

بسم الله الرحمن الرحيم

Sudan University of Science & Technology (SUST)

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Structural Behavior of Power Transmission Towers

السلوك الإنشائي لأبراج نقل الطاقة الكهربائية

**A Thesis submitted for partial fulfillment for M Sc. Degree in
Civil Engineering (Structural Engineering)**

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بسم الله الرحمن الرحيم

قال تعالى :

(لَقَدْ أَرْسَلْنَا رُسُلَنَا بِالْبَيِّنَاتِ وَأَنْزَلْنَا مَعَهُمُ الْكِتَابَ وَالْمِيزَانَ لِيَقُومَ النَّاسُ بِالْقِسْطِ وَأَنْزَلْنَا
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الحديد : (25)

DEDICATIONS

This research is lovely dedicated to my parents whose words of encouragement and push for tenacity light on my way, my wonderful daughter Maryam and my friends who were always to my side. They support me a lot in doing this research.

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This dissertation would not have been possible without assistance of many, either directly or indirectly.

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ABSTRACT

This research is concerned with analysis and design of the power transmission towers. Three types of the power transmission towers were considered in this research to investigate their structural behavior. Data have been collected about the types of towers, their usage, and the types of the applied loads. The study concentrated on the 220 kV double circuit's Wawa-Wadi halfa Transmission Line Project, the three types of the transmission towers has different configurations and same height and conductor tension. SAP 2000 program was used to carry out structural analysis and design of transmission towers under different load cases.

The specifications involved were American Standards. Analysis results was used to make a comparison between three types of power transmission towers and to discuss their behavior under different load combination. The results consist of axial forces distribution on leg, displacements, weight due to dead load and elastic buckling. In analysis it was considered 6 buckling modes and was shown significant increment of buckling loads and buckling factors for each transmission tower.

The results indicates that displacement increases in direct proportion to height and that the axial force increase in inverse proportion to height, It was shown decrement the buckling load for each transmission tower models by applying dead and lateral load. The structural behavior of the transmission towers varies depending on the change of transmission towers configuration. Finally it was appeared transmission tower (2) was the most efficient configuration of transmission tower model because it was the most economical and lowest in design sections size, weight, member's density and axial forces distribution on leg.

المستخلص

أهتمت هذه الدراسة بتحليل وتصميم أبراج نقل الطاقة الكهربائية، حيث تم إعتبار ثلاثة أنواع من أبراج نقل الطاقه الكهربائيه ودراسة سلوكها الإنشائي تحت ظروف مختلفه من التحميل. شملت معلومات هذه الأبراج أنواعها، إستخداماتها وأنواع التحميل التي تعمل عليه. ركزت الدراسة على الأبراج المزدوجه ثنائيه الموصلات بمشروع أبراج دنقلا وادى حلفا استخدمت ثلاثه أنواع من الأبراج ذات قوة شد وإرتفاع موحدين وأشكال متباينه . أستخدم برنامج ساب 2000 لعمل النمذجة الأنشائية من اجل تحليل الأبراج والحصول علي النتائج التي من شأنها أن تسهم في عملية التصميم الآمن ، ودراسة السلوك الإنشائي لها تحت تأثير أحمال الرياح ووزنها الذاتي ، استخدمت المواصفات الأمريكيه في التحليل والتصميم وتم الحصول علي النتائج حيث شملت النتائج دراسة توزيع القوى المحوريه، الإزاحات ،تحليل ودراسة الإنبعاج الخطي لكل برج على حده. وأفادت مقارنة النتائج بان الاستطاله الناتجه عند تعرض البرج لاحمال تتناسب طرديا مع زيادة ارتفاع البرج كما تتناسبت القوه المحوريه في الذراع تناسبا عكسيا مع الارتفاع. وقد وجدت الدراسه ان السلوك الأنشائي للأبراج نقل الطاقة الكهربائيه يختلف تبعا لتغير تكوين هذه الأبراج وتشكيلها. وقد قررت الدراسه ان النموذج الثاني هو الافضل كفاءة لكونه ذو تصميم آمن ، إقتصادي والأقل حجما" في المقاطع التصميميه والوزن وتوزيع القوى المحوريه.

TABLE OF CONTENTS

Topic	Page No
الآية	I
Dedication	II
Acknowledgement	III
Abstract	IV
المستخلص	V
Table of contents	VI
List of figures	IX
List of tables	XI
CHAPTER 1 – INTRODUCTION	
1.1 Background	1
1.2 Objectives of the study	2
1.3 Research problem	2
1.4 Research methodology	2
1.5 Thesis outline	3
CHAPTER 2 - LITERATURE REVIEW	
2.1 Introduction	4
2.2 Geometric configurations	6
2.3 Main components of transmission line	7
2.3.1 Transmission tower	7
2.3.2 Conductors	10
2.3.3 Insulators	13
2.3.4 Earth wire (Ground wire)	15
2.3.5 Auxiliary components	15
2.4 Types of towers	15
2.4.1 Types according to structural function	15
2.4.1.1 Suspension towers	15
2.4.1.2 A dead-end tower and anchor tower	16
2.4.1.3 Transposition towers	18
2.4.1.4 Angle towers	19
2.4.2 Types according to purposes	19

2.4.2.1 Mild steel towers	19
2.4.2.2 Self-supporting towers	20
2.4.2.3 Guyed towers	21
2.4.2.4 Tubular towers	22
2.4.3 Other classifications	23
2.5 Loading system	24
2.5.1 Types of loads	24
2.5.1.1 Wind load	24
2.5.1.2 Dead load	25
2.5.1.3 Ice load	25
2.5.1.4 Earth quake load	25
2.5.1.5 Temperature load	25
2.5.1.6 Special load	25
2.5.2 Loading cases	25
2.5.3 Effect of temperature	26
2.5.4 Transverse forces on support structure	26
2.5.5 Combined loads	27
2.5.6 Conductor sags and tensions	28
2.6 Foundations of transmission towers	28
2.6.1 Classification of foundations in different soils	29
2.6.2 Type of loads on foundation	29
2.6.3 Stability analysis of transmission tower foundation	30
2.6.3.1 Resistance against Uplift of Transmission Tower Foundation	30
2.6.3.2 Resistance against down thrust of transmission tower foundation	30
2.6.3.3 Resistance against side thrust of transmission tower	31
2.6.4 foundation types	31
2.7 Bracing systems	34
2.8 Buckling in transmission tower	35
CHAPTER 3 – METHODOLOGY	
3.1 Introduction	37
3.2 Case study	38
3.2.1 Transmission line material classification	39
3.3 Analysis of towers	39
3.3.1 Introduction of analysis using SAP 2000	39

3.3.2 Description of the structural analysis modules	40
3.3.3 Steps of analysis	40
3.3.3.1 Defined of transmission tower	40
3.3.3.2 Assign joints and joints load	43
3.3.3.3 Models analysis	44
3.3.3.4 Display results	45
3.4 Transmission tower design	45
3.4.1 Climatic loads	45
3.4.2 Design consideration	45
3.4.3 Design basis	46
3.4.4 Design approaches for steel transmission towers	46
3.4.5 Design parameters	46
CHAPTER 4 ANALYSIS AND DESIGN OF POWER TRANSMISSION TOWERS USING SAP 2000	
4.1. Introduction	47
4.2 Power transmission towers modules	47
4.3Assign load on tower cross arm	57
4.4 Wind load calculation	58
4.5Design of towers	61
4.5.1Case study design data and climatic data	61
4.6 Structure analysis and design results	62
4.7 Relationship between height, displacement and axial force	69
4.8 Buckling in transmission towers members	74
4.9 Final Design of transmission towers	78
4.10. Comparison between design sections results and company design sections	81
4.11 Discussion of Results	82
CHAPTER 5 CONCLUIONSAND RECOMMENDTIONS	
5.1 Conclusions	85
5.2 Recommendation	85
References	87
Appendix A	89
Appendix B	92
Appendix C	93
Appendix D	94
Appendix E	95

LIST OF FIGURES

Figure 2.1: Main parts of power transmission tower	08
Figure 2.2: Height of transmission tower	09
Figure 2.3: Conductor arrangements for different CSR combinations	12
Figure 2.4: Line post and cap-and-pin insulators	14
Figure 2.5: Long rod insulators	14
Figure 2.6: Typical application of in - slating cross arms	14
Figure 2.7: Suspension steel tower	16
Figure 2.8: Dead end tower	17
Figure 2.9: Transposition Tower	18
Figure 2.10: Guyed tower	22
Figure 2.11: Tubular steel Poles	23
Figure 2.12: Combined loads	27
Figure 2.13: Bracing systems	35
Figure 3.1: New model window	40
Figure 3.2: Data input	41
Figure 3.3: Define load patterns	42
Figure 3.4: Define load combinations	43
Figure 3.5: Assign joint constraints	43
Figure 3.6: Assign joint load	44
Figure 4.1, Tower one configuration (Side view)	51
Figure 4.2, Tower two configuration (Side view)	52
Figure 4.3, Tower three configuration (Side view)	51
Figure 4.4, Tower one (3Dview)	54
Figure 4.5, Tower two (3Dview)	55
Figure 4.6, Tower three (3Dview)	56
Figure 4.7: Cross arm loading	57
Figure 4.8: Relation between height and displacement Transmission tower 1, combination 2	69
Figure 4.9: Relationship between height and displacement Transmission tower 1, combination 3	70
Figure 4.10: Relationship between height and axial force in legs Transmission tower 1, combination 2	70

Figure 4.11: Relation between height and displacement Transmission tower 2, combination 2	71
Figure 4.12: Relationship between height and displacement Transmission tower 2, combination 3	72
Figure 4.13: Relationship between height and axial force in legs Transmission tower 2, combination 2	72
Figure 4.14: Relation between height and displacement Transmission tower 3, combination 2	73
Figure 4.15: Relationship between height and displacement Transmission Tower 3, Combination 3	73
Figure 4.16: Relationship between height and axial force in legs Transmission tower 3, combination 2	74
Figure 4.17: Buckling load diagram of transmission tower (1) for all load combinations.	75
Figure 4.18: Buckling load diagram of transmission tower (2) for all load combinations.	75
Figure 4.19: Buckling load diagram of transmission tower(3) for all load combinations.	76
Figure 4.20: Axial force diagram (Buckling in cross arm) - transmission tower (1)	76
Figure 4.21: Axial force diagram (Buckling in cross arm) - transmission tower (2)	77
Figure 4.22: Axial force diagram (Buckling in cross arm) - transmission tower (3)	77
Figure 4.23: Steel frame design preferences for AISC-ASD89.	78
Figure.4.24 Comparison of buckling load of three transmission towers under load case (BUCK 1)	84
Figure.4.25 Comparison of buckling load of three transmission towers under load case (BUCK 2).	84

LIST OF TABLES

Table 4.1: Data input of transmission tower 1	48
Table 4.2: Data input of transmission tower 2	49
Table 4.3: Data input of transmission tower 3	50
Table 4.4: Tension for tower design	57
Table 4.5: Wind directionality factor, k_d	59
Table 4.6: Importance factor, I (wind load)	59
Table 4.7: Velocity pressure exposure coefficient K_z	60
Table 4.8: Joint Reactions - tower one	63
Table 4.9: Maximum axial force – tower one	64
Table 4.10: Joint Reactions – tower two	65
Table 4.11: Maximum axial force – tower two	66
Table 4.12: Joint Reactions – tower three	67
Table 4.13: Maximum axial force – tower three	68
Table 4.14: Transmission Tower one- Design sections	79
Table 4.15: Transmission Tower two- Design sections	79
Table 4.16: Transmission Tower three - Design sections	70
Table 4.17: Transmission Towers weight and Total numbers of members	70
Table 4.18: Design sections properties	81

CHAPTER 1

INTRODUCTION

CHAPTER 1

INTRODUCTION

1.1 Background

Transmission towers is the main supporting unit of overhead transmission electrical line. Transmission towers have to carry the heavy transmission conductor at a sufficient safe height from ground [1]. In addition to that all transmission tower have to sustain all kinds of natural calamities. The transmission towers are structural objects compose of members made of carbon steel , they are used for transmitting the extreme importance of energy in life, there comes the importance of wide generation of electricity to cover the needs related to it. The generation of electrical energy is done in vast stations. The main part of these stations is the generator, which produce the energy .It is necessary to transport the produced energy to distance relatively away, so that the consumer can make use of it. During the transmission process there appears the problem of the losses in transmission lines .To face these difficulties, it was necessary to raise produced voltage so as to reduce the losses. Many voltages appeared such as 33kV, 66 kV, 70 kV, 150 kV, 110kV, 220 kV and 400kV...etc. Safety regulation requires that a specified ground and wire clearance for each voltage should be made. Therefore many types of steel transmission line towers were used to carry conductors, shield wires, and other related equipments and accessories. The cost of transmitting electric power to the consumers is embrace, of which cost of the towers may range between 20 to 25 percent. So, any improvement in the design of towers can reduce the total cost. It is for this reason and since all the towers constructed in Sudan have been designed by foreign companies, this research has been conducted. The study

will concentrate on the 22 0kv towers because more than 50 percent of transmission lines in Sudan use this type.

1.2 Objectives of the study

This study considered different types of power transmission towers. Analysis and design of three different configurations of power transmission towers was performed under different loading conditions. The objectives of the study is

- To make a comparison between some different configurations of power transmission towers under different load cases.
- To perform analysis and design of towers using software program SAP2000.
- To study structural behavior of three power transmission towers.
- To know types of towers and their components.

1.3 Research problem

The main problem of this research is to select the most efficient configuration of transmission tower model. This must be achieved by studying three different transmission towers under different load cases.

1.4 Research methodology

The methodology adopted to achieve the above mentioned objectives of this study are:

- 1- To consider the previous studies in analysis and designed of transmission towers including the configurations and the loadings conditions.
- 2- SAP 2000 program used to give structural analysis modules .Then, the main features of the proposed work will be pointed out.

3-Three types of the power transmission towers considered in this research were analyzed to study their structural behavior under different load cases using Allowable Stress Design (ASD) according to American Institute for Steel Construction (AISC).

1.5 Thesis outline

This research contains five chapters. Chapter 1 gives brief introduction, objectives and research methodology, Chapter 2 study the transmission towers including introduction, historical background, types of power transmission towers, types of load acting on towers and the type of their foundation. Chapter 3 gives the methods and steps to analyze and design of power transmission towers using structural analysis program SAP2000. Chapter 4 gives configuration of the three transmission towers, assign loads to analysis and design transmission towers and discusses the results. Chapter 5 covers conclusion and recommendation.

CHAPTER 2

LITERATURE REVIEW

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Transmission line towers are usually latticed steel structure .In addition to their self-weight; the main loadings acting on them are the weight of the wires and accessories, and the wind load acting on the wires and the towers. Transmission line towers are an economic solution for transportation and distribution of electricity over all countries, which needs power for its large development and progression. The increase in production of electricity power nowadays is credited to the large distribution of dams and electricity stations. For all these reasons countries need this kind of establishment and construction to satisfy their needs. Due to the importance of this type of structures special codes of practice and specification were issued to deal with their design and construction.

The first guide for design of steel transmission towers was issued by the American Society of Civil Engineers (ASCE) [2]. Then after, the American Society of Civil Engineers established a committee to develop a standard for the design of latticed steel transmission structures .This standard has been completed in 1990 and approved by the American National Standards Institute (ANSI), in December 1991.Then published as ANSI/ASCE 10 in 1992 and updated in 1997.Substantial efforts has been going on to improve methods for determining structural loads on transmission line structures. The task committee on structural loading of electrical transmission structures has gathered ,discussed and presented results of these effort as an ASCE Manual No.74 in 1991 .The manual presented detailed guidelines and procedures for dev eloping transmission line structure loads. In addition to the ASCE, the Institute of

Electric and Electronic Engineers (IEEE) has issued some publications concerning their recommendations and safety regulations in order to have a good background on the design of steel transmission line tower.

The first transmission of electrical impulses over an extended distance was demonstrated on 14th of July 1729 by physical Stephen Gray, in order to show that one can transfer electricity by that method. The demonstration used damp hemp cords suspended by silk threads (the significance of metallic conductors not being appreciated at that time). However the first practical use of overhead lines was in the context of telegraphy. In 1873 experimental commercial telegraph systems ran as far as 13 miles (20 km). Electric power transmission was accomplished in 1882 with the first high voltage transmission between Munich and Bad Brook. 1891 saw the construction of the first three-phase alternating current overhead line on the occasion of international Electricity Exhibition in Frankfurt, between Lauffen and Frankfurt.

In 1912 first 110kV –overhead power line entered service followed by the first 220 kV –overhead power line in 1923. In 1920 RWE AG (Rheinisch-Westfälisches Elektrizitätswerk AG-a German electric utilities company) built the first overhead power line for this voltage and in 1926 built a Rhine crossing with the pylons of Voerde, two masts 138 meters high. In Germany in 1957 the first 380 kV overhead power line was commissioned (between the transformer station and Rommerskirchen). The construction of the highest overhead line pylons of the world started in 1997 in Russia, and also in the USA Canada, overhead lines for voltage 765kV were built in 1982 overhead power lines were built in Russia between Elketrostal and the power station at Elkibastuz, this was three-phase alternating current line at 1200 kV (powerline Elkibastuz-kokshetau). In 2003 the building of the highest overhead line commenced in China, the Yangtze River Crossing [1].

2.2 Geometric configurations

The geometric configuration of a latticed transmission tower is based on the overhead ground wire shield coverage, number of circuits, conductor phase arrangements selected to satisfy the electrical and mechanical clearances, right of way requirements, and aesthetic design criteria. Three basic tower definitions recommended are: suspension, strain, and dead end structures. The conductor phases pass through and are suspended from the insulator support points of a suspension tower. The strain tower conductor attachment points are made by attaching the conductor to a dead-end clamp, a compression or bolted fitting, and connecting the damply through the insulator string, directly to the tower. The jumper looped through or around the tower body to electrically connect the adjacent spans. Dead-end tower conductor attachments are the same as for the strain tower. Generally, dead-end tower have different tensions or conductor sizes on each side of the structure; this creates an intact unbalanced longitudinal load. Overhead ground wires are attached to the tower using similar methods as outlined for the conductors [1].

The nomenclature for the basic tower types is used to help to identify the line angle at a particular structure caused by a change in direction of the line. The term “tangent” is prefixed to the basic tower type for zero line angle and the term “angle” is used when there is a line angle. Therefore, the following terminology is recommended: tangent suspension, angle suspension, tangent strain, angle strain, tangent dead end, and angle dead end.

