = 14.0 mm

Mass (per unit length) = 324.5 kg/km

The self-weight of the conductor was computed using the mass of the conductor and a span of 100 and 50 meters for high tension and low-tension distribution, respectively.

The force generated due to wind action was calculated according to EN 50341-1. The force generated is dependent on the arrangement of the distribution poles as well as the angle at which the wind hits the conductor as illustrated in Figure 3.6.

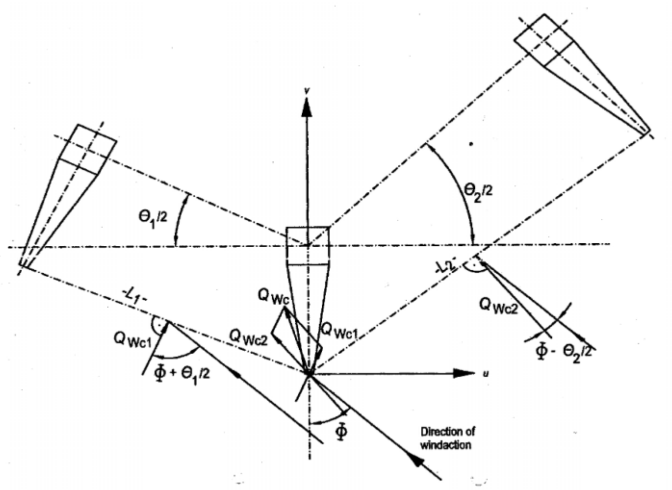


Figure 3.6: Wind forces on conductors – General case (*En 50341-1 - Overhead Electrical Lines Exceeding AC 1 KV - Part 1: General Requirements - Common Specifications*, 2012)

For this design, it was assumed that the poles are arranged in a straight line and also that the wind hits the conductor at a 90° angle hence the equation:

$$Q_{wc} = q_p(h) * G_c * C_c * dcos^2\phi * L_m \qquad 3.12$$

where

$q_p(h)$ = peak wind pressure

h = height to be used for the conductor;

G_c = structural factor for the conductor (also termed span factor);

C_c = drag factor (or force coefficient) for the conductor which was taken to be 1

d = diameter of the conductor;

φ = angle between wind direction and the longitudinal axis of the cross-arm defined in Figure 3-3

L_m = mean lengths of the two adjacent spans, L_1 and L_2

The structural factor G_c is given by:

$$G_c = \frac{1 + 2k_p\, I_v(h)\, \sqrt{B^2 + R^2}}{1 + 7I_v(h)} \qquad 3.13$$

where

k_p = peak factor defined as the ratio of the maximum value of the fluctuating part of the response to its standard deviation. Its recommended value is 3

$I_v(h)$ = turbulence intensity

R^2 is the resonance response factor, allowing for turbulence in resonance with the vibration mode. The recommended value for R^2 is 0 because resonance in the wind direction can be neglected for a line conductor.

B^2 is the background factor, allowing for the lack of full correlation of the pressure on the span, and is given by:

$$B^2 = \frac{1}{1 + \frac{3}{2} * \frac{L_m}{L(h)}} \qquad 3.14$$

L(h) = is the turbulent length scale (average size of gust in m) at the reference height, h of the conductors, given by the expression:

$$L(h) = 300\left(\frac{h}{200}\right)^{0.67+0.05\ln(z_o)} \qquad 3.15$$

Table 3-3: Values of wind force action on tapered and circular pole as well as on conductors

Pole height (m)	Wind Load (kN)		
	Tapered Pole	Circular Pole	Conductor
9	0.061	0.018718	0.0091
11	0.078	0.031796	0.0184

Also, safety factors were applied to load cases based on BS EN1992-1-1

3.4 POST-PROCESSING

The initial design results were checked to establish the success or failure of the design. The initial sizes for the pole design was unsuccessful due to its inability to withstand the loads applied to it. Besides, the members were too small to contain the minimum required reinforcement bars safely.

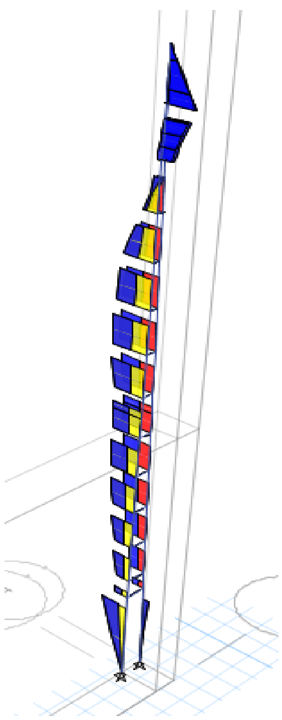
The pole size was varied until the design successfully passed all design requirements after which an analysis of the output data was carried out.

4 CHAPTER FOUR: RESULTS AND DISCUSSION

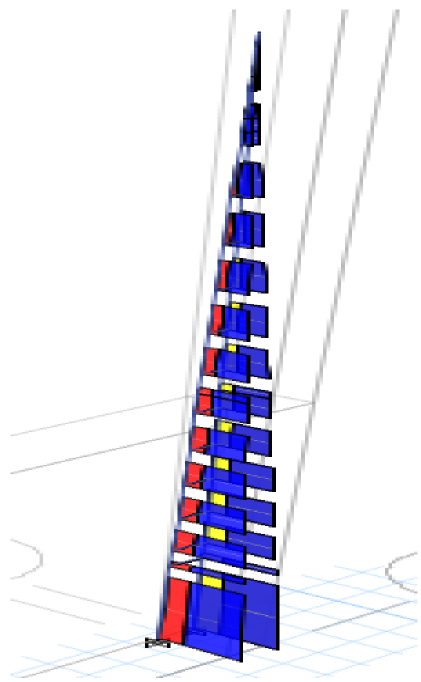
4.1 MOMENT DISTRIBUTION

Bending moments are internal forces induced when an external force is applied to a structure. As the name implies, the induced force causes the structural member to bend or turn. It is known that a small external force can cause a large turning effect.

The moment diagram is a pictorial description of how the moments are distributed throughout the structural member depending on the geometry of the member as well as the location and magnitude of the external forces. The type of support will also affect the moment distribution in a structural member.



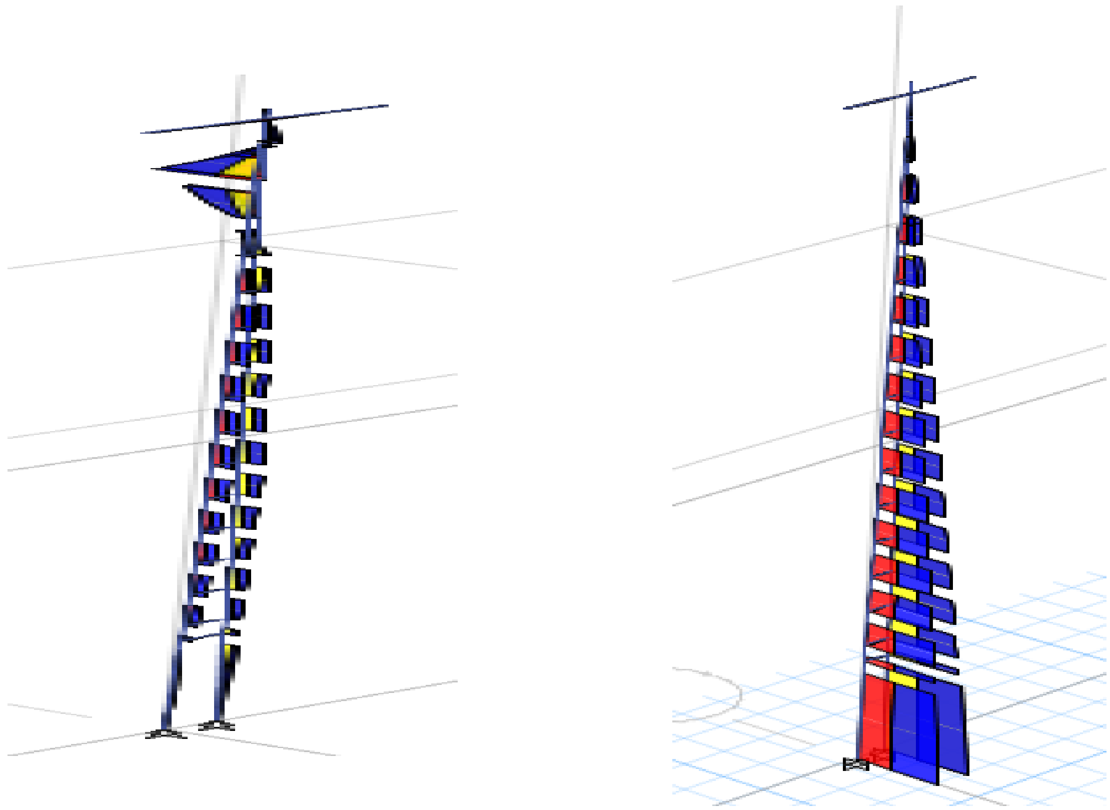
a



b

Figure 4.1: a. Moment distribution for 9meter pole with pinned support

b. Moment distribution for 9meter pole with fixed supports



a

b

Figure 4.2 a. Moment distribution for 11meter pole with pinned support

b. Moment distribution for 11meter pole with fixed supports

Figures 4-1 and 4-2 show the moment distribution for the 9- and 11-meter pole for respectively two support conditions;

