Çelik Kafes Enerji İletim Kulelerinin Sismik Analizi

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# Seismic Analysis of Steel Lattice Transmission Towers

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# Seismic Analysis of Steel Lattice Transmission Towers

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by

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## ETHICAL STATEMENT

I hereby declare that this thesis study titled “Seismic analysis of steel lattice transmission towers” has been prepared in accordance with the thesis writing rules of Eskişehir Osmangazi University Graduate School of Natural and Applied Sciences under academic consultancy of my supervisor Dr. Uğur Albayrak. I hereby declare that the work presented in this thesis is original. I also declare that, I have respected scientific ethical principles and rules in all stages of my thesis study, all information and data presented in this thesis have been obtained within the scope of scientific and academic ethical principles and rules, all materials used in this thesis which are not original to this work have been fully cited and referenced, and all knowledge, documents, and results have been presented in accordance with scientific ethical principles and rules.

Loai Morshid

Signature

26/07/2020

# ÖZET

Elektrik iletim sistemleri modern toplumlar için önemli bir yaşam çizgisidir. Çelik Kafes Enerji Iletim Kuleleri; bu enerji iletim hatlarında destekleyici yapılar olarak kullanılırlar. Enerji nakil hatlarında kullanılan direkler, iletkenlerin ağırlığına, rüzgar ve buz yükleri gibi çevresel etkilere dayanarak şekilde tasarlanırlar. Ayrıca kablo kırılması ve buz kırma etkileri gibi diğer olağanüstü etkiler de dikkate alınır . İletim kulelerinin depreme karşı dayanımı genellikle ayrıntılı olarak dikkate alınmamaktadır. Örneğin, deprem risklerinin yüksek olduğu Türkiye'deki iletim kulesi altyapısının önemli bir kısmında mevcut standartlar herhangi bir deprem tasarım ve performans kontrolü içermemektedir.

Bu araştırmanın temel amaçları şunlardır: i) Türkiyede kullanılan tipik TL (iletim hattı) kulelerinin deprem yüklerine karşı davranışını belirlemek, ii) Eğer yeterli güvenlikte davranış yoksa yeni bir kule tasarımı önermek veya merkezden merkeze (CTC) bir kesit kullanarak mevcut çelik kafes iletim kulesini güçlendirmek. Bu çalışmada, Türkiye'de genellikle kullanılan 154 KV iletim kulesinin 3-D sonlu eleman modelleri oluşturulmuş ve bu modellerin sismik analizleri, kaydedilmiş 10 farklı deprem yer hareketi seti kullanılarak yapılmıştır. 42,95 m yüksekliği sahip dört ayaklı kare kesitli iletim kuleleri; Eskişehir deprem bölgesi kabulüyle modellenmiştir. Modelleme ve sonrasında yapılan analizler sonucunda varolan ve halen kullanılan enerji nakil hattı kulelerinin bazı elemanlarının güvensiz olduğu görülmüştür. Türkiye'de bulunan toplam kule sayısı düşünüldüğünde, yıkılıp tekrar yapmak yerine, güvensiz olduğu görülen elemanları değiştirmeden ama güçlendirerek varolan kuleleri kullanmak, maliyet ve işçilik açısından çok daha uygun bir çözüm olacaktır.

Bu kapsamda analizler sonucu yetersiz çıkan kesitleri -literatürde yapılan araştırmalara dayanarak- güçlendirme yöntemleri önerilmiş ve bu öneriler F.E.M modellerinde yapılarak işe yaradığı gösterilmiştir.

**Anahtar Kelimeler:** Deprem hasarı; Doğrusal olmayan sismik analiz; güçlendirme; Sismik değerlendirme; İletim kulesi.

## SUMMARY

The electricity transmission systems are an important lifeline for modern societies. Steel Lattice Transmission Towers are used as supporting structures for overhead power lines. Transmission towers are designed according to the weight of conductors and environmental effects, such as wind and ice loads. Other extraordinary stresses such as cable breakages and ice-breaking effects have been taken into consideration as well. Because of a common perception that transmission towers show low sensitivity to earthquakes, the effects of earthquakes in the transmission line tower construction have not been previously considered. For example, the current standards do not involve an earthquake design check or studying the seismic performance, although there is a considerable proportion of the transmission tower infrastructure in Turkey, where the earthquake risks are high. The principal objectives of this research are: i) to assess the seismic performance of typical TL (transmission line) towers constructed in Turkey to earthquake loads, ii) to retrofit the existing steel sections of the lattice transmission tower - in case they collapse because of the earthquake loads- by suggesting a new tower design or using a new section called Centre To Center (CTC). In this study, a seismic analysis for a finite element model of a representative 154 KV transmission tower in Turkey was performed using a set of 10 recorded earthquake ground movements. The four-legged square transmission tower with 42.95 m height has been analyzed and designed for Turkey, Eskisehir's seismic zone. As a result of the existing and currently used power transmission line tower's analysis and design, it has been observed that some elements are unsafe. When considering the total number of TL towers in Turkey, rather than reconstructing the existing TL towers or changing sections that are unsafe under the earthquake loads, the retrofitting method in terms of cost and labor will be a much more appropriate solution. In this context, this study used a retrofitting method based on conducted researches to strengthen the unsafe sections of the TL tower using F.E.M models. The results show that after retrofitting a load of failure increased, therefore, the retrofitting method is effective and easy to conduct in fields.

**Keywords:** Earthquake damage; Non-linear seismic analysis; Retrofitting; Seismic evaluation; Transmission tower.

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# LIST OF SYMBOLS AND ABBREVIATIONS

| **Abbreviations** | **Statements** |
|---|---|
| A | Peak ground motion acceleration |
| $A_y$ | Value of the mode shape corresponding to tower section y |
| $A_i$ | Value of the mode shape corresponding to tower section i |
| $\alpha_{max}$ | Peak ground acceleration |
| $\alpha_{RMS}$ | Root mean square acceleration |
| ASCE | American Society of Civil Engineers |
| ACSR | Aluminum Conductor Steel Reinforced |
| AC | Alternating Current |
| α | Reduction Factor |
| BPA | Bonneville Power Administration |
| BC-T | Bottom Crossarms Top |
| BC-B | Bottom Crossarms Bottom |
| CTC | Center to Center |
| CD | Drag Coefficient |
| CENELEC | European Committee for Electrotechnical Standardization |
| cct. | Circuit |
| $C_{cap}$ | Compression Capacity Based on Member Slenderness Column |
| DC | Direct Current |
| D/C | Double Circuit |
| DDOF | Dynamic Degree of Freedom |
| DLT | Design Loading Tree |
| DAF | Dynamic Amplification Factor |
| DOF | Degree of Freedom |

## LIST OF SYMBOLS AND ABBREVIATIONS (continued)

| Abbreviations | Statements |
|---|---|
| DL | Dead Load |
| D | Diagonal Members |
| 2D | Two Dimensional |
| 3D | Three Dimensional |
| DOF | Degree of Freedom |
| EHV | Extra High Voltage |
| EN | European Standard |
| ε | Strain |
| E | Modulus of elasticity, Young's modulus |
| Fa | Design Axial Compressive Stress |
| Ft | Design Axial Tensile Stress |
| σ | Engineering Symbol for Normal Stress (Axial or Bending) |
| FEA | Finite Element Analysis |
| FEM | Finite Element Model |
| FFT | Fast Fourier Transform |
| Fy | Minimum Yield Stress |
| FE | Finite Element |
| G | Gust Response Factor |
| GMR | Ground Motion Record |
| HVAC | High-Voltage Alternating Current |
| HVDC | High-Voltage Direct Current |
| HVAC | High Voltage Alternating Current |

## LIST OF SYMBOLS AND ABBREVIATIONS (continued)

| **Abbreviations** | **Statements** |
|---|---|
| HVDC | High Voltage Direct Current |
| IEC | International Electrotechnical Commission |
| IEEE | Institute of Electrical and Electronics Engineers |
| ISO | International Organization for Standardization |
| IS | Indian Standards |
| JR | Withstand an Impact Energy of 27J at +20°C |
| J0 | Withstand an Impact Energy of 27J at 0°C |
| JL | Joint Label |
| kV | Kilo Volt |
| Kz | Height Adjustment Factor of the Wind Velocity at Height z |
| KL/r | Slenderness Ratio |
| K | Effective Length Coefficient |
| K | Stiffness Matrix |
| LC | Load Cases |
| L | Unbraced Length |
| L | Longitudinal |
| ".lca" | Load CAse format |
| MDOF | Multiple Degree of Freedom |
| MW | Megawatts |
| M | Bending Moment |
| $N_{cap}$ | Tension Capacity Based on Net Section |
| NGL | Natural Ground Level |

## LIST OF SYMBOLS AND ABBREVIATIONS (continued)

| **Abbreviations** | **Statements** |
|---|---|
| NESC | National Electrical Safety Code |
| NERC | North American Electric Reliability Corporation |
| NNAs | National Normative Aspects |
| OHTL | Overhead Transmission Line |
| PEER | Pacific Earthquake Engineering Research Center |
| P0 | Pressure |
| PL | Pressure in the Longitudinal Direction |
| PT | Pressure in the Transverse Direction |
| PLS-CADD | Power Line Systems - Computer Aided Design and Drafting |
| PLS | Power Line System |
| ρ | Mass Density |
| r | Radius of Gyration |
| RMSD | Root Mean Square Deviation |
| ROW | Right of Way |
| SP | Single Phase |
| SC | Short Circuit |
| S | Suffix for Secondary Joint |
| SAE | Single Angle Equal |
| SI | International System of Unites |
| λ | Slenderness Ratio |
| TBDY | Turkey Seismic Code |
| TP | Three Phase |

## LIST OF SYMBOLS AND ABBREVIATIONS (continued)

| **Abbreviations** | **Statements** |
|---|---|
| T | Return Period in Years |
| TSC | Turkey Seismic Building Code |
| t | Thickness of Element |
| τ | Engineering Symbol for Shearing Stress |
| TL | Transmission Line |
| TEDAS | Turkish Electricity Distribution Corporation |
| T | Transverse |
| TC-T | Top Crossarms Top |
| TC-B | Top Crossarms Bottom |
| 2t | Twin Teal |
| U | Use Factor |
| Un | Projection of Unit Wind Velocity Vector in same Direction as V0 |
| V | Voltage |
| V | Vertical |
| V0 | Wind Velocity |
| ν | Poisson's Ratio |
| Vnz | Wind Speed Perpendicular to Member and at Height of Member |
| WL | Wind Load |
| WAF | Wind Area Adjustment Factor |
| W | Weight |
| w | Flat-width of Element |
| WW | Wind Width |

# 1 INTRODUCTION AND PURPOSE

The demand for electricity in each country continued to increase and the demand in developing countries was stronger. The towers of the transmission line are considered to be one of the most important structures for the power transfer. For electricity distribution in different regions of the country, the transmission towers are important. In the current situation, the construction of power plants will expand and energy distribution traces as well from the production facilities to the various corners increase as a result. Connections among structures are also increasing to boost reliability and the economic system. Strong and punctilious transmission power lines should be designed to prevent herbal accidents now and to commit to success across the country and globally. The design and construction of the transmission power lines require some electrical and structural specifications. In electrical terms, insulation and security clearances for strength cable from the floor are the most essential specifications. Towers and foundations shall be constructed with the cross-section of cable, the distance between conductors and area of earth wires which is very important to the conductor. The transmission line contains one unit for each class of guidance design, including the conductive subsystem, surface wire subsystem and other subsystem. The technical support of the transmission line is a major part of the road cost and plays a key role in the efficient transfer of electricity. The forms, styles, dimensions, and materials were designed and constructed in great shape. The component styles used in the power lines are typically one in three classifications: guyed, lattice and pole. The supports for Extra-high voltage (EHV) traces are typically steel towers The cost of towers is approximately half of just the transport charge, and therefore substantial savings are gained through the design of the ultimate tower (Kashyap, 2018).

Overhead transmission lines (OHTLs) constitute a critical component of domestic infrastructure throughout the world that guarantees safe and effective energy supply to customers. The design criteria for transmission power lines have also become greatly complicated with the ever-growing requirement for electricity and for this energy to be delivered through greater and greater ranges to reach often far distant cities and factories. These are all components that require detailed analysis by groups of engineers and construction professionals in their design, fabricate, installation and maintenance. In order

to avoid power failure, the structural quality of certain lines is important. Such incidents can have huge social consequences and impact both ordinary citizens and including commercial activities, leading to major economic repercussions and enormous frequent disturbances. Despite this, there is a relatively frequent structural collapse of these sections. This is usually the situation that the strongest pressures imparted on this line refer to storm conditions and periods of severe ice accumulating in colder weather. It is estimated that America's hurricane lost damages from $270 million to $2.5 billion yearly to infrastructure and customers (Kiessling, Nefzger, Nolasco, and Kaintzyk, 2003).

Transmission line steel lattice towers are commonly used as systems to support overhead transmission power lines. The towers and self-supporting towers are categorized into two major categories depending on their support structure. The primary design loads assumed for the towers are the weight of the conductors and climate loads resulting from ice and wind, or combinations of both, as per the latest design procedure. During the design of such structures, environmental loads are generally the governing load. Also considered other exceptional probably loads, including cable break and icing. Those loads are generally determined by the equivalent static methods as defined by the current transmission line Tower standards. In designing a transmission line tower, the effect of earthquakes is not normally taken into account. For areas with small seismicity, this negligence might be reasonable, because climatic loads are expected to rule the design Nevertheless, in areas with high seismicity, the forces of member sections and connections in a tower due to the loading of the earthquake can go beyond those produce from standard load cases taken into consideration in design. Concern for earthquake's effects over the local environment already has risen in several years (De Macedo, 2016).

Transmission line Towers are indeed designed to overcome climate stresses (cold climates) generally without taking earthquakes into account, for example, the accretion of ice and wind load on their elements. Nonetheless, certain of these power transmission towers might be critical structures and their operator may demand that they be functional or even withstand a major earthquake, particularly towers in high-risk seismic regions (Khedr, 1998).

In a wide range of Civil Engineering projects, latticed systems have been used. A latticed steel structure consists of elements and nodes that resist the load applied. Standard lattice steel structures consist of structure's roofs, several domes, and support lattice

towers. Lattice systems are suitable for circumstances of large capacity of load carrying, low self-weight, efficient utilization of materials, and quick manufacturing and constructing. For these purposes, towers that are self-supporting are mostly used for transmission and distribution. As a latticed steel tower design can be used on a power transmission line for several of towers so an economical and high-efficiency design is very necessary. The design of the TL tower section members must simplify the tower structure using a few section members as achievable and under several loads, the state should be stressed. The aim is to create a well-proportioned and attractive economic structure. Standard towers with equal bracing system in all directions have a squared body arrangement. The towers varied between 30 m and 50 m in terms of height and carry cables between 200 m and 600 m. Many transmission power towers are designed with symmetrical slim-walled angle members which have an excellent connection, a high level of resistance against non-linear materials and non-linear geometrics, and have slippage or semi-strength at joints. It leads to many hypotheses for simplifying the computations, many software programs that model design and evaluate towers (Kroeker, 2000).

The objective of this transmission line components is to outline the different components comprising transmission lines in some details. The context is given for main and minor roles of transmission line components. The definition of "transmission lines" is usually underground or Overhead Transmission Lines (OHTL). A transmission line is mainly concerned with the transmission of bulk power from the source to the load center.

Different components consist of transmission lines including poles, lattice tower, cables, insulators, conductors, earthing control systems and foundations. In this section, these components are further identified in details.

Transmission line structures are mechanical supports for conductors is the main role of transmission power line systems. This is accomplished by keeping mechanical stability under final load conditions without continuous structural deformity while keeping structural design geometry to maintain the operating electric-powered clearances in the specified serviceability and greatest loaded conditions Figure 1.1 shows typical Transmission Line Tower.

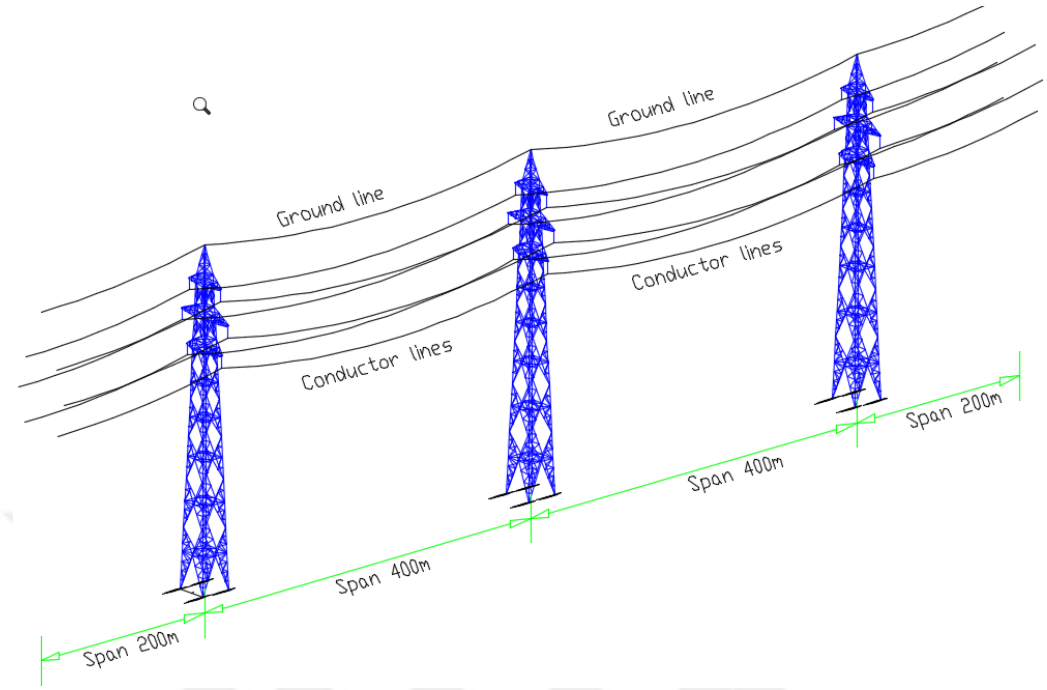



**Figure 1.1 Typical Transmission Line Tower**

The minor role of the structures of the transmission line are:

(a) Ensure human and environmental safety.
(b) Preserve geometrical structure to ensure secure maintenance of serviceability and maximum load conditions.
(c) Give energy directly to the earth for failure currents.
(d) Offer a cost-effective operation during life.

Examples of structures include self-supported and guyed:

(a) Lattice tower
(b) Tube poles of steel.
(c) Stobie poles.
(d) Poles made of concrete.

Transmission line conductors in the specified efficiency, operational and environmental circumstances, power transmission systems are primarily assisted by electrical transfer between defined locations.

The minor functions of the conductors of the transmission line are:

(a) Maintaining the safety of electricity and minimizing environmental damage.
(b) Provides cost-effective service throughout the life.

The transmission line isolation of the transmission line has two main functions:

(a) Isolate energy components in measured operating voltages as well from earthed support structures and defined switching and lighting impulses.
(b) Support of the conductor framework for final structural load limit and pass to structure loads.

The equipment for the transmission line has four main functions:

(a) To fully support the insulating entire system to the limits load of electricity.
(b) Support the system of insulators up to final mechanical load limitations.
(c) Provide an effective connection interface for safe transferring weight to the supporting structure between conductor and isolator.
(d) To supply a cost-effective quality service throughout life.

Transmission line earthing is the main practical requirement of an earthing system for the transmission line is:

(a) Provide electrical pathways to the ground to ensure security for individuals, property and the environment, for lighting or faulty currents;
(b) Make sure faults are remedied and components on the transmission line not either damaged.
(c) Provide a reference of earth potential to earth for the dispersion of leak current under ordinary circuit circumstances.