2.3 Main components of transmission line

2.3.1 Transmission tower

Transmission tower consists of the following parts:

- 1- Peak of transmission tower: The portion above the top cross arm is called peak of transmission tower. Generally earth shield wire connected to the tip of this peak.
- 2- Cross arm of transmission tower: Cross arms of transmission tower hold the transmission conductor. The dimension of cross arm depends on the level of transmission voltage, configuration and minimum forming angle for stress distribution.
- 3- Boom of transmission tower.
- 4- Cage of transmission tower: The portion between tower body and peak is known as cage of transmission tower. This portion of the tower holds the cross arms.
- 5- Transmission Tower Body: The portion from bottom cross arms up to the ground level is called transmission tower body. This portion of the tower plays a vital role for maintaining required ground clearance of the bottom conductor of the transmission line.
- 6- Leg of transmission tower.
- 7- Stub/Anchor Bolt and Base plate assembly of transmission tower.

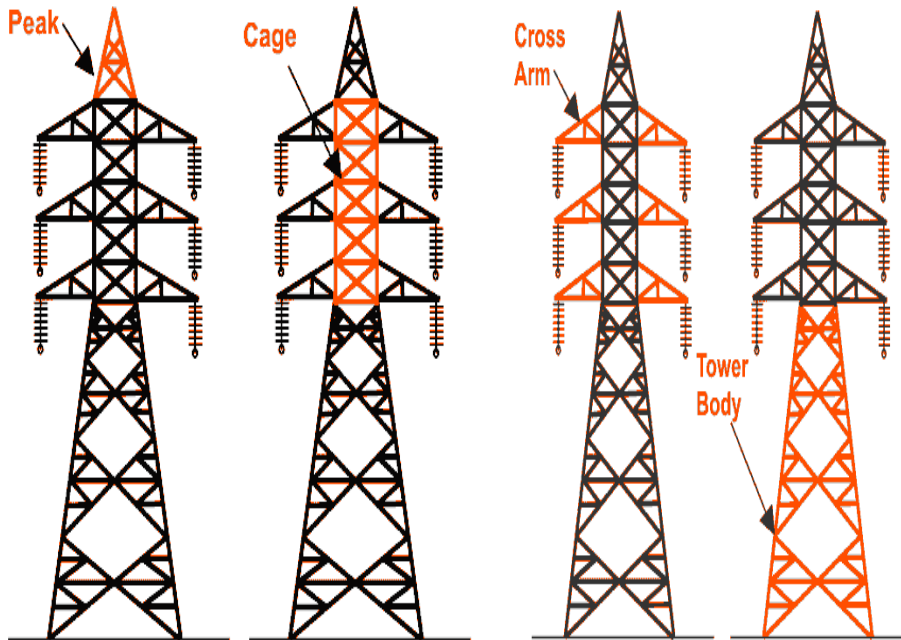


Figure 2.1: Main parts of power transmission tower [3].

The configuration of a transmission line tower depends on following points [4]

- a) The minimum ground clearance of the lowest conductor point above the ground level.
- b) The length of the insulator string.
- c) The minimum clearance to be maintained between conductors and between conductor and tower.
- d) The location of ground wire with respect to outer most conductors.
- e) The mid span clearance required from considerations of the dynamic behavior of conductor and lightning protection of the line.

To determine the actual transmission tower height by considering the above points, the total height of tower were divided into four parts as follows [4]

1. Minimum permissible ground clearance (H_1)
2. Maximum sag of the conductor (H_2)
3. Vertical spacing between top and bottom conductors (H_3)
4. Vertical clearance between ground wire and top conductor (H_4).

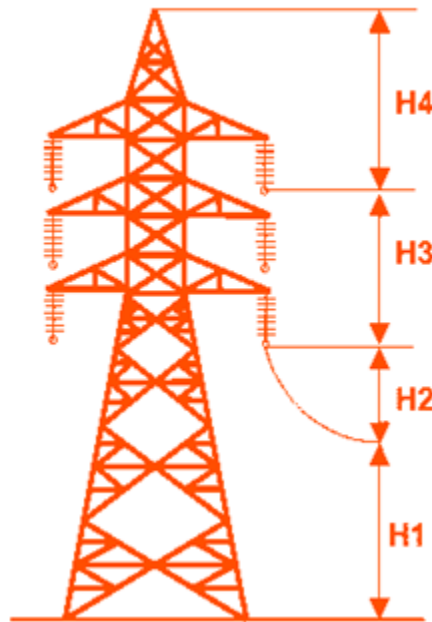


Figure 2.2: Height of transmission tower [4].

2.3.2. Conductors

Overhead power lines are aimed at reasonable and reliable transmission of electric energy between two points. The conductors carry the electric energy and are the most important components of an overhead power line. The expenditures necessary to purchase and install them is about 30 to 50 % of the total investment for an overhead line [1]. Many different types of conductors have been used since overhead lines were first installed. In many industrial countries there are standards for conductors, and also international ones from IEC [7.1] [5] and CENELEC [7.2] [6]. US American standards like [7.3, 7.4] [7] and [7.5] [8] are of widespread use as well. The European standards (EN standards) replaced the national standards valid up to now in European countries; e. g. in Germany the conductor standards of the DIN 48200 series. From the standards, the best-suited conductor can be selected for a specific application.

Besides that, special overhead conductors can also be manufactured, whenever deemed necessary. According to [7.6], conductors are bare or covered, insulated or earthed cables strung between the supports of an overhead line, irrespective of whether they are alive or not. Bundle conductors are arrangements of two or more sub conductors used instead of a single conductor and usually kept at an approximately constant spacing on their entire length. According to [7.7] [9], conductors are wires or combinations of wires not insulated and suitable for carrying an electric current. Conductors can be wires, stranded conductors or cables made of electrically conductive materials. Also according to with the definition given in [17.6], non-metallic optical fiber cables are used for telecommunication purposes.

Conductors are made either of one material - single material- conductors or of two materials – composite material conductors. Single- material conductors can

be formed by mono- metallic or metal-clad steel wires. Composite conductors include combinations of mono-metallic and metal-clad steel wires. Aluminum and aluminum alloys, copper and copper alloys are applied as base materials, as well as steel. The conductors are manufactured with at least one or more successive layer with changing layer direction, arranged helically around a core wire. The direction of layer is designed as right-hand or left-hand. With right-hand layer, the wires conform to the direction of the central part of the letter Z when the conductor is held vertically. With left-hand layer, the wires conform to the central part of the letter S when the conductor is held vertically. The outermost layer is preferably right-hand. The standards listed in Table 2.1 contain conductors often used for overhead power lines. Beside the compositions and conductor structures mentioned there, other designs can be found in national standards. Not-standardized special conductor types, in particular types with integrated optical fibers, are adopted as well.

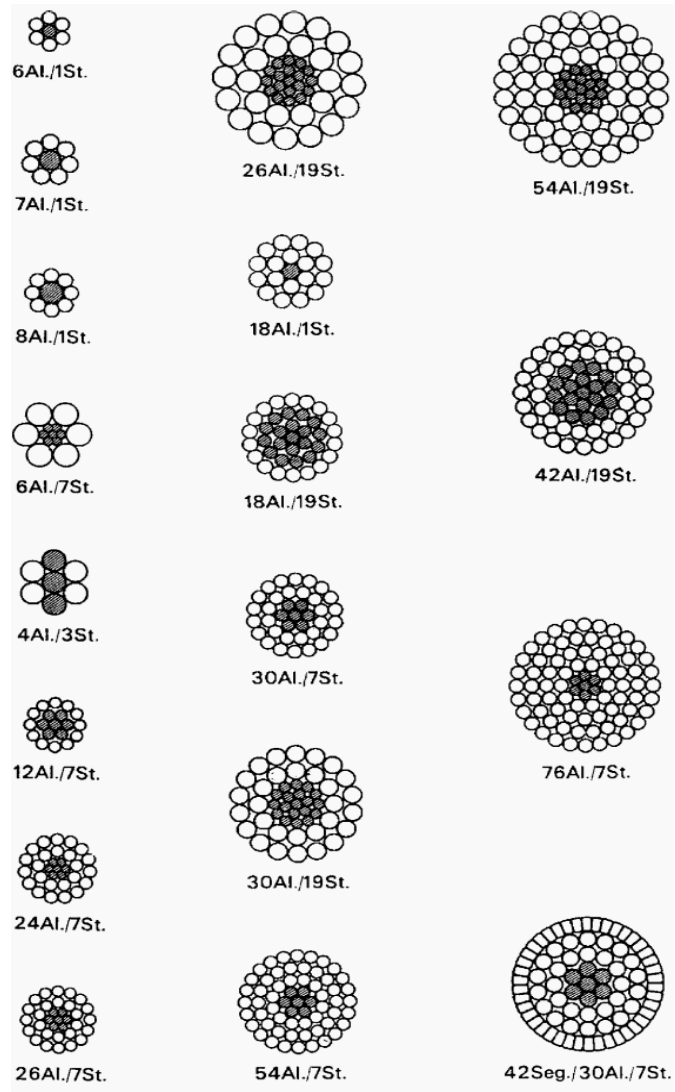


Figure 2.3: Conductor arrangements for different CSR combinations [1].

2.3.3 Insulators

The insulators are overhead line components installed between live conductors and earthed parts of the structures, being simultaneously subjected to mechanical and electric stresses. The insulation performance needs to be designed for the most adverse operating conditions resulting from climatic impacts, such as ambient temperatures, humidity, dew, fog, rain, as well as pollution by deposits of dusts, salts, firing residuals and industrial gases. The mechanical resistance should be so high that every incident load is carried with enough operational security [1]. Disruptive strength and electrical arc resistance should be large enough to withstand the resulting stresses.

Definitions can be found in **The International Electro technical Commission IEC 60 050-471** [9.1] firur [10]. Porcelain as the first insulator material developed has been used until today, though with improved composition design. Toughened glass, plastic of different types and a recipes appeared standards that are used for a long time ago as insulator raw materials International reflect the high quality available today, but do not exclude new raw materials and further development to new insulator types and designs. According to IEC 60 383-1 [9.2] [11], overhead line insulators are classified in two types, type A and type B, respectively. Type an insulators are characterized by the fact that the length of the shortest puncture path through the insulating body is at least half of the flashover path on the insulator surface. This applies to long rod insulators. Such insulators are considered as puncture-proof. Insulators for which the length of the shortest puncture path through the body is less than the half of the flashover path are classified as type B insulators for instance cap-and-pin insulators and line post insulators. They are considered as not puncture-proof. According to present technology, puncture-proof solid-core insulators cannot be manufactured from glass.

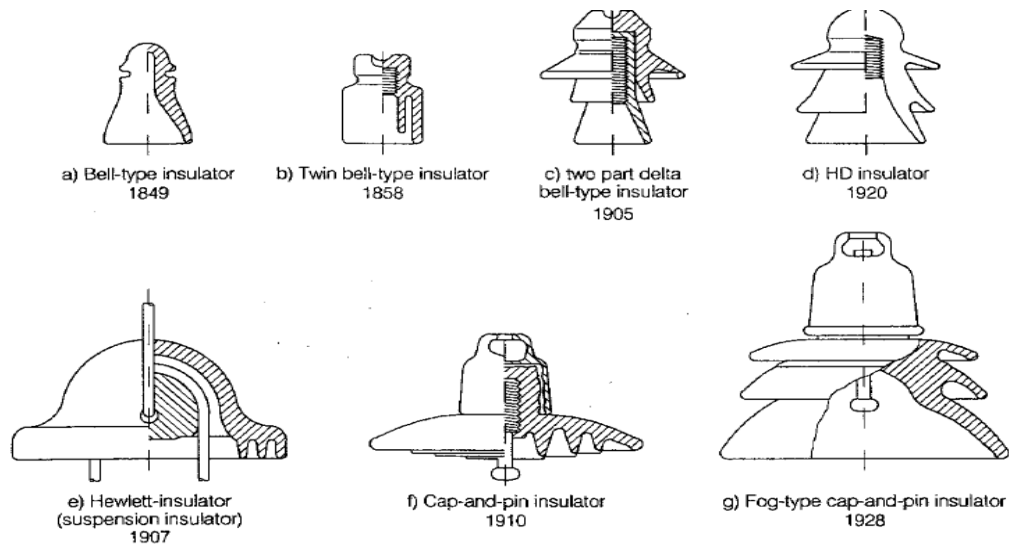


Figure 2.4: Line post and cap-and-pin insulators [1].

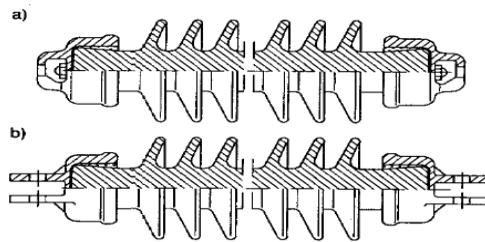


Figure 2.5: Long rod insulators: a) With socket caps b) With clevis caps.

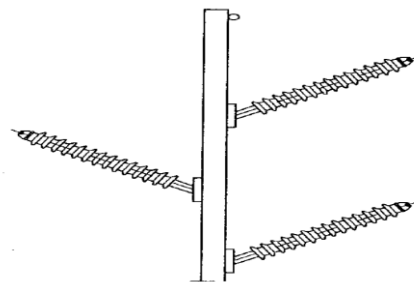


Figure 2.6: Typical application of in - slating cross arms.

2.3.4 Earth wire (Ground wire)

The earth wire used to protect the tower from the thunder shocks and also used for telecommunication services.

2.3.5 Auxiliary components

- 1- Compression Joints.
- 2- Vibration Dampers.
- 3- Copper Earth Bounds.
- 4- Clamp.
- 5-Cable connector.

2.4 Types of towers

According to different classifications, there are different types of transmission towers:

2.4.1 Types according to structural function

2.4.1.1 Suspension towers

This tower is supposed to carry a downward force, and a lateral force, but not a longitudinal force. These may have, for each conductor, an insulator string hanging down from the tower, or two strings making a "V" shape. In either case, sometimes several insulator strings are used in parallel to give higher mechanical strength. These are used where a transmission line continues in a straight line, or turns through a small angle [1]. Figure 2.7 show the assembly of suspension steel tower.



Figure 2.7: Suspension steel tower.

2.4.1.2 A dead-end tower and anchor tower

Is a fully self-supporting structure used in construction of overhead transmission lines. A dead-end tower uses horizontal strain insulators and where the conductors mechanically terminate. Dead-end towers may be used at a substation as a transition to a "slack span" entering the equipment, when the circuit changes to a buried cable, when a transmission line changes direction by more than a few degrees, or just once in a while to limit the extent of a catastrophic collapse.

Since dead-end towers require more material and are heavier and expensive than suspension towers, it is uneconomic to build a line with only self-

supporting towers. Dead-ends towers are used at regular intervals in a long transmission line to limit the cascading tower failures that might occur after a conductor failure. An in-line dead-end tower will have two sets of strain insulators supporting the lines in either direction, with the lines connected by a jumper between the two segments. Dead-end towers can resist unbalanced forces due to line weight and tension, contrasted with suspension towers which mostly just support the conductor weight and have relatively low capacity for unbalanced load. Dead-end towers may use earth anchor cables to compensate for the asymmetric attachment of the conductors. They are often used when the power line must cross a large gap, such as a railway line, river, or valley. They may be constructed of the same materials as other structures of the line. They may be steel or aluminum lattice structures, tubular steel, concrete, or wood poles [1]. Figure 2.8 show dead end tower.



Figure 2.8: Dead end tower.

2.4.1.3 Transposition towers

Is a transmission tower that changes the relative physical positions of the conductors of a transmission line. A transposition tower allows these sections to be connected together, while maintaining adequate clearance for the conductors. This is important since it balances electrical impedances between phases of a circuit. Double-circuit lines are usually set up with conductors of the same phase placed opposite each other. This reduces the reactance due to mutual inductance; the reactance of both circuits together is less than half that of one circuit. For example, a section of a line may be (top-to-bottom) phases A-B-C on the left, also phases C'-B'-A' on the right. The next section may be B-C-A on the left, also A'-C'-B' on the right. Therefore the rotation on each side of the tower will be opposite [3]. Figure 2.9 show transposition tower.

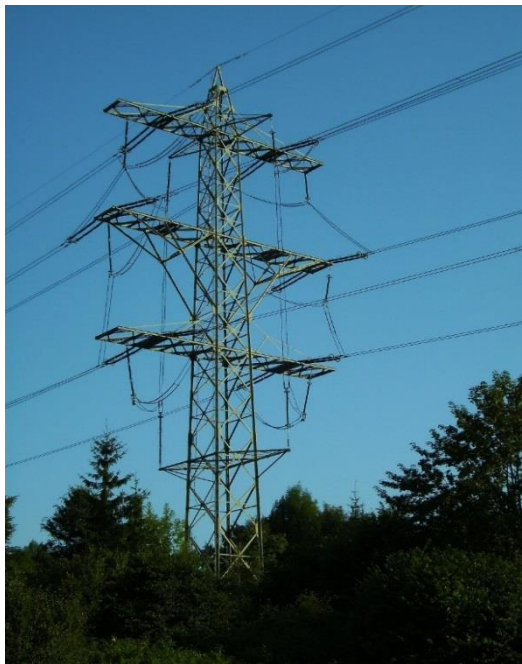


Figure 2.9: Transposition Tower.

2.4.1.4 Angle towers

The transmission line goes as per available corridors. Due to unavailability of shortest distance straight corridor transmission line has to deviate from its straight way when obstruction comes. In total length of a long transmission line there may be several deviation points. According to the angle of deviation there are four types of transmission tower [3]:

1. A – type tower – angle of deviation 0° to 2° .
2. B – type tower – angle of deviation 2° to 15° .
3. C – type tower – angle of deviation 15° to 30° .
4. D – type tower – angle of deviation 30° to 60° .

2.4.2 Types according to purposes

Serviceability requirements vary greatly depending on the purpose of its location. Steel towers and connection are normally galvanized and are also painted with durable paint system if the environment is likely to be polluted or corrosion may happen. There for regular maintenance is carried out; such that climbing access is normally provided for inspections.

Deflections of towers are generally significant only if they would result in loss of Serviceability. This can be critical for the design of telecommunication structures using dish antennas [1].

2.4.2.1 Mild steel towers

It is manufactured from galvanized with high tensile mild steel metal. Our clients offer an exclusive range of superior quality mobile phone communication steel tower at minimal cost.

2.4.2.2 Self-supporting towers

A single circuit structure may have phases in horizontal (flat) configuration, a vertical configuration or in a delta configuration. The horizontal configuration provides the lowest profile, the vertical configuration requires the minimum width right-of-way, and the delta configuration can reduce electrical line losses [1].

The conductor phases for a double circuit tower can be replaced directly over one another. An alternative is to offset the phases horizontally, this is usually the practice where ice un loading (steel jump) or galloping conductors is possible. Offsets also provide clearance to minimize possible contact between wires during stringing. A delta phase configuration can be also used.