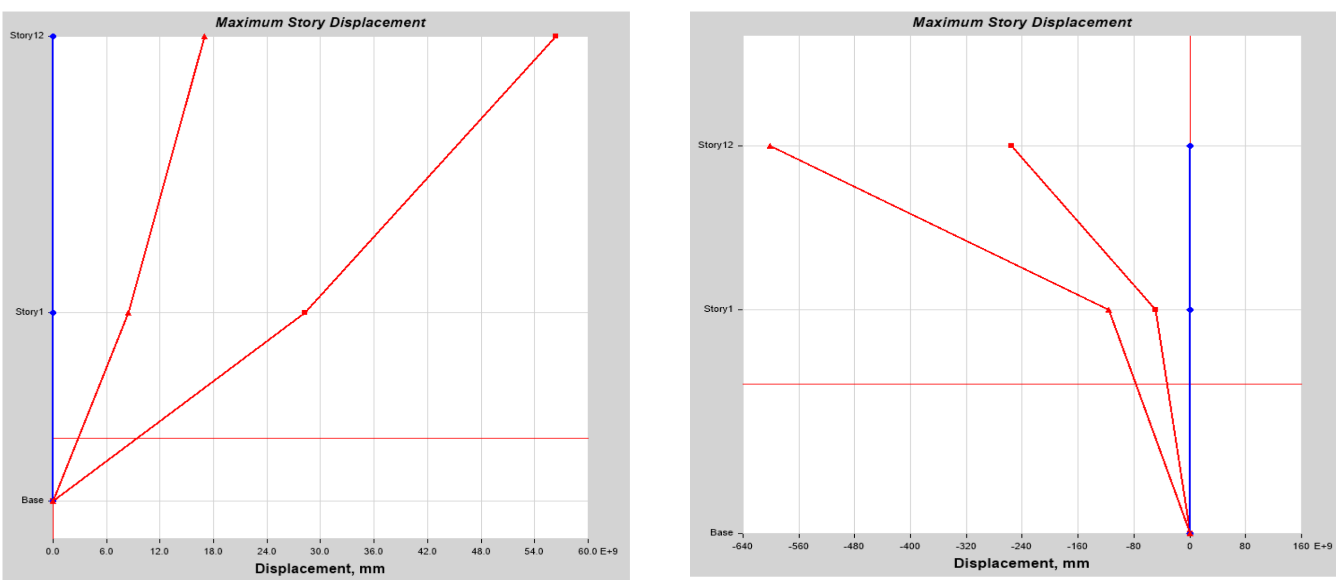
- Fixed support
- Pinned support

Figures 4-1a and 4-2a show the bending diagram for the pole with pinned supports. It can be seen that; the moments are distributed over the entire length of the pole with maximum moments being recorded at the top of the pole. Figures 4-1b and 4-2b show the bending moment diagram for fixed supports. The pole in this case behave like a cantilever where the applied forces at the unsupported end of the pole are carried to the supported end hence the maximum moment occurs at the pole supports.

To construct a fixed support means that the foundation of the pole should be designed such that the pole can be fixed into it. However, such extreme lengths are taken in special cases when geotechnical reports indicate the soil at the location of the pole cannot support the pole. In Ghana, poles are pinned, hence for this study, the pole design was analysed with pinned supports.

4.2 Pole Structure Displacement

Displacement of the pole is the change in position of the pole about the supports as a result of applied loads. Figures 4.3a and 4.3b show the displacement graph for the 9-meter and 11-meter poles, respectively.



a b

Figure 4.3: a. Un-guyed displacement graph, 9meter pole b. Un-guyed displacement graph, 11meter pole

The poles were designed to be light in weight. The weight reduction of the pole makes it more slender and hence increases the overall displacement of the pole. From the displacement graphs shown in Figure 4, the displacement in the 9 meter pole is significantly less than that of the 11 meter pole. This is attributed to the difference in length since all other parameters are the same.

According to Angeling, 2017, decreasing length of the pole, while keeping all other parameters the same will decrease the displacements of the pole as is evident in the analysis results of the 9 meter and 11 meter poles. However, pole lengths are specific to their uses; hence a height reduction for this case is not possible. An alternative to this is the introduction of down guys. Per the analysis, it was realised that when the pole was guyed, the overall stability is increased; hence a reduction in the displacements as shown in Figures 4.4a and 4.4b.

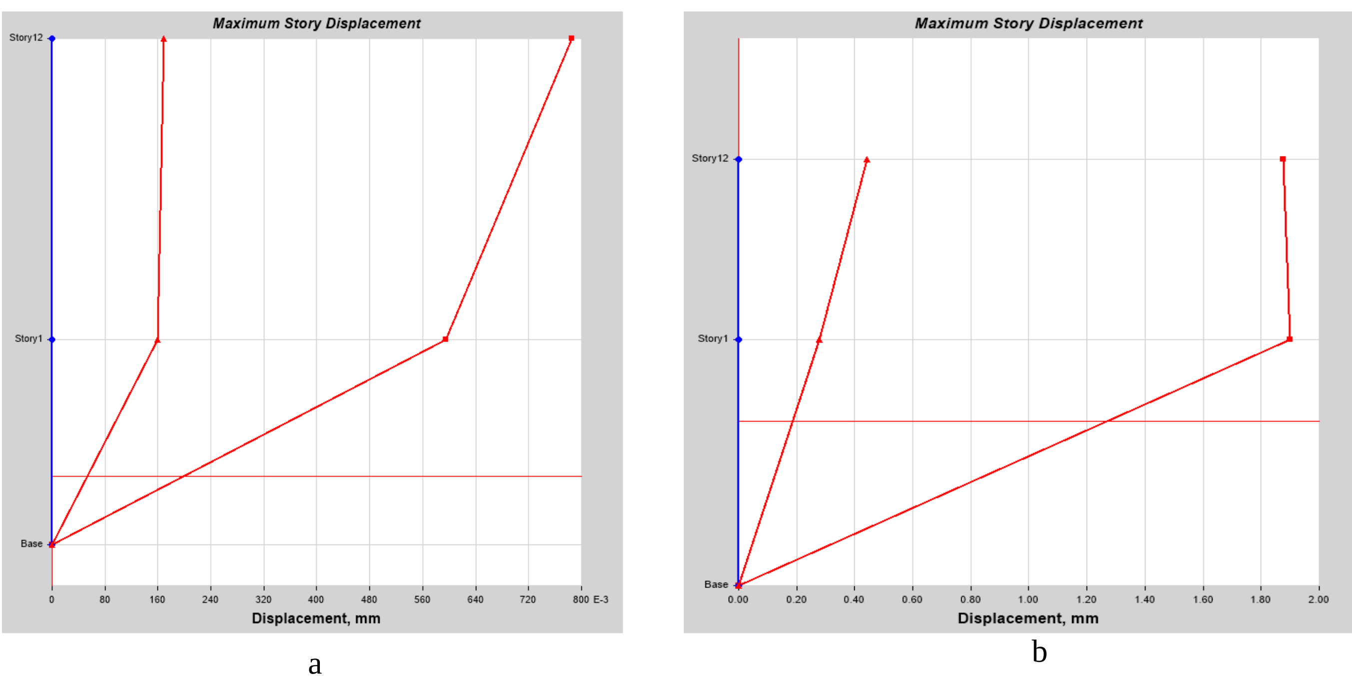


Figure 4.4: a. Guyed displacement graph – 9meter pole **b. Guyed displacement graph – 11meter pole**

4.3 INTERACTION DIAGRAM FOR POLE STRUCTURE

Assuming an axial load is applied directly at the centroid of the column, no moments will be induced in the column. In reality, however, taking into account accuracy and precision errors, an axial load will usually be applied some distance away from the centroid as shown in Figure 4.5.