For the design life, the minor operational specifications of an earth transmission system are:

(a) Maintaining electrical security and minimizing environmental harmful effects.
(b) Providing an appropriate comprehensive solution.
(c) Provide such a cost-effective service throughout life.

Transmission high voltage cables are the principal functions of high voltage power cables are to carry electricity across designated locations, in specified operational, environmental and quality requirements, and to insulate powered elements from earthed power structures at valued operating different voltages and defined lightning pulses and switching.

High voltage cable minor functions are to:

(a) Maintain electrical security and reduce environmental adverse effects.
(b) Providing isolation by electricity.
(c) Provide cost-effective service throughout the life

The cable elements of high voltage power voltage are:

(a) Cable and attachments for joints, sealing generally ends, connecting boxes and partial detectors.
(b) System monitoring condition / Temperature sensor distributed.
(c) Cable trench, bays, pits for connection boxing new equipment, support structures, chambers for expansion (Number, 2018).

Several power lines can be used, as the transmission voltage for high energy transmissions can range from 60 Volt and can exceed 1000 kilovolt. Almost every power line in every country is AC in three phases. Here you can find a table 1.1 with the most popular properties for identifying type of lines (Kroeker, 2000).

Three-phase Alternating Current (AC) powerlines are electric power three phases which is a common way of generating, transmitting and distributing current electric alternately. That is a kind of poly phase network which is the most popular way of transferring power through electricity grids globally. This is also used for driving big generators and other high charges. Circuit of three-phase is typically more efficient to translate a specified quantity of electrical energy than single-phase of a two-wire circuit at the identical line at ground voltage ("Three-phase electric power - Wikipedia", 2019).

**Table 1.1: The most popular properties for identifying type of lines ("Classification Of Power Lines - Openstreetmap Wiki" 2020)**

| Designation | Votage Range | Type of pylons used | Ending points | Wire count per system | Ground conductor use | Ground conductor use |
|---|---|---|---|---|---|---|
| Low-voltage line | 0 – 1000 V | Wooden, concrete, steel- tube, lattice poles, also poles on rooftops | Indoor subtations, poles (not surrounded by switchyard), walls of buildings | 4 | Single | No |
| Medium-voltage line | 1000 V – 50000 V | Wooden, concrete, steel-tube, lattice poles | Indoor substations, poles (not surrounded by switchyard) | 3 | Single | Normally no, but exceptions exist |
| High-voltage line | 50000 V – 200000 V | Lattice towers, sometimes steel-tube towers or wooden poles | Outdoor substations, rarely termination towers (sometimes surrounded by switchyard) or indoor substations | 3 | Single (double, triple or quadruple rarely) | Normally yes |
| Extreme-high voltage line | >200000 V | Lattice towers, sometimes steel-tube towers (until 500 kV) or wooden poles ( until 345 kV) | Outdoor substations, rarly termination towers ( sometimes surrounded by switchyard) or indoor substations | 3 | 2- 8, single rarely > 250 kV | Normally yes |

Single-phase Alternating Current (AC) lines are electrical trains use single-phase AC to frequencies except those in the national network of France, Norway, Switzerland, Austria, Scandinavian and the eastern of the United States.

Although these lines are utilized for railway applications, they do not always suit railways. In several instances, lines are mounted on supports/ pylons of the total railway line, which is used primarily in the 138 (kV) single-phase lines of Amtrak (ex-Pennsylvania Railroad) in the North-East Corridor with (12 kV, 25 Hz) of traction control, where most of them operate along the central catenary poles.

The used frequencies and voltages can be illustrated with the following examples:

- 16.7 Hz, 110 kV, in Austria and Germany.
- 16.7 Hz, 55 kV, in Norway and Austria.
- 16.7 Hz, 66 kV, in Switzerland.
- 16.7 Hz, 132 kV, in Sweden and Switzerland.
- 25 Hz, 27.5 kV, in Austria.
- 25 Hz, 138 kV, 24 kV, in the United States.

Normally conductors are single but there are also bundled conductors line (Kroeker,2000).

Direct Current (DC) lines is often used for lengthy-distance or ocean-cable transmissions. DC lines usually consists of two conductors, but there are also schemes for 1 and 3 conductors. A unique function of the DC lines is the use of ground-return systems in a reason to avoid unwanted electrochemical degradation by adding a specialized unusual electrode. Special cables, or electrode lines, are attached to the cable terminals. These can, but mostly, not be assembled on the primary cable towers, which they can offer as an earth conductor, provided they have an isolator mounted just above leads on the primary line with a lightning stopper. If electrode wires are located in a different line, that line usually appears like a medium-voltage wire, but with a number of one or two conductors, however certain wires with higher voltages have been placed on towers. While the DC line typically uses ground conductors and multiple wires as triphase AC line, electrodes use individual cables and no earth conductors, with an exceptional exception. Electrodes do not have any ground conductors (Kroeker, 2000).

Hybrid lines In some situations, power lines for various kinds of current are carried by line support towers. The illustrated combinations can be addressed:

- DC – single-phase AC
- DC – three-phase AC
- Single-phase AC – three-phase AC
- DC – single-phase AC – three phase AC
- DC – single phase AC
- DC – three phase AC
- Single -phase AC – three-phase AC
- DC – single-phase AC – three phase AC

Both DC and single-phase AC lines have been installed on the unchanged supporting towers until now. DC and AC three-phase lines are exceptionally rare (Kroeker, 2000).

The HVAC (High Voltage Alternating Current) and HVDC (High Voltage Direct Current ) alternatives to electricity transmission and distribution started a major battle in the power supply industry. That finally represents a gained to AC, which retained its dominance in nearly all residential, commercial and industrial energy supplies to consumers.

HVDC has now become a proven and efficient technology for long-distance bulk electricity transmission. Most of the difficulties experienced over the last 40 years in the previous years were solved. HVDC systems with DC electricity extending to 3 x1000 MW and +500 or -500 kV voltage have been developed over the last ten years.

The main reason why HVDC is preferred from the AC is that because HVDC is easier than AC to transfer large quantities of energy from point to point across long-distances. A high-power HVDC transmission long-distance system usually has lower initial costs and lesser loss than that an AC connection. According to other technical advantages, HVDC transmission can also be used for electrical systems and a significant decrease in energy losses. The combined technical and economic advantages of HVDC also can consider it a convenient choice to connect sources of energy far enough from the primary loading centers. Figure 1.2 demonstrates Overhead power lines HVDC vs HVAC.

Nevertheless, the current flow purely to do charge the capacity of the lines can be considered for an overhead long AC transmission line, and this decreases the line's capacity to transport helpful current all at the end of the remote. The influence on a skin, which results in a non-uniform distribution current through the cross-section of the conductor, decreases the beneficial current carrying capacity of AC lines. Conductors of transmission lines with HVDC present do not face any of these limitations. Consequently, that same conductor can handle more current than AC when operating to HVDC in connection with that same conductor losses or heating effect. As can be seen in the pictures, the environment is less harmful to HVDC.

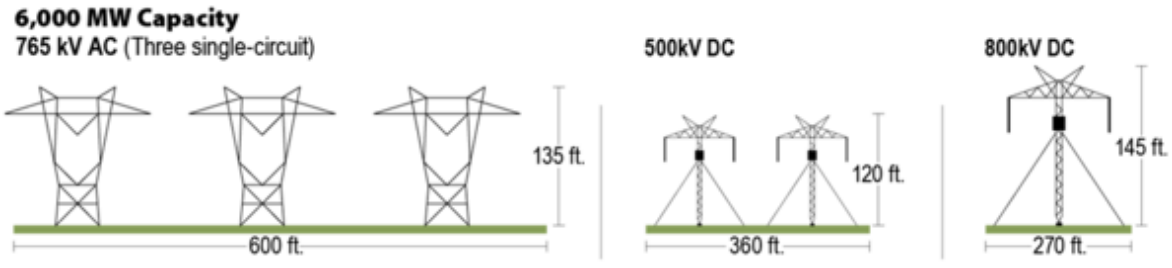



**Figure 1.2: Overhead power lines HVDC vs HVAC**

The main difference between AC and DC transmission power line here is that there are three power transmission conductors in the AC transmission line, while two conductors are required for the DC transmission power line.

The transmission power line is already a closed power system that transfers the power from the power plant to the consumer.

The AC transmission power line carries the majority of the output of electricity generation basically to the user end. In the power generation station, electricity is generated. The power line transmits electricity outside the power generator to the user.

The Mercury arc rectifier transforms the alternative stream into a DC in the DC transmission line. The DC power line passes over large distances the electricity supply. The thyratron converts DC into AC at the end of the consumer.

There are a number of important differences between AC and CD ("Difference Between AC & DC Transmission Line - Circuit Globe", 2019):

- The AC transmission power line transmits a long-distance of the AC. The DC transmission power line guarantees a very long-distance power transmission.
- Three conductors are used for lengthy power transfer in the AC transmission line. And for the power transmission, the DC transmission line utilizes two conductors.
- The AC line requires surges and inductance while the DC line is clear from surges and inductance. The surges and inductance are nothing except the short-lived high power voltage wave.
- The high-voltage decrease usually occurs across AC terminal transmission lines where their terminal point voltage is equivalent. The DC transmission power line is clear from induction and therefore there is no voltage fall throughout the line.
- Only on the AC transmission power line the circumstance of the normal skin impact takes place. The effect of the normal skin induces the losses and it can be minimized if the cross-section of the conductor's area is lowered. In the DC transmission power line, the normal skin influence phenomenon is absent.
- At same voltage, the DC transmission line has less stress as compared to the AC transmission line. Hence, DC requires the less insulation as compared to AC.
- In comparison with the DC transmission line, internet communication power line state interference is very much in the type AC transmission power line.
- The corona influence is the occurrence in which the conductor is ionized. And this is an ionization that creates the conductor's losses. The corona influence process takes place only on the AC line but does not occur in the DC line.

- The dielectric failure occurs on the AC line but not with the DC line.
- The AC line has problems with synchronization and stability, while the DC line is safe of stability and synchronization.
- Contrary to just the DC power line, the AC power line is much less costly.
- Compared with the DC transmission, the small conductors have been utilized for the AC transmission line.
- In order to increase and decrease the voltage, the AC power line needs the transformer. However, The chopper and booster are utilized in the DC power line for stepping up and lowering the voltage.

In conclusion, for small electricity transmission, the AC transmission line is being used. And the DC transmission is being used for long-distance power transmission.

There are examples of several types of structures (towers or poles) employed main role in the transmission of power since they used as a supporter for the overhead wires. Furthermore, they named line supports. This maintained the appropriate space between all the conductors and holding the conductor out of its ground sections at the specified distance. The required earth clearance has also been preserved. The mechanical and electric considerations determine these clearances. Low cost, low cost of maintenance, and long service life are the initial needs for line supports ("What are Line Supports? Definition & Types of Line Supports - Circuit Globe", 2019).

The power tower is a significant part, and it is very necessary for electrical transmission to work. Various types can be categorized for pylons or power towers. Here we are going to try to explain it in general. The categories that are most visible and obvious are ("Transmission Tower Types", 2019):

Self-supporting:

For electric power transmission towers, typically self-supporting steel lattice towers are used (As seen in figure 1.3).

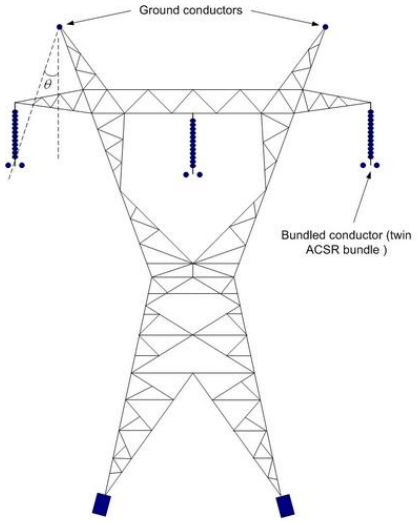



**Figure 1.3: Self-supporting Lattice Tower (single circuit)**

In most energy companies, self-supporting lattice towers are more used for overhead power lines. The construction of the tower can easily be installed in very difficult locations as it is easy to transport the members of the tower. Additionally, the lattice towers are cost-effective light ("Transmission Tower Types", 2019). These are typically chosen wherever property prices are high or the construction areas are highly limited. Even though there are many towers with four-legs, the most widely constructed tower in America is a three-legged, galvanized tower with three legs. As the height of the structure increases, the base segment face diameter, the width between both the centers of the two legs is increased. Nonetheless, many tower manufactures can design the transmission tower to meet the requirements for height, the wind load, while keeping the same dimensions ("Towers/Installation - Self Supporting Tower - Material", 2019).

Semi-flexible and flexible tower:

Broad towers are more resistant to switchover and have less inductive line reaction. At voltages, 1000 kV as well as higher than average, semi-flexible or flexible towers with higher switching increases stand up to the level and maybe even lower average inductive reactivity due to their narrower size. The type of tower that is semi-flexible considers more economy and more used in overhead power line with one-circuit three-phase beside

conductor with horizontal configuration. Guy wires can be used for supporting the building in the elastic or guy towers. Such guy wires were tensed between the cross-arms as well as the anchor as of the base. The tower's two legs are placed on the unchanged base in the usual structure in V shape while the two separate legs are divided into a chatelain model. This contains two steel lattice structures or the legs of steel tower placed on the hinged foundation with wire and hooks to support the two arms ("Towers for Extra and Ultra High Voltage Transmission lines", 2014). A picture of a rigid self supporting type tower is seen in Fig.1.4.



**Figure 1.4: A rigid self supporting type tower used for 764 KV transmission line**

Guyed tower (Guyed-V, or Guyed-Y):

Towers such as these are V-types or portal types. Both contained two supports attached with a cross-arm also they had four guys at the peak.

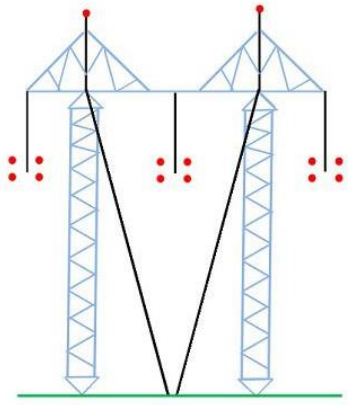


**Figure 1.5: Portal Type Guyed Towers**

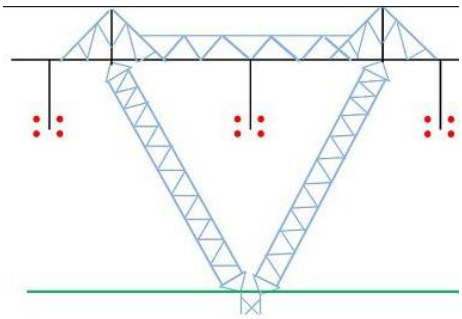


**Figure 1.6: V-type Guyed Towers**

As seen at the tower drawings (Fig.1.5 and Fig.1.6) the support is based on its basis in the portal construction while all supports in the V-support structure only stand on one thrust base which is more common, at the angle with each other (Kashyap, 2018).

The Guyed-V towers were also used in situations in which greater space is accessible by the transmitting companies. These are easy to assemble and less costly. The towers need less time usually to be installed. The major disadvantage here is that with guy wires, such towers need more such space. As seen at the tower drawing (Fig. 1.7) a certain tower utilizes two isolators in V-type per phase (De Macedo, 2016).

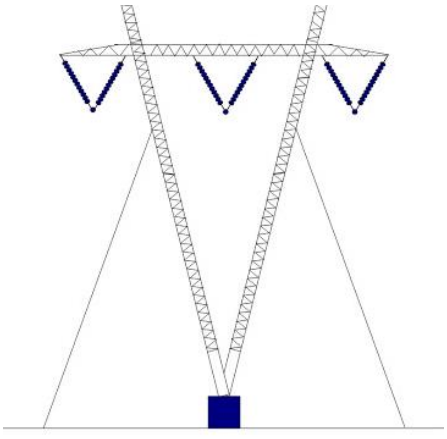


**Figure 1.7: Guyed-V Tower with Double insluatro Strings per Phase Conducotr**

The tubular or rolling sections of steel, concrete, and wood are widespread structural types of materials. The choice is related to quality, climate, deterioration

resistance (e.g. oxidation of steel and wood termites) and sometimes transport and installation problems (Taher, 2017).

Tubular steel: Steel tubular electric power transmission Pole which is typically constructed of steel tubular, as one of the usual electric power transmission poles, is collected in a factory and then placed on its position later. Many public companies prefer to use monopoly or concrete towers, a lattice steel tower, for complete new electricity power transmission and replacements of towers. These power transmission towers are commonly used to substitute the concrete and wooden towers on the street of the town for a great function and save more space and durability. In every country around the world, it is normal to see that the tower of steel tubular electric power transmission poles has varying criteria for choosing the tower of poles. Inside Germany, For the medium-voltage transmission line, the steel tubular pole is mostly built. However, for 2 electrical circuits of equivalent to 110 kV, for functioning voltages and high-voltage lines. The steel tower pole is used mostly for 500 KV inside the United States. And in France for 380 KV electric power transmission ("Steel Tower – Good Building Material", 2019).

Lattice: Lattice transmission towers are a frame structure made from sections of aluminum or steel. The Lattice transmission towers are the most popular form for high-voltage electric power transmission designed for transmission lines of any voltages. The tower is often constructed from galvanized metal. Aluminum is design for lighter weight, for example in mountain regions where helicopter used for placed such structures. In conditions where metal is corrosive, aluminum is also used. Installation costs will still be lower in the additional material costs of aluminum towers. Aluminum towers are similar to these for steel, yet aluminum lower modulus must be considered. Such a tower is generally constructed at the place where to be built, allowing towers until 100 m tall and sometimes higher in unique cases, for instance, the Elbe Crossing 1 and 2. Crane can be used to assemble the steel lattice towers. Towers made of L- or T-beams consist typically of steel angle-profiled beams. Trusses are commonly used for very high towers.

Wood: Wood represents a type of material restricted for design high voltage electrical transmission. The greatest height for the wooden transmission pylons is narrow, due to the restricted height of the trees available, to about 30 m. For the lattice frame, wood is seldom used. These are mostly used for the construction of multi-pole systems, including

K-frame and H-frame. They also contain limited voltages, for instance in other areas where wooden structures convey just voltages up till around 30 kV. Wooden transmission towers take voltages of up until 345 kV in countries like the United States or Canada; they can become less expensive than steel towers, and use the surge voltage insulation property of wood. Since 2012, there are 345 kV power lines of wood transmission towers in the United States and some of these systems still have to be installed. Wood can be also utilized as a long term replacement for a temporary structure.

Concrete: Throughout Germany, concrete transmission pylons are usually utilized for voltages lower than 30 kV. Concrete transmission pylons are in rare circumstances design for lines with 110 kV and also the regional grid or traction network present. In Switzerland, 380 kV overhead lines use concrete pylons up until 59.5 meters in height (Littau's tallest one pylon of the world's prefabricated concrete). In the United States and Canada, concrete transmission poles are still used. Concrete transmission pylons, that are not pre-made, can be used also for buildings up to 60 m. One instance is a 380 kV power line pylon, which is 66 m high near Berlin's 'Reuter West Power Plant'. Several pylons seem equal to chimneys for production. In China, certain pylons were constructed of concrete for lines that crossed the rivers. The tallest pylon in Nangingen, with 257 meter height, belongs to the powerline crossing of Yangtze ("Transmission tower - Wikipedia", 2019).

Transmission structures tended to be utilized to support the phase wire and safeguard the transmission line wires and the type of lattice transmission lines is often used. One of three shown modes in Figure 1.8 that may rely on the design of the phase conductors may be designed under the following basic designs:

- Delta
- Vertical
- Horizontal

A structure analysis to figure out how well the system is built depends more usually than not on the costs, the building, and the maintenance requirements, and the effect of fields of electromagnetic.