The development of the tower configuration starts with upper portion. This section of the tower is designed for the selected vertical and horizontal phase spacing and electrical clearances around each conductor. The configuration should be as compact as possible around conductor. The lower portion of the tower is designed next. The wider the tower base smaller the footing loads, but widening the tower base increases the length and weight of bracing members. Therefore, an economical balance must be reached between the tower base width and the size of the bracing members. This is controlled by the face slope or level; the tower legs which vary from $1/6$ to $1/5$ normally the heavier towers will have the larger face slopes.

The arrangement of the tower members should keep the tower geometry simple by using as few members as possible. Ideally, the tower members should be fully stressed under more than one loading condition. The ultimate goal is to strive for an economical structure that is well proportioned and attractive.

The web bracing can be designed using tension-compression system, a tension system, or combinations of these systems. For towers with high web member

stresses under intact or stringing conditions, such as dead-end or angle towers with over 20° line angle, it is common practice to use a tension-compression bracing system.

Typical transmission towers have square body configuration, and in the tower section the bracing in all faces is identical. Rectangular configurations have been used very successfully when proper attention is given to the longitudinal strength. This configuration has less duplication of pieces in addition, closer attention must be given to foundation movements due to the increased height-to-width ratio of the longitudinal faces of the structure. Variable tower heights are obtained by adjusting the heights of leg extension and/or adding tower body extension. Heights of leg extensions can vary from 5 to 50 ft.

2.4.2.3 Guyed towers

Guyed towers[12] are often used for single circuit lines. Typical guyed tower configurations are guyed-portal, guyed-vee, guyed-wye, guyed-laced columns of guyed structures have tension-compression bracing systems. Long slender laced columns must be designed as beam columns. Shear deformations from wind loads and eccentricities can reduce the buckling capacity of the overall column. The analysis of chainette structure requires that the tower assembly be considered under the displacement of the conductor support. transverse loading. Generally, guyed towers are used in flat to rolling terrain. They can be used in rough terrain if guy slopes are sufficiently steep so that the downhill guy leads are not excessively long.



Figure 2.10: Guyed tower.

2.4.2.4 Tubular steel poles

These poles are being used on city streets and in congested areas where a wide right-of-way cannot be gained. They have been used for voltages up to and including 345 kV. Figure 2.11 show tubular steel poles [12].



Figure 2.11: Tubular steel poles.

2.4.3 Other classifications

As per the force applied by the conductor on the cross arms, the transmission towers can be categorized in another way:

- Tangent suspension tower and it is generally A - type tower.
- Angle tower or tension tower or sometime it is called section tower, all B, C and D types of transmission towers come under this category.

Apart from the above customized type of tower, the tower is designed to meet special usages listed below these are called special type tower:

- River crossing tower.
- Railway/ Highway crossing tower.
- Transposition tower.

Based on numbers of circuits carried by a transmission tower, it can be classified as:

1. Single circuit tower.
 2. Double circuit tower.
- Multi circuit tower.

2.5 Transmission tower loads

2.5.1 Type of loads

Electric power transmission structure must be designed to resist the following loads [12].

2.5.1.1 Wind loads

Wind code use a simple quasi static method of assessing the wind load, which has some limitations for calculating the along wind response but it adequate for majority of structure. Tower structure with aerodynamically solid section and some individual member can be subject to aero elastic wind forces, Caused by vortex shedding galloping. Flutter and a variety of other mechanisms which are either poorly covered or ignored by current codes such as factors have been responsible for more tower collapses and serviceability failure worldwide than any fall in resistance to along wind loads. Wind loads specify in terms of design wind speed either mean hourly or gust, that will recur on average once in 50 years period (with an annual probability of 2%) , guidance is sometimes given on wind shape factors for typical section and lattices. Wind loads classified to:

- a) Non – snowy region.
- b) With ice snowy regions.
- c) Without ice snowy regions.

2.5.1.2 Dead loads

- a) Weight of tower.
- b) Weight of conductors.
- c) Hardware and insulators.

2.5.1.3 Ice load

The radial thickness of ice applied uniformly around the exposed surface of structure type of ice is also covered but neither mentions the very significant influence of topography on the form actions of ice. To be subject to icing well in excess of the code requirement. The combination of wind and ice loads is even less well understood although some guidance is gives.

2.5.1.4 Earth quake force

This are significant in the design of some tower especially those supporting water tank.

2.5.1.5 Temperature load

In the design of guyed towers the stress resulting from temperature changes in the guys must be considered.

2.5.1.6 Special loads

It is external loads during construction and maintenance.

2.5.2 Loading cases

The loads on transmission line tower consist of three mutually perpendicular systems of load acting vertical, normal to the direction of line, and parallel to the direction of the line. It has been found convenient in practice to standardize the loads as under [4]:

- (a) Weight of structure
- (b) Vertical loads are weight of conductors and earth wire and structures as well as down – pull caused by level differences between towers, which is taken into account when determining the weight span.
- (c) Transverse loads are caused by wind and horizontal pull from deviation angle in the line.
- (d) Longitudinal loads are caused by pretension of conductor tension on one side only of tension towers and by an abnormal (broken wire) load on suspension towers, subject to definition by standards or national of practice.

2.5.3 Effect of temperature

The effect of temperature appearance as stresses in member always may be small effect. But the real effect of change in temperature appearance in conductor as sag and tension stresses for that the effect of change in temperature is considered to take place after the wires is relived of all stress thus eliminating the complicated adjustments between change In length due to temperate and change in stretch from the resulting change in tension [4].

2.5.4 Transverse forces on support structure

Transverse forces acting on towers or poles are due to wind on the conductors and ground cables (and ice coating if in ice districts), wind on the structure, and horizontal components of the tensions in the cables at angle turns in the line. The stress due to an angle in the line is computed by finding the resultant force produced by the wires in the two adjacent spans [4].

2.5.5 Combined loads

The simultaneous application of individual worst caseloads is unlikely to occur in practice and the simple arithmetic addition of all such load cases would lead to an uneconomic and over – engineered solution. The individual loads are therefore factored to arrive at a sensible compromise [3] . For example. wind load plus ice load is often taken as full ice loading plus wind load at , say , 50 % basic wind speed . Similarly, wind load plus seismic load is normally taken as full earthquake load plus 50 % wind load. The forces involved on an overhead line tower are shown in figure, (2.12).

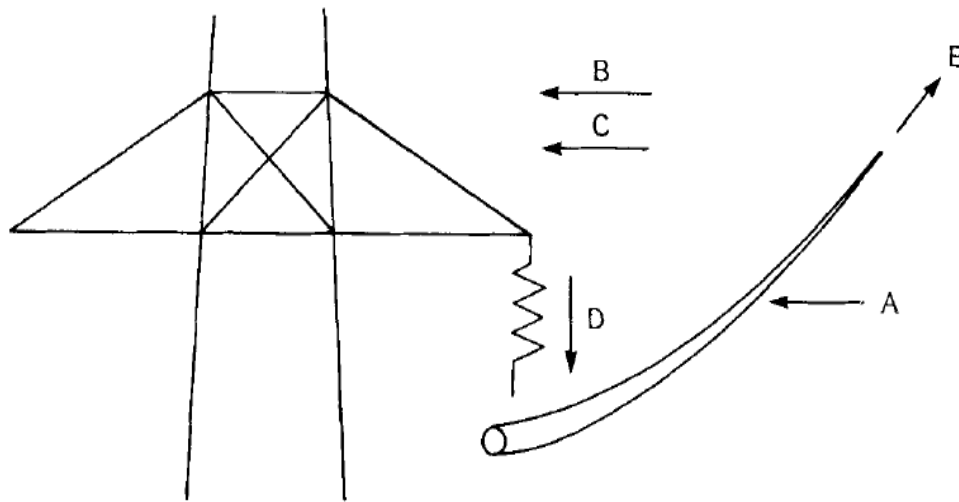


Figure 2.12: combined loads.

A=horizontal conductor wind load.

B= horizontal structure wind load.

C=component of wind loading due to direction of wind and effective structure area normal to the wind.

D= Vertical conductor weight span.

E=longitudinal loads due to conductor tension.

This will occur under uneven loading , such as for broken wire condition or at a terminal tower with a slack span on one side of the tower entering to a substations gantry these forces will , in general , result in a turning moment causing compression on one side of a tower and tension (‘ uplift ‘) on the opposite side[12].

2.5.6 Conductor sags and tensions

Variations in conductor sags tensions result from changes in temperature and loading and conductors must be strung to that sage do not exceed that which ground clearance permits, nor do tensions exceed the required factors of safety [4].

2.6 Foundations of transmission towers

Foundation of any structure plays an important role in safety and satisfactory performance of the structure as it transmits mechanical loads of the electrical transmission system to ground. A transmission structure without having a safe foundation, it cannot perform the functions for which it has been designed. The foundations in various types of soils have to be designed to suit the soil conditions of particular type [3]. In addition to foundations of normal towers, there are situations where considering techno-economical aspect for special towers required or river crossing which may be located either on the bank of the river or in the mid-stream or both, pile foundation may be provided. There are many suitable types of tower foundations such as steel grillages, pressed plates, concrete footings, precast concrete, rock foundations, drilled shafts with or without bells, direct embedment, pile foundations, and anchors.

2.6.1 Classification of foundations in different soils

The transmission tower may be situated in different locations. Power System transmission networks are being spreading all over the world. The soil condition of different places are also different. Depending upon the nature of soil, the type's foundation of transmission towers should be selected and constructed accordingly. There is a brief Guidelines for classification of foundations of transmission towers in different soil conditions. See Table A-1 appendix A.

2.6.2 Type of loads on foundation

The foundation of towers are normally subjected to three types of forces. These are:

- (a) The compression or downward thrust.
- (b) The tension or uplift.
- (c) The lateral forces of side thrusts in both transverse and longitudinal directions.

The magnitude or limit loads for foundations should be taken 10% higher than these for the corresponding towers.

The base slab of the foundation shall be designed for additional moments developing due to eccentricity of the loads.

The additional weight of concrete in the footing below ground level over the earth weight and the full weight of concrete above ground level in the footing and embedded steel parts also be taken into account; adding to the down-thrust.

Soil parameters for designing the foundations, following parameters are required [4].

(a) Limit bearing capacity of soil.

(b) Density of soil.

(c) Angle of earth frustum.

The above values will be estimated according to the soil classifications.

2.6.3 Stability analysis of transmission tower foundation

In addition to the strength design, stability analysis of the foundation shall be done to check the possibility of failure by overturning, uprooting of stubs, sliding and tilting of foundation etc. The following primary type of soil resistance shall be assumed to act in resisting the loads imposed on the footing in earth [3].

2.6.3.1 Resistance against uplift of foundation of transmission tower

The uplift loads shall be assumed to be resisted by the weight of earth in an inverted frustum of a pyramid of earth whose sides make an angle equal to the angle of report of the earth with the vertical in average soil. The volume of earth computation shall be as per enclosed drawing. The weight of concrete embedded in earth and that above the ground level shall also be considered for resisting the uplift.

2.6.3.2 Resistance against down thrust of transmission tower foundation

The following load combinations shall be resisted by the bearing strength of the soil:

(1) The down thrust loads combined with an additional weight of concrete above earth are assumed to be acting on the total area of the bottom of the footing.

(2) The moment due to side thrust forces at the bottom of the footing.

The structural design of the base slab shall be developed for the above load combination. In case of toe pressure calculation due to above load combination the allowable bearing pressure to be increased by 25%.

2.6.3.3 Resistance against side thrust of transmission tower foundation

The chimney shall be designed as per limit state method for the combined action of axial forces, tension and compression and the associated maximum bending moment. In these calculations, the tensile strength of concrete shall be ignored.

2.6.4 Foundation types

The results from the soil investigation allow the civil engineer to decide which type of foundation will most economically support the structure. The actual practical solution will take into account the access requirements for a piling rig, availability and transportation of materials. Large concrete raft type platforms are used where the upper layers of soil have relatively low bearing capacities. This type of foundation will evenly distribute the load over a wide area thus avoiding potential bearing capacity failure [12].

(a) Steel grillages

These foundations consist entirely of steel members. The surrounding soil should not be considered as bracing the leg. There are pyramid arrangements that transfer the horizontal shear to the base through truss action. Other types transfer the shear through shear members that engage

the lateral resistance of the compacted backfill. The steel can be purchased with the tower steel and concrete is not required at the site [12].

(b) Cast in place concrete

Cast in place concrete foundation consists of a base mat and a square of cylindrical pier. Most piers are kept in vertical position. However, the pier may be battered to allow the axial loads in the tower legs to intersect the mat centroid. Thus, the horizontal shear loads are greatly reduced for dead ends and large line angles. Either stub angles or anchor bolts are embedded in the top of the pier so that the upper tower section can be spliced directly to the foundation. Bolted clip angles, welded stud shear connectors, or bottom plates are added to the stub angle [12].

(c) Drilled concrete shafts

The drilled concrete shaft is the most common type of foundation now being used to support transmission structures. The shafts are constructed by power auguring a circular excavation, placing the reinforcing steel and anchor, and pouring concrete. Tubular steel poles are attached to the shafts using base plates welded to the pole with anchor bolts embedded in the foundation. Lattice towers are attached through the use of stub angles or base plates with anchor bolts. Loose granular soil may require a casing or a slurry. If there is a water level, term concrete is required. The casing, if used, should be pulled as the concrete is poured to allow friction along the sides. A minimum 4" slump should allow good concrete flow. Belled shafts should not be attempted in granular soil [12].

If conditions are right, this foundation type is the fastest and most economical to install as there is no backfilling required with dependency on compaction.

(d) Rock foundations

If bedrock is close to the surface, a rock foundation can be installed. The rock quality designation (RQD) is useful in evaluating rock. Uplift capacity can be increased with drilled anchor rods or by shaping the rock. Blasting may cause shatter or fracture to rock. Drilling or power hammers are therefore preferred. It is also helpful to wet the hole before placing concrete to ensure a good bond [12].

(e) Direct embedment

Direct embedment of structures is the oldest form of foundation as it has been used on wood pole transmission lines since early times. Direct embedment consists of digging a hole in the ground, inserting the structure into the hole, and backfilling. Thus, the structure acts as its own foundation. The disadvantage of direct embedment is the dependency on the quality of backfill material. In order to get deflection and rotation of direct embedded structures, the stiffness of the embedment must be considered [12].

(f) Vibratory shells

Steel shells are installed by using a vibratory hammer. The top 6 or 8 ft (similar to slip joint requirements) of soil inside the shell is excavated and the pole is inserted. The annulus is then filled with a high strength non-shrink grout. The pole can also be attached through a flange connection which eliminates excavating and grouting [12].

(g) Piles

Piles are used to transmit loads through soft soil layers to stiffer soils or rock. The piles can be of wood, pre stressed concrete, cast in place concrete, concrete filled shells, steel H piles, steel pipes filled with concrete, and pre

stressed concrete cylinder piles. The pipe selection depends on the loads, materials, and cost. Pile foundations are normally used more often for lattice towers than for H-framed structures or poles because piles have high axial load capacity and relatively low shear and bending capacity.

Besides the external loading, piles can be subjected to the handling, drying, and soil stresses. If piles are not tested, the design should be consulted for bearing, uplift, lateral capacity, and settlement. Driving formulas can be used to estimate dynamic capacity of the pile or group [12].

2.7Bracing systems

The primary members of a tower are the leg and the bracing members which carry the vertical and shear loads on the tower and transfer them to the foundation. Secondary or redundant bracing members are used to provide intermediate support to the primary members to reduce their unbraced length and increase their load carrying capacity. The slope of the tower leg from the waist down has a significant influence on the tower weight and should be optimized to achieve an economical tower design. A flatter slope results in a wider tower base which reduces the leg size and the foundation size, but will increase the size of the bracing. Bracing members below the waist can be designed as a tension only or tension compression system as shown in Figure 2.13 a tension only system shown in (a) [13].

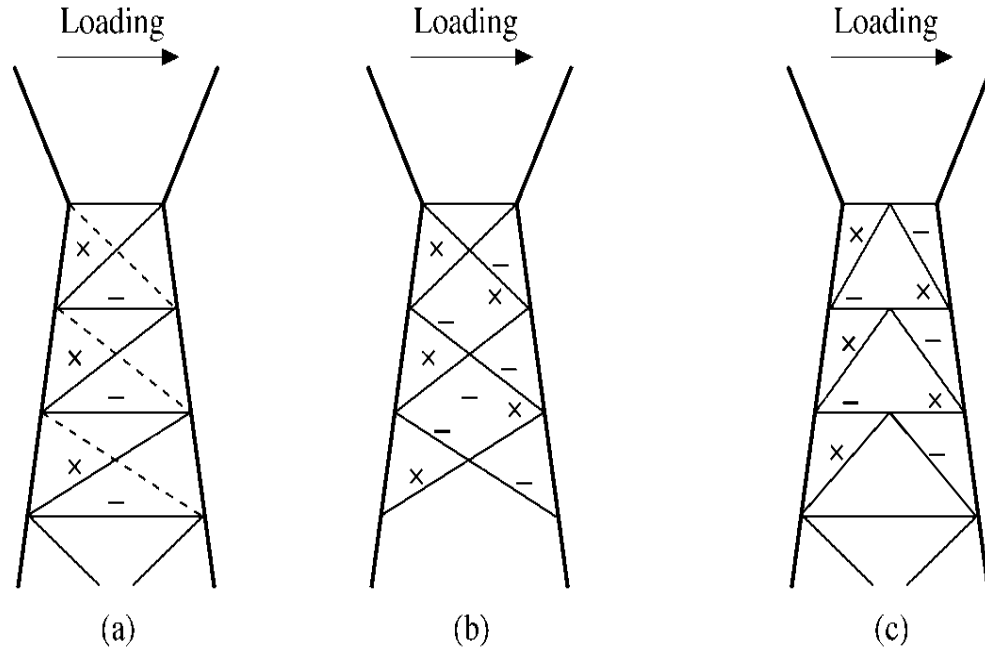


Figure 2.13: Bracing systems.

2.8 Buckling in transmission tower

The high-voltage transmission tower transmission lines is a major component and typically a high steel tower, is a tall, flexible structures. The finite element method to establish a large-scale three-dimensional model of the transmission tower space, computational analysis of the transmission tower structure. Six buckling modes, examined the order buckling mode characteristics [14].