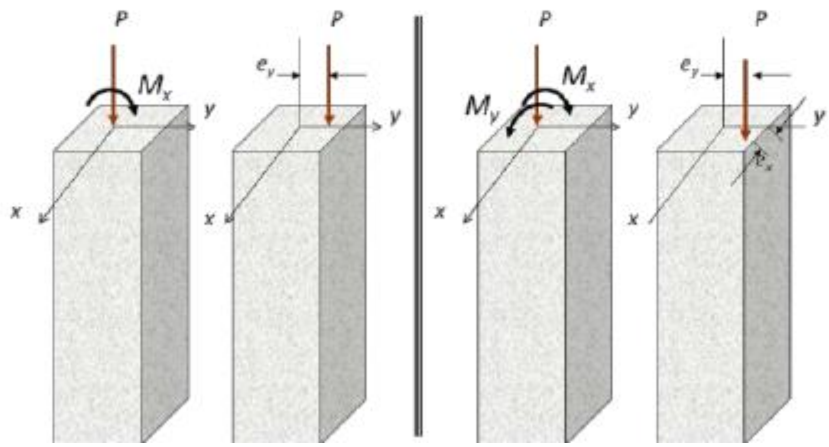


Figure 4.5: Axially loaded column with both uniaxial and biaxial loading

This introduces an eccentricity that causes moments in either one (uniaxial) or two (biaxial) moments or bending in the column. With the induced moment, the capacity or ability of a column to carry an axial load is reduced.

An interaction diagram is a visual representation of the combined loads (bending and Axial) that will cause a column to fail, a plot of axial loads against moment reactions as shown in figure 4.6. It investigates the capacity of the column to carry the different combinations of moment and axial loads. The curve is the failure plane.

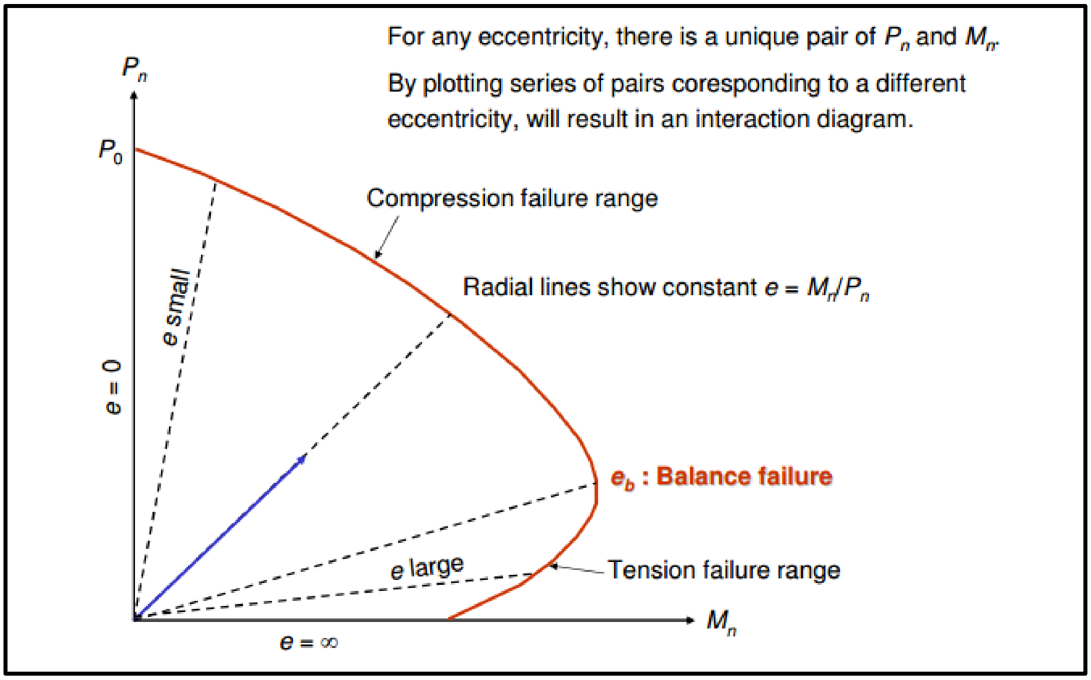
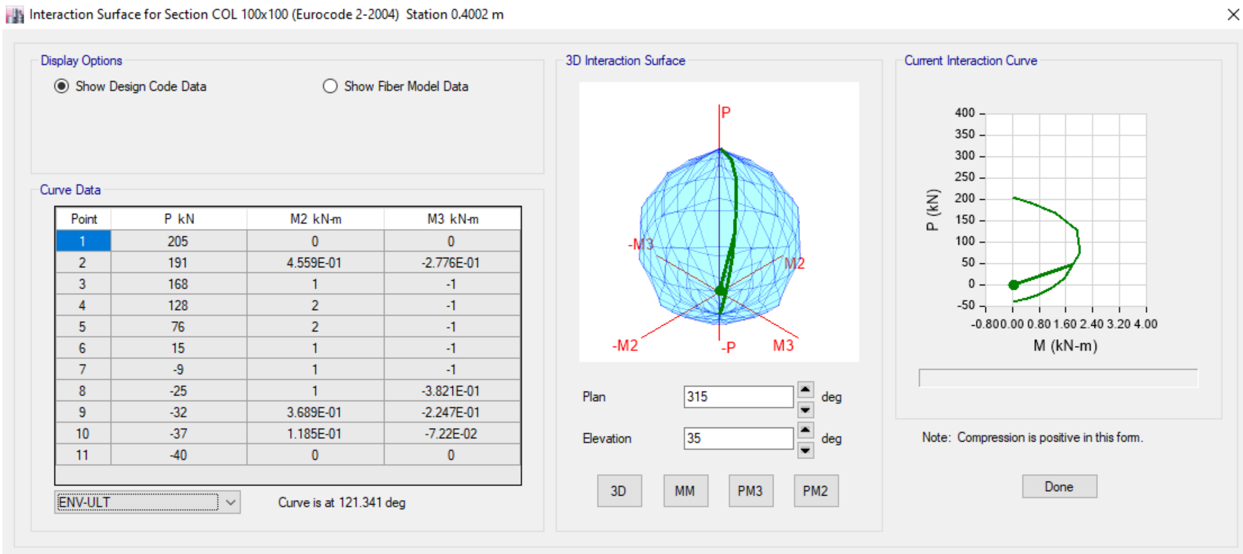


Figure 4.6 Interaction diagram for combined bending and axial load

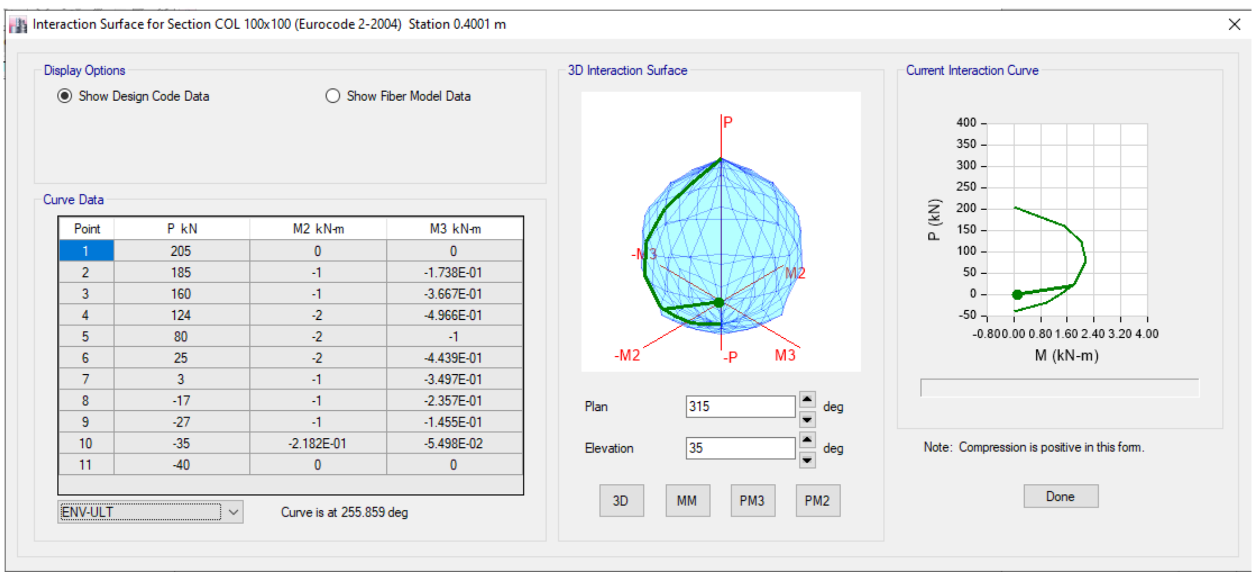
Suppose the axial load is greater than the moments. In that case, the column is described as brittle and characterised by a stocky structure, that is, a larger cross-section. This implies that the load combination (PMM ratio) for a brittle column will lie closer to the compression failure range shown in Figure 4-6. In the same way, when the moment reaction is greater, the column is described as ductile and characterised by a much slender column with longitudinal reinforcement to cater for the turning effect. The PMM ratio for a ductile column will lie closer to the tension failure range shown in Figure 4.6.

That being said, the load combinations for both the 9 meter and 11-meter poles fell within the curve as shown in figures 4.7 and 4.8. This indicates that the distribution poles designed can withstand the loads applied to it. Also, the region the load combination (PMM ratio) falls on a point close to the tension failure range indicating that the pole will behave in a ductile manner.