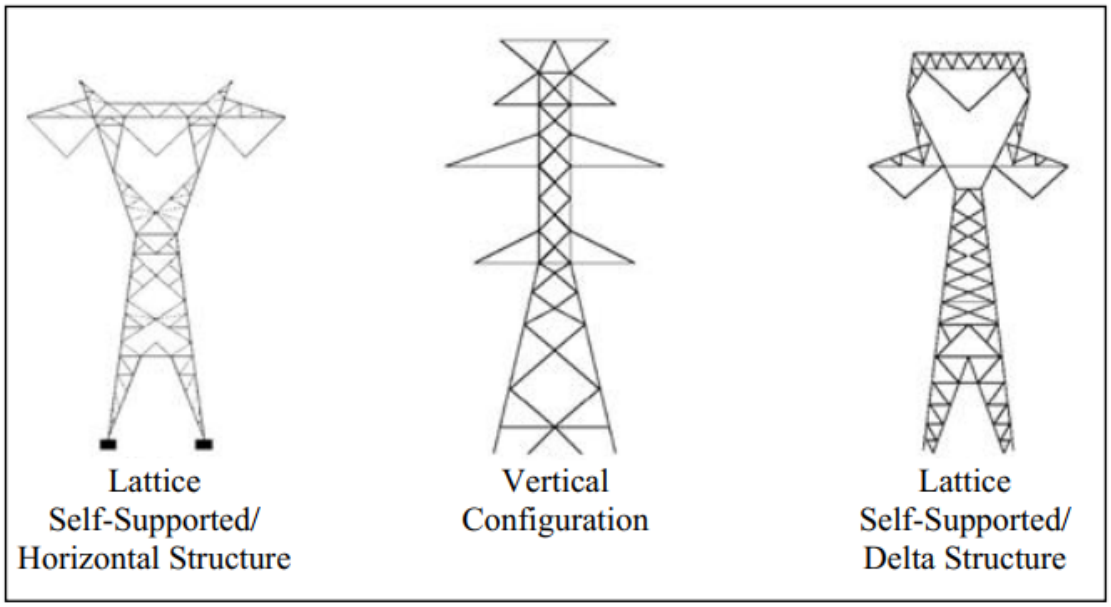



**Figure 1.8: Configuration of transmission line structures (Castro, 1995)**

The following points that recognize when evaluation configuration of the structure are:

- A horizontal design aims to achieve the lowest structural expense.
- If the price of the right of way is high, or its distance is small, and the line blocks certain lines, the most cost-effective option can be the vertical model.
- In contrast to a wide right of way, horizontal models in usual demand more clearance than the vertical designs.
- In contrast to being taller, vertical forms have less range than horizontal ones. It makes the vertical arrangements more aesthetically appealing.
- Electric field strength manages to be seen as an issue and the process design is considered as essential to reducing these areas. In comparison with horizontal models on the right of way, vertical models provide narrow field capabilities. Delta systems provide us with the lowest double and single circuit ground strengths as well as the lowest ground strength be able to provide with inverse or low reaction phases.

The selection of the tower model relying on both the design weights and the associated costs for the various tower and materials will intend to change when this final change occurs with other considerations. The town design is conducted by both the electrical

power engineer and structural design engineer, which the first responsible for electricity specifications and the second responsible for efficiency and adequacy of the structure (A. Taher, 2017).

The three-phase cables typically are designed as either of the two single or double-circuit transmission lines. Three conductors for three-phases have a single-circuit configuration. There are six conductors and three-phases for each circuit conductor in the double-circuit configuration. Figure 1.9 shows a tower with three-phases for each circuit conductor.

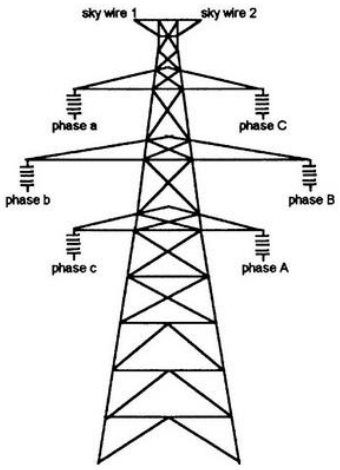



**Figure 1.9: A Tower with three-phases for each circuit conductor**

Double-circuits can be used when larger reliability is required. This transmitting method allows more electricity to be transferred over a certain distance. The change is, therefore, easier and takes not as much of land and also is found optimal from aesthetically and ecologically desirable. Two-circuits going close to one another, however, require an inductive connection between both the conductors. When determining the fault rate and establishing protection systems, that has to be carried into consideration. In most cases, double-circuit lines comprise bundled of conductors as well as conductors positioned to reduce inductance as much as possible (Nagachandramoulitati, 2017).

From the perspective of the tower feature, another primary classification is an angle of deviation. This means basically whether the transmission tower is a kind of suspension, dead-end or angle. The tower is selected according to the specific angle of a transmission line deviation. The tower type of suspension only carries the conductor only in usual

circumstances. However, suspension transmission towers are normally suitable for quite low angular line deviation.

In various countries, the standard code defines the total angle of divergence for suspension transmission towers. When the power line path deviates from the specified maximum angle, the angle kind of transmission towers can be used. Of various angular deviation sizes, the angular towers can almost always be subgrouped. The towers can, therefore, be classified as small, medium, and large angle transmission towers. The type of towers which is at termination points are dead-end towers and have a wide unequaled load. The strongest and heaviest type of towers is the dead-end transmission tower. In practice, wide corner towers are designed to use as dead-end towers. This eliminates the requirement to design another type of tower that is dead-end. The tension isolator strings use angle towers. See the following figure 1.10.



**Figure 1.10: Dead-end transmission tower**

Depending on the route topography the number of overhead powerline towers must be installed per kilometer. The line length thus relies on topography. For specific conductors, the span must be that so the line has a minimum clearance on the earth or other items at the maximum temperature (according to local standard). There must certainly be more towers in such hilly or some other mountainous terrain per kilometer. If the line direction varies from a straight line more often, more towers are required per kilometer. Angle towers can be used wherever such distances deviate from the line route which is impossible to use the suspension tower.

In the topic above, it is obvious that there are several reasons to choose the categories of the transmission tower. You should also have noted that the phase conductor is commonly arranged horizontally (or even in triangular) once the tower is equipped with only a single circuit. More right of way is needed throughout this arrangement however the height of a tower is decreased and tower materials are saved, thus reducing the tower costs. That phase conductors generally have a vertical arrangement (see the Fig. 1.11 sketch) once the power tower supports two or even more circuits.

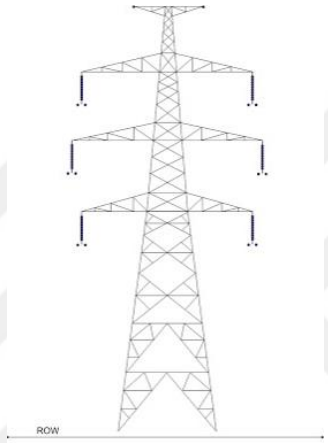



**Figure 1.11: Lattice Tower With Double Circuts**

The necessity of the right of way is lower throughout this configuration however the height of a tower is greater. In double or even more circuit cases, this is commonly the choice. Double-circuits are sometimes organized horizontally and vertically in line with the right of way accessibility and optimized overall cost ("Transmission Tower Types", 2019).

Motivation for the research  that a transmission line is identified as a thread-disaster structure, designers shall try to apply standardized building codes or adopt the standards established for the design. However, as evidenced in several studies, such structures respond differently to seismic loads than the concentric earthquake-resistant frame buildings. For intance, in buildings, the structure configuration, size, and type of supporting loads are different from those designated to the TL tower.

Therefore, the analysis of towers' response to seismic pressures is in high demand, especially when the TL infrastructure is in the high-risk seismic zone. Even though these

TL towers are designed to support the weight of the conductors and environmental impacts, such as the growth of ice and the gustiness of the wind, as well as unusual stresses such as cable breakage and the effects of ice spreading. There are few load combinations between which the effects of the earthquake design can determine. Also, there is an encouragement to develop a method to evaluate the seismic loads' sensitivity for these structures.

This research has the following objectives:

- To assess the sensititivity of typical TL towers to earthquake
- To provide a better understating of the dynamic modeling of tall overhead transmission line towers that are subjected to a dynamic earthquake load and to compare the computed response of such a model to results from the computational model on static analysis and loads.
- Designing the best and withstanding system against various loads.

To achieve these objectives, an existing 42.95 m height used in Turkey with 154 KV double circuit free-standing TL tower (self-supporting tower), subjected to ten seismic ground motions. Comprehensive simulated numerical models in SAP2000 software program are highly-developed and nonlinear time history analysis used to emphasize the differences in demand.

Detailed nonlinear analysis simulations numerical of the free-standing TL tower system are performed with using ten records of the Earthquake ground motions and outcomes are compared to those acquired from static loads.

The content and organization of the thesis are:

Chapter 1: Background, types of towers, lattice structures, aim and objectives of the thesis.

Chapter 2: A literature review including analysis and design of tower.

Chapter 3: The methodology used in this thesis, the structural features of the transmission line tower that selected in this study, the selection of ground motion records.

Chapter 4: Assessment of selected transmission line tower's static as well as dynamic characteristics is provided. The nonlinear time-history analysis is conducted to determine the capability of the tower to earthquake ground motions, discussion of the found results is provided. As well as the design of the transmission tower using the AISC360-16 code is provided which is the most suitable for Turkey in terms of design has been used. As for the 2018 turkish code.

In Chapter 5: Conclusions based on this thesis are provided for future work that prefers to be made.

# 2 LITERATURE REVIEW

## 2.1 Lattice Structures

A truss or lattice tower defines as a stand-alone frame tower consisting of a metal frame including several welded or bolted structural components ("Lattice tower", 2019). Transmission line of high-voltage which is usually consists of conductors and ground wires supported by lattice steel tower. The category of these towers depends on their configurations as self-supporting free-standing towers and Self-supporting guyed towers (De Macedo, 2016).

In a wide spectrum of Civil Engineering fields, such as grids, roofing, domes and transmission systems, latticed towers are utilized. These structure scans can be used as electricity transmission towers, especially like a radio or observation tower for voltages raised 100 kV. For instances requiring high load carrying capacity, light self-weight, less-used materials, and quick manufacturing and construction these structures are ideal. On this basis, the most desirable system for transmitting and also distributing electricity is the self-supporting lattice structure. Since an individual latticed structure design can operate on a transmission line for loads of structure, an ideal, economical and significantly efficient design is highly essential. The arrangement of the members of the structure is significantly important to keep the geometry of the structure simple through as small segments as possible, that are recommended under various load conditions to be completely stressed. The objective is to establish a tower that is cost-effective and should be attractive and accuracy proportioned (Kroeker, 2000).

In the design of lattice tower structures, environmental loads, such as those caused by wind and ice accretion are generally controllable loads. Earthquake impacts in TL Tower Design are not considered in the present design practice, although they are placed in high-risk seismic areas. Such ignorance was based largely on a general perception that TL structures are quite vulnerable to earthquake ground motions. This view can, however, be justified in low seismic activity, not in seismic regions, in which forces in tower members and connections exceed the limit of the design forces derived from typical load cases in design practice (De Macedo, 2016).

A transmission tower is an aluminum or steel frame structure. Lattice transmission towers are the most prevalent form of high-voltages transmission power lines service for power electrical transmission lines for whole voltages. Usually, the lattice structures are produced of galvanized steel. Aluminum is used for weight reduction, for example in hilly regions where helicopter places structures. Aluminum is still used in steel-corrosive conditions. Lower assembly costs will compensate for the additional fabric expense of aluminum towers. The design of aluminum lattice transmission towers is comparable to that of steel, but the reduced elasticity module of aluminum must be taken into consideration. Commonly a lattice transmission tower is constructed where the tower is being installed. This allows it feasible to have a very high tower, above 100 meters. Lattice transmission steel towers usually consist of angled steel panels such as L-beams or T-beams (Taher, 2017).

The majority of work published on TL tower is dedicated to the analysis in climatic conditions like wind and ice accretion of these structures. Some exceptional load cases, including dynamic loads, were studied because of cable breakage and ice shedding. Seismic impact work on TL towers has only began in the last few years (De Macedo, 2016).

## 2.2 Overview of High-Voltage Lattice Transmission Line Towers

TL towers have been designed to support conductors and ground wires. The structural design of such towers is based on the form of high voltage network, including HVAC and HVDC, number of circuits and amount of ground wires. As shown in images, multi circuit towers typically have a vertical configuration. 2.1a, 2.1b and 2.1d, while towers with the single circuit are either vertical (Fig. 2.1.e) or horizontal or flat, illustrated by figures. 2.1c, 2.1 g & 2.1 h (De Macedo, 2016).

Lattice steel structures appear to be used for the largest voltage concentrations, while wood pole structures are deemed cost-effective for comparatively lower and lower voltages. Steel towers are a commercial selection in areas, including severe weather loads choose on greater voltage wires with various sub-conductors per phase. In order to be regarded in such the design for bigger longitudinal stresses to address a variety of unbalanced weight contingencies, H- design tower is less efficient in handling such stresses. Steel structures in additions have the capacity for any load quality and direction to

be designed professionally. Characteristically, the greater complexity of these constructions requires that peak stress tests be performed on new types of structures and at least on the tangent framework to ensure that all parts and connections are properly designed and detailed (Castro, 1995).

The load cases necessary for the current TL tower design are normally related to minimum electrical clearance for the conductors (depending on the voltage level), weather conditions (such as wind pressure and ice accretion loads on the conductors and structure of the tower) and longitudinal loading induced by broken conductors, a tower failure or some other element failure. As mentioned previously, TL towers can be categorized in a transmission line system due to geometrical configuration and support types and their role in a transmission line system (De Macedo, 2016).

More often than not, the lattice structures are analyzed assuming that the elements to be connected by hinged joints are therefore the load that is applied in the elements are only axial. Taking this assumption, the stresses are incredibly low, which is why they are not counted in the linear analysis model. However, there seems to be no axial force on the main legs and bracing elements and the redundant stresses are not considered low. This case can be referred to the following reasons (Prasad Rao and Kalyanaraman, 2001):

- The main supports are often constant throughout the joint.
- The used joints are usually semi-rigid due to the use of not only one bolt placed in the connections.
- The angle elements are typically bolted in only one support and the load is transferred in the parts is therefore unusual.
- The joints are flexible due to the deformation occurs on the support angles induced by the determined bolt forces.
- The structure designed for extreme electrical levels and it is generally flexible and stability, therefore, it is extremely recommended to take into consideration in the deformed design.
- Moments of bending are improved by compression elements deformation.

Accordingly, the tower's angle elements come into connection with the axial load and bending moment.

In the construction of steel towers, galvanized steel angle members are generally used because of their ideal compromise between cost and durability. Structural steel is commonly used in, steel grades of 350 W (G.41 21 CSA) or ASTM A572 Gr.50, with minimum yield strength 345 MP a for members with the tower supports used in North America. The steel lattice tower structures are generally the best reasonable solution for voltages exceeding 150 kV (De Macedo, 2016).

The most common types of towers utilized in electric power transmission lines are the self-supporting lattice steel tower, most of which are implemented when tight structure sites and right-of-way are required depending on regional and environmental circumstances. Their designs could be modified to have the ability for a variety of circuits, therefore, all kinds of conductor designs and the design of lattice steel are also cost-effective for high towers. If necessary, upgrading current towers can be done relatively simply and replacing cross arms is likely (Kiessling, Nefzger, Nolasco and Kaintzyk, 2003).

A family of towers supports overhead power lines in which each tower has a separate function to support that same conductor. TL towers can be divided into the following categories as per their function: **suspension** (or tangent**), strain, terminal, transposition,** and **river-crossing structure.**

**The suspension towers** are usually designed to fit small transmission line deviation angles (generally 3 degrees) in relatively straight segments of the transmission line. The minimum costs are designed as a primary concern, making them lightweight and highly flexible. Guided towers are typically used as suspension towers because the straight sections of the TL system usually provide the most cost-effective solution. In a suspension tower, the conductor phases passed through the insulator support points and suspended.

**Strain towers** are designed for different line variations up to $90^{o}$ angles. These towers are designed to withstand the net tension of the conductors. The conductors are connected by strain insulators to the tower structure.

**Terminal towers** are in a tower family the highest and most strong structure. The towers are used to withstand the total tension of all conductors and ground wires on the terminals of transmission lines. Self-supported towers are commonly used as terminal

tower structures or a mixture of self-supported towers and guy supports because they are the most laterally fixed and heavier structures in the towers family.

**Transposing towers** are typically used to change the relative position of the phases in longer segments of a transmission line.

**River-crossing towers** are typically the tallest structures in a tower family as they have been used for a relatively long span. Such systems are typically large self-supported suspension towers that demand specific designs to accommodate ground conditions and spans.

The TL tower may be designed to support single, double and multi circuits and may have geometrical configurations such as flat (Figs. 2.1c, 2.1 g, and 2.1h), delta (Fig. 2.1.e, Fig. 2.1.f) and vertical (Figs. 2.1a, 2.1b and 2.1d ). TL towers can even be classed as per their support systems, including the traditional Self-supporting (Figs. 2.1a to 2.1d), lattice guyed single masts (Figs. 2.1e and 2.1f), and lattice guyed frame and cross-rope suspension (Fig. 2.1h).

All of these towers represent a technological development that leads to cost savings. Guyed towers can represent cost reductions of up to 30% for self-supporting towers in the suspension towers used in relative straight segments of the transmission line.

The selection of tower forms also refers to available space dimensions footprints and esthetics. The design of self-supporting towers needs relatively smaller footprint dimensions, which makes it a greater option for townscapes where land prices are a large portion of the expense of a transmission system project. The basic configuration of the tower is based on phase spacing, attachment height limits and line angles. These variables are determined in a diagram for the tower outline and the clearance of the conductor, which are the basis of a detailed design.

The figure (Fig. 2.2) shows a typical TL tower configuration. The structural components of a tower are categorized as: i) leg members; ii) primary bracing; and iii) secondary bracing or redundant. Insulators are usually found in towers that work at carrying loads from the conductor and the ground wires to the foundation of the tower. A leg component is the main part of a tower framework which protects the corner and transfers loads of the towers to the base. The overall structure of the tower is determined

by those members. In the tower structure demonstrated in Fig. 2.2, leg members are addressed in green color. Fig.2.3 shows the concept of the orthogonal directions usually used in the tower design. The path of the overhead cable alignment is related to the longitudinal direction.

Primary bracing (in blue color shown in Figure 2.2) are components that hold horizontal stresses such as wind loads and conductors loads and earth wires. For the distribution of torsional and shear forces through the tower structure, horizontal braces are needed. Slightly loaded redundant members (in yellow in Figure 2.2) are intended to decrease the load-carrying length of the members (primary bracing and primary leg ). Therefore, a major improvement in their compression capacities is accomplished by increasing the size of the structural members. The sections of the tower are generally labeled in detail.

Since transmission lines have to cross large areas of land with a changing topography while preserving the horizontal and vertical orientation of conductors as frequently as can be, Transmission towers are generally intended to fit into a structural frame, which has a variety of different heights to suit differences of their supporting members (body extension, tower legs, and tower body).The tower waist, the tower's part that transitions from the top to the highest head, is typically the segment of a tower that is more demanding because of the horizontal loading of the structural members. The top of the tower (cross-arms, K-frame, and ground-wire peaks) designed as per the conductor clearance needs and it supported the conductor's forces (De Macedo, 2016).

## 2.3 Design of TL Lattice Towers

Some standard sets the strength and loading specifications obtained from design concepts relying on reliability. The possibility that a specific structural system satisfies requirements over a specified period can be described as reliability. The particular approach to the designing of transmission system elements presented in figure 2.4.