When a slender structure is loaded in compression, for small loads it deforms with hardly changing in geometry and load-carrying capacity. On reaching a critical load value, the structure suddenly experiences a large deformation and it may lose its stability to carry the load. For a cruciform column under axial compression, it shortens and then buckles in torsion buckling, also

known as structural instability, maybe classified into two categories; bifurcation buckling and limit load buckling

In bifurcation buckling the deflection under compressive load changes from one direction to a different direction. The load at which the bifurcation occurs in the load-deflection curve is called the critical buckling load or critical load. The deflection path that exists prior to bifurcation is known as the primary path, and the deflection path after bifurcation is called the secondary or post buckling path. Depending on the structure and loading, the secondary path may be symmetric or axsymmetric, and it may rise or fall below the critical buckling load. In limit load buckling, the structure attains a maximum load without any previous bifurcation with only a single mode of deflection. The snap-through and finite-disturbance buckling is examples of limit load buckling. Other classifications of buckling are made according to the displacement magnitude (small or large) or static versus dynamic buckling, or material behavior such as elastic buckling or inelastic buckling.

Buckling is a process by which a structure can't withstand loads with its original geometry, so that it changes this shape in order to find a new equilibrium configuration. This is an undesired process, and occurs for a well-defined value of the load. The consequences of buckling are basically geometric. There are large displacements in the structure, to such an extent that the shape changes [15].

CHAPTER 3
METHODOLOGY OF ANALYSIS AND DESIGN

CHAPTER 3

METHODOLOGY

3.1 Introduction

The American Society of Civil Engineers (ASCE) guide for design of steel transmission towers is the industry document governing the analysis and design of lattice steel towers [2]. Lattice tower is analyzed as a space truss. Each member of the tower is assumed pin-connected at its joints carrying only axial load and no moment. Today, finite element computer programs are the typical tools for the analysis of towers for ultimate design loads. In the analytical model the tower geometry is broken down into a discrete number of joints (nodes) and members (elements). User input consists of nodal coordinates, member end incidences and properties, and the tower loads. For symmetric towers, most programs can generate the complete geometry from a part of the input. Loads applied on the tower are ultimate loads which include over load capacity factors. Tower members are then designed to the yield strength or the buckling strength of the member. Tower members typically consist of steel angle sections, which allow ease of connection. Both single- and double-angle sections are used. Steel types commonly used on towers are ASTM A-36 ($F_y = 36$ ksi) or A-572 ($F_y = 50$ ksi). The most common finish for steel towers is hot-dipped galvanized. Self-weathering steel is no longer used for towers due to the “pack-out” problems experienced in the past resulting in damaged connections. Tower members are designed to carry axial compressive and tensile forces. Buckling of a member occurs about its weakest axis, which for a single angle section is at an inclination to the geometric axes.

3.2 Case study

Line of 220 KV Double Circuit Wawa- Wadi halfa Transmission Line Project [16]. The project site located in Northern Sudan region (Northern State), which will extend the national grid to the Sudan-Egypt border. The Northern State is located northern of Khartoum state up to the Egyptian porter, between longitudes (25, 30 and 32, 10) and between latitudes (16 and 32). The geographically position of the project area covers the area between Wawa and Wadi Halfa. Climatic conditions are extraordinary. This area has desert climate, with long windy winter season and the minimum temperature reach about 1°C, and very hot summer season, the maximum temperature reach up to 50°C. The weather is generally dry with rare rain. The soil is generally deserts in the transmission line rout, the desert levels varies from the sandy land to rocky land in the transmission line route from Wawa to Wadi-Halfa. The basic services like education, health, water supply and electricity are available in the state's villages and towns. The telecommunication services are available throughout the state. The project includes two substations:

- I. Wawa Substation: contains of two transformers 2X60 MVA (220/33kV), two bays to Wadi-Halfa Substation.
- II. Wadi-Halfa Substation: contains of two transformers, 2X60 MVA, (220/33kV) and two bays from Wawa Substation

The transmission line,(Wawa – Wadi-Halfa) Approximately 205 km of 220 KV double circuits transmission line using twin bundle ACSR, of 568 steel towers.

3.2.1 Transmission line material classification

- Type of line conductor is ACSR- 240/40 .the lighting shielding conductor consist of OPGW and GSW.
- The insulator string made of porcelain disk insulator. The following shall be considered as included in the overhead line.
- Down Leads to outdoor equipment's such as lightning arresters, isolators, capacitive voltage transformers, and bushing are included but the connection clamps to the above mentioned outdoor equipment itself will be provided the substation contractor.
- Earth wire /OPGW lighting terminal towers and S/S gantries, including jumpers and hardware for earthing connection to gantry, as well as down leads and the jointing boxes S/S side for OPGW.

3.3 Analysis of towers

The analysis was carried out using structural analysis program (SAP2000) assuming that all members are of steel angles. Show the distribution of axial forces in plane x-z for tower.

3.3.1 Introduction of analysis using SAP 2000

SAP2000 is a full-featured program that can be used for the simplest problems or the most complex projects. SAP2000 will run analysis, save result and design all members. In the output file, we can get required data such as frame stress and joint displacements

The template structures available using the 3D Trusses form include a roof truss, one of four types of transmission towers, or a guyed tower.

3.3.2 Description of the structural analysis models

The purpose of the structural analysis model to provide framework for the development of a mathematical that captures the important aspects of the response of the structure when subjected to combinations load. The models of three power transmission towers is same height and different configurations. Result of analysis include axial force, shearing force, and bending moment in beam members, axial force in truss members, deflections/ rotations, and support reactions.

3.3.3 Steps of analysis

3.3.3.1 Define of transmission tower

- Startup screen of SAP2000, select working unit to be “kN-m” at drop-down menu on the bottom-right of screen and click on to start new model with template.

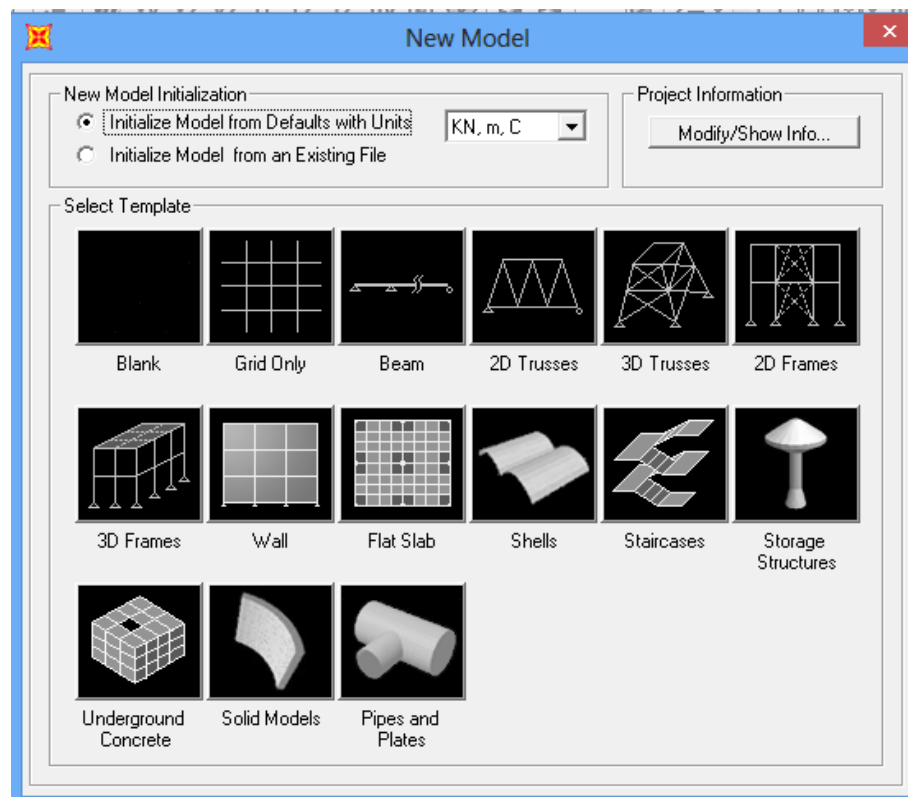


Figure 3.1: New model window.

1- Click the “File menu”→ “New model” command to display the new model form.

2- Set the units to Metric or English using the Initialize model from Defaults with Units drop-down list or the Initialize from the Existing Model option.

3- Click the 3D truss button and choose the type of truss by clicking on it. A drawing of the selected truss type will be shown in the small display box. Data of tower interred as follows:

(a) Elevation column use the cells in this column to specify the coordinates for the elevation of each bay of the tower.

(b) Width column. Use the cells in this column to specify the width, in the current units, for each bay of the tower.

© a [H] column. Use the cells in this column to specify the height of the bottom of the brace.

(d) b[W] column. Use the cells in this column to specify the width at the top of the brace. Figure 3.2 show data input window.

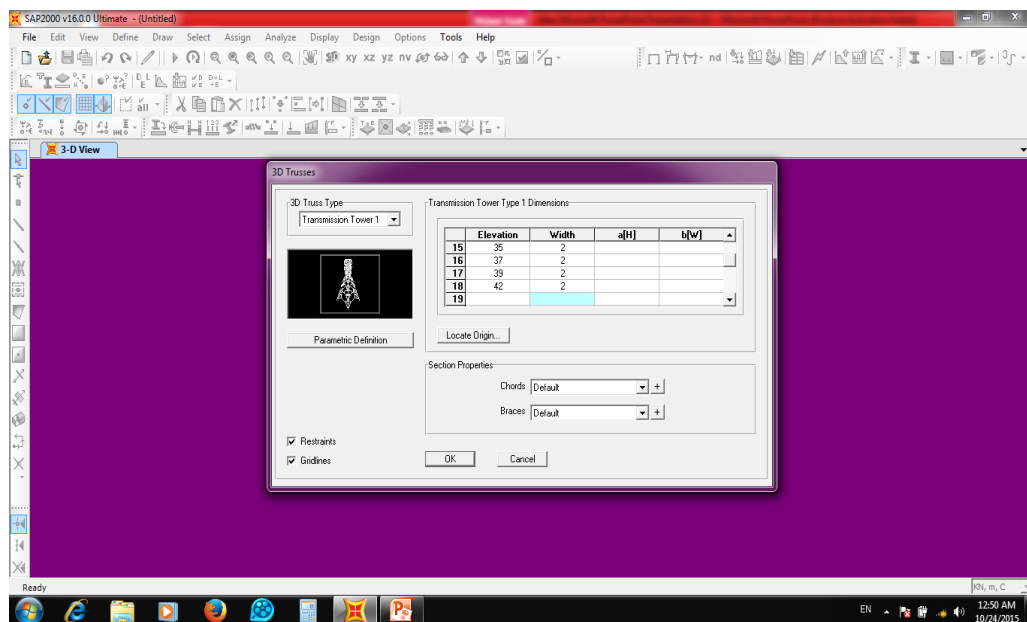


Figure 3.2: Data input.

- Import angle members and define auto selection member, all angle member properties will be imported from built-in database define all imported L-Shaped member to the list of section (“Auto”) for auto member selection go to Define > Section properties /Frame section/ Import new property.

(b) Define others

- Define loads patterns = DL, LL, WL from define loads patterns window, enter the load pattern name and self-weight multiplier as shown in figure below

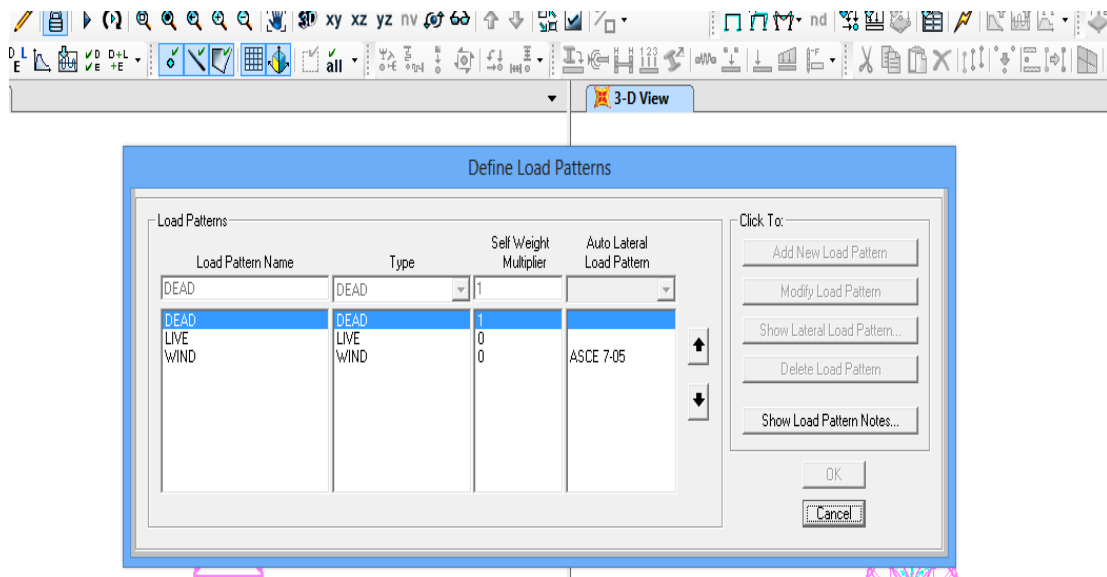


Figure 3.3: Define load patterns.

- Define Load cases DL, LL, and WL.
- Define Load Combinations (D.L+W.L), (DL+.75LL+.75WL) and (0.6DL+WL) as (COMB1, COMB2 and COMB3 respectively). Figure 3.4 presented the definition of load combinations window.

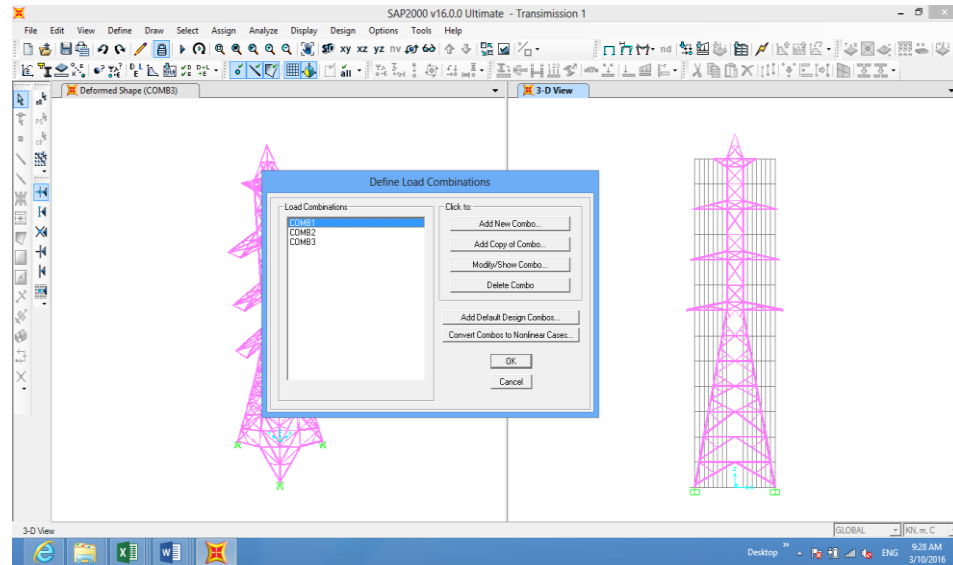


Figure 3.4: Define load combinations.

3.3.3.2 Assign joints and joints load

- Assign – Joint – Constrains, choose Diaphragm – Add new constraint press ok to apply wind load on transmission tower from Assign window as shown in figure 3.5 .

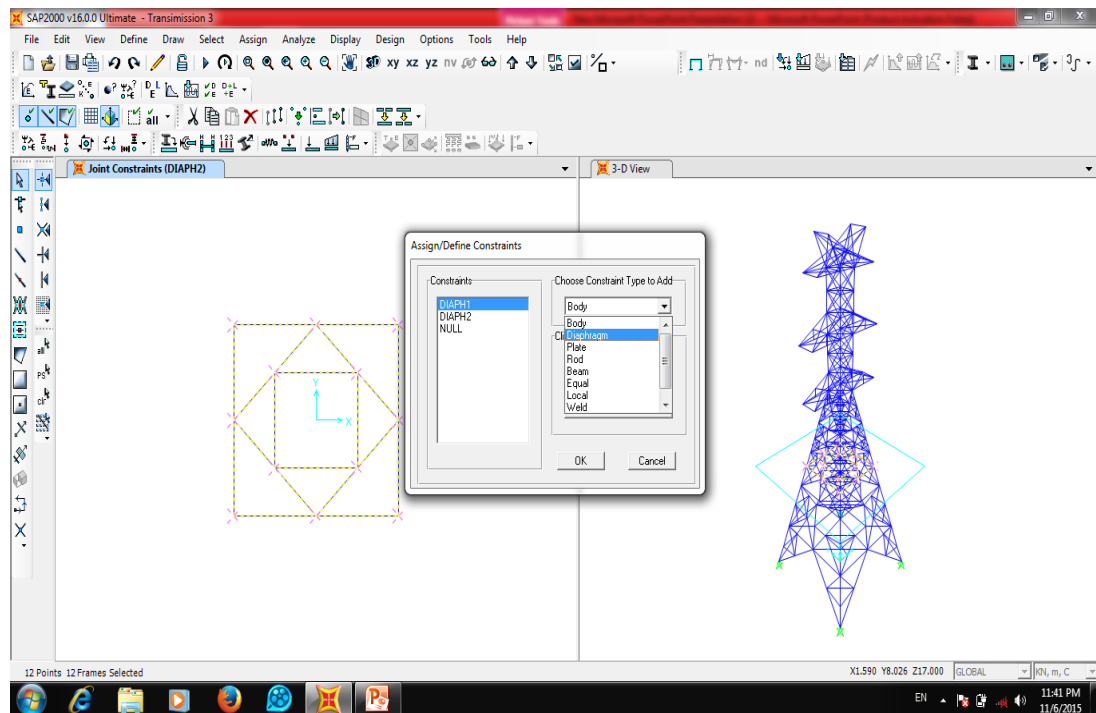


Figure 3.5: Assign joint constraints.

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3.3.3.4 Display results

From display menu

- Show tables.
- Show Forces-frames.
- Save named display.

3.4 Transmission tower design

The design of power transmission tower was carried out using Structural Analysis Program SAP 2000 and the selected angular section and design the models by;

- Select design code go to Design >> Preference >> Steel Frame Design and select preferences for “AISC-ASD89” from design code.
- Start design go to Design >> Steel Frame Design >> Start Design/ Check of Structures and wait until SAP2000 show the design output.

3.4.1 Climatic loads

- Return periods of climatic events
 - 1) 50 years.
 - 2) 150 years.
 - 3) 500 years.
- Drag coefficient of conductor.
- Terrain categories.

3.4.2 Design consideration

- Reliability or probability of survival.
- Security.
- Safety.

3.4.3 Design basis

- Economic factors.
- Network safety.