Point	P kN	M2 kN-m	M3 kN-m
1	205	0	0
2	191	4.559E-01	-2.776E-01
3	168	1	-1
4	128	2	-1
5	76	2	-1
6	15	1	-1
7	-9	1	-1
8	-25	1	-3.821E-01
9	-32	3.689E-01	-2.247E-01
10	-37	1.185E-01	-7.22E-02
11	-40	0	0

Figure 4.7: PMM interaction diagram for 9meter pole provided by ETABS 2016



Point	P kN	M2 kN-m	M3 kN-m
1	205	0	0
2	185	-1	-1.738E-01
3	160	-1	-3.667E-01
4	124	-2	-4.966E-01
5	80	-2	-1
6	25	-2	-4.439E-01
7	3	-1	-3.497E-01
8	-17	-1	-2.357E-01
9	-27	-1	-1.455E-01
10	-35	-2.182E-01	-5.498E-02
11	-40	0	0

Figure 4.8: PMM interaction diagram for 9meter pole provided by ETABS 2016

4.4 DESIGN SUMMARY

After multiple variations of the pole size, the dimensions displayed on Table were used for the final design.

Table 4-1: Final Pole design dimensions

	Tapered Pole	
	9 m	**11 m**
Top(mm)	200x 100	200x 100
Butt(mm)	300 x 100	300 x 100

The forces applied were quite small hence stresses induced within the pole were equally minor as discussed in Section 4.3. Due to this, the minimum recommended area of reinforcement was calculated as one percent of the area of the pole.

NB. The area referred to is the area of one leg of the pole which is 100 x 100.

Per the minimum reinforcement required, 12 mm high yield reinforcement bars are provided in each leg of the pole with 8 mm tie rods. A cover to reinforcement of 25 mm was provided as required for this design according to BS EN12483.

The weight of the designed poles was computed and compared to the weight of previously used concrete poles. It was found that by reducing the size of the pole, the weight of the pole is reduced significantly. Table 4-2 shows the percentage weight reduction.

Table 4-2: Comparison between previously used concrete poles and the lighter weight concrete pole design

Height of Pole (m)	Weight of pole (kg)		Percentage weight reduction (%)
	Normal Concrete pole	Lighter weight concrete pole design	
9	865	450	48.0
11	1078	575	46.7

Table 4-3: Geometry parameters of distribution pole with reinforcement requirements

Pole height(m)	Volume (m3)	Weight (kg)	Embedment depth(m)	Min. Area of reinforcement (mm^2)	Area of reinforcement provided (mm^2)
9	0.18	450	1.5	100	452.4
11	0.23	575	1.8	100	452.4

5 CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The overall wind loads applied to the pole were a combination of the wind load acting on the conductor and the pole itself which were calculated using BS EN01991-1-4 action. The calculated loads along with the self-weight of the pole, the weight of the conductors and construction and maintenance loads were the overall load cases considered for the design analysis.

A tapered structure with a rectangular cross section was modelled and analysed using finite element analysis. A free body diagram of the model was drawn in AutoCAD and the analysed in ETABS 2016. The analysis of this model was based on the stress strain and equilibrium equations with differing scenarios using pinned and fixed supports.

An interaction diagram was generated for each pole. It showed that the load combination for each pole was within the capacity limits for the pole structure. This implies that the poles designed have the ability to withstand loads applied to it.

The stability of the pole was also established by analyzing the displacement charts produced by ETABS 2016. It showed the maximum displacement suffered by each pole and the significant decrease in displacements when a down guy was introduced.

From the analysis results, the pole design was found to have successfully passed all design requirements with a weight of 450kg and 575kg for the 9 meter and 11-meter pole respectively. Though these pole designs are not as light as timber poles, they are about half the weight of previously used concrete poles. This study could enhance the electricity distribution infrastructure in Ghana.

Should these designs be implemented, they may prove to be more cost effective because;

- Materials are readily available in the local market
- Concrete poles generally require low maintenance
- No specialised skill set or machinery is required to construct the pole, thereby reducing the cost of production.

Finally, in anticipation of the introduction of nuclear power into the energy generation mix of the country, should there be an overhaul of the distribution infrastructure, the lighter weight reinforced concrete poles designed in this study could be utilised to increase the accessibility of electricity to the end-user.

5.2 RECOMMENDATION

For future work, it is recommended that the proposed pole designs be constructed and subjected to field and laboratory testing to validate the findings of this study.

Secondly a comprehensive cost estimate analysis should be conducted to evaluate the cost benefits of using this lighter weight reinforced concrete pole design.

REFERENCES

A Wide Creosote Ban is Proposed by E.P.A. (1984, August 16). *The New York Times*. https://www.nytimes.com/1984/08/16/garden/a-wide-creosote-ban-is-proposed-by-epa.html

Adaam, I. (2014). *Establishing Wood Pole Treatment Plant in Ghana* [KARELIA UNIVERSITY OF APPLIED SCIENCES]. https://www.theseus.fi/bitstream/handle/10024/80097/Adaam_Isaac_2014_08_15.pdf?sequence=1&isAllowed=y

Africa, & Support, P. A. (2016). *Ghana Energy Sector Overview*. *April 2015*.

Amankrah, K. A. (2015). *Finite Element Assessment of Precast Concrete Slab Using* (Issue July). University of Ghana.

Angeling, J. B. (2017). *Weight reduction of concrete poles for the Swedish power line grid Using a Finite Element Model to optimize geometry in relation to Load requirements*. Linnaeus University,Faculty of Technology.

Asiedu-Addo, S. (2017). *ECG spends over GH¢94,000 to replace burnt poles*. Graphic Online. https://www.graphic.com.gh/news/general-news/ecg-spends-over-gh-94-000-to-replace-burnt-poles.html

Badger, J., Bauwens, I., Casso, P., Davis, N., Hahmann, A., Hansen, S. B. K., Hansen, Brian Ohrbeck Heathfield, D., Olsen, B. T., Knight, O. J., Lacave, O., Lizcano, G., Bosch i Mas, A., Mortensen, N. G., Onninen, M., & Potter Van Loon, Albertine Volker, P. (n.d.). *Global Wind Atlas* (3.0). Global Wind Atlas. Retrieved October 16, 2020, from https://globalwindatlas.info/area/Ghana

Bhatt, P., MacGinley, T. J., & Choo, B. S. (2017). *Reinforced concrete design to eurocode - Design Theory and Examples* (4th ed.).

Bokpe, S. J. (2019). *Ghana's nuclear source documents go to Cabinet this month*. Graphic Online. https://www.graphic.com.gh/news/general-news/ghana-s-nuclear-source-documents-go-to-cabinet-this-month.html

British Standards Institution. (2004). *BS EN12843:2004 - Precast concrete products – Masts and poles*. *3*(November 2004), 1–8.

British Standards Institution. (2007). *BS EN13369:2004 - Common rules for precast concrete products* (Issue October).

British Standards Institution. (2008). *BS EN1992-1-1:2004 – Design of concrete structures* (Vols. 2-1–1). https://doi.org/10.1007/978-3-642-41714-6_51755

BSI. (2010). *Bs En 1991-1-4:2005+a1:2010* (Vol. 3, Issue January).

Dagher, H. J. (2006). Reliability-based design of utility pole structures. In *Reliability-Based Design of Utility Pole Structures*. https://doi.org/10.1061/9780784408452

Durocrete Engineering Services Pvt. Ltd. (2000). *Durocrete Mix Design Manual*.

En 50341-1 - Overhead electrical lines exceeding AC 1 kV - Part 1: General requirements - Common specifications. (2012).

Gezer, E. D., Temiz, A., & Yüksek, T. (2015). Inspection of Wooden Poles in Electrical Power Distribution Networks in Artvin , Turkey. *Advances in Materials Science and Engineering*, *2015*, 11. http://dx.doi.org/10.1155/2015/659818

Ghana Energy Situation - energypedia.info. (n.d.). Retrieved October 25, 2020, from https://energypedia.info/wiki/Ghana_Energy_Situation

Graham, R. D. (1960). Causes and Prevention of Deterioration in Wood. *Wood Pole Conference*.

Guo, Z. (2014). Chapter 4: Various Structural Concrete. In *Principles of Reinforced Concrete*.

Hedjazi, S. (2016). Compressive Strength of Lightweight Concrete. *Intech*, 13. https://doi.org/http://dx.doi.org/10.5772/57353

House, H., Place, M., Kingdom, U., & Report, F. (2003). *Overview of the Potential for Undergrounding the Electricity Networks in Europe*. *February*, 1–49.

Hutton, D. V. (2004). *Fundamentals of Finite Element Analysis* (O. Plant & L. K. Williams (Eds.)). MaGraw-Hill.