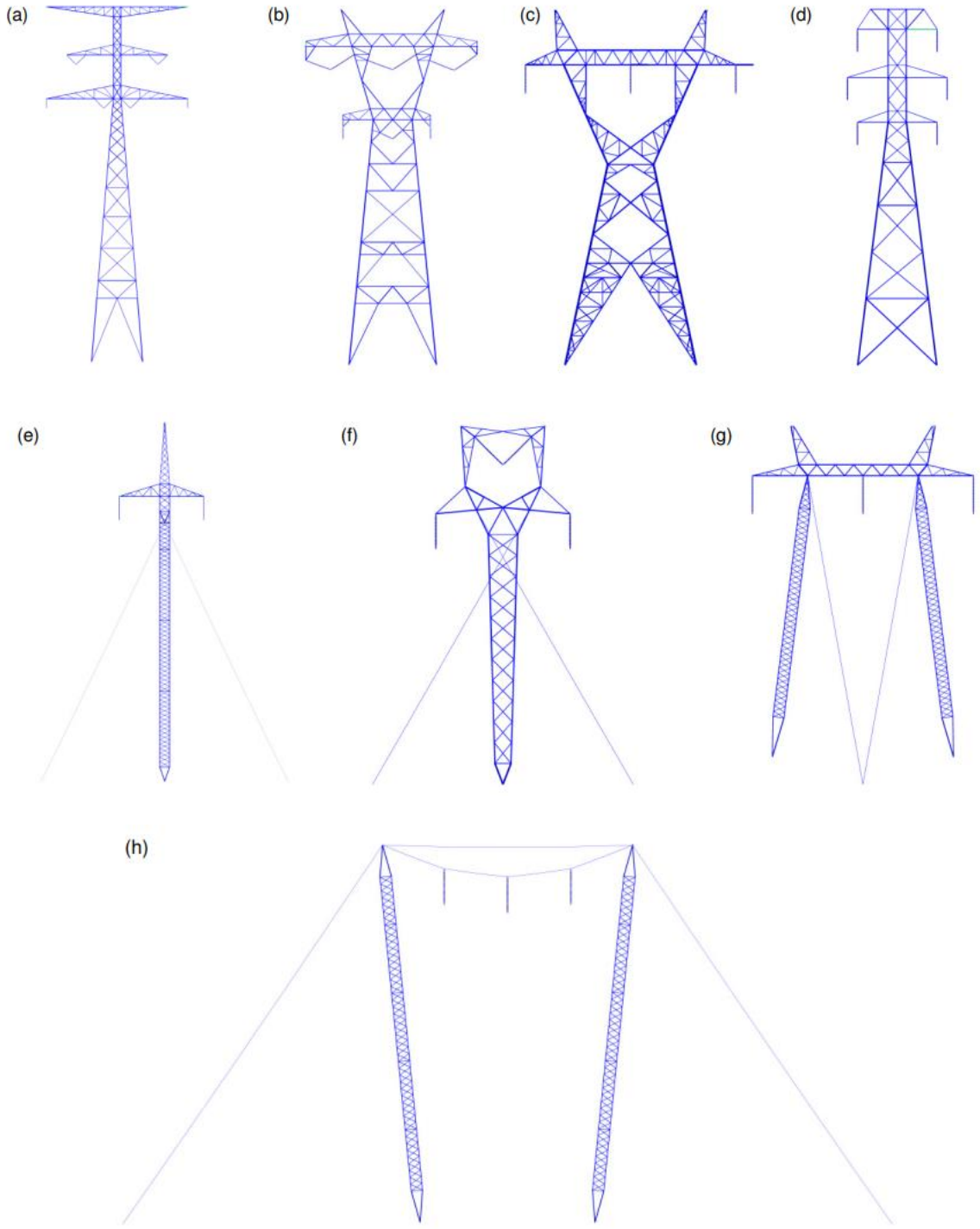



**Figure 2.1 Examples of transmission Line towers. (a) 85 m high vertical self-supported double-circuit tower used for river-crossing span; (b) 30 m high vertical sef-supported double-circuit tower; (c) flat self-supported single-circuit tower; (d) vertical self-supported double-circuit tower; (e) single- circuit guyed mast tower; (f) single-circuit lattice guyed delta tower; (g) single-circuit flat internally guyed portal tower; (h) single-circuit cross-rope suspension tower.**

Overhead cable specifications and route selection are specified in the initial design stage and required climate details are obtained. Design standards include climate data with a fifty-year return period, for example, ice thickness and reference speed of wind. The failure containment (safety requirements) and reliability rates for weather limit loads are specified in forms of the return period. According to the specifications, loads relevant to safety and weather loads shall be measured and utilized to design of transmission line's components.

The Transmission line lattice towers design generally follows the following steps: select a tower, describe of the geometry and detail the design. The method of choosing a tower is defined by selecting the right tower model for a particular project of a transmission line. The fundamental definition of geometry or standard definition of the outline is usually focused on the requirements for transmission line design, like attachment heights, phase spacing, line angles and maximum span limits. In the diagram of a conductor clearance and tower description, all these factors are taken into consideration.

The latticed steel transmission line tower structural process design includes materials definition, load cases, and combinations, efficient slenderness and limiting conditions, strength factors, minimum thickness, and element connections (De Macedo, 2016).

## 2.4 Loading on Transmission Tower Components

The first stage in the design of the tower is to determine the tower loading. The load should be correctly determined which is the parameter of the design. The main stage in designing a tower is tower loading. Any error of loading makes the design of the building incorrect. Depending on the designed parameters, a variety of loading types must be precisely calculated. The wind performs the most significant part in the load calculation and the proper evaluation of this load leads to a suitable load evaluation and a reliable structure design (Varma and Lal, 1998).

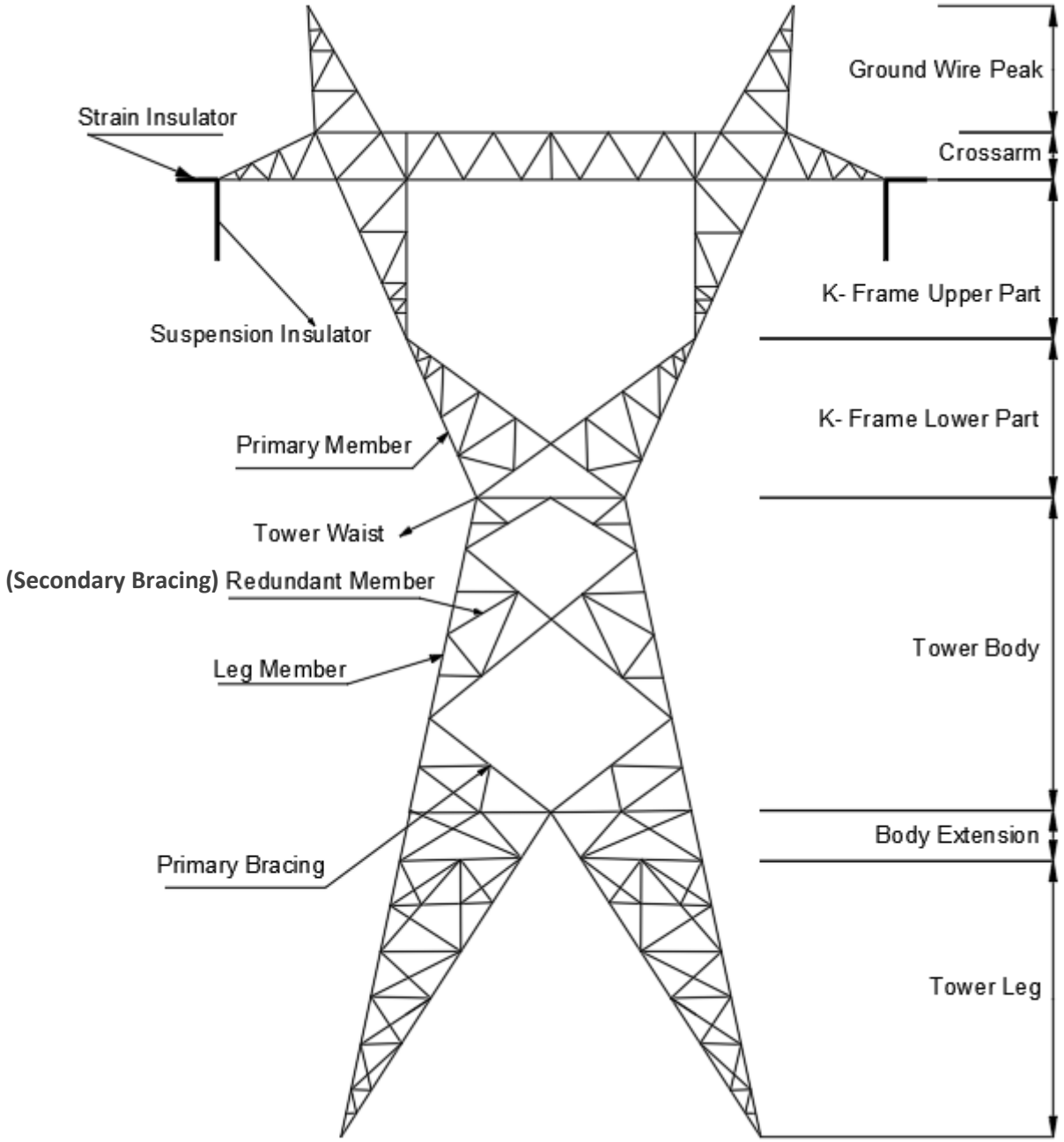



**Figure 2.2 Example of a self-supported transmission tower and its components**

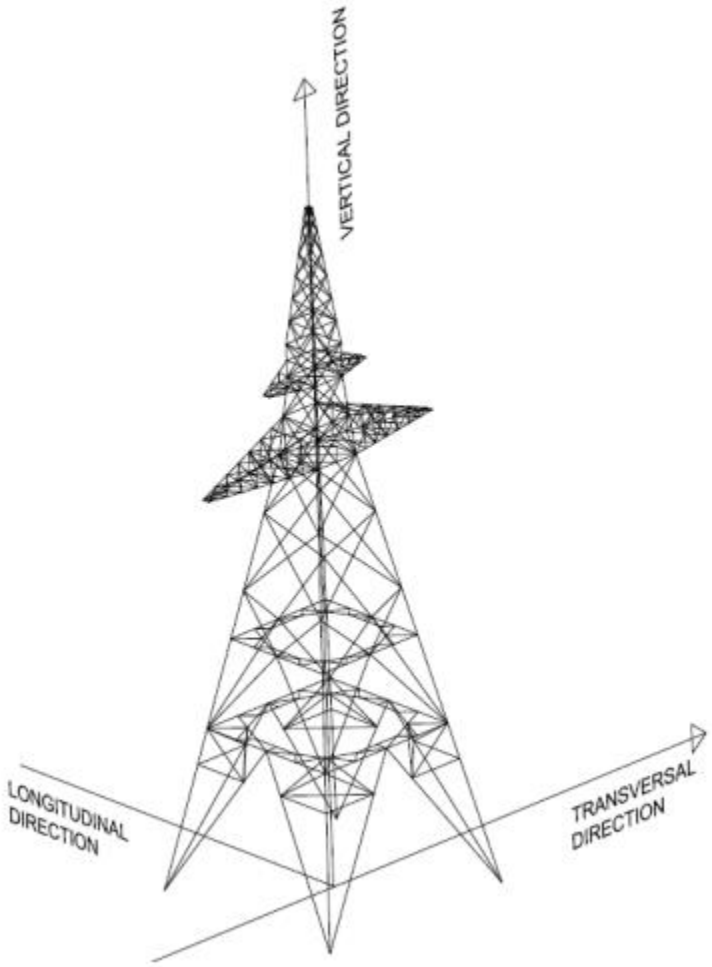



**Figure 2.3 Standard orthogonal directions definition**

The tower design load case is using to ensure a safety structure capable of withstanding climatic load (e.g. ice accretion and wind pressure) and containment loads for failure (e.g. unexpected broken conductors). Tower design does not generally take seismic loads into consideration. Indeed, in most standards, there are no provisions of seismic. The structural design loads can be categorized into two major groups the structure loads themselves and the loads acting at the point where the ground wire or conductors attached. Tower loads, which include the added weight caused by galvanizing, the steady dead load of the attached equipment (e.g. insulators) and the wind action, and ice accretion on the structural members are usually attributed to the structure. The loads at the attached points of the structure are due to the ground wires and tension caused by conductors due to a

broken wire, the self-weight, and conductors, the constant dead weight of wind pressure and ice accretion (De Macedo, 2016).

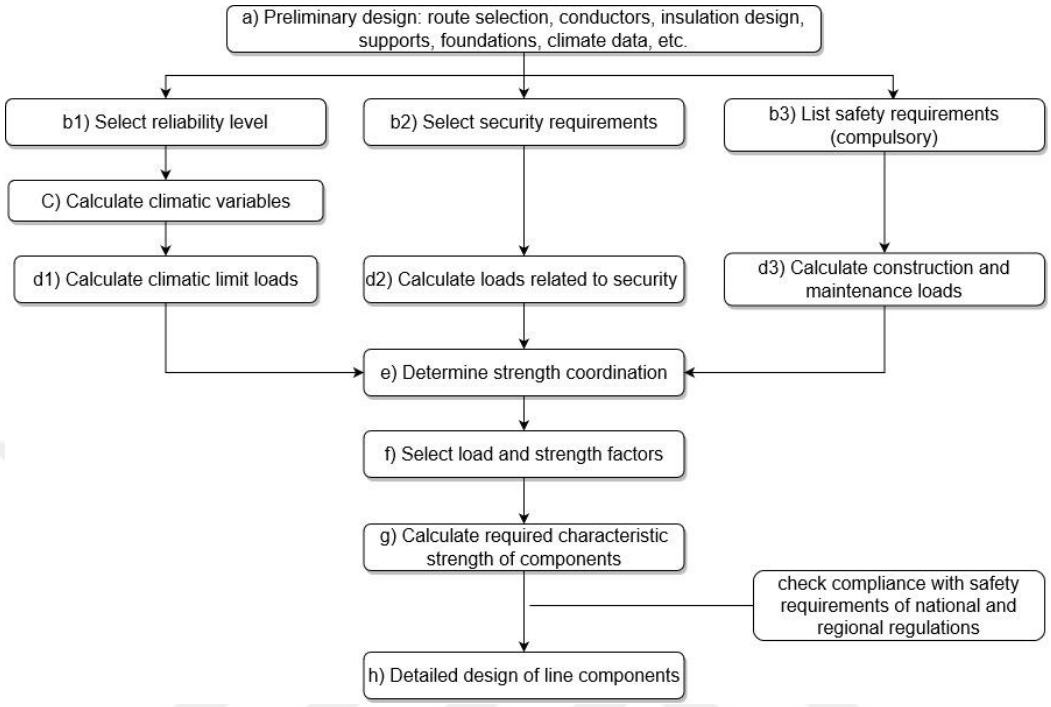



**Figure 2.4 Transmission line design methodology.**

### 2.4.1 Requirements of loads on transmission line tower

Diverse feed overhead transmission lines loads can be categorized into four separate categories over their entire lifetime (Varma and Lal, 1998):

1.Dead load or continuous load associated with the basic requirement of design.

2.Climate conditions such as ice, wind and heat cover associated with the necessities of dependability (this is considered a standard situation).

3. Containment failure loads linked to safety demands and considered a condition of broken wire.

4. Maintenance and construction of safety-related loads.

#### 2.4.1.1 Dead Loads

The weight of conductors, insulator strings and support weight are due to dead loads. Dead loads usually thought to be permanent in basic nature, but due to differences in the support load span of electrical conductors and height, they Cause to change among supports. These essential items contain the growth of vertical forces throughout construction and maintenance that occur in conductors such as stringing, lowering or lifting. This deadweight is the product constant weight of the bare per unit length as well as the load of the span that may vary depending on the spacing of the support and the change in height and tension of the conductor, which varies based on temperature.

Generally, the weight range of a given support type has the greatest assigned number used for support design. The calculation of the load of the conductor is detailed in the design standards (EN 50341-1, 2001).

#### 2.4.1.2 Climatic loads

For reliability demands, this load situation is essential. When the data about the largest quantity of wind or snow a year is available, the tendency towards the intense distribution function is often appropriate, as in the C.4 Clause (IEC 60826), for example, in the Gumbel type I distribution. The threshold and generalized distribution of Pareto, as some latest research suggest, can be used for particular circumstances of not observing ice and snow accretions every year. The function Gumbel defines the mean and deviation standard of the variable in question. These values must be obtained by evaluating comments made over several years and this duration will affect the distribution and estimation of long return period T (Geneva,, 2003).

In design standards, the calculation of weather loads has to be found in detail (Moon, B. W., Park, and others, 2009). There is a definite impact on wind pressures in the construction of transmission lines. Snowfall may or may not be in this area. Three classifications, therefore, exist as follows:

- Wind Loads (Non-Snowy Areas).
- Wind Loads with ice (Snowy Areas).
- Wind Loads without ice (Snowy Areas)

Due to the weight of the snow on conductors and tower, the transmission lines across snowy areas handle additional vertical loads. The calculations for tension and drop must also be performed with and without snow weight taking into account (Varma and Lal, 1998).

#### 2.4.1.3 Failure containment loads

- Unbalanced longitudinal and torsional loads caused by broken wires: All towers have to be able to withstand the longitudinal and torsion loads caused by breaking the specific amount of conductors and/ or earth wire.
- Anti-cascading loads: The cascading condition could also be met by reason of the failure of items such as hardware joints, insulators and so on. The angle towers for anti-cascading loads including whole conductors and earth wire, broken such in the unchanged span, should be checked. If the cascading failures are to be overcome. This load is considered a necessary and fundamental requirement as part of the safety necessities. As far as maintenance and construction practices are concerned, regulations are recommended to decrease impermanent and avoidable forces that require the permanently high-priced strengthening of towers (Varma and Lal, 1998).

#### 2.4.1.4 Construction and maintenance loads

Construction and maintenance forces are considered to be constant. The total of these loads goes beyond common operations unexpectedly. If the weights within this area, they are risky, and the all-over the regularity of the line is changing compared with external and dead loads (Geneva, 2003).

- Construction loads: Additional loads are placed on towers during the construction of the transmission line, generally involving the weight due to cables, pulleys, components of various loads and towers also a man load, etc.
- Maintenance Loads: Additional loads on the tower, which include loads of maintenance tools, tackles, handles, pulls, etc., are imposed during maintenance of a transmission line (Varma and Lal, 1998).

### 2.4.2 Nature of loads

#### 2.4.2.1 Transverse loads (T)

- Wind load on tower structure acting vertically, earth-wire conductor, and insulator strings.
- Horizontal elements of a tension of earth-wire and conductor.

#### 2.4.2.2 Vertical loads (V)

- Loads due to each conductor's weight, earth wire depend on the appropriate weight span, insulator strings weight and fittings.
- The own-weight of the structure.
- Loads due to the maintenance and construction periods.

#### 2.4.2.3 Longitudinal loads (L)

A broken wire cause unbalance horizontal loads of tension of conductors and/ or ground wires in a longitudinal direction, therefore it notes that the end of towers are usually designed for total longitudinal tension of the conductors throughout accepted cases (Varma and Lal, 1998).

### 2.4.3 Load combination

Different external loads that operate simultaneously on supports of the power lines are combined in an adequate way to all load cases. Such combinations of acts require reliability safety and security to act by the requirements. The load cases must pay attention to whole load conditions can be expectable throughout the construction and throughout an overhead line's entire lifetime, so harm will be uncertain. For designing the components of the transmission tower, all process of load cases are considered to be operating simultaneously, and the maximum load of the element will be selected as the design load. Extraordinary and normal loads are distinguished in several standards with different requirements for the reliability or differing allowable stresses applied. Such particulate loads may be classified to be picked without any rhyme or reason(real explanations). Generally, all cases that occur during an overhead line’s normal operation are considered normal load. Thus, wind load is an instance of normal loads. Load or load combinations

with small incidence potential are known to be extraordinary loads, like non-uniform spans' ice accretion or shedding of ice.