3.4.4 Design approaches for steel transmission towers

It is recommended that the designer provides at least the following informations

- Applied loads, including safety factors at attachment point of insulator and earth wire.
- Wind load on support.
- Load combinations.
- Deformation of structure.

3.4.5 Design parameters:

- No. of circuits.
- Climatic conditions
 - 1) Wind.
 - 2) Temperature.
 - 3) Seismic intensity.
 - 4) Ice formation.
- Environment and Ecological considerations.

CHAPTER 4
ANALYSIS AND DESIGN OF POWER
TRANSMISSION TOWERS USING SAP 2000

CHAPTER 4

ANALYSIS AND DESIGN OF POWER TRANSMISSION TOWERS USING SAP 2000

4.1. Introduction

During the last century many studies have been made to investigate the behavior of different types of transmission towers under different load conditions using various methods of analysis applied to those types of space structures [17]. Nowadays, electronic computers of large capacity, enable engineers to carry out analysis of transmission towers using Theoretical methods. The analysis of such type of space structure is always based on the assumption that the cross-sectional areas of members and their shapes are known, that affects magnitudes of the final axial forces. In this chapter the analysis of transmission towers under three load combinations ($D.L+W.L$), ($DL+.75LL+.75WL$) and ($0.6DL+WL$) according to ASCE 7 section 2.4 standard was carried. The provision of load combinations for use with allowable stress design (ASD) was adopted.

4.2 Power Transmission towers models

Three types of transmission towers were modeled in the same heights and different configurations, Tables (4.1 to 4.3) presents data input of three towers. The types of transmission towers were shown in Figures 4.1 to 4.3 as aside view for tower and Figures 4.4 to 4.6 as 3- dimensional view for each tower.

Table 4.1: Data input of transmission tower 1.

Level	Elevation (m)	Width (m)	a[H]	b[W]
1	0	10	0	0
2	3	8.8571	0	0
3	3	7.7143	0	0
4	3	6.5714	0	0
5	3	5.4286	0	0
6	3	4.2857	0	0
7	3	3.1429	0	0
8	3	2	0	0
9	1	2	0	0
10	2	2	0	0
11	3	2	0	0
12	1	2	0	0
13	2	2	0	0
14	3	2	0	0
15	1	2	0	0
16	2	2	0	0
17	3	2	0	0
18	3	0	0	0
	42			

Table 4.2: Data input of transmission tower 2.

Level	Elevation (m)	Width (m)	a[H]	b[W]
1	0	8.224	0	0
2	2.9	7.476	0	0
3	2.1	6.934	0	0
4	2.1	5.468	0	0
5	3.6	4.532	0	0
6	3.6	3.996	0	0
7	2.05	3.462	0	0
8	2.05	2.4	0	0
9	4.1	2.4	0	0
10	1	2.4	0	0
11	2.35	2.4	0	0
12	2.35	2.4	0	0
13	1	2.4	0	0
14	2.35	2.4	0	0
15	2.35	2.4	0	0
16	1	2.4	0	0
17	1.75	2.4	0	0
18	1.75	2.4	0	0
19	1	2.4	0	0
20	2.6	0	0	0
	42			

Table 4.3: Data input of transmission tower 3.

Level	Elevation (m)	Width (m)	a[H]	b[W]
1	0	14	0	0
2	3	12.666	0	0
3	4	10.888	0	0
4	4	9.111	0	0
5	3	7.777	0	0
6	3	6.444	0	0
7	2	5.555	0	0
8	2	4.666	0	0
9	2	3.777	0	0
10	2	2.888	0	0
11	2	2	0	0
12	2	2	0	0
13	2	2	0	0
14	2	2	0	0
15	2	2	0	0
16	2	2	0	0
17	2	2	0	0
18	3	0	0	0
	42			

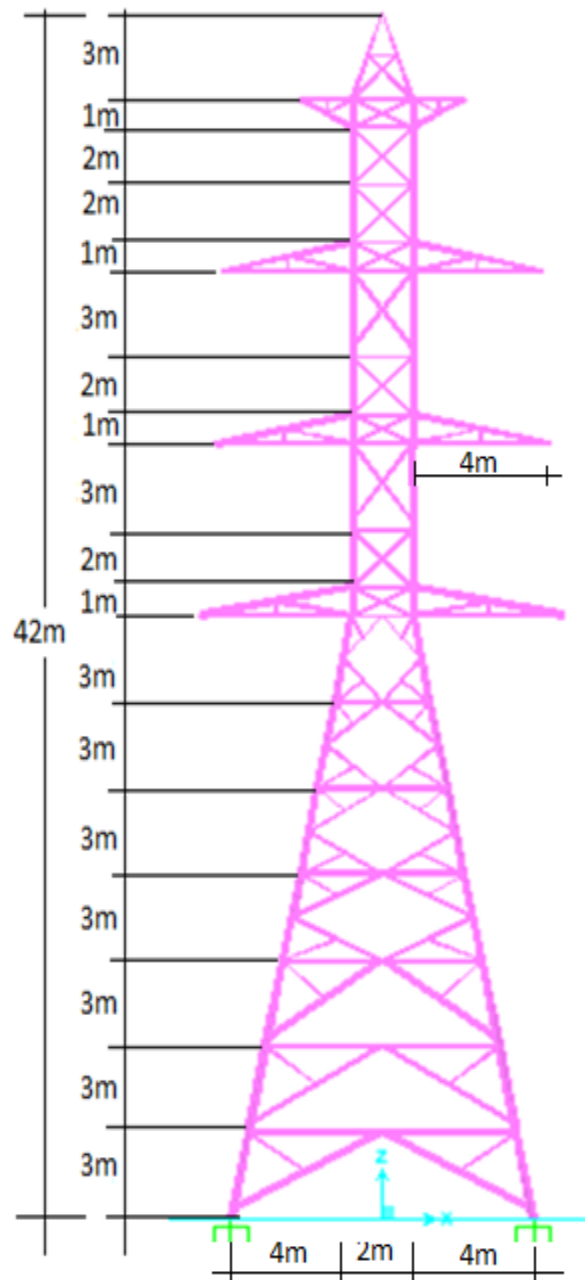


Figure 4.1, Tower1 configuration (Side view).

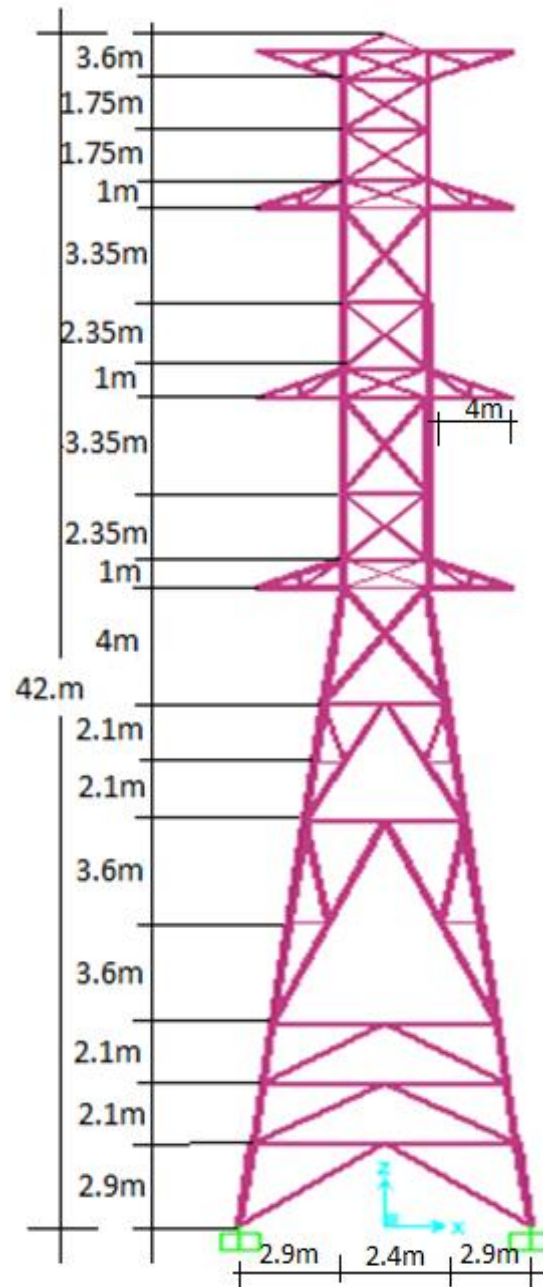


Figure 4.2, Tower2 configuration (Side view).

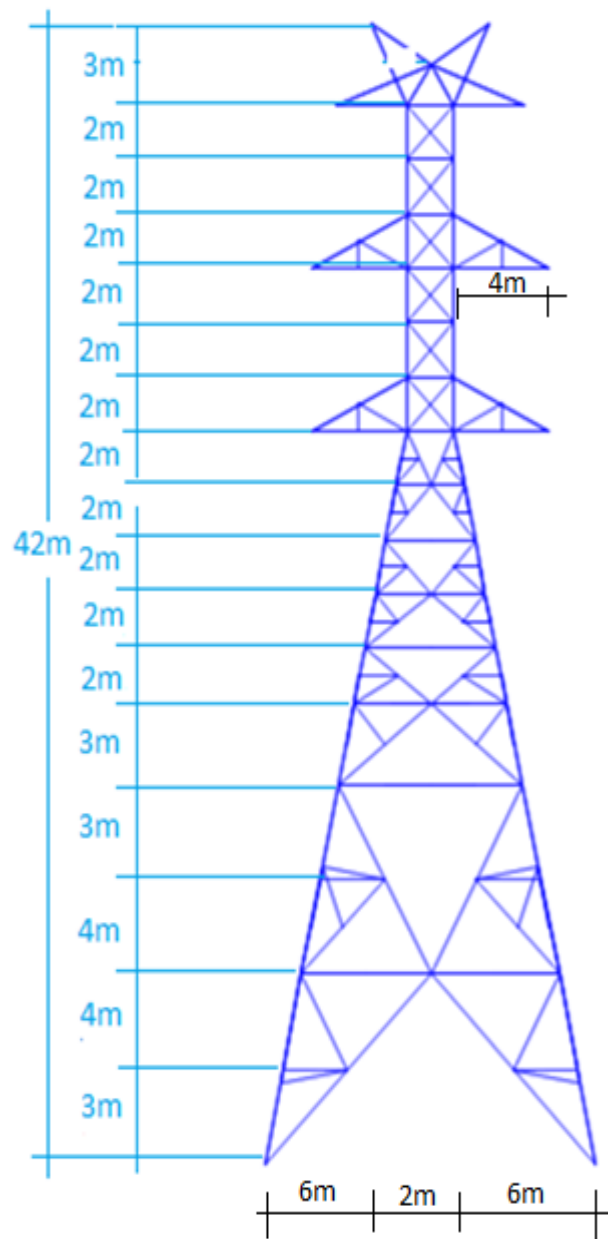


Figure 4.3, Tower 3 configuration (Side view).

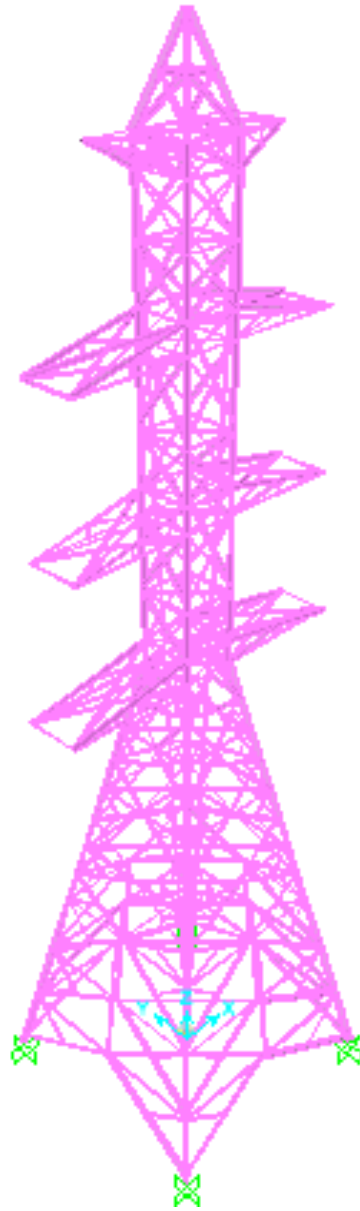


Figure 4.4, Tower1 (3D view).

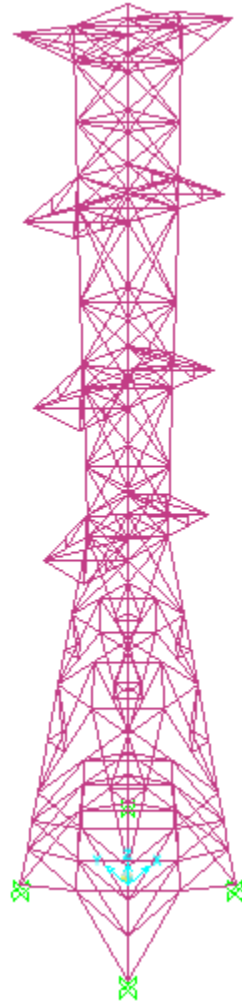


Figure 4.5, Tower 2 (3D view).

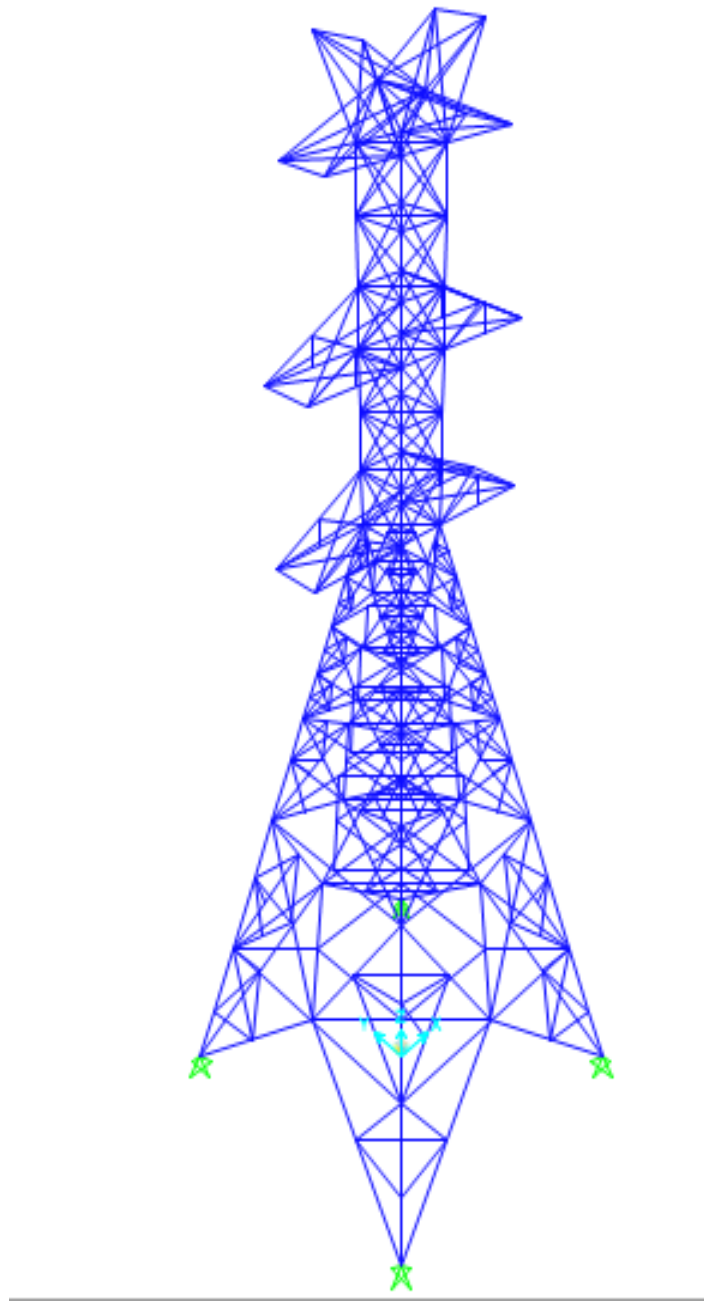


Figure 4.6, Tower 3 (3D view).

4.3 Assign loads on towers cross arm

The tension for transmission towers design is: Conductor 86.46 kN, Ground Wire 116.08kN, OPGW 91.10 kN) according to national electricity corporation design data, load assigned on towers after calculate it by analysis the design tension in two forces, vertical force and Horizontal force according to the angle of conductor with cross arm of transmission tower as shown in (Figure 4.7) and table 4.1.

Wind load calculated automatically in sap2000 program after define it and from assign menu choose, (Assign - Joint - Constrains, choose Diaphragm – Add new constraint –ok), to apply wind load over all, x y plane

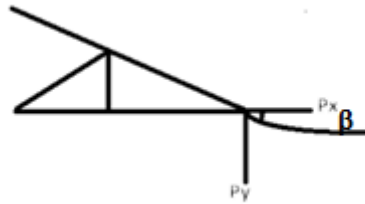


Figure 4.7: cross arm loading.

Assume that $\beta=30^\circ$. T = tensile strength, $PY = T \sin\beta$, $PX = T \cos \beta$

Table 4.4: Tension for tower design.

Load Type	Tension for Tower Design	PX	PY
Conductor	86.46	75	43.23
Ground weir	116.08	100.53	58
OPGW	91.1	79	45.5

4.4 Wind load calculation

Referring to ASCE 7-05 for simplified procedure, one can notice that the simplified procedure is applicable only to building with mean roof heights less than 30 ft (9 m), which is not applicable to building of this study. The wind tunnel procedure consists of developing a small scale model of the building for testing in wind tunnel to determine the expected wind pressure etc. It is expensive and may be utilized for difficult or special situations. The analytical procedure is used in most. It is fairly systematic but some that complicated to account for various situations that can occur. Wind velocity will cause pressure on any surface. The velocity pressure depends on the height from the ground level. The following equation is recommend by ASCE 7-05 CODE of practice for calculation the velocity pressure, q_z , resulting from winds:

$$Q_z = 0.613 K_z * K_{zt} * K_d * V^2 * I \quad (\text{N/m}^2)$$

where:

V: is the basic wind speed (m/s)

K_d : is directionality factor from Table (4.5)

K_{zt} : is topographic factor

$k_{zt} = 1$ for flat ground

k_z : varies with height z above the ground level obtained from Table (4.6)

I: is the importance factor obtained from Table (4.7)

• Design load data

- a. Partially enclosed structure.
- b. exposure type C (ASCE).
- c. category III (ASCE).
- d. non hurricane region

Table (4.5): Wind directionality factor, k_d . (ASCE 7-05 CODE).