Institute of Statistical, Social and Ecconomical Research (ISSER) Annual Report. (2015). In *Institute of Statistical, Social and Ecconomical Research (ISSER)*. http://isser.edu.gh/images/Publication_files/ISSER ANNUAL REPORT 2014-2015..pdf

Jenkins, C., & Khanna, S. (2005). Mechanics and Materials. In *Mechanics of Materials, A Modern Integration of Mechanics and Materials in Structural Design* (1st ed., pp. 1–28).

Kolgiri, S. G. (2009). *STATIC AND DYNAMIC ANALYSIS FOR ROTOR SHAFT OF ELECTRIC MOTOR*. Walchand Institute of Technology/ Solapur University.

Kuenyehia, K. (Kimathi & P. C. A., Odame, S. (Kimathi & P. C. A., & Arde-Acquah, P. (Kimathi & P. C. A. (2019). *Electricity Regulation in Ghana*. Lexology. https://www.lexology.com/library/detail.aspx?g=910beca2-f3bf-420f-8597-e7e3e6f53b38

Kumi, E. N. (2017). The Electricity Situation in Ghana: Challenges and Opportunities. *CGD Policy Paper*, *September*, 30. https://www.cgdev.org/ publication/electricity-situation-ghana-challenges-and-opportunities

Liu, G. R., & Quek, S. S. (2013). The Finite Element Method: A Practical Course: Second Edition. In *The Finite Element Method: A Practical Course: Second Edition* (Second Edi). https://doi.org/10.1016/C2012-0-00779-X

Lunuwilage, R. H. (2013). *Study of Pole-top Fire Development in Power Distribution Networks* (Issue October). University of Moratuwa, Sri Lanka.

Mai, C., & Militz, H. (2007). Wood Preservatives. In U. Kues (Ed.), *Wood production, wood technology and biotechnology impacts* (pp. 259–271). http://univerlag.uni-goettingen.de

Moaveni, S. (1999). Finite Element Analysis - Theory and Application with ANSYS. In B. Stenquist, C. Suraci, M. Horton, & A. Baker (Eds.), *Minerals Engineering*. Prentice - Hall Inc. https://doi.org/10.1016/s0892-6875(99)90030-4

Mosley, B., Bungey, J., & Hulse, R. (2012). *Reinforced concrete design to Eurocode 2* (7th ed.). Palgrave Macmillan. https://doi.org/10.1680/edpfb.64553.193

Mrema, G. C. (2011). Structural design. In *Rural structures in the tropics: design and development* (pp. 115–147). Rome, FAO. https://doi.org/10.1080/00038628.1965.9696133

Mulqueen, A. (Carlifonia P. U. C.-P. and P. D. (2017). *A Natural History of the Wooden Utility Pole* (Issue July).

Neulicht, R., & Shular, J. (1999). *Wood Preserving* (Issue 4601).

Neupane, D. (2014). *Comparison of Some Fem Codes in Static Analysis* [HAMK University]. https://www.theseus.fi/bitstream/handle/10024/87106/Neupane_Dilip.pdf?sequence=1

Neville, A. M., & Brooks, J. J. (2010). *Concrete Technology* (Second). Pearson Education Limit.

Nunoo, S., & Attachie, J. C. (2011). A Methodology for the design of an electricity theft monitoring system. *Journal of Theoretical and Applied Information Technology*, *26*(2), 112–117.

Rao, S. S. (2011). *The Finite Element Method in Engineering* (Fifth). Butterworth–Heinemann.

Saeed, S. S. (GNA). (2019). *ECG loses GH¢120,000 in two months to bushfires*. Ghana News Agency (GNA). https://www.ghananewsagency.org/social/ecg-loses-gh-120-000-in-two-months-to-bushfires-145326

Shupe, T. (Ph. D. L. F. P. D. C., Lebow, S. (Ph. D. U. F. P. L., & Ring, D. (Ph. D. D. of E. (2008). Causes and Control of Wood Decay , Degradation & Stain. *Louisiana State University Agricultural Center*, 1–28. https://doi.org/10.1128/AEM.00508-11

Słowik, M. (2019). The analysis of failure in concrete and reinforced concrete beams with different reinforcement ratio. *Archive of Applied Mechanics*, *89*(5), 885–895. https://doi.org/10.1007/s00419-018-1476-5

Ugural, A. C., & Fenster, S. K. (2016). *Advanced Mechanics of Materials and Applied Elasticity* (5th ed.). Prentice Hall, Pearson Education, Inc. https://doi.org/10.1201/9781420057775

Utility poles - Aged Woods, Inc. (2017). https://www.agedwoods.com/utility-poles/

Wood Boring Insects and Beetles | Western Exterminator. (n.d.). Retrieved March 18, 2020, from https://www.westernexterminator.com/wood-boring-insects/

APPENDIX A

LOAD CALCULATION TABLES AND SAMPLE CALCULATION OF A 9m POLE

WIND FORCE ON CONDUCTORS

C_c = 1

L_2 = 50

L_m = 25

L_1 = 0

P=1.25kg/m

Lh = 28.63

9meter pole

Table A-0-1: Wind force action on conductors for 9meter poles at Terrain IV

Terrain IV: Zo=1										
Region	**Vbmap**	**Kr**	**Cr**	**Vm**	**Iv**	**Qp**	**Lh**	**Bsqr**	**Gc**	**Qw**
Ashanti	3.02	0.234329	0.47215	1.425893	0.496302	0.005685	31.43837	0.456036	0.672967	0.001339
Brong Ahafo	3.02	0.234329	0.47215	1.425893	0.496302	0.005685	31.43837	0.456036	0.672967	0.001339
Central	3.35	0.234329	0.47215	1.581702	0.496302	0.006996	31.43837	0.456036	0.672967	0.001648
Eastern	4.05	0.234329	0.47215	1.912207	0.496302	0.010225	31.43837	0.456036	0.672967	0.002408
Greater Accra	4.14	0.234329	0.47215	1.9547	0.496302	0.010684	31.43837	0.456036	0.672967	0.002517

Terrain IV: Zo=1										
Region	**Vbmap**	**Kr**	**Cr**	**Vm**	**Iv**	**Qp**	**Lh**	**Bsqr**	**Gc**	**Qw**
Northern	2.93	0.234329	0.47215	1.383399	0.496302	0.005352	31.43837	0.456036	0.672967	0.001261
Upper East	3.11	0.234329	0.47215	1.468386	0.496302	0.006029	31.43837	0.456036	0.672967	0.00142
Upper West	3.05	0.234329	0.47215	1.440057	0.496302	0.005799	31.43837	0.456036	0.672967	0.001366
Volta	3.46	0.234329	0.47215	1.633638	0.496302	0.007463	31.43837	0.456036	0.672967	0.001758
Western	2.79	0.234329	0.47215	1.317298	0.496302	0.004852	31.43837	0.456036	0.672967	0.001143
										0.002517

Table A-0-2: Wind force action on conductors for 9meter poles at Terrain III

Terrain III: Zo=0.3										
Region	**Vbmap**	**Kr**	**Cr**	**Vm**	**Iv**	**Qp**	**Lh**	**Bsqr**	**Gc**	**Qw**
Ashanti	3.02	0.215389	0.693312	2.093801	0.310667	0.008699	38.50183	0.506591	0.732897	0.002231
Brong Ahafo	3.02	0.215389	0.693312	2.093801	0.310667	0.008699	38.50183	0.506591	0.732897	0.002231
Central	3.35	0.215389	0.693312	2.322594	0.310667	0.010703	38.50183	0.506591	0.732897	0.002746
Eastern	4.05	0.215389	0.693312	2.807912	0.310667	0.015644	38.50183	0.506591	0.732897	0.004013
Greater Accra	4.14	0.215389	0.693312	2.87031	0.310667	0.016347	38.50183	0.506591	0.732897	0.004193
Northern	2.93	0.215389	0.693312	2.031403	0.310667	0.008188	38.50183	0.506591	0.732897	0.0021
Upper East	3.11	0.215389	0.693312	2.156199	0.310667	0.009225	38.50183	0.506591	0.732897	0.002366
Upper West	3.05	0.215389	0.693312	2.1146	0.310667	0.008872	38.50183	0.506591	0.732897	0.002276
Volta	3.46	0.215389	0.693312	2.398858	0.310667	0.011418	38.50183	0.506591	0.732897	0.002929
Western	2.79	0.215389	0.693312	1.934339	0.310667	0.007424	38.50183	0.506591	0.732897	0.001904
										0.004193

Table A-0-3: Wind force action on conductors for 9meter poles at Terrain 0

Terrain 0: Zo=0.003										
Region	**Vbmap**	**Kr**	**Cr**	**Vm**	**Iv**	**Qp**	**Lh**	**Bsqr**	**Gc**	**Qw**
Ashanti										
Brong Ahafo										
Central	3.35	0.156036	1.220831	4.089784	0.127811	0.019807	83.59127	0.690316	0.86408	0.00599
Eastern										
Greater Accra	4.14	0.156036	1.220831	5.054241	0.127811	0.03025	83.59127	0.690316	0.86408	0.009148
Northern										
Upper East										
Upper West										
Volta	3.46	0.156036	1.220831	4.224076	0.127811	0.021129	83.59127	0.690316	0.86408	0.00639
Western	2.79	0.156036	1.220831	3.406119	0.127811	0.013738	83.59127	0.690316	0.86408	0.004155
										0.009148