The EN 50341-1 defines five standards for load cases. They have a varying effect on the various elements. It is also not a possibility to determine which load cases would dominate for all the tower elements. The load cases dependent on EN 50341-1 are shown below:

1a ‘Extreme wind load’

1b ‘Wind load at a lowest temperature’

2a ‘Uniform ice loads on all spans’

2b ‘Uniform ice loads and transversal bending’

2c ‘Unbalanced ice loads and longitudinal bending’

2d ‘Unbalanced ice loads and torsional bending’

3 ‘Combination of wind and ice loads’

4 ‘Construction and maintenance loads’

5a ‘Security and torsional loads’

5b ‘Security and longitudinal loads’

Load cases are described in each overhead line standard or specification of a project for the design of supports and foundations. The load cases based on EN 50341- 3- 4 are presented as an instance for useful definitions in the following below:

A ‘Wind load in direction of cross-arms and no ice loads on conductors’

B ‘Wind load in line direction no ice loads on conductors’

C ‘Wind load below 45° no ice loads on conductors’

D ‘Reduced wind load in direction of cross-arms with ice loads on conductors’

E ‘Reduced wind load in line direction with ice loads on conductors’

F ‘Reduced wind load below 45° with ice loads on conductors’

G ‘Conductor tensile forces at -20°C, unbalanced ice loads, conductors particularly with ice loads’

H ‘Conductor tensile forces at -20°C or -5°C with ice load, ice loads on conductors’ differing conductor tensile forces. This case does only carried out for strain towers’

I ‘Construction and maintenance loads and no ice loads on conductors’

J ‘Torsional load, one conductor tensile forces reduced, ice loads on conductors’

K ‘Longitudinal bending, all conductors tensile forces reduced, ice loads on conductors’

L ‘Load after failing of one insulator string and ice loads on conductors’

The load cases were subdivided into consideration the design taking into account the variations in loads of span and line deflection correlated with the operation of each particular support type. For example, for angle supports designed with line deflections from 0 ° to 20 °, whole load cases for these two angles should be conducted to accommodate the prevailing stresses on individual components. If these acts reduce the effects of another behavior, the minimal amount of the permanent load should be used to evaluate elements of tensile forces and uplift the foundations. In this scenario, it is advised to presume the shortest weight range of dead loads of the conductor (Kiessling, Nefzger, and others, 2003).

### 2.4.4 Other considerations

Loads have to be certainly multiplied by defined load factors to get the design-factored loads. The factors defined by the "National Electrical Safety Code" (IEEE 2012) for overload capacity were load factors mainly based on this standard's terminology. The Guidelines for "Electrical Transmission Line Structural Loading" (ASCE 2009) and also the "National Electrical Safety Code" (IEEE 2012) offer extensive background data on the use of design factors loads (American Society of Civil Engineers, 2015).

The support of the transmission line vulnerable to extraordinary loads such as galloping lines and shaking of construction. Although the movement of the galloping structure does not usually result in significant loads on the systems, the loads produced by wires galloping could harm cross-arms, connections of cross-arms, and hardware. In addition, some member shapes of the structure are primarily vulnerable to wind-induced oscillation and failed in weakness. The designer must then consider the potential problems involved with these phenomena (Picard and Beaulieu, 1987).

There are load cases of unexpected processes like those of segments breakage, fatigue or wear, natural disaster or terrorism, structure breakdown, and other unexpected incidents were evaluated to provide designs to minimize their impact on the overhead transmission line as an all and avoid uncontrolled cascade-type process damage. Specific safety requirements were known for these cases. Safety evaluations are accomplished for more planned functional, construction and maintenance incidents where defined loads are evaluated through both concepts and standard practice codes (Boca Raton, 2012).

By evaluating the external force that influenced the system, they can usually be analyzed Because the axial loads are considered the only truss element force of the truss, each component has to be designed as compression or tension Such members can handle compression and tension loads with several load conditions. Load reversal may induce alternative characteristics of loads; truss components should, therefore, be designed to handle compression and tension. Under the standard case, the overall load impacting every single element and at the same time the broken cable is factored by appropriate safety factors and values should be examined to be within the maximum strength allowable of the particular steel used (S.R. and A.R, 2014).

### 2.4.5 Design Strength Checks

Once the strength of members is determined, connections and members are checked. The check process of designed members is to compare the tension forces and axial compression generated by the members to the permissible capacity calculated as stated by the given standard. Bolted connection design checks are done to test the capacity of shear, bearing and tension. The shear capacity is proportional to bolt’s number, and shear plane’s number per bolt. The capacity of the bearing are directly relative to the bolt's number and the bearing area's number per bolt. The capacity for tension is linked to the net

section or limited cross-section area, which depends on the account of holes (De Macedo, 2016).

The compression capacity of a component is defined by:

- The slenderness of member (kL /r ratio controlled) – control the overall member buckling and slenderness of cross-section which described as "local buckling" (b /t or w /t ratios controlled).
- Member's capacity ends the bolted connections (e.g. The connected gusset plate buckling capacity, Bolts ' shear capacity in the connected bolt, and Increased blot hole deformation of bearing).

The tension capacity of a member is described by the minimum of the mentioned bellow:

- Net fracture due to the capacity tension of the members .
- Tensile members capacity ends connected blot (e.g. shear failure block );
- Tensile members capacity ends connected blot (e.g. bolt shear capacity);
- Tensile members capacity ends connected blot (e.g. connected plates bearing capacity).
- Tensile members capacity ends connected blot (e.g. gusset plate yield capacity)

## 2.5 Analysis of Tower

For the design of transmission line structures, linear elastic truss designs seem to be basically used. There are variations between the actual results produced from full-scale model experiments and the usual analytical results due to the assumptions used in the analysis Linear static analysis might not point to the transmission tower structural feature. Design engineers are therefore real in assessing the specific stress levels in TL tower structures (R.b, Ranjith and Bharath, 2014).

These days, the design forces determination procedure for the tower members, caused by the applied design load is based almost primarily on FEA (Finite Element Analysis ). Geometrically nonlinear techniques, which take secondary forces into account related to massive displacements (e.g. P-Delta) are commonly used to analyze guy towers; whereas self-supporting towers are typically studied in a Geometrically Linear FEM. In design practices, non-linearity of the materials (i.e. nonlinear behavior of stress-strain of

the members ' materials). The main reason for which the towers are designed concerning the design load in the elastic zone of steel material is mostly assumed by the guidelines and standards (as those North America used) (De Macedo, 2016).

Generally, the standard structural engineering techniques utilized in the designing of steel transmission towers are considered to be directly-forward trussed behavior where whole links to the steel element are assumed hinged. While this reality, the tower geometries that are most widely used have structural mechanisms that basically could be reached a compromise of the presumed structural behavior. A possible reason for the reliability of the system is due to the actual behavior that is an almost semi-rigid connection as a substitute for the hinge connections (da Silva, Vellasco, and others, 2005).

The linear programming methods and stability static equations were used by the undetermined space truss limit analysis. The normal formulation has been developed for both limit evaluation and design issues. This is important in order to enhance the potential use of the transmission structures limit design (Lee and Jensen, 2007).

Nonlinear analyses, which take into account both material and geometric nonlinearity, are usually done for research projects and are generally implemented when the researcher wants to investigate such structural problems, like the effects of connections eccentricities or the bolt slips effects that are usually carried out at large loads. In research projects, dynamic analyzes in connection are also used (De Macedo, 2016).

Eccentrically connected irregular thin-walled L- section members are typically used to create TL towers. They are widely regarded as one of the most challenging ways of analyzing the lattice structure. Proof-loading and full-scale testing of these structures have historically been an essential part of tower construction growth. Stress estimated in the structures is typically obtained from a linear-elastic analysis in which members are presumed to be loaded axially and pin-connected for the majority of cases (Roy, Fang and Rossow, 1984).

Testing is typically done by independent testing of the towers on the location of the transmission line. Forces created by the max span limits are predetermined by using the max wind and weight span limits to change static wires and conductors. Instead tower changes are designed and extended to all towers on the entire line without any actual configuration being regarded.

The TL Towers are simulated in numeric modeling as 3-dimensional trussed structures throughout the design stage and the members of the towers are expected to carry only axial forces. This conclusion is focused on the recognition that axial forces in all structural components will primarily be generated by the triangular member's configuration and the connections' features whereas the flexural strain is low to consider in design. Though steel tower is modeled as truss members pin-connected, all design codes consider the impact on members ' ability of conditions of end-members (e.g. actual bolted rotational restraint and connectivity eccentricities). Thus, design codes modify the design stresses to take these ending requirements into account.

For instance, the ASCE-10-15 design standard acknowledges that short length members with a ratio of slenderness equal to or less than 120 are affected by the end connections eccentricity. It is observed that the connection's eccentricity does not considered. Instead, the standard ASCE-10-15 examines if the eccentricities are existing at one end or both ends to adjust short member’s capacity. The capacity of compressive force for members which they are long (described as having a slender ratio greater than 120) is dependent on the connection and member end. once again, the ASCE-10-15 design codes examine only if restrictions are available in both or one end to adjust long member load capacities, without respecting the value of bolted connection that is rotational restraint (De Macedo, 2016).

It is rare for transmission line tower structures to be utilized with the maximal span limits, however. Such adjustments that may not be required in all structures can be made by expanding the design factors. For an entire line design, optimizing transmission lines is important.

In fact, the optimization procedure must allow user-defined controls to be managed efficiently, with severe restrictions imposed by the physical obstacles, landholder criteria, and the surrounding regulations. The least expensive mix of towers that it is still very important for the plan also in lines with different restrictions. Financial constraints are classified into four classes and more much than not: prohibited, additional costs; the position of structures necessary; and the structures required ("Re-Engineering The Transmission Line Design Process", 2019).

The mechanisms and planar joints problem is a recurrent problem with structures modeled such a 3-dimensional truss structure towers. The planar joints problem in the model of 3D truss is that there is no mathematical rigidity in the perpendicular direction of the plane with all connecting members. The solution to the designed joints problem is generally to use imaginary members, with quite small stiffness or using beam components to bring a certain rigidity to the connecting members plan directed perpendicularly (De Macedo, 2016).

## 2.6 Design Code

The basic equations used to model the tower component systems ASCE Standard are highlighted. Such basic equations refer to the transmission mechanisms of latticed steel Such systems can be self-supporting as well as guyed. They involve a lot of components that are cold-formed or hot-rolled and linked by bolts. Components of the system (members, connections, guys) that are selected to resist design-factory loads that are at stresses basically approaching yield failure, buckling, fracture, or any more particular limited event.

The design of steel lattice transmission line structures identifies the design, manufacture, and testing of the electrical transmission structure and connections. These requirements are suitable for hot-rolled and cold-forming steel forms (American Society of Civil Engineers, 2015).

Overhead power lines specifications have been in effect for several years in many industrial nations. E.g. for the German, Austrian, Swiss and Brazilian countries: DIN VDE0210, ÖV E-L11, LeV, and the NBR 5422.

The International Technical Commission for Electrotechnology (IEC) practice on the standards for worldwide use. In relation to IEC 60828, it speaks about the evaluation of climate loads and line strength.As a national overhead electrical line standard, EN 50341-1 code has been released and distributed in Europe. This standard consisted mainly of an all-purpose center body with standard requirements. For the single CENELEC Member States, the same applies to national standard aspects, e. g. In Germany, the EN 50341-3-1 will apply. EN 50341-3-3 will apply in Switzerland.

The EN 50341-1 and IEC 60826 guidelines describe methods of calculating climate loads, e.g. g. No specified values for line design ice load and wind speed. This kind of specific figures is accomplished by evaluating the measures in the specific implicational area and by providing practical experience in CENELEC member countries, or in project specifications, in the 'National Normative Aspects'. They prefer to use the IEC 60826 as a side of standards in non-European countries (Kiessling, Nefzger and others, 2003).

So long as the overhead lines tower major concern, the design of like structures is protected by Code EN 50341 of the CENELEC, in relation to the wind- and ice-loading, safety matters, loaded combinations, and special requirements (such as conductors, isolators, clearance, etc.).

Following this paragraph, the strength specifications of steel members can be called ‘deemed to satisfy'. The rules to comply with EN 50341 of Overhead line towers and the specifications of that code can be used as different criteria (Eurocode 3. Brussels: European Committee for Standardization, 2005).

Practice code, design codes and technical documents performing alike task are available for various countries. It is necessary that a designer has regional needs or suggestions on the right practice on the expected level (Mrema, 2011).

A line or any other classification, a nominal voltage, a line width, an elevation variety, and a design load field shall be the most important conceptual specifications.

This is important as around every aspect of line construction, weather-related effects and environmental effects are involved. Another climate replacement is the model load area. The National Electrical Safety Code (NESC) and also some local governments define these districts. NESC significant loading, NESC medium loading, and NESC light loading. These districts include The wind and ice load on the towers and lines are based on the load zone. That affects the specifications of the isolator and the size of the towers and the design, span-lengths, and strength of mechanical and wind damping of the conductor (Molburg and Kavicky, 2007).

### 2.6.1 Full-Scale Prototype Tests

Complete testing is required and is performed on many overhead towers before such towers are manufactured. The tests a tower are established to adapt to the model

requirements and only the full-scaled tower prototype is loaded with static loads. The suitability of just the connections and members is checked under controlled circumstances to handle static designed loads. In lately designed TL towers, there are a variety of reasons which motivate full-scale testing. The most important of these are:

- Since towers are generally designed to be as possible lightweight, the capacity of the full member is used. Consequently, the margin of error is reduced;
- Although FEM is relatively accurate in describing designed forces in the members of the tower, this numerical model is a general approximation similarity of the actual structure. Usually, this numerical model does not involve the complexity of the connections between structural members
- The recurrent use of the TL system's standard tower design, along with its varying environments and circumstances, explain the thorough evaluation of the technical abilities of the tower structure.

Nevertheless, tower checks can not verify how well the tower is performed on the transmission line in which dynamic loads in nature are performed.

Research has been done the development of an advanced numerical model to accomplishing existing tower tests over past years. Although these models constitute considerable progress in the area of analyzing structure, the numerical model still has to be ensured that the data input reflects the actual structure precisely (De Macedo, 2016).

## 2.7 Experience from past Earthquakes

Recent earthquake reports on destroyed TL structures show that foundation settlement, land sliding, and deformation of the soil are the main cause of damage. The EPRI (2009), discusses several TL tower designs problems triggered and caused by earthquakes. During the Northridge earthquake in 1994 six tower collapses are reported. The earthquake occurs in Taiwan ChI. Chi in 1999 recorded 15 faults in Tower.

Major causes of the damage caused by these events have been recorded to be sliding of land and cascading by the snapping of conductors. The 1923 Kanto earthquake that occurred in Japan and the 1964 Alaska earthquake have also been recorded to have caused many TL towers to be destroyed and damaged by FEMA (1991).

No structural collapse has been recorded in other seismic events. However, the damage caused by the deformation of soil leading to the foundation and tilting were detected by the member on many TL towers. The earthquake which occurred in 1995 Kobe in the country of Japan (35 TL towers were damaged) and also the earthquake that occurred in 1999 Kocaeli in Turkey are examples of earthquake activities reported by a large account of damaged towers. As a consequence of increased sag of the conductors, or tension due to large varying displacements among towers, excessive damage to the supporting structures is also recorded.

Experts agree that the number of reports of broken towers and collapsed towers in previous earthquakes reported in literature doesn't really reflect the current magnitude and extent of the damage to this structure due to earthquakes. The publication of these data can lead to legal problems and designers and tower operators are not able to share experiences. It has also been observed that the earthquake impact experiences recorded in literature on transmission line towers mainly relate to self-support. Guided towers, which depend only on their cables for their lateral stable, may be more vulnerable to deformation of soil and settlement after such an earthquake as most of their guy-anchors can be removed from the base of the tower and result whether in a slack cable without functions on the mast's lateral stability, or more stretched guy's cable (De Macedo, 2016).

## 2.8 Learning from Previous Studies

Moon et al. performed a semi-scaled substructure test to assess the behavior and the fault position of an existed transmission tower exposed to wind loads. It was observed from the experiment that local, regional occurred on the two legs elements that were exposed to compression. In order to avoid associated regional buckling and unbalanced deformation, the elements must be enlarged or bracing added to weak joints (Moon, B. W., Park, and others, 2009).

Alam and Santhakumar carried out a test of load on 34 m elevated transmission tower under a 200 K.V capacity and discovered that the total bending of the tower's legs and the transverse components caused the tower to fail (Lei, H., and Chien, L., 2009). In the results of the tests, they proposed to reduce the maximum slenderness ratio from 150 to 110, as indicated in the steel transmission towers design code (American Society of Civil

Engineers Task Committee on Tower Design, 1971). A limited number of works can be found in the literature on the seismic behavior of transmission towers: .

Lei and Chien examine the dynamic behavior of a coupled tower conductor system during strong earthquake movements. A detailed finite element model of structural towers and the overhead line was implemented taking into account the geometric nonlinearities. The interaction model of a soil-structure was also taken into account in the numerical simulations. The authors stated that neglecting the contribution to overhead lines of the earthquake reaction to support towers would lead to considerable errors in estimating the maximum strength of supporting tower elements (Lei, Y. H., and Chien, L., 2009).

Chen et al. provided an overview of the state of the art on the topic of dynamics and control of vibration in transmission tower systems. In the article, investigations into dynamic reactions to transmission line towers under ice, wind, and earthquake load conditions are carried out and discussed. Considering the seismic behavior of transmission towers, the authors made the following concluding comments: a) The transmission lines span is fairly large compared to today's civil engineering constructions and therefore the effects of multiple excitations must be considered in detail; b) The common failure of transmission line tower systems indicate that the load patterns given in the codes still do not represent extreme load conditions, like those resulting from seismic ground movements and that the design method is based on them. The static analysis is a restricted and dynamic analysis of the interaction of Tower-line systems (Chen, B., Guo, W. H., Li, P. Y., and Xie, W. P., 2014).

# 3 METHODOLOGY

## 3.1 General

The tower selected was suspension (tangent) tower. Suspension tower used to straight runs or with a line deviation of $0^o$ to $2^o$ . The model of the tower bracing is Diamond lattice system. This model of tower has been selected because it is one of the most widely used models of the tower. The sections used for the tower are all steel angles conforming to Turkish standard grade S355. The transmission tower has been modeled in AutoCAD and then imported to SAP2000 (SAP 2000, computers and structures). This program was chosen because of its dynamic analysis capabilities. The transmission tower is fixed at the base. The height of the tower is 42.95 m and the base width of the tower is 4 m.

## 3.2 The tower models (Towers used in the Study)

The geometry of the upper tower is essentially controlled by electrical considerations. For example, the elevation of the upper part of the tower structure on the cross arm, which relies on shielding considerations, to reduce protection. The width of the structural base is influenced by the inclination of the structural support. The elevation of the tower is constrained by the distance of the span between the towers (Chen and Lui, 2010).

The transmission line towers support overhead power lines that go from that power generation plant directly to the transformer substations and to the distribution station. One of the typical towers designed in Turkey is a 154 kV type transmission powerline. The 154 kV tower transmits power to widely residential complexly and large areas of demand. Towers made-up of mild steel. The cross-sections available in this study are angle-type cross sections for the elements of transmission line towers. Figure 3.1 demonstrate pictures of angle-type transmission towers (Park, Choi, Kim and Lee, 2015).