Structure type	Directionality Factor k_d
Building	
Main wind force resisting system	0.85
Components and cladding	0.85
Arched roofs	0.85
Chimneys, Tanks, and similar Structure	
Square	0.9
Hexagonal	0.95
Round	0.95
Solid sign	0.85
Open sign and lattice formwork	0.85
Trussed Towers	
Triangular , square , rectangular	0.85
All other cross sections	0.95

Table (4.6): Importance factor, I (wind load). (ASCE 7-05 CODE).

Category	Non - hurricane prone regions and hurricane prone regions with $V=85-100$ mph=$37.78-44.44$ m/s	Hurricane prone regions with $V > 100$mph $V > 44.44$ m/s
I	0.87	0.77
II	1.00	1.00
III	1.15	1.15
IV	1.15	1.15

Table (4.7): Velocity pressure exposure coefficient K_z . (ASCE 7-05 CODE).

Height above ground level z	Exposure			
	B		C	D
(m)	Case1 of 2	Case1 of 2	Case2	Case1
0.46	0.7	0.57	0.85	1.03
6.10	0.7	0.62	0.90	1.08
7.60	0.7	0.66	0.94	1.12
9.10	0.7	0.70	0.98	1.16
12.20	0.76	0.76	1.04	1.22
15.20	0.81	0.81	1.09	1.27
18.00	0.85	0.85	1.13	1.31
21.30	0.89	0.89	1.17	1.34
24.40	0.93	0.93	1.21	1.38
27.40	0.96	0.96	1.24	1.40
30.50	0.99	0.99	1.26	1.43
36.60	1.04	1.04	1.31	1.48
42.70	1.09	1.09	1.36	1.52
48.80	1.13	1.13	1.39	1.55
54.90	1.17	1.17	1.43	1.58
61.00	1.20	1.2	1.46	1.61
76.20	1.28	1.28	1.53	1.68
91.40	1.35	1.35	1.59	1.73
106.70	1.41	1.41	1.64	1.78
121.90	1.47	1.47	1.69	1.82
137.20	1.52	1.52	1.73	1.86
152.40	1.56	1.56	1.77	1.89

- **Calculte wind pressure**

Basic wind speed take 45 m/s. for both direction.

$k_d = 0.85$

$I = 1$

$k_{zt} = 1$

For partially enclosed building.

$$V = 45 \text{ m/s}$$

$$k_z(42) = 1.595$$

$$q_{h_0} = 0.613 * 1 * 1 * 0.85 * 45^2 * 0.85 = 896.85 \text{ N/m}^2$$

$$q_h(42) = 0.613 * 1 * 1 * 1.595 * 45^2 * 0.85 = 1722.23 \text{ N/m}^2$$

4.5 Design of transmission towers

4.5.1 Case study design data and climatic data

(a) Site and tower details

- 1) Structures height 42m.
- 2) Lattice towers.
- 3) Location (Wawa- Wadih alfa, North State).

(b) General characteristics

- | | |
|-------------------------------|---------|
| 1) Rated voltage | 220 kV. |
| 2) No. of circuits per line | 2. |
| 3) Basic span | 400 m. |
| 4) No. of conductor per phase | 2. |
| 5) Phase conductor | |
| 6) Earth conductor | |

(c) Select reliability level:

- | | |
|--------------------------|-----------|
| 1) Period of design load | 50 years. |
|--------------------------|-----------|

(d) Climatic data

- | | |
|---|-----------|
| 1) Mean monthly average temperature | 30 C. |
| 2) Maximum ambient air temperature | 45 C. |
| 3) Minimum ambient air temperature | 1 C. |
| 4) Maximum wind speed | 100 km/h. |
| 5) Mean monthly Maximum rain fall | 7.5 mm. |
| 6) Radial thickness of ice on conductor | 0.0 mm. |

(e) Wind Pressure

1) On Tower	2.200 kN/m.
2) On Insulator	1.334 kN/m.
3) On Conductor	1.334 KN/m.
4) On Ground Wire/Opgw	1.334 KN/m.
(f) Dynamic Pressure Coefficient	
1) For conductors	1.0
2) For Ground wire & OPGW	1.1
3) For Insulator string	1.2.
4) For Tower	1.5.
(g) Tension for Tower Design,(Ultimate Tensile Strength (UTS)	
1) Conductor	86.46 KN.
2) Ground Wire	116.08kN.
3) OPGW	91.10 KN.
(i) For maintenance loads weight of line man shall be considered	
	2.0 KN

4.6 Structure analysis and design results

After set analysis options and run analysis in a few time analysis results appeared and be used. Here we discuss joint re actions, maximum axial force by divided towers in two parts, relationship between height and displacement in transmission towers for combination load two and three, and relationship between height axial forces acting on legs of transmission towers. To see the effect of applied load on transmission towers, (Dead load deformation, Wind load deformation, Combination of load deformation and axial force diagram for transmission towers one, two and three go to appendix B ,C,D respectively. The tables below demonstrate Structure analysis results. Table 4.8 show re actions

on the base of tower one and table 4.9 show maximum axial force on the leg of transmission tower one (for two parts of leg incline part and straight part).

Table 4.8: Joint reactions for transmission tower 1.

Transmission Tower 1		
Base No	Load Case	(kN)
1	DEAD	216.0
	COMB1	218.0
	COMB2	71.0
	COMB3	66.0
2	DEAD	254.7
	COMB1	257.4
	COMB2	412.4
	COMB3	360.3
3	DEAD	245.3
	COMB1	256.9
	COMB2	97.6
	COMB3	58.9
4	DEAD	217.1
	COMB1	219.3
	COMB2	368.5
	COMB3	329.8

Table 4.9: Maximum axial force for transmission tower 1.

part one Z = 0 to Z =21 m		
Member ID	Load Case	Maximum axial force (kN)
Leg	COMB1	262.6
	COM B2	112.5
	COMB3	74.2
Horizontal	COMB1	0
	COMB2	0
	COMB3	0
Brace	COMB1	6.0
	COMB2	5.7
	COMB3	-6.2

part two Z = 21 to Z =42 m		
Member ID	Load Case	Maximum axial force (kN)
Leg	COMB1	213.5
	COMB2	162.5
	COMB3	-136.1
Horizontal	COMB1	3.7
	COMB2	94.7
	COMB3	106.5
Brace	COMB1	198.7
	COMB2	206.4
	COMB3	129.4

Table 4.10 below show re actions on the base of tower one and table 4.11 show maximum axial force on the leg of transmission tower two (for two parts of leg incline part and straight part).

Table 4.10: Joint reactions for transmission tower 2.

Transmission Tower 2		
Base No	Load Case	Joint Reactions (kN)
1	DEAD	221.7
	COMB1	23.91
	COMB2	239.78
	COMB3	142.74
2	DEAD	221.9
	COMB1	238.03
	COMB2	239.9
	COMB3	142.82
3	DEAD	221.4
	COMB1	237.72
	COMB2	239.59
	COMB3	142.63
4	DEAD	221.5
	COMB1	237.79
	COMB2	239.66
	COMB3	142.67

Table 4.11: Maximum axial force for transmission tower 2.

part one Z = 0 to Z =22 m		
Member ID	Load Case	Maximum axial force (kN)
Leg	COMB1	139.8
	COMB2	115.4
	COMB3	-73.6
Horizontal	COMB1	0
	COMB2	2.2
	COMB3	-1.3
Brace	COMB1	-18.7
	COMB2	23.4
	COMB3	21.6

part two Z = 22 to Z =42 m		
Member ID	Load Case	Maximum axial force (kN)
Leg	COMB1	-138.2
	COMB2	-91.5
	COMB3	-57
Horizontal	COMB1	72.2
	COMB2	70.2
	COMB3	42.2
Brace	COMB1	-105.2
	COMB2	110.9
	COMB3	66.2

Table 4.12 below show re actions on the base of tower one and table 4.13 show maximum axial force on the leg of transmission tower two (for two parts of leg incline part and straight part).

Table 4.12: Joint reactions for transmission tower 3.

Transmission Tower 3		
Base No	Load Case	Joint Reactions (kN)
1	DEAD	235.9
	COMB1	238.4
	COMB2	104.3
	COMB3	36.5
2	DEAD	234.1
	COMB1	236.5
	COMB2	374.4
	COMB3	325.1
3	DEAD	235.9
	COMB1	238.4
	COMB2	99.2
	COMB3	43.2
4	DEAD	234.6
	COMB1	237.1
	COMB2	370.1
	COMB3	318.9

Table 4.13: Maximum axial force for transmission tower 3.

part one Z = 0 to Z =27 m		
Member ID	Load Case	Maximum axial force (kN)
Leg	COMB1	-179.5
	COMB2	-178.4
	COMB3	-152.7
Horizontal	COMB1	-1.5
	COMB2	-1.6
	COMB3	-1.8
Brace	COMB1	-88.6
	COMB2	-44.3
	COMB3	-23.0

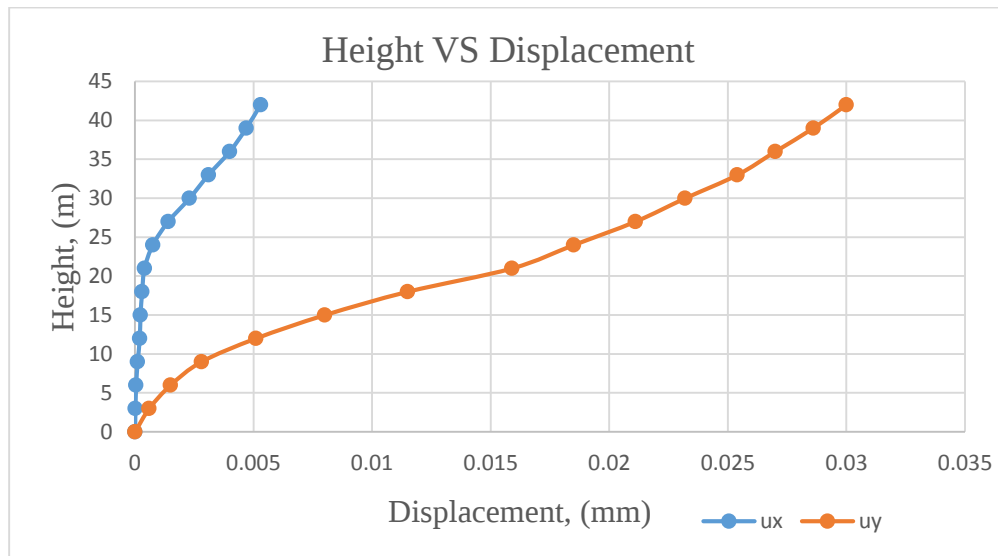
part two Z = 27 to Z =42 m		
Member ID	Load Case	Maximum axial force (kN)
Leg	COMB1	-192.8
	COMB2	-175.5
	COMB3	-135.5
Horizontal	COMB1	0
	COMB2	0
	COMB3	0
Brace	COMB1	72.2
	COMB2	71.4
	COMB3	43.2

4.7 Relationship of height to displacement and axial force

Figures below discuss the relationship of height to displacement in transmission towers for combination load 2 and 3, also discusses the relationship of height to axial forces acting on legs of transmission towers.

Figures (4.8, 4.9) implies that the displacement under combination 3 ($0.6DL+WL$) is greater than displacement under combination 2 ($DL+.75LL+.75WL$) for both x and y direction, and the displacement increases in direct proportion to height.

Figure (4.10) indicates that the axial force increase in inverse proportion to height.



**Figure 4.8: Relation between height and displacement
Transmission tower 1, load combination 2.**

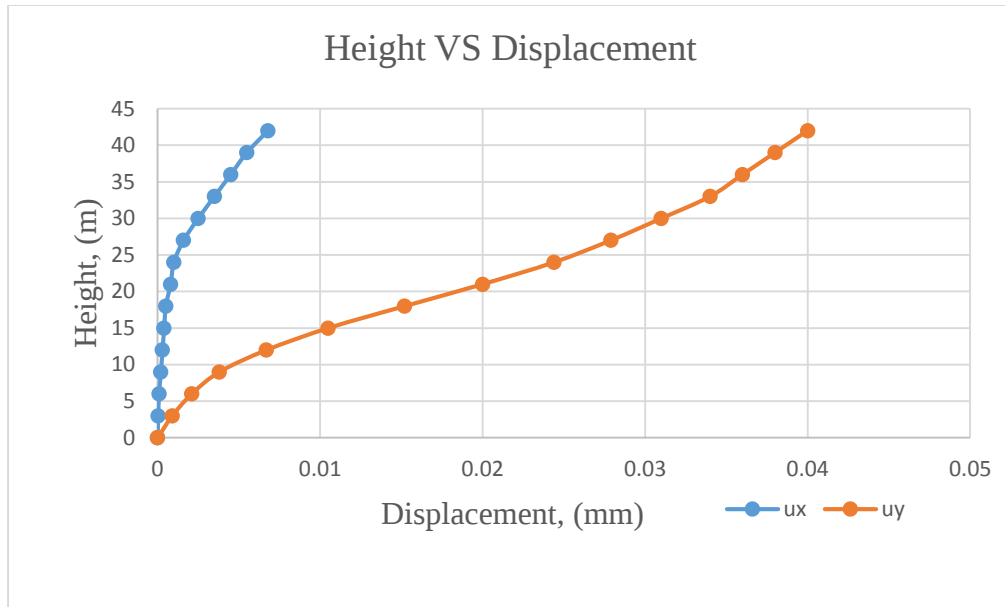


Figure 4.9: Relationship between height and displacement
Transmission tower 1, load combination 3.

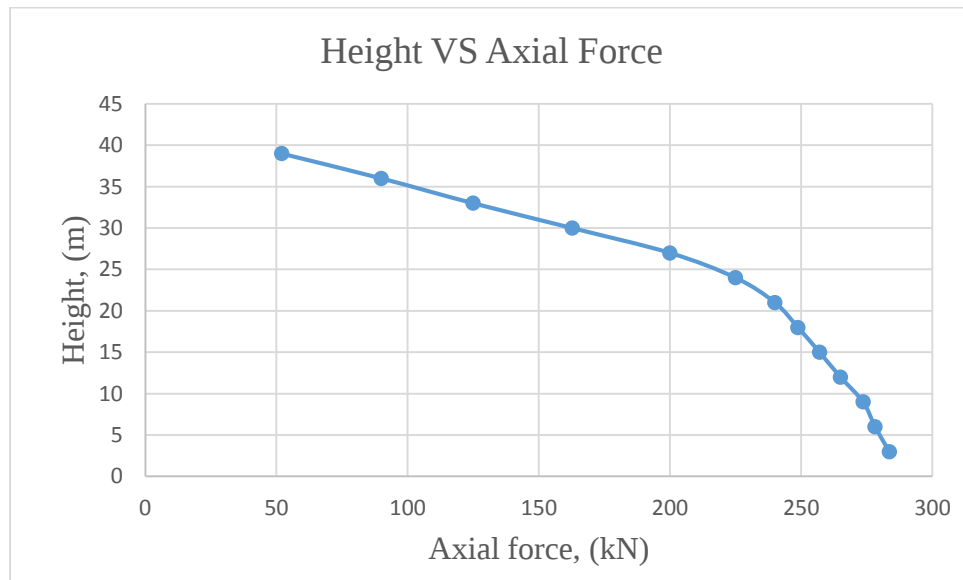
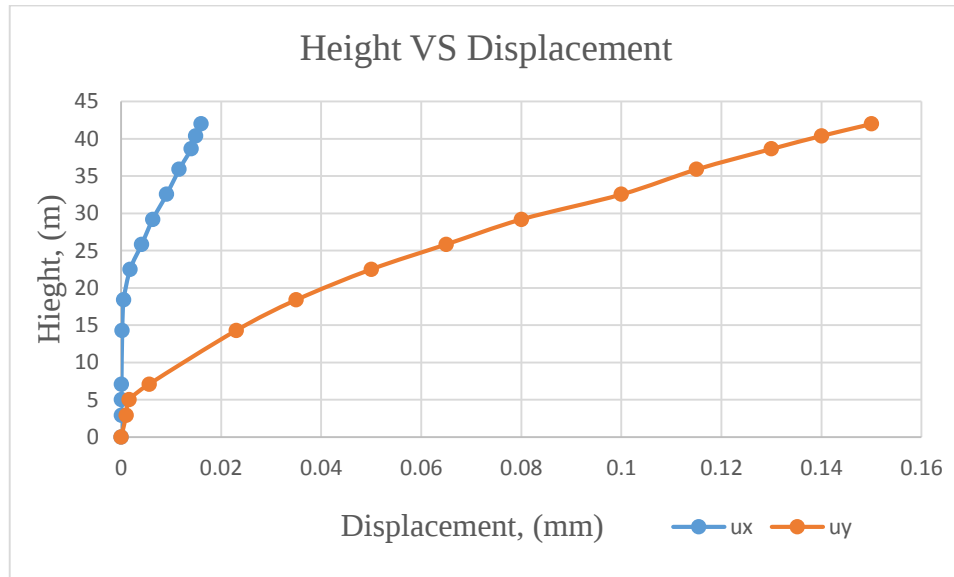


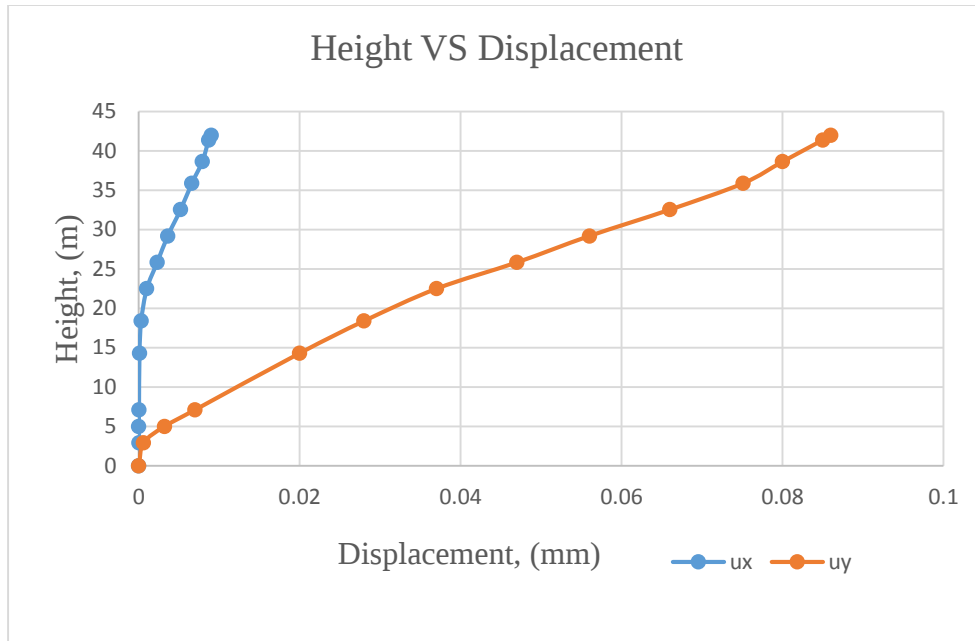
Figure 4.10: Relationship between height and axial force in legs
Transmission tower 1.