11 **meter Pole**

Table A-0-4: Wind force action on conductors for 11meter poles at Terrain IV

Terrain IV: Zo=1										
Region	**Vbmap**	**Kr**	**Cr**	**Vm**	**Iv**	**Qp**	**Lh**	**Bsqr**	**Gc**	**Qw**
Ashanti	3.02	0.234329	0.522557	1.578121	0.448428	0.006443	38.39854	0.338616	0.619875	0.002795
Brong Ahafo	3.02	0.234329	0.522557	1.578121	0.448428	0.006443	38.39854	0.338616	0.619875	0.002795
Central	3.35	0.234329	0.522557	1.750565	0.448428	0.007927	38.39854	0.338616	0.619875	0.00344
Eastern	4.05	0.234329	0.522557	2.116354	0.448428	0.011586	38.39854	0.338616	0.619875	0.005028
Greater Accra	4.14	0.234329	0.522557	2.163384	0.448428	0.012107	38.39854	0.338616	0.619875	0.005253
Northern	2.93	0.234329	0.522557	1.531091	0.448428	0.006064	38.39854	0.338616	0.619875	0.002631
Upper East	3.11	0.234329	0.522557	1.625151	0.448428	0.006832	38.39854	0.338616	0.619875	0.002965
Upper West	3.05	0.234329	0.522557	1.593798	0.448428	0.006571	38.39854	0.338616	0.619875	0.002851
Volta	3.46	0.234329	0.522557	1.808046	0.448428	0.008457	38.39854	0.338616	0.619875	0.003669
Western	2.79	0.234329	0.522557	1.457933	0.448428	0.005499	38.39854	0.338616	0.619875	0.002386
										0.005253

Table 0-5: Wind force action on conductors for 11meter poles at Terrain III

Terrain III: Zo=0.3										
Region	**Vbmap**	**Kr**	**Cr**	**Vm**	**Iv**	**Qp**	**Lh**	**Bsqr**	**Gc**	**Qw**
Ashanti	3.02	0.215389	0.739644	2.233726	0.291207	0.009475	46.18833	0.381129	0.684122	0.004538
Brong Ahafo	3.02	0.215389	0.739644	2.233726	0.291207	0.009475	46.18833	0.381129	0.684122	0.004538
Central	3.35	0.215389	0.739644	2.477808	0.291207	0.011659	46.18833	0.381129	0.684122	0.005583
Eastern	4.05	0.215389	0.739644	2.995559	0.291207	0.017041	46.18833	0.381129	0.684122	0.008161
Greater Accra	4.14	0.215389	0.739644	3.062127	0.291207	0.017806	46.18833	0.381129	0.684122	0.008527
Northern	2.93	0.215389	0.739644	2.167158	0.291207	0.008919	46.18833	0.381129	0.684122	0.004271
Upper East	3.11	0.215389	0.739644	2.300293	0.291207	0.010048	46.18833	0.381129	0.684122	0.004812
Upper West	3.05	0.215389	0.739644	2.255915	0.291207	0.009664	46.18833	0.381129	0.684122	0.004628
Volta	3.46	0.215389	0.739644	2.559169	0.291207	0.012437	46.18833	0.381129	0.684122	0.005956
Western	2.79	0.215389	0.739644	2.063607	0.291207	0.008087	46.18833	0.381129	0.684122	0.003873
										0.008527

TableA-0-6: Wind force action on conductors for 11meter poles at Terrain 0

Terrain 0: Zo=0.003										
Region	**Vbmap**	**Kr**	**Cr**	**Vm**	**Iv**	**Qp**	**Lh**	**Bsqr**	**Gc**	**Qw**
Ashanti										
Brong Ahafo										
Central	3.35	0.156036	1.254396	4.202227	0.124391	0.020647	93.61869	0.555209	0.831822	0.012022
Eastern										
Greater Accra	4.14	0.156036	1.254396	5.1932	0.124391	0.031533	93.61869	0.555209	0.831822	0.018361
Northern										
Upper East										
Upper West										
Volta	3.46	0.156036	1.254396	4.340211	0.124391	0.022025	93.61869	0.555209	0.831822	0.012825
Western	2.79	0.156036	1.254396	3.499765	0.124391	0.014321	93.61869	0.555209	0.831822	0.008339
										0.018361

WIND FORCE ON POLE STRUCTURE

C_f = 1.5 **L_m = 50**

ψ = 0.91 **P = 1.25kg/m**

λ = 70 **$C_{f,o}$ = 1.65**

C_sC_d = 1 **Lh = 28.63**

9 meter pole

Table 0-7: Wind force action on poles for 9meter poles at Terrain IV

Terrain IV: Zo=1							
Region	**Vbmap**	**Kr**	**Cr**	**Vm**	**Iv**	**Qp**	**Qw**
Ashanti	3.02	0.234329	0.47215	1.425893	0.496302	0.005685	0.011524
Brong Ahafo	3.02	0.234329	0.47215	1.425893	0.496302	0.005685	0.011524
Central	3.35	0.234329	0.47215	1.581702	0.496302	0.006996	0.014181
Eastern	4.05	0.234329	0.47215	1.912207	0.496302	0.010225	0.020726

Terrain IV: Zo=1							
Region	**Vbmap**	**Kr**	**Cr**	**Vm**	**Iv**	**Qp**	**Qw**
Greater Accra	4.14	0.234329	0.47215	1.9547	0.496302	0.010684	0.021657
Northern	2.93	0.234329	0.47215	1.383399	0.496302	0.005352	0.010848
Upper East	3.11	0.234329	0.47215	1.468386	0.496302	0.006029	0.012222
Upper West	3.05	0.234329	0.47215	1.440057	0.496302	0.005799	0.011755
Volta	3.46	0.234329	0.47215	1.633638	0.496302	0.007463	0.015127
Western	2.79	0.234329	0.47215	1.317298	0.496302	0.004852	0.009836
							0.021657

TableA-0-8: Wind force action on poles for 9meter poles at Terrain III

Terrain III: Zo=0.3							
Region	**Vbmap**	**Kr**	**Cr**	**Vm**	**Iv**	**Qp**	**Qw**
Ashanti	3.02	0.215389	0.693312	2.093801	0.310667	0.008699	0.017632
Brong Ahafo	3.02	0.215389	0.693312	2.093801	0.310667	0.008699	0.017632
Central	3.35	0.215389	0.693312	2.322594	0.310667	0.010703	0.021696

Terrain III: Zo=0.3							
Region	**Vbmap**	**Kr**	**Cr**	**Vm**	**Iv**	**Qp**	**Qw**
Eastern	4.05	0.215389	0.693312	2.807912	0.310667	0.015644	0.031711
Greater Accra	4.14	0.215389	0.693312	2.87031	0.310667	0.016347	0.033136
Northern	2.93	0.215389	0.693312	2.031403	0.310667	0.008188	0.016597
Upper East	3.11	0.215389	0.693312	2.156199	0.310667	0.009225	0.018699
Upper West	3.05	0.215389	0.693312	2.1146	0.310667	0.008872	0.017984
Volta	3.46	0.215389	0.693312	2.398858	0.310667	0.011418	0.023144
Western	2.79	0.215389	0.693312	1.934339	0.310667	0.007424	0.015049
							0.033136

Table A-0-9: Wind force action on poles for 9meter poles at Terrain 0

Terrain 0: Zo=0.003							
Region	**Vbmap**	**Kr**	**Cr**	**Vm**	**Iv**	**Qp**	**Qw**
Ashanti							
Brong Ahafo							

Terrain 0: Zo=0.003							
Region	**Vbmap**	**Kr**	**Cr**	**Vm**	**Iv**	**Qp**	**Qw**
Central	3.35	0.156036	1.220831	4.089784	0.127811	0.019807	0.040149
Eastern							
Greater Accra	4.14	0.156036	1.220831	5.054241	0.127811	0.03025	0.061318
Northern							
Upper East							
Upper West							
Volta	3.46	0.156036	1.220831	4.224076	0.127811	0.021129	0.042829
Western	2.79	0.156036	1.220831	3.406119	0.127811	0.013738	0.027848
							0.061318