**Figure 3.1: Image of the Tramsmission tower 154 KV Angle-type**

Figure 3.2. is shown the geometry of the tower that is analyzed and designed. Its base width is 4x 4 m and its height is 42.95 m. The tower consists of several sections as seen in Figure 3.4. Those are the peak of the tower, the transverse arms of the tower, the box of the transmission tower, the common body and the legs of the tower. The lengths of the transverse arm, as can be seen in Figure 3.3. The tower support is the fixed type at the tower foundations.

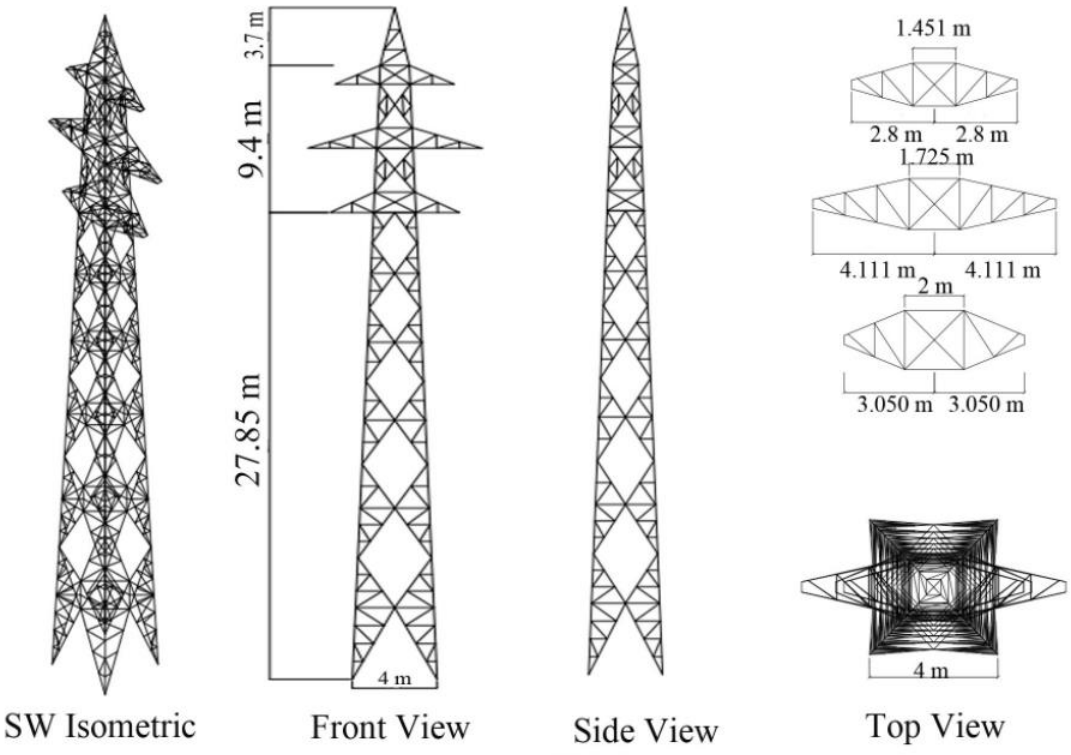



**Figure 3.2: Geometry of 154 kV lattice tower**

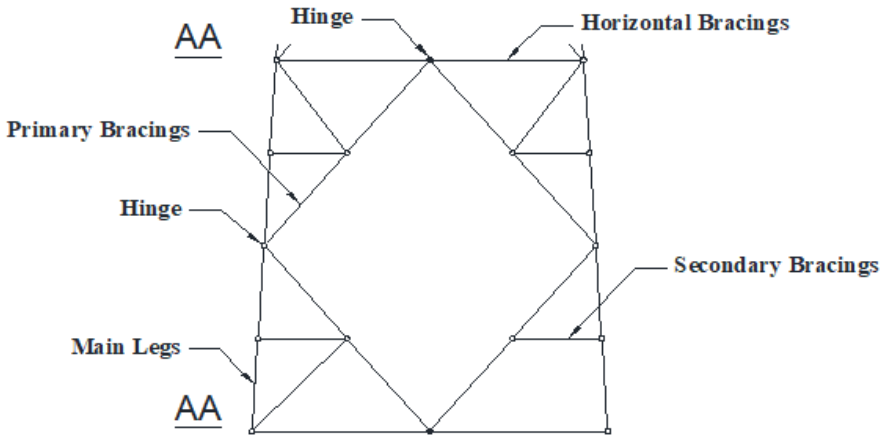



**Figure 3. 3: Dummy bars sued in the structure vertical plan**

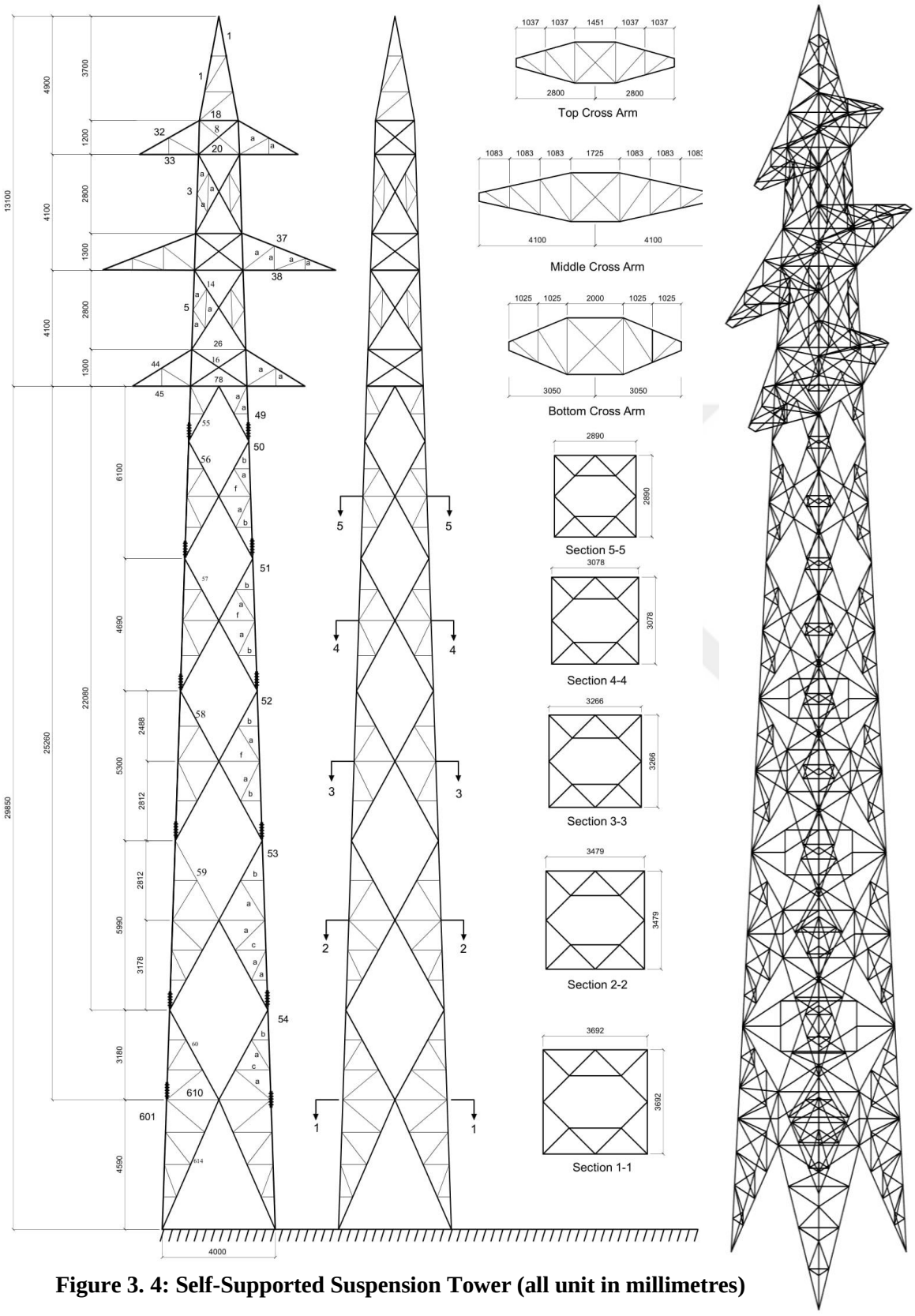



**Figure 3. 4: Self-Supported Suspension Tower (all unit in millimetres)**

### 3.2.1 Steel and section profiles

For the objective of this study, all members have been carefully modeled for the size of the profiles and the grade of steel for guaranteed realistic contributions for the dead load on the models. Nevertheless, it has not been in the scope of this thesis to analyze steel connections, so elements including bolts holes and bolt have been omitted.

The tower used in this study is modeled with different steel equal angles (L - profile) sizes. Figure 3.5 and Figure 3.6 show instances of L-profile arrangements.

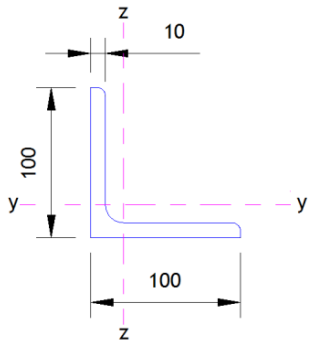



**Figure 3.5: Single angle L100x10 profile**

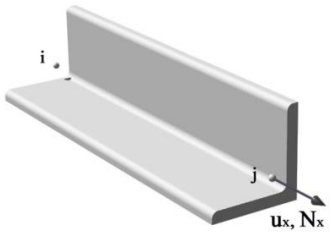



**Figure 3.6: Truss element**

**Table 3.1: List of member profiles used in the study**

| Section | NO | Profile size | Unit Weight [Nm$^{-1}$] | Area [mm2] | Radius of Gyration Rx = Ry [mm] | Ix=Iy [cm4] | Wx=Wy [cm3] |
|---|---|---|---|---|---|---|---|
| Peak legs | 1 | L60X60X5 | 44.83 | 581.9 | 18.245 | 19.4 | 4.45 |
| Cage legs | 2 | L120X120X11 | 195.22 | 2537 | 36.641 | 340.6 | 39.41 |
| | 3 | L120X120X11 | 195.22 | 2537 | 36.641 | 340.6 | 39.41 |
| | 4 | L120X120X11 | 195.22 | 2537 | 36.641 | 340.6 | 39.41 |
| | 5 | L120X120X11 | 195.22 | 2537 | 36.641 | 340.6 | 39.41 |
| | 6 | L150X150X14 | 310 | 4004 | 46.308 | 845.4 | 78.33 |
| Cage | 8 | L50X50X5 | 36.99 | 480.3 | 15.106 | 11 | 3.05 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Primary Bracing | 10 | L80X80X7 | 83.28 | 1082 | 24.355 | | |
| | 12 | L70X70X7 | 72.50 | 939.7 | 21.214 | 42.4 | 8.43 |
| | 14 | L100X100X10 | 147.54 | 1900 | 30.78 | 177 | 24.7 |
| | 16 | L80X80X7 | 83.28 | 1082 | 24.355 | | |
| Cage Horizontal Bracing | 18 | L60X60X5 | 44.83 | 581.9 | 18.245 | 19.4 | 4.45 |
| | 20 | L80X80X7 | 83.28 | 1082 | 24.355 | | |
| | 22 | L70X70X7 | 72.50 | 939.7 | 21.214 | 42.4 | 8.43 |
| | 24 | L100X100X8 | 119.49 | 1551 | 30.555 | 145 | 20 |
| | 26 | L70X70X7 | 72.46 | 939.7 | 21.214 | | |
| Top Cross Arm Beams | 32 | L60X60X5 | 44.83 | 581.9 | 18.245 | 19.4 | 4.45 |
| | 33 | L80X80X10 | 116.35 | 1511 | 24.064 | 87.7 | 15.5 |
| Middle Cross Arm Beams | 37 | L70X70X6 | 62.69 | 812.7 | 21.302 | 36.9 | 7.27 |
| | 38 | L100X100X10 | 147.54 | 1915 | 30.376 | 177 | 24.7 |
| Bottom Cross Arm Beams | 44 | L60X60X6 | 53.17 | 684 | 18.468 | 22.9 | 5.25 |
| | 45 | L80X80X7 | 83.28 | 1082 | 24.355 | | |
| Main legs | 49 | L150X150X14 | 310.00 | 4004 | 46.308 | 845.4 | 78.33 |
| | 50 | L150X150X14 | 310.00 | 4004 | 46.308 | 845.4 | 78.33 |
| | 51 | L180X180X16 | 426.74 | 5504 | 55.681 | 1682 | 129.7 |
| | 52 | L180X180X18 | 476.77 | 6191 | 54.9 | 1866 | 144.7 |
| | 53 | L200X200X18 | 531.70 | 6911 | 61.336 | 2600 | 180.6 |
| | 54 | L200X200X20 | 587.91 | 7635 | 61.107 | 2854 | 199.3 |
| | 601 | L200X200X20 | 587.91 | 7635 | 61.107 | 2854 | 199.3 |
| Leg Primary Bracings | 55 | L120X120X11 | 195.22 | 2537 | 36.641 | 340.6 | 39.41 |
| | 56 | L100X100X12 | 174.91 | 2271 | 30.169 | 207 | 29.2 |
| | 57 | L100X100X10 | 147.54 | 1900 | 30.78 | 177 | 24.7 |
| | 58 | L100X100X10 | 147.54 | 1900 | 30.78 | 177 | 24.7 |
| | 59 | L100X100X8 | 119.49 | 1551 | 30.555 | 145 | 20 |
| | 60 | L100X100X8 | 119.49 | 1551 | 30.555 | 145 | 20 |
| | 614 | L100X100X8 | 119.49 | 1551 | 30.555 | 145 | 20 |
| Leg Horizontal Bracing | 610 | L60X60X5 | 44.83 | 625 | 20.217 | 19.4 | 4.45 |
| | 510 | L70X70X6 | 62.69 | 812.7 | 21.302 | 36.9 | 7.27 |
| | 410 | L60X60X5 | 44.83 | 581.9 | 18.245 | 19.4 | 4.45 |
| | 310 | L70X70X6 | 62.69 | 812.7 | 21.302 | 36.9 | 7.27 |
| | 110 | L80X80X7 | 83.28 | 1082 | 24.355 | | |
| Secondary Bracings | a | L35X35X3 | 15.70 | 203.7 | 10.605 | 2.3 | 0.9 |
| | b | L40X40X4 | 23.74 | 307.9 | 12.052 | 4.49 | 1.55 |
| | c | L45X45X4 | 26.98 | 349.3 | 13.568 | 6.47 | 1.97 |
| | d | L50X50X4 | 30.12 | 389.3 | 15.182 | 9.01 | 2.47 |
| | e | L50X50X5 | 36.98 | 480.3 | 15.106 | 11 | 3.05 |
| | f | L60X60X5 | 44.83 | 581.9 | 18.245 | 19.4 | 4.45 |

The TL tower is designed in Turkish standard steel grade S355 for each structural member. Table 3.2 summarizes the properties of steel material grade S355 used in this study.

**Table 3.2: Material properties of S355 steel**

| Property | Symbol | Unit | Value |
|---|---|---|---|
| Modulus of elasticity | E | [MPa] | $210x10^3$ |
| Yield strength | $F_y$ | [MPa] | 355 |
| Ultimate strength | $F_u$ | [MPa] | 510 |
| Poisson's ratio | $\nu$ | [-] | 0.3 |

### 3.2.2 Foundation numbering

The numbering convention utilized in this work is shown in Fig. 3.7. Every foundation is connected to the predefined leg member via a fixed connection, which limits rotations in the three principal orthogonal directions and is also restricting displacements on every one of these axes (Brewer, 2017).

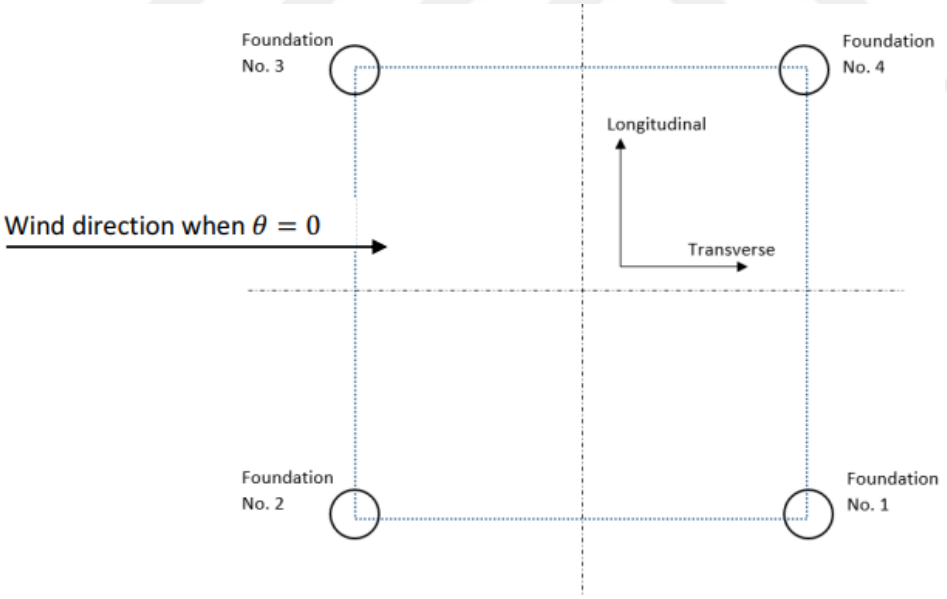



**Figure 3.7: foundation numbering convention**

## 3.3 Load Cases

The loading calculations on tower according to TS IEC 60826 standard and a set of load cases that has been taken into consideration for the transmission tower design in this study .This thesis is concerned with the application of static and dynamic earthquake loads, therefore load cases involving wind and ice loads cases as well as broken wire condition were calculated.

When defining wind direction, the following terminology was used: transversal direction for loads act on the tower side; longitudinal direction for loads which act on the tower face (in the direction of the line); vertical direction for loads which act downwards or upwards. Figure 3.8 is schematically illustrates these terms of conventions.

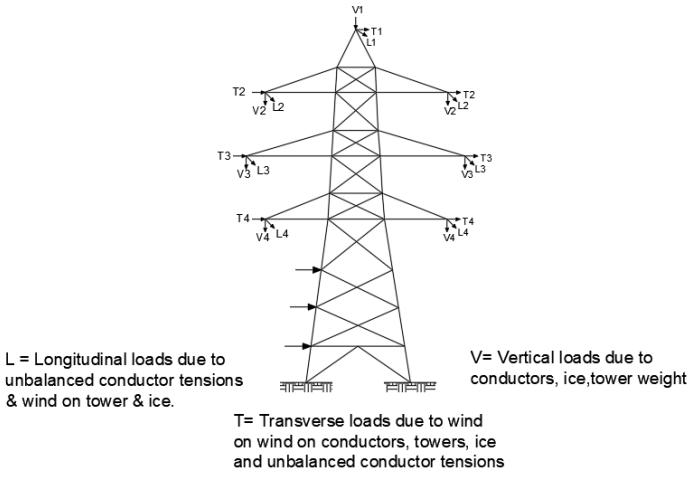



**Figure 3.8: Load direction conventions**

In all cases, several loads effect on the TL tower were analyzed to simulate the actual properties of the possible wind angles and other load cases. Table 3.3 has been shown the load cases to be examined.