Figures (4.11, 4.12) suggests that the displacement under combination 2 ($DL+.75LL+.75WL$) is greater than displacement under combination 3 ($0.6DL+WL$) for both x and y direction, and the displacement increases in direct proportion to height.

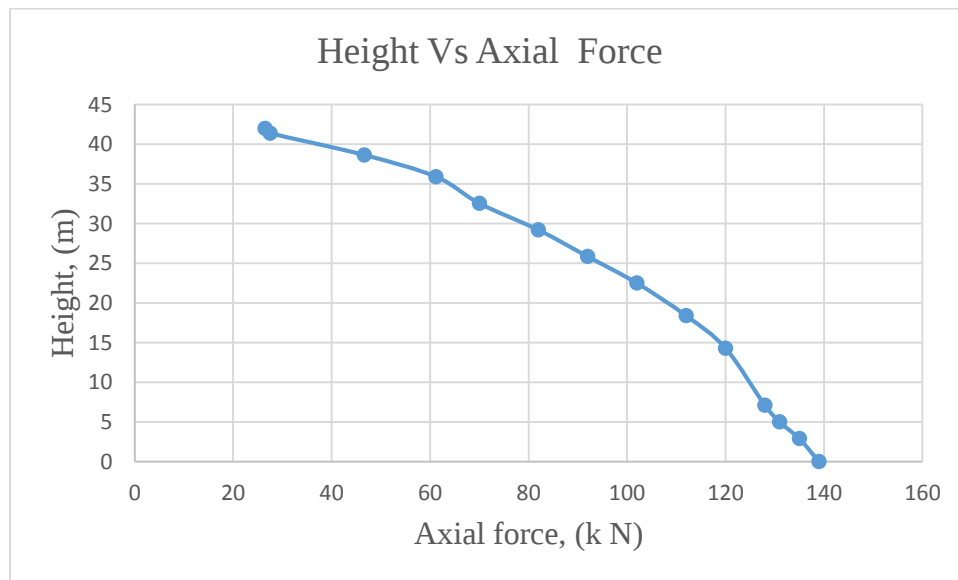
Figure (4.10) indicates that the axial force increase in inverse proportion to height.



**Figure 4.11: Relationship between height and displacement
Transmission tower 2, load combination 2.**



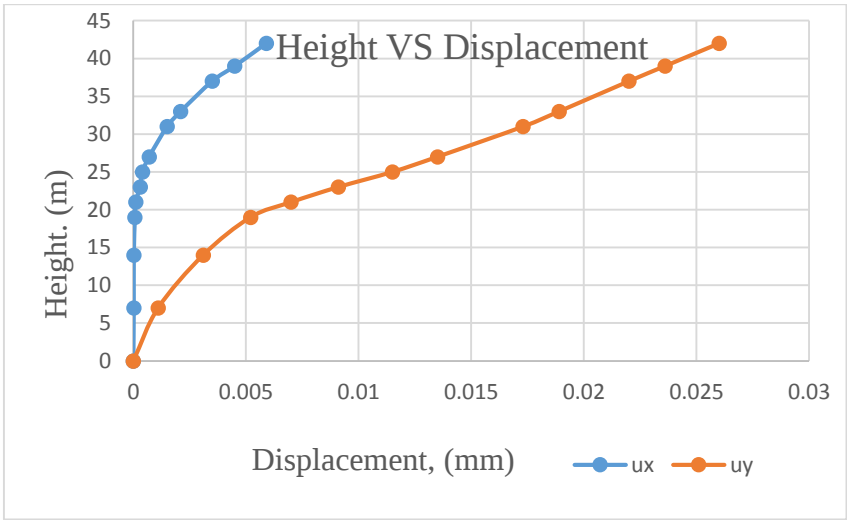
**Figure 4.12: Relationship between height and displacement
Transmission tower (2), load combination 3.**



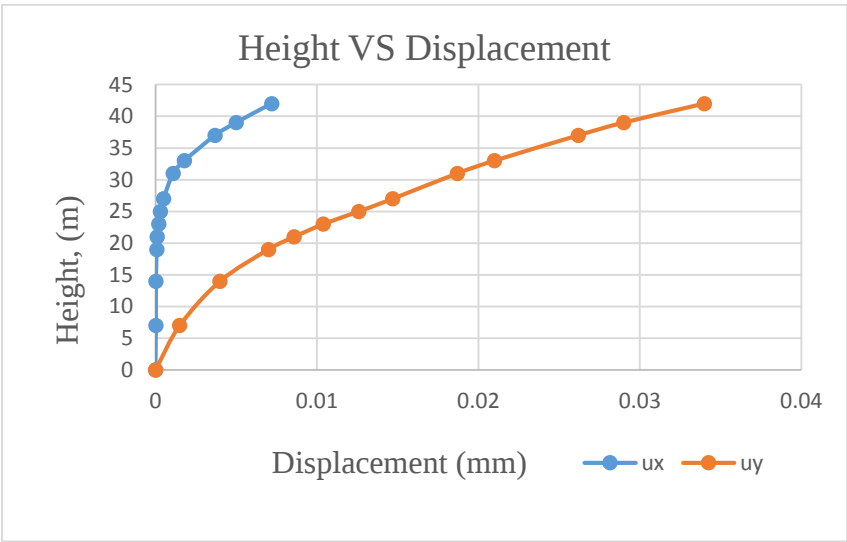
**Figure 4.13: Relationship between height and axial force in legs
Transmission tower (2).**

Figures (4.14, 4.15) show that the displacement under combination 3 (0.6DL+WL) is greater than displacement under combination 2 (DL+.75LL+.75WL) for both x and y direction, and the displacement increases in direct proportion to height.

Figure (4.16) indicates that the axial force increase in inverse proportion to height.



**Figure 4.14: Relationship between height and displacement
Transmission tower (3), load combination 2.**



**Figure 4.15: Relationship between height and displacement
Transmission tower (3), load combination 3.**

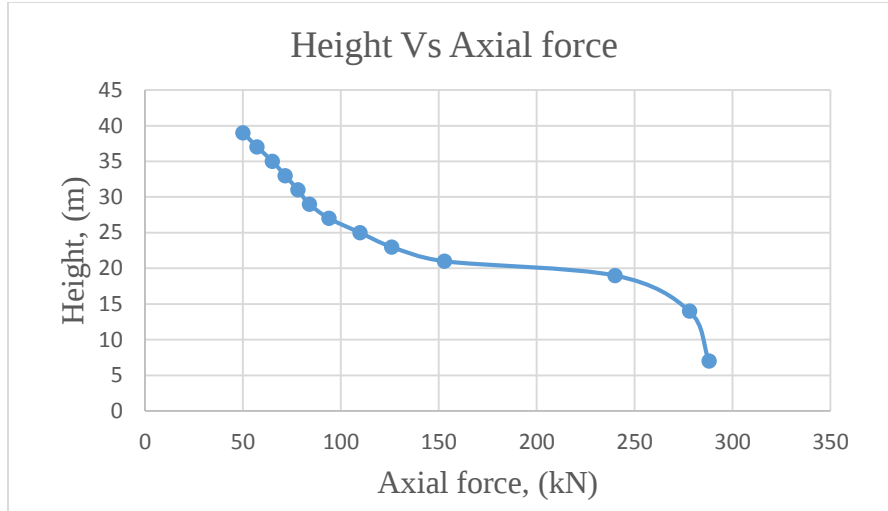


Figure 4.16: Relationship between height and axial force in Legs Transmission tower (3).

4.8 Buckling in transmission tower members

In this research three model of transmission towers have been chosen for a detailed study of buckling behavior. Results presented in buckling modes for the three transmission towers under three load combination, Buck1 = (D.L. + L.L.).

Buck 2 = (D.L. + 0.75(L.L. + W.L.).

Buck 3 = (0.6D.L. + W.L.).

Results presented in buckling modes for the three transmission towers under three load cases it was taken six buckling modes for each load cases. The corresponding buckling factor for the load cases were presented in figures 4.17 - 4.19 and buckling shapes discussed in figures 4.20 - 4.22.

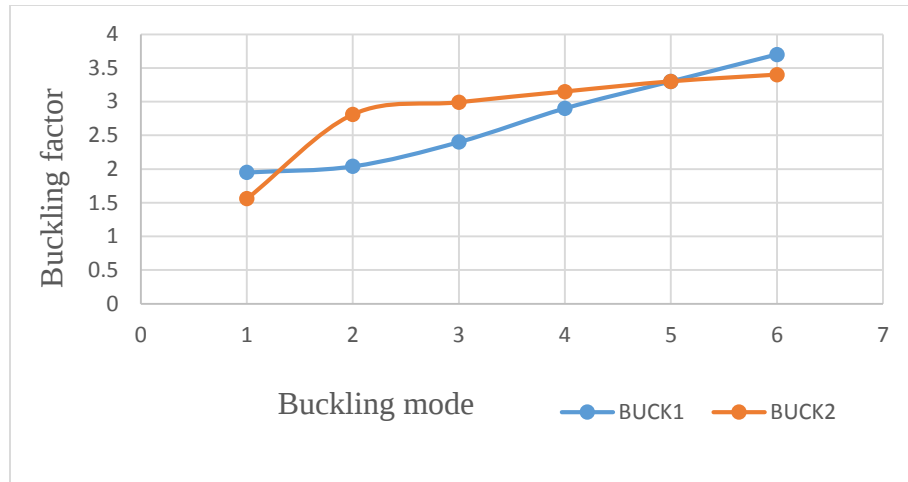


Figure 4.17: Buckling factor diagram of transmission tower (1) for all load combinations.

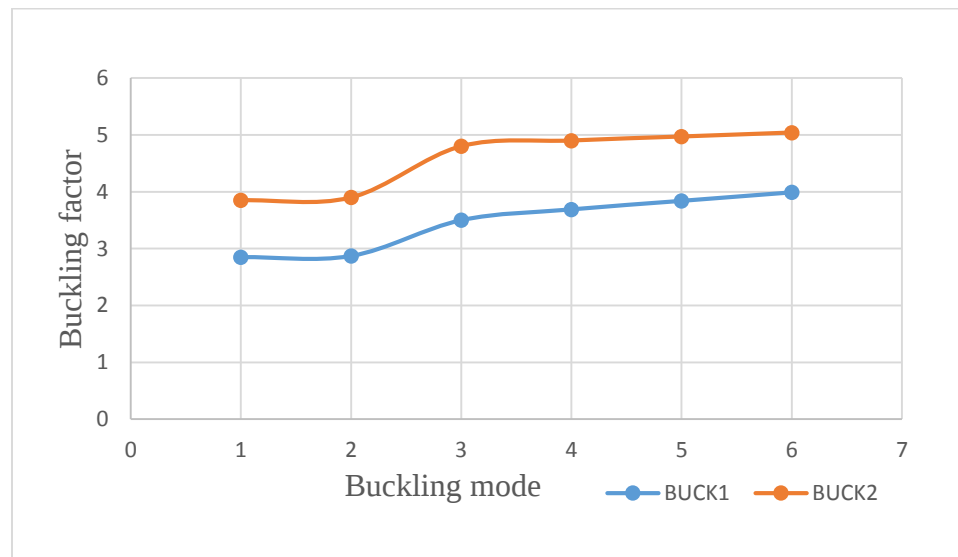


Figure 4.18: Buckling load diagram of transmission tower (2) for all load combinations.

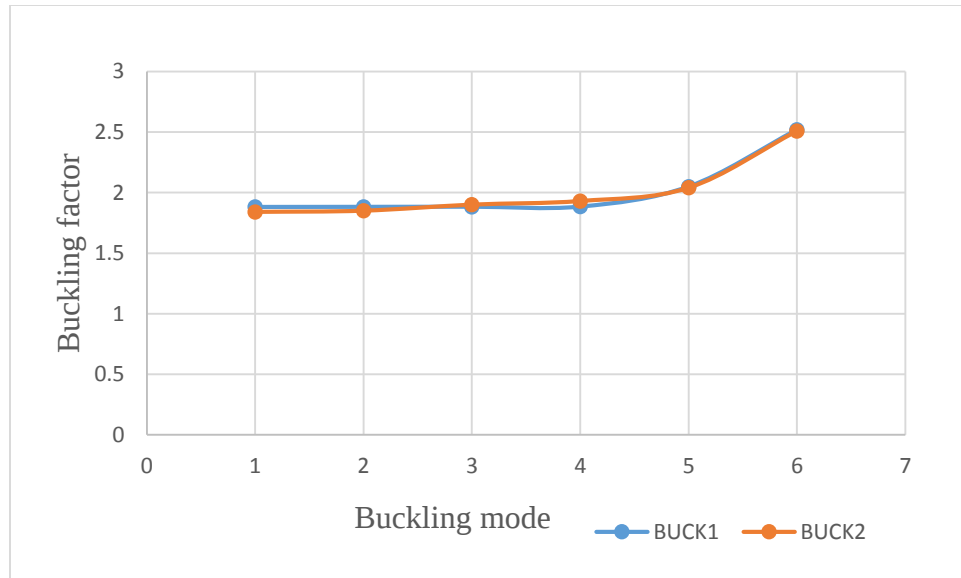


Figure 4.19: Buckling factor diagram of transmission tower (3) for all load combinations.

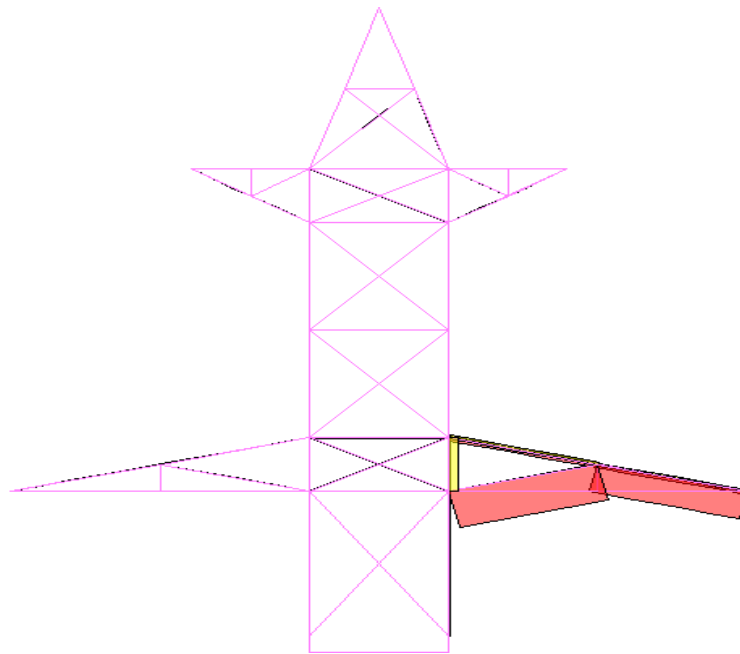


Figure 4.20: Axial force diagram (Buckling in cross arm) - transmission tower (1).

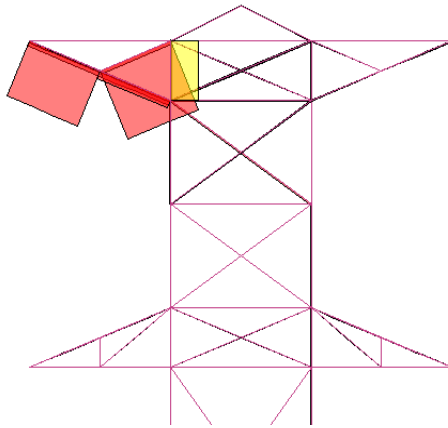


Figure 4.21: Axial force diagram (Buckling in cross arm) - transmission tower (2).

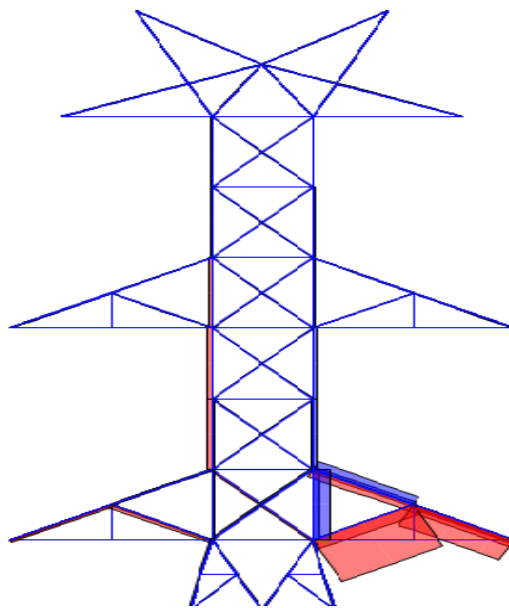


Figure 4.22: Axial force diagram (Buckling in cross arm) - transmission tower (3).

4.9 Final design of transmission towers

After set design options, choose design code, (AISC-ASD89) and set all parameters, (Figure 4.23), run the program to design Transmission Towers. From Design >> Steel Frame Design >> Display Design Info select second drop-down menu and select “Design Sections”. Tables 4.14 – 4.16 below show simplified of the results by choosing suitable sections for transmission towers by comparison between design sections results and company design sections. Table 4.17 show the total number of members and the weight of transmission towers.

Steel Frame Design Preferences for AISC-ASD89

	Item	Value
1	Design Code	AISC-ASD89
2	Multi-Response Case Design	Envelopes
3	Framing Type	Moment Frame
4	Lateral Factor for Wind	1.
5	Lateral Factor for Seismic	1.3333
6	Consider Deflection?	Yes
7	DL Limit, L /	120.
8	Super DL+LL Limit, L /	120.
9	Live Load Limit, L /	360.
10	Total Limit, L /	240.
11	Total-Camber Limit, L /	240.
12	Pattern Live Load Factor	0.75
13	Demand/Capacity Ratio Limit	0.95
14	Cm Calculation Option	Program Determined
15	Cm Calculation Tolerance	
16	Cb Calculation Option	Program Determined
17	Cb Calculation Tolerance	

Item Description

Explanation of Color Coding for Values
Blue: Default Value
Black: Not a Default Value
Red: Value that has changed during the current session

Set To Default Values Reset To Previous Values

All Items Selected Items All Items Selected Items

OK Cancel

Figure 4.23: Steel frame design preferences for AISC-ASD89.

Table 4.14 Transmission tower one- Design sections.