11 meter pole

Table A-0-10: Wind force action on poles for 11meter poles at Terrain IV

Terrain IV: Zo=1							
Region	**Vbmap**	**Kr**	**Cr**	**Vm**	**Iv**	**Qp**	**Qw**
Ashanti	3.02	0.234329	0.522557	1.578121	0.448428	0.006443	0.011608
Brong Ahafo	3.02	0.234329	0.522557	1.578121	0.448428	0.006443	0.011608
Central	3.35	0.234329	0.522557	1.750565	0.448428	0.007927	0.014284
Eastern	4.05	0.234329	0.522557	2.116354	0.448428	0.011586	0.020877
Greater Accra	4.14	0.234329	0.522557	2.163384	0.448428	0.012107	0.021815
Northern	2.93	0.234329	0.522557	1.531091	0.448428	0.006064	0.010927
Upper East	3.11	0.234329	0.522557	1.625151	0.448428	0.006832	0.01231
Upper West	3.05	0.234329	0.522557	1.593798	0.448428	0.006571	0.01184
Volta	3.46	0.234329	0.522557	1.808046	0.448428	0.008457	0.015237
Western	2.79	0.234329	0.522557	1.457933	0.448428	0.005499	0.009907
							0.021815

Table 0-11: Wind force action on poles for 11meter poles at Terrain III

Terrain III: Zo=0.3							
Region	**Vbmap**	**Kr**	**Cr**	**Vm**	**Iv**	**Qp**	**Qw**
Ashanti	3.02	0.215389	0.739644	2.233726	0.291207	0.009475	0.017073
Brong Ahafo	3.02	0.215389	0.739644	2.233726	0.291207	0.009475	0.017073
Central	3.35	0.215389	0.739644	2.477808	0.291207	0.011659	0.021007
Eastern	4.05	0.215389	0.739644	2.995559	0.291207	0.017041	0.030704
Greater Accra	4.14	0.215389	0.739644	3.062127	0.291207	0.017806	0.032084
Northern	2.93	0.215389	0.739644	2.167158	0.291207	0.008919	0.01607
Upper East	3.11	0.215389	0.739644	2.300293	0.291207	0.010048	0.018105
Upper West	3.05	0.215389	0.739644	2.255915	0.291207	0.009664	0.017413
Volta	3.46	0.215389	0.739644	2.559169	0.291207	0.012437	0.02241
Western	2.79	0.215389	0.739644	2.063607	0.291207	0.008087	0.014571
							0.032084

Table A-0-12: Wind force action on poles for 11meter poles at Terrain 0

Terrain 0: Zo=0.003							
Region	**Vbmap**	**Kr**	**Cr**	**Vm**	**Iv**	**Qp**	**Qw**
Ashanti							
Brong Ahafo							
Central	3.35	0.156036	1.254396	4.202227	0.124391	0.020647	0.037201
Eastern							
Greater Accra	4.14	0.156036	1.254396	5.1932	0.124391	0.031533	0.056816
Northern							
Upper East							
Upper West							
Volta	3.46	0.156036	1.254396	4.340211	0.124391	0.022025	0.039685
Western	2.79	0.156036	1.254396	3.499765	0.124391	0.014321	0.025803
							0.056816

SAMPLE CALCULATIONS – 9m Pole

Typical ruling span: 50m

Conductor: AAC 120 mm2, BS-EN50183 Code: Oak

Diameter: 14 mm

Data and calculation step by step

$V_{b,0}$ = 4.14 m/s	Basic wind velocity	3.1
c_{dir} = 1	directional factor	
c_o = 1	orography factor	
z_o = 0.003 m	Roughness length: terrain category 0	
c_r = 1.22	roughness factor	3.3
$V_m(h)$ = 5.0543 m/s	Mean velocity	3.2
k_r = 0.156	terrain factor	3.5
h = 6.6m		
ρ = 1.25 kg/m	Density of air	
I_v (h) = 0.128	Wind turbulence intensity	3.7
q_p (h) = 0.0302 kPa	Peak wind pressure	

Wind Action on Conductor

L_1 = 50 m	Adjacent pole lengths

$L_2 = 0$ m		
$L_m = 25$ m	Mean Span	
$L(h) = 85.59$ m	Turbulence length scale	3.15
$B^2 = 0.690$	Background factor	3.14
$k_p = 3$	Peak Factor	
$R^2 = 0$	Resonance factor	
$G_c = 0.864$	Structural factor	3.13
$\varphi = 0$	Angle of incidence	
$C_c = 1$	Conductor drag factor	
$Q_{wc} = 0.0091$ kN		3.12

Wind Action on Pole

$C_sC_d = 1$	Structural factor	
$C_f = 1.5$	Pole drag factor/force coefficient	
3.10		
$A_{ref} = 1.35$	Projected Area	
$F_w = 0.061$ kN		3.9

APPENDIX B

TABLES AND CHARTS FOR WIND LOAD CALCULATIONS - EUROCODE DESIGN MANUAL

Table B-1: Terrain type description

Terrain category	Description	z_0 (m)	z_{min} (m)
0	Sea or coastal area exposed to the open sea	0.003	1
I	Lakes or flat and horizontal area with negligible vegetation and without obstacles	0.01	1
II	Area with low vegetation such as grass and isolated obstacles (trees, buildings) with separations of at least 20 obstacle heights	0.05	2
III	Area with regular cover of vegetation or buildings or with isolated obstacles with separations of maximum 20 obstacle heights (such as villages, suburban terrain, permanent forest)	0.3	5
IV	Area in which at least 15 % of the surface is covered with buildings and their average height exceeds 15 m	1	10
NOTE: The terrain categories are illustrated in A.1.			

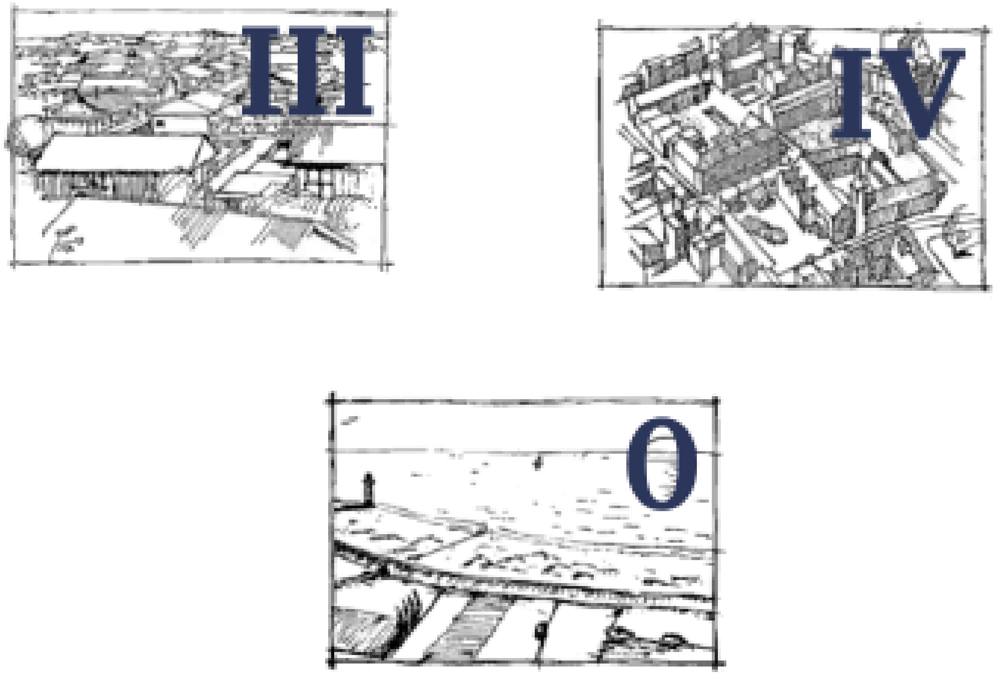


Figure B.1: Terrain images for Terrain types 0, III and IV

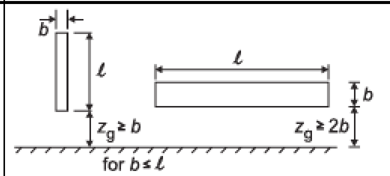
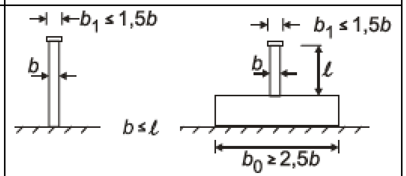
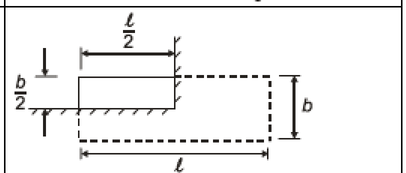
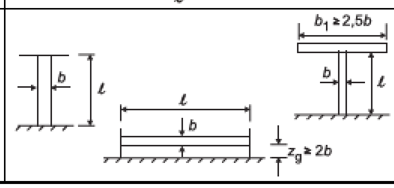
No.	Position of the structure, wind normal to the plane of the page	Effective slenderness λ
1		For polygonal, rectangular and sharp edged sections and lattice structures: for $\ell \geq 50$ m, $\lambda = 1{,}4\ \ell/b$ or $\lambda = 70$, whichever is smaller for $\ell < 15$ m, $\lambda = 2\ \ell/b$ or $\lambda = 70$, whichever is smaller For circular cylinders: for $\ell \geq 50$, $\lambda = 0{,}7\ \ell/b$ or $\lambda = 70$, whichever is smaller for $\ell < 15$ m, $\lambda = \ell/b$ or $\lambda = 70$, whichever is smaller For intermediate values of ℓ, linear interpolation should be used
2		
3		
4		for $\ell \geq 50$ m, $\lambda = 0{,}7\ \ell/b$ or $\lambda = 70$, whichever is larger for $\ell < 15$ m, $\lambda = \ell/b$ or $\lambda = 70$, whichever is larger For intermediate values of ℓ, linear interpolation should be used