**Table 3.3: Description of the load case**

| Case # | Load case description |
|---|---|
| 1 | 1.unstable loads left hand side |
| 2 | 2.unstable loads left hand side |
| 3 | right top and middle conductor coupling |
| 4 | right top conductor closing single circuit |
| 5 | right middle and bottom conductor coupling |
| 6 | right middle conductor closing single circuit |
| 7 | right top and bottom conductor coupling |
| 8 | right bottom conductor coupling single circuit |
| 9 | 1.earth wire broken right hand side |
| 10 | 2.earth wire broken right hand side |
| 11 | even wind |
| 12 | one vertical wind single circuit |
| 13 | 1.maximum angle drawing right hand side |
| 14 | 2.maximum angle drawing right hand side |
| 15 | 1.unbalanced icing left hand side |
| 16 | 2.unbalanced icing left hand side |
| 17 | 1.down opening right hand side |
| 18 | 2.down opening right hand side |
| 19 | net up lifting opening |
| 20 | down opening right hand side |

## 3.4 Coordinates system

SAP2000 uses both global and also the local coordinate systems for applying equilibrium equations of algebraic. Similar principles have been used in the program for the local coordinate system. There be a distinction in the axis mapping for the global coordinates to be clarified here. Figure 3.9 shows the global coordinate assignments for SAP2000 (Brewer, 2017).

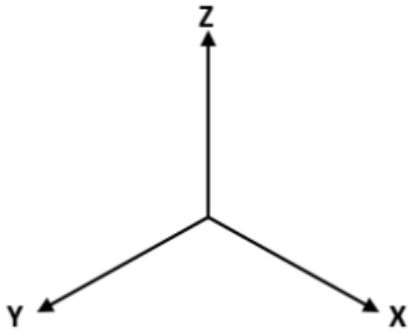



**Figure 3.9: SAP2000 global coordinates system**

For the purpose of ensuring continuity in explaining the outcomes, the guidelines for the global coordinates are immediately described in the three directions (vertical, longitudinal and transverse) phrasing as characterized in Figure 3.10. Longitudinal direction is parallel with line direction of the overhead transmission line.

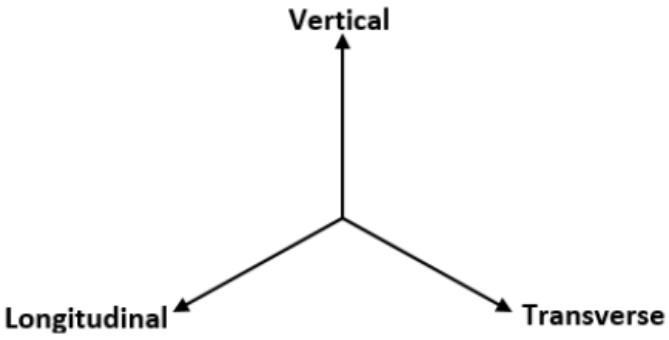



**Figure 3.10: Global coordinates system in this thesis**

## 3.5 Selection and scaling of Earthquake Records

The controlling load case designed for the towers studied here is related to the wind loads operating on the steel lattice tower, the conductors and the earth cables. Such wind loads have been determined by the wind speed, with a return period of 50 years, for the sites where these towers have been designed for. Set up a number of places where these TL

towers can dislocate. Note that the possible position must have the alike ice and wind load conditions.

After selecting these similar positions in seismic zones, the design spectrums for every location are created and scaled the ground motions which are selected to fit the design spectrum within the duration of interest (De Macedo, 2016).

It should be noted that a position With high acceleration spectral values (e.g. ESOGU) has been maintained. One of the aims of this research is to evaluate the suitability of the seismic load in the construction of electrical transmission towers for different sorts of typical load cases. If it is shown that such greater values of spectral acceleration are not relevant to the structural behavior of the tower has been examined here, no further analysis will be needed for lower values of spectral acceleration. If the seismic loads determine the design of the tower, the results of the current analyses are suggesting that further analysis with lower spectral acceleration values are needed to quantify the relevance of the considerations on the seismic load in the structural analysis and, to a certain extention. point, to improve the design of the transmission towers. The spectral values that are selected as a target spectral that have been utilized in the current study are illustrated in Table 3.4.

**Table 3.4: Indentified locations and their respective seismic spectral values (site class ZA)**

| Province | Location | Seismic Data | | | | |
|---|---|---|---|---|---|---|
| | | Hourly Wind Pressure (kPa) | Short period map spectral acceleration coefficient Ss | Map spectral acceleration coefficient for 1.0 second period (S1) | Maximum ground acceleration [g] (PGA) | Maximum ground speed [cm / sec] (PGV) |
| Eskisehir | ESOGU | 1.01 | 0.703 | 0.186 | 0.298 | 17.934 |

This study uses a set of ten ground motion registers from the 'PEER Ground Motion Database' (2019). These records contain:

- time-series of ground motion
- acceleration (i.e. accelerograms)
- velocities
- displacements

in perpendicular directions (one vertical and two horizontal).

In the current study, merely the time series with the greatest peak of ground acceleration for the horizontal component is taken into account. This ground motion data and parameters of concern for the structural dynamic analysis are described in Tables 3.5 and 3.6. Figure 3.11. shows the Acceleration- time diagrams.

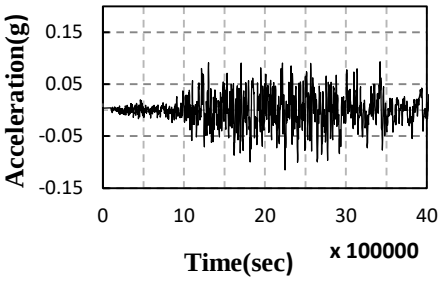
**Table 3.5: Coefficients Fs and Fv specified in Turkey Earthquake Hazard Interactive Web Application for site class ZA**

| Local Soil Effect Coefficient for the short period region, Fs | | | | | |
|---|---|---|---|---|---|
| $S_s \leq 0.25$ | $S_s = 0.50$ | $S_s = 0.75$ | $S_s = 1.00$ | $S_s = 1.25$ | $S_s \geq 1.50$ |
| 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| Local Soil Effect Coefficient for 1.0 second period, F1 | | | | | |
| $S_1 \leq 0.10$ | $S_1 = 0.20$ | $S_1 = 0.30$ | $S_1 = 0.40$ | $S_1 = 0.50$ | $S_1 \geq 0.60$ |
| 0.8 | 0.8 | 0.8 ` | 0.8 | 0.8 | |

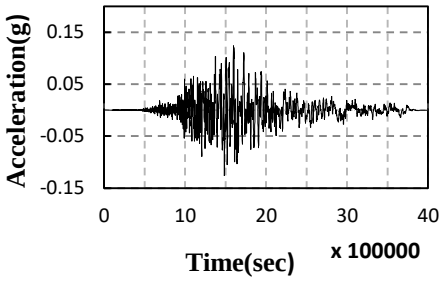
**Table 3.6: Earthquake records selected – horizontal component (Fahjan, 2008)**

**Local Site Class: ZA**

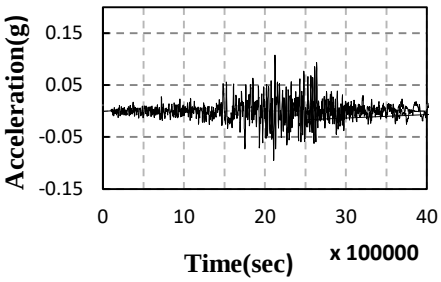
| Record No | Earthquake | Date | Station | Record | Closest to Fault Rupture | Record Durartion | Significant Duration | Bracketed Duration | Fault type |
|---|---|---|---|---|---|---|---|---|---|
| P0856 | Landers | 28.06.1992 | 21081 Amboy | ABY090 | 69.20 | 50 | 25.2 | 32.8 | SS |
| P0969 | Northridge | 17.01.1994 | 24611 LA-Temple & Hope | TEM090 | 32.30 | 40 | 14.6 | 20.5 | RN |
| P0859 | Landers | 28.06.1992 | 32057 Baker Fire Sattion | Bak140 | 88.50 | 50 | 19.9 | 30.9 | SS |
| P1108 | Kocaeli, Turkey | 17.08.1999 | Mecidiyekoy | MCD000 | 62.30 | 44 | 16.3 | 23.9 | SS |
| P0740 | Loma Prieta | 18.10.1989 | 57064 Fremont-Mission San Jose | FRE090 | 43.00 | 39.9 | 16.7 | 20.1 | RO |
| P0903 | Northridge | 17.01.1994 | 24157 LA – Baldwin Hills | BLD090 | 31.30 | 40 | 16.6 | 17.9 | RN |
| P0988 | Northridge | 17.01.1995 | 90009 N.Hollywood – Goldwater Can | CWC270 | 14.60 | 21.9 | 16.4 | 18.4 | RN |
| P1100 | Kocaeli, Turkey | 17.08.1999 | Goyunk | FMS180 | 35.50 | 25.5 | 10.4 | 20.8 | SS |
| P0763 | Loma Prieta | 18.10.1989 | 1686 Fremont – Emerson Court | NPS000 | 43.40 | 39.7 | 17.9 | 22.3 | RO |
| P0818 | Landers | 28.06.1992 | 5070 North Palm Springs | | 24.20 | 70 | 36.3 | 43.1 | SS |



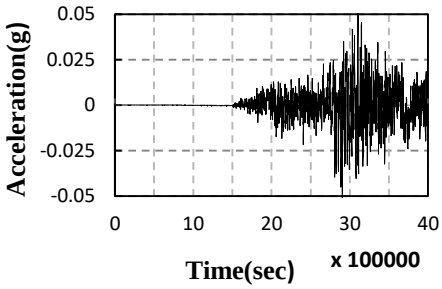

**Record No: P0856, Landers earthquake**



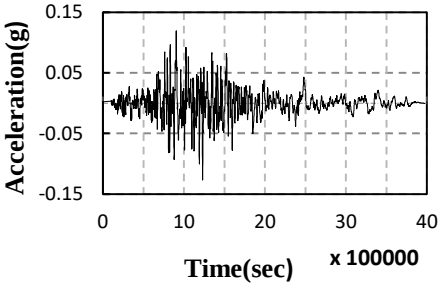

**Record No: P0969, Northridge earthquake**



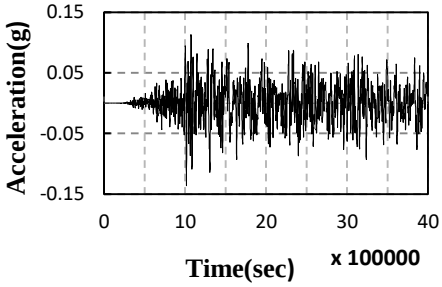

**Record No: P0859, Landers earthquake**




**Record No: P1108, Kocaeli, Turkey earthquake**




**Record No: P0740, Loma Prieta earthquake**




**Record No: P0903, Northridge earthquake**

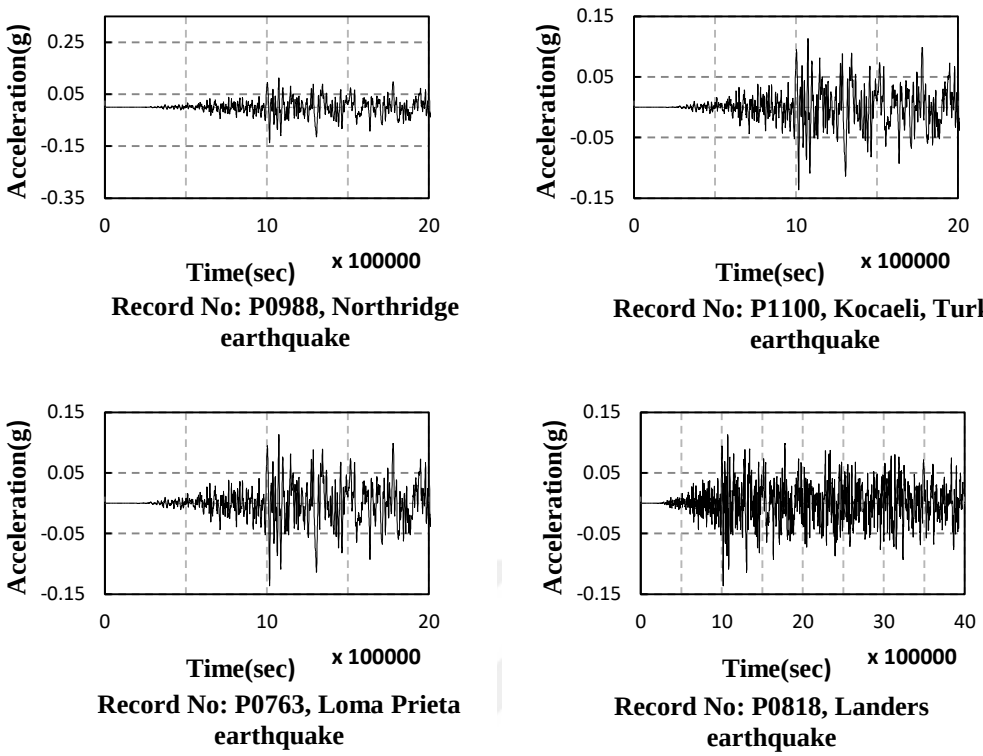



**Figure 3. 11: Acceleration- time diagrams of the selected records motions from PEER Ground Motion Database (2019).**

Ten of those records are typical of soil class AZ, which has a soil profile distinguished by dense soil also hard rock.

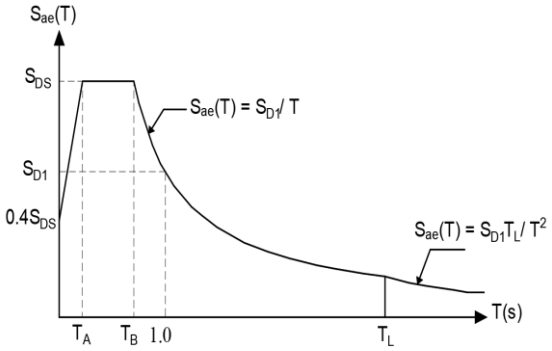
It is noted that every record of the ground motions examines in the study has to be scaled for the sake of match the defined design spectrum at the structure fundamental period (T1). TBDY-2018, provisions require that the mean of the 5% damped response spectra of ground motion records should match or be above the target spectra over the defined interval. As shows below the Horizontal Elastic Design Spectrum (Fig. 3.12.) According to TBDY-2018, the average of 5% damped for soil movement records over the defined interval must be matched to or exceed the target spectra. As shown below, the horizontal elastic design spectrum.

$$S_{ae}(T) = \left(0.4 + 0.6\,\frac{T}{T_A}\right) S_{DS} \qquad (0 \le T \le T_A)$$

$$S_{ae}(T) = S_{DS} \qquad (T_A \le T \le T_B)$$

$$S_{ae}(T) = \frac{S_{D1}}{T} \qquad (T_B \le T \le T_L)$$

$$S_{ae}(T) = \frac{S_{D1} T_L}{T^2} \qquad (T_L \le T)$$




$$T_A = 0.2\frac{S_{D1}}{S_{DS}} \qquad T_B = \frac{S_{D1}}{S_{DS}} \qquad T_L = 6s$$

$$T_A = 0.053(s), \qquad T_B = 0.265(s), \qquad T_L = 6.00(s)$$

$S_{ae}$ = Design Spectral Response Acceleration.

$T$ = the fundamental period of the structure (s), $T_L$ = long-period transition period (s)

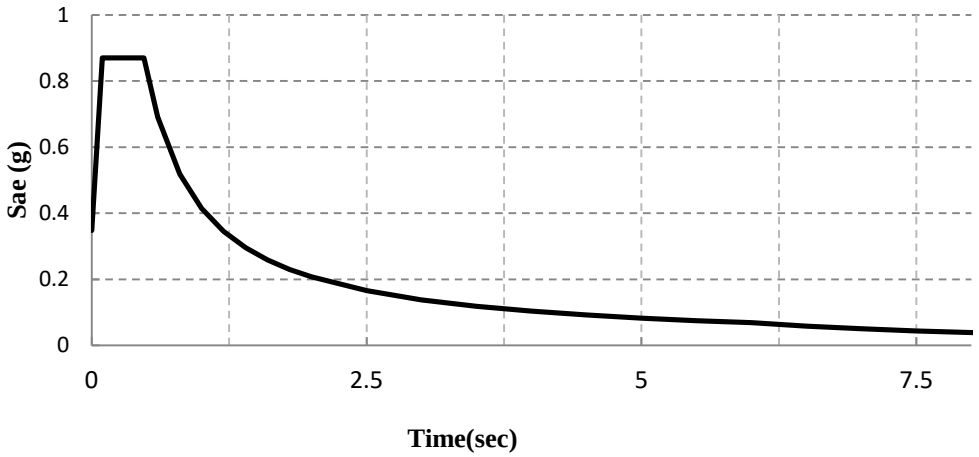



**Figure 3.12: Horizontal Elastic Design Spectrum**

The current study included this provision to scale the selected records of soil movement. Figures 3.13 shows the scale acceleration response spectrum of the ZA class. It has been noticed that just the frequency content was scaled for the acceleration response spectrum.

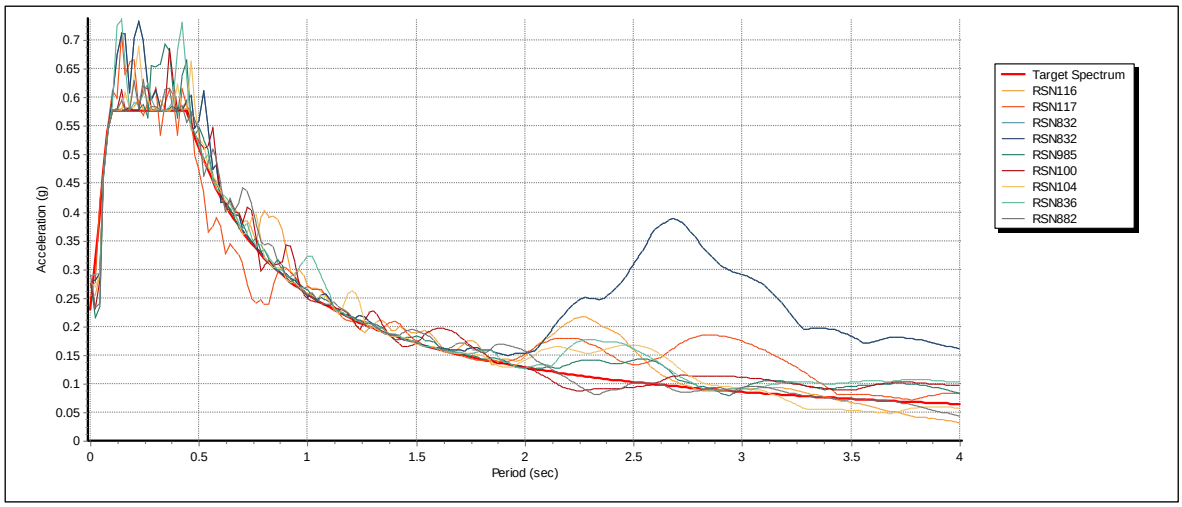



**Figure 3.13: Design response spectrum for 5% damping, site Class ZA (TBDY-2018) and the response spectra of selected scaled records.**

# 4 RESULTS AND DISCUSSION

## 4.1 Static load results

The static analysis of the model was perfomed in SAP2000. Components lengths, profiles, and the properties of steel are demonstrated as recently depicted. The point Conductor loads and fundamental pressure of wind at a stature of 10 m were determined beforehand. The base pressure is considered based on load cases of ice and wind. Both are considered conventional value for the country of Turkey. Since one objective of this work is to contrast the load of the foundations, the choice of base Wind velocity here is not essential. The applied conductors and ground line point loads and the basic wind pressure for every load case are provided in Appendix-A.

### 4.1.1 SAP2000 static loading

Since the wind and dead loads are determined, the point loads representing the conductors are manually entered. These loads consider the dead load of the cables and, depending on the load, the action of strong forces of wind or normal wind plus ice. The ice takes into account the extra mass accumulated on the conductors and thus the extra surface exposed to the wind.

**Foundation reactions**

Tables 5-1 through 5-20 highlighting the outcomes of SAP2000 static load analysis for the general base of every tower with foundational reactions (see Figure 3.7). corresponds to the wind, which blows precisely in a transverse direction as well as a wind angle of 90 ° corresponds to the wind, which blows precisely in the longitudinal direction.