Member ID	Load Case	Design Sections
Column	COMB1 COMB2 COMB3	L8 * 8* 9/8
Beam	COMB1 COMB2 COMB3	L6 * 4* 5/16
Brace	COMB1 COMB2 COMB3	L6*6*9/16

Table 4.15: Transmission tower two - Design sections.

Member ID	Load Case	Design Sections
Column	COMB1 COMB2 COMB3	L8 *8* 9/8
Beam	COMB1 COMB2 COMB3	L5 * 5* 5/16
Brace	COMB1 COMB2 COMB3	L6*6*9/16

Table 4.16: Transmission tower three - Design sections.

Member ID	Load Case	Design Sections
Column	COMB1 COMB2 COMB3	L8 * 8* 9/8
Beam	COMB1 COMB2 COMB3	L6 * 6* 5/16
Brace	COMB1 COMB2 COMB3	L6*6*3/8

Table 4.17: Transmission towers weight and total numbers of members.

ID	Transmission Tower One	Transmission Tower Two	Transmission Tower Three
Weight of Transmission Tower	981.12 kN	951.444 kN	941.51 Kn
Total Number of Members	572	431	552

4.10. Comparison between design sections results and company design sections

All design sections of transmission towers using Structural Analysis Program SAP 2000 were presented in **Table 4.18**. These sections were compared with national electricity corporation design data as shown in Appendix F, Table 3 company sections

Table 4.18: Design sections properties.

Design Sections	Section area	I _x	I _y	R _x	R _y
L 130* 130* 8	1.955E-03	3.088E-06	3.088E-06	.0397	.0397
L 150 * 100* 8	1.955E-03	4.745 E-06	1.740 E-06	.0493	.0298
L 150 * 150* 8	2.355E-03	5.411E-06	5.411E-06	.0479	.0479
L 150*150*14	4.148E-03	9.199 E-06	9.199 E-06	.0471	.0471
L 150*150*10	2.813E-03	6.410 E-06	6.410 E-06	.0477	.0477
L 200*150* 12	3.826E-03	1.632 E-05	68.033 E-06	.0653	.0458
L 200 * 200* 28	.0108	4.079 E-05	4.079 E-05	.0615	.0615

4.11. Discussion of results

In order to study structural behavior of three transmission towers, it was noticed that:

1. Power transmission tower two is more economical in comparison with other types.
2. Transmission tower one and three consist of big numbers of member that make them more stable.
3. The displacements in transmission tower two is greater than transmission tower three for load combinations 2 and 3.
4. The displacements in y axis for transmission tower one is greater than transmission tower two for load combinations 2 and 3
5. Displacements in transmission tower three is best for all load combinations.
6. Axial forces on the legs of transmission tower three with respect to height were greater than both transmission tower one and two.
7. Weight of transmission tower one due to dead load is biggest.
8. Figures 4.17 - 4.19 provide the general comparison of buckling factors and buckling loads of the three mentioned transmission tower models for the two load cases $\text{Buck1} = (\text{D.L.} + \text{L.L.})$ and $\text{Buck 2} = (\text{D.L.} + 0.75(\text{L.L.} + \text{W.L.}))$. The elastic buckling analysis was carried out using structural analysis program SAP

2000 and it was considered 6 buckling modes for each transmission tower. The comparison may be summarized as follows:

- I. For all load cases (Buck1 and Buck2), it was shown significant increment of buckling loads and buckling factors for all transmission towers.
- II. For all transmission towers, it was shown that the load case (Buck1) gives minimum value of buckling load. Figure 4.21.
- III. For all transmission towers, it was notice that the load case (Buck2) gives maximum value of buckling load. Figure 4.22.
- IV. By applying dead and live loads, it was notice that the buckling load for each transmission tower models increased.
- V. By applying dead and lateral load, it was shown decrement the buckling load for each transmission tower models.
- VI. The comparison of buckling behavior of three transmission tower models show that transmission tower model 2 appear to be more stable in comparison of other two transmission towers models for all load cases.

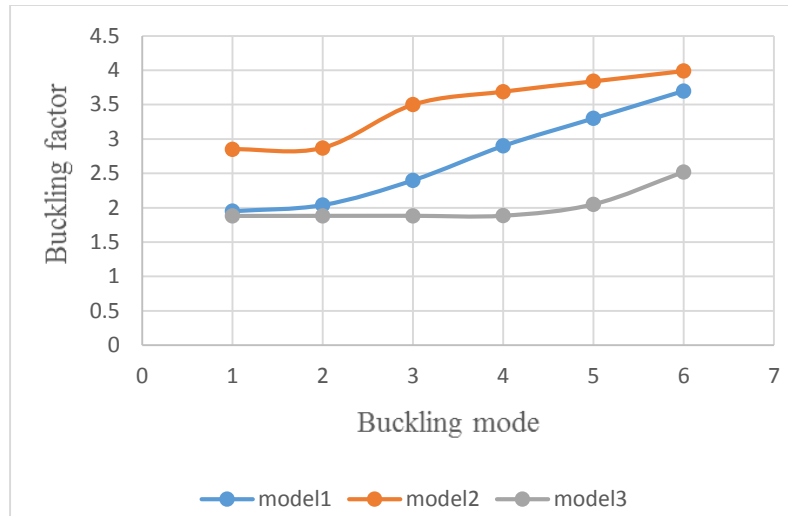


Figure.4.24 Comparison of buckling load of three transmission tower under load case (BUCK 1).

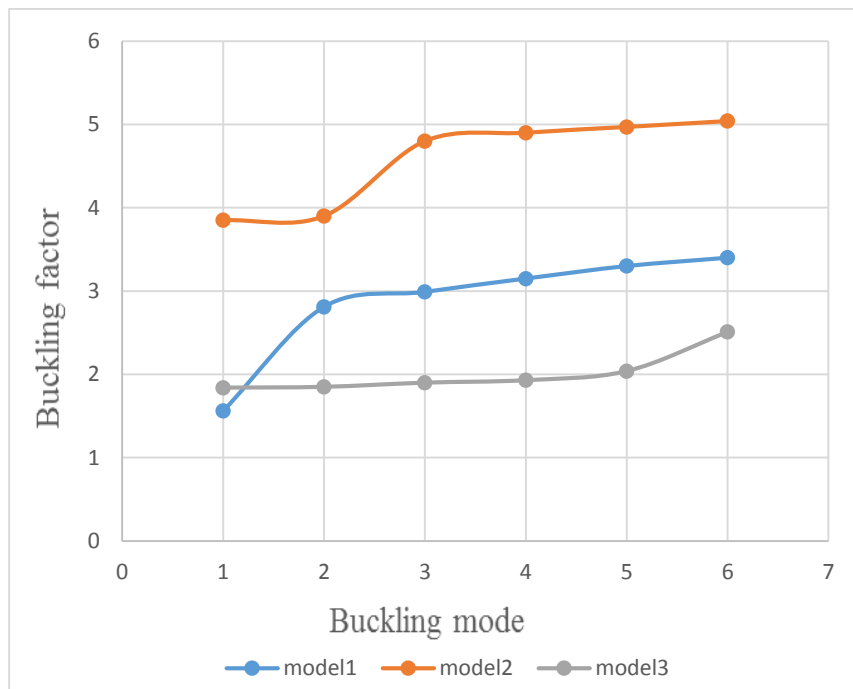


Figure.4.25 Comparison of buckling load of three transmission tower under load case (BUCK 2).

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

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5.1. Conclusions

This study considered different types of electrical power transmission towers. Analysis and design of three different configurations of transmission towers was performed. Different loading conditions were used to study the structural behavior. Results include displacement, axial force and buckling of different elements of transmission towers.

Based on the results of the design of three transmission towers the following conclusions can be drawn:

- a) From design, it was appeared transmission tower (2) was the most economical in comparison with other type. Also the weight of transmission tower (2) is less than other type as shown in table 4.11
- b) From linear buckling analysis, it was noticed that transmission tower (1) results give a minimum buckling factor with respect to other types figure 4.17 show that.
- c) For axial distribution of forces on leg, it was found that transmission tower (2) was less than other types.

5.2. Recommendations

Recommendations from the study

- 1. Structural behavior of the transmission towers varies depending on the change of transmission towers configuration.
- 2. The analysis results of this study may be guidelines for other studies of analysis and design transmission towers.

Recommendations for future work

3. It may be recommended to study structural behavior transmission towers under dynamic loads (earth quack) to give stability.
4. It was recommended to use another computer programs for analysis and design of power transmission towers.

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APPENDICES

Appendix A

Table A-1: Guidelines for classification of transmission towers in different Soil conditions.

SL	Describe of soil encountered	Type of foundation to be adopted
1	In good soil (silty sand mixed with clay)	Normal Dry
2	Where top layer of Black Cotton soil extends up to 50% of the depth with good soil thereafter.	Partial Black Cotton
3	Where top layer of black cotton soil exceeds 50% and extends up to full depth or is followed by good soil.	Black Cotton
4	Where top layer is good soil up to 50% of the depth but the lower layer is a black cotton soil	Black Cotton
5	Where subsoil water is met at 1.5 m or more below the ground level in good soil	Wet
6	Good soil locations which are in surface water for long period with water penetration not exceeding 1.0 m below ground level (e.g. paddy fields).	Wet
7	In good soil where subsoil water is encountered between 0.75m and 1.5m depth from ground level.	Partially submerged
8	In good soil where subsoil water is encountered within 0.75 m depth from ground level	Fully Submerged

9	Where top layer of normal dry soil extends up to 85% of the depth followed by fissured rock without presence of water.	Dry Fissured Rock
10	Where top layer is fissured rock followed by good soil/sandy soil with/without presence of water	Special foundation
11	Where normal soil/fissured rock extends up to 85% of the depth followed by hard rock	Dry fissured Rock with under cut in Fissured Rock combined with anchor bar for hard rock design
12	Where fissure rock of encountered with subsoil water within 0.75m or below 0.75m from G.L. (Top layer may be either a good soil or black cotton soil)	Submerged Fissured Rock
13	Where Hard Rock is encountered at 1.5 m or less below ground level.	Hard Rock
14	Where Hard Rock is encountered from 1.5 m to 2.5m below G.L. (Top layer being good soil)	with chimney for Normal Soil Hard Rock Foundation
15	Where hard rock is encountered from 1.5m to 2.5 m below G./L. (Top layer either in Black cotton) soil or fissured Rock	Hard Rock Foundation design with chimneys designed for wet black cotton soil.
16	Where fissured rock is encountered at the bottom of pit (with black cotton soil at top)	Composite Foundation
17	Where hard rock is encountered at bottom with water and black cotton soil at top and hard rock layer depth is less than 1.5 m.	Hard Rock
18	Sandy soil with clay content not exceeding 10%	Dry Sandy soil foundation

19	Sandy soil with water table in the pits	Wet sandy soil design to be developed considering the depth of water
20	Where top layer up to 1.5 m below G.L. is normal dry soil and thereafter hard soil/murum	Normal dry with undercut
21	Where bottom layer is marshy soil with top layer of good soil/fissured rock/black cotton	Soil investigation is to be carried out and special foundation design to be developed.
22	Where the top layers are a combination of clinker mixed with firm soil, gravel and stone chips up to 60% of foundation depth from ground level followed by hard murum	Normal dry with undercut
23	Where top layers are combination of hard murum, soft rock etc. followed by yellow/black clayey soil	Special foundation design is to be developed after carrying out soil investigation.

Appendix, (B) – Transmission tower one

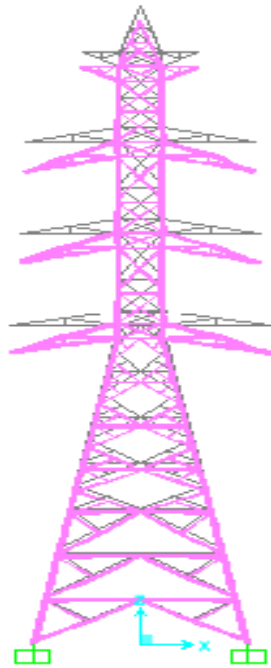


Figure: B-1 Deformation shape due dead load –transmission tower one.

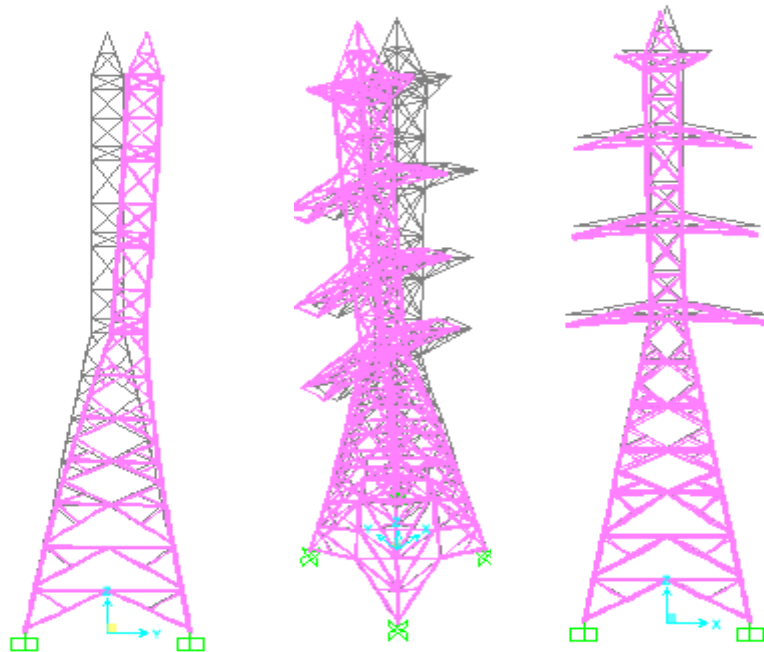


Figure: B-2 Deformation shape due to wind load and load combination.

Appendix, (C) – Transmission tower two

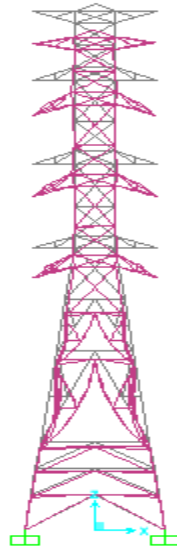


Figure: C-1 Deformation shape due dead load –transmission tower two.

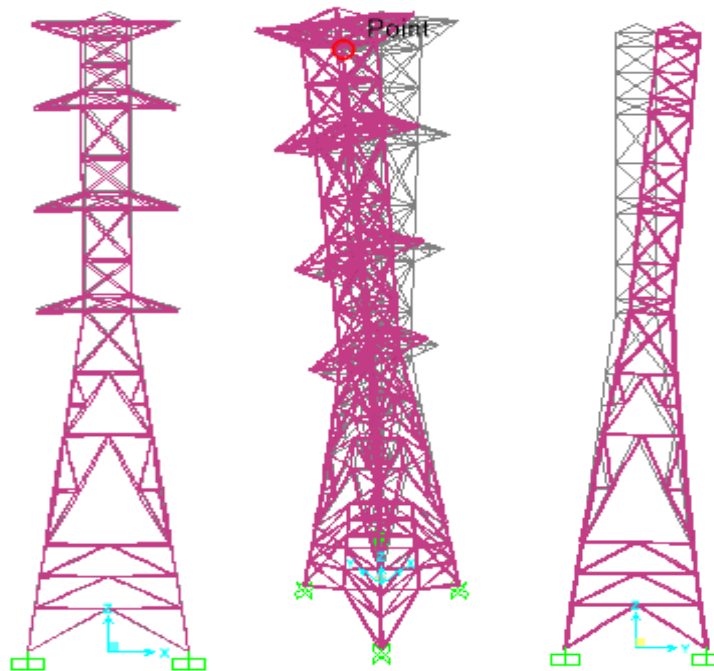


Figure: C-2 Deformation shape due to wind load and load combination.

Appendix, (D) – Transmission tower 3

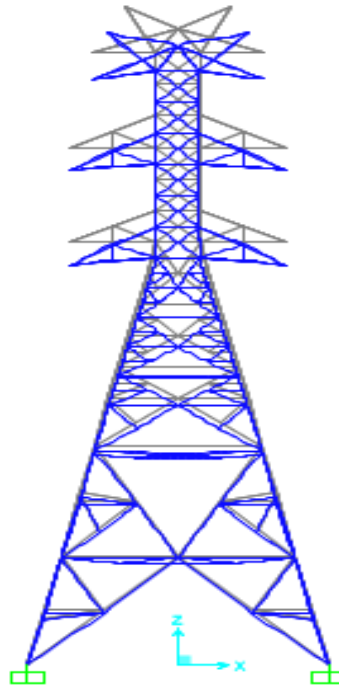


Figure: D-1 Deformation shape due dead load –transmission tower three.

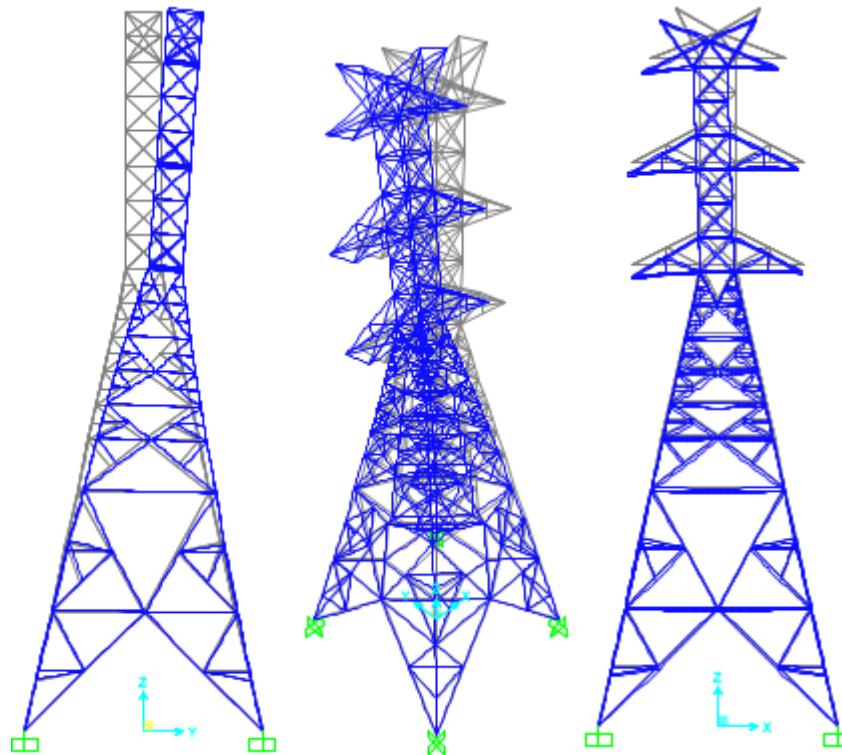


Figure: D-2 Deformation shape due to wind load and load combination.

Appendix, (E) – National electricity corporation design data