Figure B-2: Recommended values of λ for cylinders, polygonal sections, rectangular sections, sharp edged structural sections and lattice structures

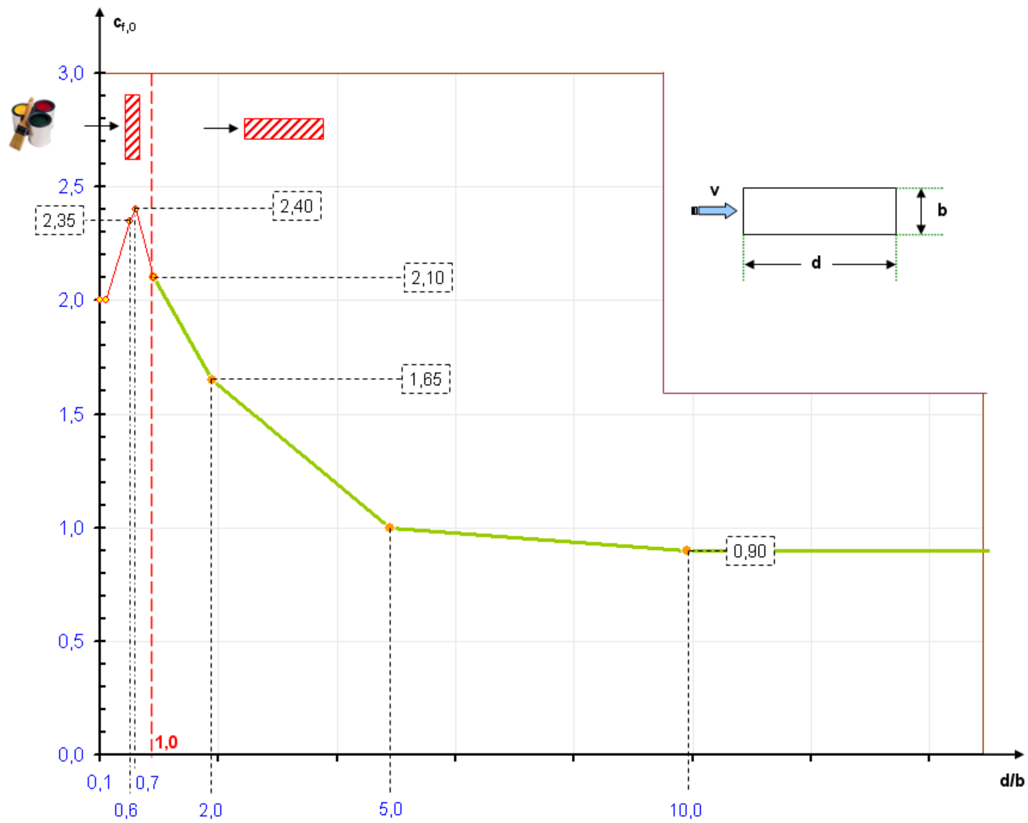


Figure B-3: Force coefficients for rectangular cross section

Table B-2:Exposure classes related to environmental conditions in accordance with EN 206-1(British Standards Institution, 2008)

Class designation	**Description of environment**	**Hydraulic engineering specific examples[1)] for the allocation of exposure classes (for information)**
1 No risk of corrosion or attack		
X0	For concrete without reinforcement or embedded metal: in environments where the concrete is not attacked.	Unreinforced core concrete with zoned building method
2 Reinforcement corrosion, triggered by carbonisation		
XC1	dry or permanently wet	Floors of lock chambers, economising basins or weirs, lock chamber walls below bottom

Class designation	**Description of environment**	**Hydraulic engineering specific examples[1)] for the allocation of exposure classes (for information)**
		water, hydraulic filling and emptying systems
XC2	wet, rarely dry	Lock chamber walls in the area between bottom water and headwater (*mutatis mutandis* for economising basin walls)
XC3	moderate humidity	Surfaces not open to the weather (outside air, protected against precipitation)
XC4	cyclic wet and dry	Freeboard of lock chamber or economising basin walls, weir columns above low water, outside surfaces open to the weather, quays
3 Reinforcement corrosion caused by chloride, except for seawater		
XD1	moderate humidity	Weir columns in the spray mist areas of road bridges
XD2	wet, rarely dry	
XD3	cyclic wet and dry	Platforms of locks, traffic areas (e.g. port areas), steps on weir columns
4 Reinforcement corrosion caused by chloride from seawater		
XS1	Exposed to airborne salt but not in direct contact with seawater	External components near the coast
XS2	Permanently submerged	Barrier floors, walls and foundation piles below lowest known low-tide level
XS3	tidal, splash and spray zones	Foundation piles, quays, moles and walls above lowest known low-tide level
5 Frost with and without de-icing agents/seawater		
XF1	moderate water saturation with fresh water, without de-icing agents	Freeboard of economising basin walls, weir columns above high water
XF2	moderate water saturation with seawater and/or de-icing agents	Vertical components in spray water area and components in direct spray mist areas of seawater

Class designation	Description of environment	Hydraulic engineering specific examples[1)] for the allocation of exposure classes (for information)
XF3	high water saturation with fresh water without de-icing agents	Lock chamber walls in the area between bottom water-1.0 m and headwater+1.0 m (applies *mutatis mutandis* to economising basin walls), inlet and outlet areas of culverts between low water and high water, weir columns between low water and high water
XF4	high water saturation with seawater and/or de-icing agents	Vertical surfaces of seawater components such as foundation piles, quays and moles in fluctuating water level areas, horizontal surfaces affected by seawater, platforms of locks, traffic areas (e.g. port areas), steps on weir columns
6 Concrete corrosion through chemical attack		
XA1	slightly aggressive chemical environment	
XA2	moderately aggressive chemical environment and marine structures	Concrete components which are in contact with seawater (underwater and fluctuating water level areas, spray water areas)
XA3	Highly aggressive chemical environment	
7 Concrete corrosion through wear stress		
XM1	moderate wear stress [2)]	Surfaces subject to stress from friction with ships (e.g. lock chamber walls above bottom water-1.0 m), components for energy conversion with wear from small-grain bed-load transport (e.g. due to construction measures such as bed-load catch basin), ice drift
XM2	severe wear stress	Weir backs and components for energy conversion (stilling basins, chute blocks) with wear from large-grain bed-load transport
XM3	very severe wear stress	Components in mountain streams or bed-load deflection tunnels
8 Concrete corrosion due to alkali silica reaction		

Class designati on	Description of environment	Hydraulic engineering specific examples[1)] for the allocation of exposure classes (for information)
WO	Concrete which after normal curing is not moist for an extended time and, after drying out, remains mostly dry during use.	Generally: Only for non-massive components (smallest component dimension ≤ 0.80 m). Internal components of hydraulic structures that are not continuously exposed to a relative air humidity of more than 80 % (e.g. interior spaces of steering stations).
WF	Concrete that in use is frequently wet or wet over extended periods of time.	Generally: Always for massive components (smallest dimension > 0.80 m) regardless of humidity exposure. Concrete components of hydraulic structures exposed to weather or subject to temporary or permanent water exposure in inland waterways (e.g. entire height of lock chamber walls). Inner components of hydraulic structures subject to a relative air humidity of 80 % or more.
WA	Concrete, which, in addition to class WF wear, is exposed to alkali frequently or for extended periods of time.	Concrete components of hydraulic structures which come into contact with seawater (underwater and fluctuating water level areas, spray water areas). Concrete components of hydraulic structures with de-icing salt exposure (e.g. subgrade areas of lock chamber walls).
WS	Concrete that is subject to high dynamic wear and direct alkali charge.	Not relevant to hydraulic engineering.

1) These examples apply to the predominant stress factors during service life. Past experience suggests that different ambient conditions during construction or use (e.g. drainage) do not cause damage.

2) Lock chamber floors and filling systems not subject to bed-load transport wear are normally not subject to concrete corrosion due to hydroabrasion.

Table B-3: Minimum concrete cover(British Standards Institution, 2008)

		Longitudinal steels		***Stirrups or spirals***	
Ambient conditions	**Exposure classes**	**≥ C40/50**	**< C40/50**	**≥ C40/50**	**< C40/50**
C	XC2/XC3	15	20	10	15
D	XC4	15	20	10	15
E	XD1/XS1	20	25	15	20
F	XD2/XS2	25	30	20	25