Table 4-1 shows the joint reactions of the four foundations modeled in SAP2000 under static load conditions.

**Table 4.1: Foundation reactions form SAP2000 – Static loading (1.UNSTABLE LOADS)**

| Load Case | Joint No. [-] | Long.Force [KN] | Trans. Force [KN] | Vert. Force [KN] |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| 1.UNSTABLE LOADS | 1 | 90.55 | 1899.66 | -87.42 |
| | 2 | 33.791 | 486.628 | 4.582 |
| | 3 | 85.414 | -1763.988 | -81.769 |
| | 4 | 30.048 | -354.908 | 0.43 |

**Table 4.2: Foundation reactions from SAP2000 – Static loading (2.UNSTABLE LOADS)**

| Load Case | Joint No. [-] | Long.Force [KN] | Trans. Force [KN] | Vert. Force [KN] |
|---|---|---|---|---|
| 2.UNSTABLE LOADS | 1 | 36.61 | 1339.62 | -89.81 |
| | 2 | 42.056 | 62.421 | -36.437 |
| | 3 | 90.676 | -1273.644 | -32.216 |
| | 4 | -17.14 | 12.097 | 16.469 |

**Table 4.3: Foundation reactions from SAP2000 – Static loading (RIGHT TOP AND MIDDLE CONDUCTOR COUPLING)**

| Load Case | Joint No. [-] | Long.Force [KN] | Trans. Force [KN] | Vert. Force [KN] |
|---|---|---|---|---|
| RIGHT TOP AND MIDDLE CONDUCTOR COUPLING | 1 | 62.48 | 927.19 | -26.12 |
| | 2 | -13.852 | -0.956 | 8.749 |
| | 3 | 18.814 | -801.949 | -59.5 |
| | 4 | 21.954 | 119.117 | -33.722 |

**Table 4.4: Foundation reactions from SAP2000 – Static loading (RIGHT TOP CONDUCTOR CLOSING SINGLE CIRCUIT)**

| Load Case | Joint No. [-] | Long.Force [KN] | Trans. Force [KN] | Vert. Force [KN] |
|---|---|---|---|---|
| RIGHT TOP CONDUCTOR CLOSING SINGLE CIRCUIT | 1 | 33.74 | 581.03 | -18.69 |
| | 2 | -9.475 | -97.305 | -0.336 |
| | 3 | 15.776 | -521.709 | -31.951 |
| | 4 | 4.658 | 154.483 | -17.919 |

**Table 4.5: Foundation reactions from SAP2000 – Static loading (RIGHT MIDDLE AND BOTTOM CONDUCTOR COUPLING)**

| Load Case | Joint No. [-] | Long.Force [KN] | Trans. Force [KN] | Vert. Force [KN] |
|---|---|---|---|---|
| RIGHT MIDDLE AND BOTTOM CONDUCTOR COUPLING | 1 | 58.06 | 745.34 | -16.36 |
| | 2 | -12.403 | 4.242 | 12.248 |
| | 3 | 15.831 | -703.993 | -53.935 |
| | 4 | 27.907 | 28.612 | -28.554 |

**Table 4.6: Foundation reactions from SAP2000 – Static loading (RIGHT MIDDLE CONDUCTOR CLOSING SINGLE CIRCUIT)**

| Load Case | Joint No. [-] | Long.Force [KN] | Trans. Force [KN] | Vert. Force [KN] |
|---|---|---|---|---|
| RIGHT MIDDLE CONDUCTOR CLOSING SINGLE CIRCUIT | 1 | 54.58 | 650.77 | -6.31 |
| | 2 | -8.076 | 119.831 | 22.985 |
| | 3 | 11.454 | -587.777 | -43.175 |
| | 4 | 31.446 | -66.327 | -18.398 |

**Table 4.7: Foundation reactions from SAP2000 – Static loading (RIGHT TOP AND BOTTOM CONDUCTOR COUPLING)**

| Load Case | Joint No. [-] | Long.Force [KN] | Trans. Force [KN] | Vert. Force [KN] |
|---|---|---|---|---|
| RIGHT TOP AND BOTTOM CONDUCTOR COUPLING | 1 | 69.002 | 1144.416 | -41.827 |
| | 2 | -20.345 | -263.715 | -8.261 |
| | 3 | 31.468 | -1020.539 | -69.467 |
| | 4 | 9.275 | 383.237 | -45.045 |

**Table 4.8: Foundation reactions from SAP2000 – Static loading (RIGHT BOTTOM CONDUCTOR COUPLING SINGLE CIRCUIT)**

| Load Case | Joint No. [-] | Long.Force [KN] | Trans. Force [KN] | Vert. Force [KN] |
|---|---|---|---|---|
| RIGHT BOTTOM CONDUCTOR COUPLING SINGLE CIRCUIT | 1 | 34.992 | 547.108 | -16.342 |
| | 2 | -10.716 | -155.282 | -1.339 |
| | 3 | 15.534 | -487.528 | -30.933 |
| | 4 | 4.889 | 212.202 | -20.285 |

**Table 4.9: Foundation reactions from SAP2000 – Static loading (1.EARTH WIRE BROKEN)**

| Load Case | Joint No. [-] | Long.Force [KN] | Trans. Force [KN] | Vert. Force [KN] |
|---|---|---|---|---|
| 1.EARTH WIRE BROKEN | 1 | 50.099 | 1257.772 | -66.618 |
| | 2 | -35.022 | -886.155 | -53.002 |
| | 3 | 44.601 | -1087.137 | -60.87 |
| | 4 | -41.478 | 1064.32 | -59.91 |

**Table 4.10: Foundation reactions from SAP2000 – Static loading (2. EARTH WIRE BROKEN)**

| Load Case | Joint No. | Long.Force | Trans. | Vert. Force |
|---|---|---|---|---|

| | [-] | [KN] | Force [KN] | [KN] |
|---|---|---|---|---|
| 2.EARTH WIRE BROKEN | 1 | 35.319 | 873.848 | -41.702 |
| | 2 | -22.366 | -566.235 | -30.29 |
| | 3 | 31.767 | -765.204 | -38.071 |
| | 4 | -26.52 | 679.491 | -34.637 |

**Table 4.11: Foundation reactions from SAP2000 – Static loading (EVEN WIND)**

| Load Case | Joint No. [-] | Long.Force [KN] | Trans. Force [KN] | Vert. Force [KN] |
|---|---|---|---|---|
| EVEN WIND | 1 | 42.873 | 1093.61 | -61.73 |
| | 2 | -38.55 | -965.61 | -57.489 |
| | 3 | 39.061 | -971.356 | -57.737 |
| | 4 | -43.383 | 1095.756 | -62.745 |

**Table 4.12: Foundation reactions from SAP2000 – Static loading (ONE VERTICAL WIND SINGLE CIRCUIT)**

| Load Case | Joint No. [-] | Long.Force [KN] | Trans. Force [KN] | Vert. Force [KN] |
|---|---|---|---|---|
| ONE VERTICAL WIND SINGLE CIRCUIT | 1 | 24.906 | 631.342 | -32.893 |
| | 2 | -22.097 | -549.677 | -30.197 |
| | 3 | 22.39 | -552.936 | -30.345 |
| | 4 | -25.198 | 632.471 | -33.465 |

**Table 4.13: Foundation reactions from SAP2000 – Static loading (1. MAXIMUM ANGLE DRAWING)**

| Load Case | Joint No. [-] | Long.Force [KN] | Trans. Force [KN] | Vert. Force [KN] |
|---|---|---|---|---|
| 1. MAXIMUM ANGLE DRAWING | 1 | 37.041 | 946.675 | -53.118 |
| | 2 | -32.485 | -811.478 | -48.543 |
| | 3 | 32.924 | -816.356 | -48.766 |
| | 4 | -37.48 | 948.559 | -53.974 |

**Table 4.14: Foundation reactions from SAP2000 – Static loading (2. MAXIMUM ANGLE DRAWING)**

| Load Case | Joint No. [-] | Long.Force [KN] | Trans. Force [KN] | Vert. Force [KN] |
|---|---|---|---|---|
| 2. MAXIMUM ANGLE DRAWING | 1 | 13.239 | 334.166 | -14.805 |
| | 2 | -10.814 | -263.386 | -12.369 |
| | 3 | 10.967 | -264.973 | -12.453 |
| | 4 | -13.392 | 334.694 | -15.073 |

**Table 4.15: Foundation reactions from SAP2000 – Static loading (1. UNBALANCED ICING)**

| Load Case | Joint No. [-] | Long.Force [KN] | Trans. Force [KN] | Vert. Force [KN] |
|---|---|---|---|---|
| 1. UNBALANCED ICING | 1 | 153.012 | 2923.15 | -129.075 |
| | 2 | 85.503 | 1261.008 | 30.946 |
| | 3 | 147.154 | -2792.191 | -122.761 |
| | 4 | 83.331 | -1143.567 | 28.29 |

**Table 4.16: Foundation reactions from SAP2000 – Static loading (2. UNBALANCED ICING)**

| Load Case | Joint No. [-] | Long.Force [KN] | Trans. Force [KN] | Vert. Force [KN] |
|---|---|---|---|---|
| 2. UNBALANCED ICING | 1 | 34.683 | 1541.076 | -114.13 |
| | 2 | 94.286 | 752.221 | -26.404 |
| | 3 | 123.071 | -1480.454 | -22.761 |
| | 4 | 0.959 | -682.643 | 60.995 |

**Table 4.17: Foundation reactions from SAP2000 – Static loading (1. DOWN OPENING)**

| Load Case | Joint No. [-] | Long.Force [KN] | Trans. Force [KN] | Vert. Force [KN] |
|---|---|---|---|---|
| 1. DOWN OPENING | 1 | 36.057 | 917.624 | -52.065 |
| | 2 | -33.472 | -840.562 | -49.597 |
| | 3 | 33.904 | -845.471 | -49.8 |
| | 4 | -36.489 | 919.41 | -52.937 |

**Table 4.18: Foundation reactions from SAP2000 – Static loading (2. DOWN OPENING)**

| Load Case | Joint No. [-] | Long.Force [KN] | Trans. Force [KN] | Vert. Force [KN] |
|---|---|---|---|---|
| 2. DOWN OPENING | 1 | 20.567 | 521.031 | -27.841 |
| | 2 | -18.819 | -470.131 | -26.207 |
| | 3 | 19.063 | -472.877 | -26.327 |
| | 4 | -20.811 | 521.978 | -28.325 |

**Table 4.19: Foundation reactions from SAP2000 – Static loading (NET UP LIFTING OPENING)**

| Load Case | Joint No. [-] | Long.Force [KN] | Trans. Force [KN] | Vert. Force [KN] |
|---|---|---|---|---|
| NET UP LIFTING OPENING | 1 | 33.573 | 845.509 | -49.503 |
| | 2 | -35.967 | -912.768 | -52.167 |
| | 3 | 36.38 | -917.666 | -52.336 |

| | | | | |
|---|---|---|---|---|
| | 4 | -33.986 | 847.125 | -50.393 |

**Table 4.20: Foundation reactions from SAP2000 – Static loading (DOWN OPENING)**

| Load Case | Joint No. [-] | Long.Force [KN] | Trans. Force [KN] | Vert. Force [KN] |
|---|---|---|---|---|
| DOWN OPENING | 1 | 17.248 | 433.993 | -26.094 |
| | 2 | -18.962 | -482.841 | -27.978 |
| | 3 | 19.175 | -485.399 | -28.068 |
| | 4 | -17.461 | 434.848 | -26.56 |

The outcomes of the static load analysis of SAP2000 show that the largest tension force occurs on an individual foundation when the leg component connected to the base is under tension take a place in the "1". UNBALANCED ICING "based on number 3 with a strength of -2792 KN so load the case" 1. UNBALANCED ICING "is the case of a critical load with maximum uplift following the static and dynamic load analysis of SAP2000.

**Selected node displacement**

An additional review of the peak nodal displacement acquired in the design was likewise performed for further review. Figure 4.1 demonstrates the nodes J1, A1, A2, B1, B2, C1 and C2, which undergo a maximum horizontal displacement subject to the Charging case "1.UNBALANCED ICING".

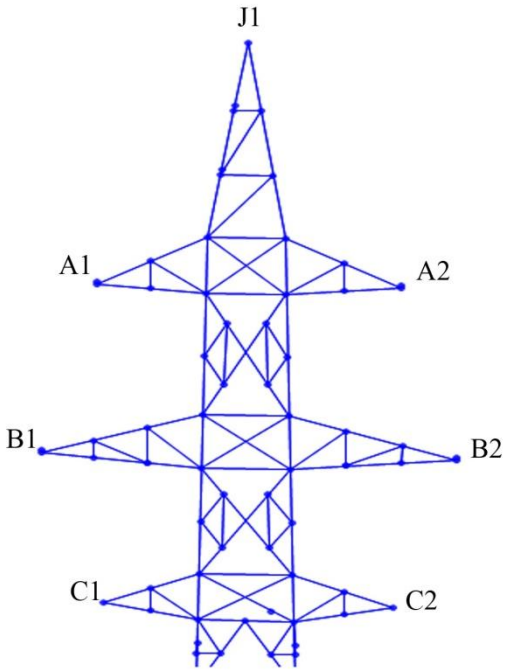


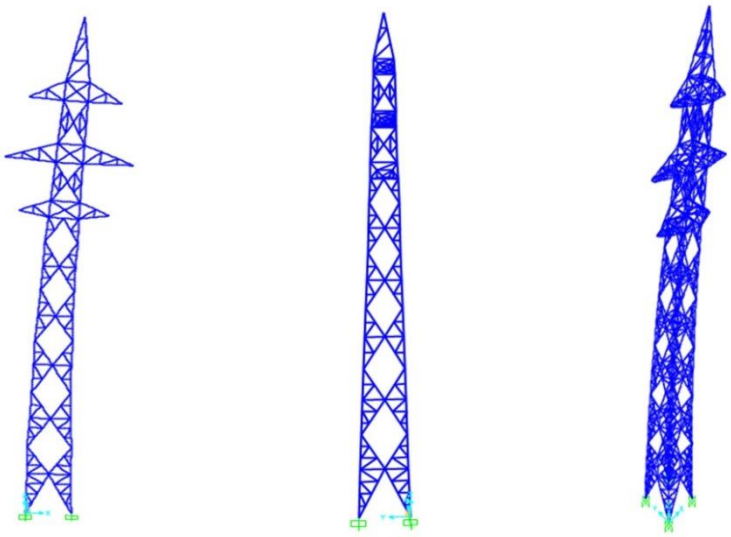

**Figure 4.1: Nodes at which peak transverse displacement occurs ( 1. UNBALANCED ICING)**

**Table 4.21: SAP2000 key joint displacements static loading for load case 1. UNBALANCED ICING**

| Joint Label [-] | Long. Displ. [mm] | Tran. Displ. [mm] | Vert. Displ. [mm] |
|---|---|---|---|
| J1 | -686 | 264 | -2 |
| A1 | -561 | 212 | 26 |
| A2 | -564 | 211 | -35 |
| B1 | -151 | 170 | 33 |
| B2 | -454 | 170 | -46 |
| C1 | -327 | 130 | 38 |
| C2 | -328 | 132 | -16 |

**Deformed shape**

The occurred deformed shape in the model loaded statically computed in SAP2000 is shown in Figures 4.2. It tends to be noticed the model act as expected when subjected to a crosswind load with a shift in such direction and a minimum of longitudinal movement.



**a) Longitudianl** **b) Transverse** **c) 3D view**

**Figure 4.2: Deformed shapes**

One of the objectives of this research, the influence of foundation reactions can be established only by analyzing the effect, the SAP2000 model has precisely concerted for the 1. UNBALANCED ICING load case can also be utilized for dynamic analysis through static loading.

## 4.2 Natural frequency analysis

### 4.2.1 Modal shapes

The model analysis for the design is carried out utilizing the eigenvector method. Once directing the modular analysis, guarantee that the outcomes incorporate a sufficient degree of structural mass. That is generally done by remembering enough modes for the analysis to catch 90% of the mass participation at every one of the three displacement direction. The mass participation proportion demonstrates the level of the basic mass for the model taking part in provided guidance and mode. It appeared in Table 4.22, this achieved at mode 330.

**Table 4.22: Modal mass participation ratios**

| Mode No. [-] | Participation mass ratio [%] | | | | | |
|---|---|---|---|---|---|---|
| | UX | UY | UZ | SumUX | SumUY | SumUZ |
| 1 | 0.000 | 0.520 | 0.000 | 0.000 | 0.520 | 0.000 |
| 2 | 0.536 | 0.000 | 0.000 | 0.536 | 0.520 | 0.000 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 3 | 0.000 | 0.000 | 0.000 | 0.536 | 0.521 | 0.000 |
| 4 | 0.000 | 0.237 | 0.000 | 0.536 | 0.757 | 0.000 |
| 5 | 0.000 | 0.000 | 0.001 | 0.536 | 0.757 | 0.001 |
| 6 | 0.250 | 0.000 | 0.000 | 0.786 | 0.757 | 0.001 |
| 7 | 0.000 | 0.000 | 0.002 | 0.786 | 0.757 | 0.003 |
| 8 | 0.000 | 0.000 | 0.000 | 0.786 | 0.757 | 0.003 |
| 9 | 0.000 | 0.000 | 0.000 | 0.786 | 0.757 | 0.003 |
| 10 | 0.000 | 0.000 | 0.008 | 0.786 | 0.757 | 0.011 |
| 11 | 0.000 | 0.005 | 0.000 | 0.786 | 0.763 | 0.011 |
| 25 | 0.019 | 0.009 | 0.000 | 0.920 | 0.867 | 0.019 |
| 150 | 0.000 | 0.000 | 0.000 | 0.991 | 0.991 | 0.704 |
| 239 | 0.000 | 0.000 | 0.000 | 0.994 | 0.994 | 0.827 |
| 330 | 0.000 | 0.000 | 0.001 | 0.996 | 0.995 | 0.900 |

Table 4-23: Shows the modal periods and natural frequencies of the modes listed in Table 4-22.

**Table 4.23: Modal periods and natural frequencies of the tower**

| **Mode No. [-]** | **Period [s]** | **Frequency [Hz]** | **Shape [-]** |
|---|---|---|---|
| 1 | 0.410 | 2.434 | Longitudinal |
| 2 | 0.400 | 2.500 | Transversal |
| 3 | 0.133 | 7.517 | Torsion |
| 4 | 0.123 | 8.123 | Longitudinal |
| 5 | 0.118 | 8.456 | Vertical |
| 6 | 0.114 | 8.756 | Transversal |
| 7 | 0.088 | 11.326 | Vertical |
| 8 | 0.088 | 11.328 | Vertical |
| 9 | 0.088 | 11.329 | Vertical |
| 10 | 0.071 | 13.978 | Vertical |
| 11 | 0.0686 | 14.578 | Longitudinal |
| 25 | 0.059 | 16.852 | Transversal |
| 150 | 0.019 | 53.730 | Vertical |
| 239 | 0.012 | 81.652 | Longitudinal |
| 330 | 0.008 | 120.940 | Vertical |

As it should be, with any particular mode in which the mode shape is longitudinal, transverse or vertical head toward. This mode is primarily caused by the corresponding direction of displacement. For torsional shaped, mass participation in all directions is virtually zero. The response of the structure is basically estimated by the initial four transverse and longitudinal modes.

Transverse mode shapes are separated here for real interest, as the high wind load that is dynamic is primarily used for this direction. Four modes 2, 6, 20, and 25 are

demonstrated in Figure 4.3 until Figure 4.6 that their mass participation highest than 1% for the direction of transverse. Point out that the shown figures are demonstrated in their easiest 'wireframe' form for reason of clarification owing to the structure height. Therefore, the figures have also been up scaled to show the mode forms better.

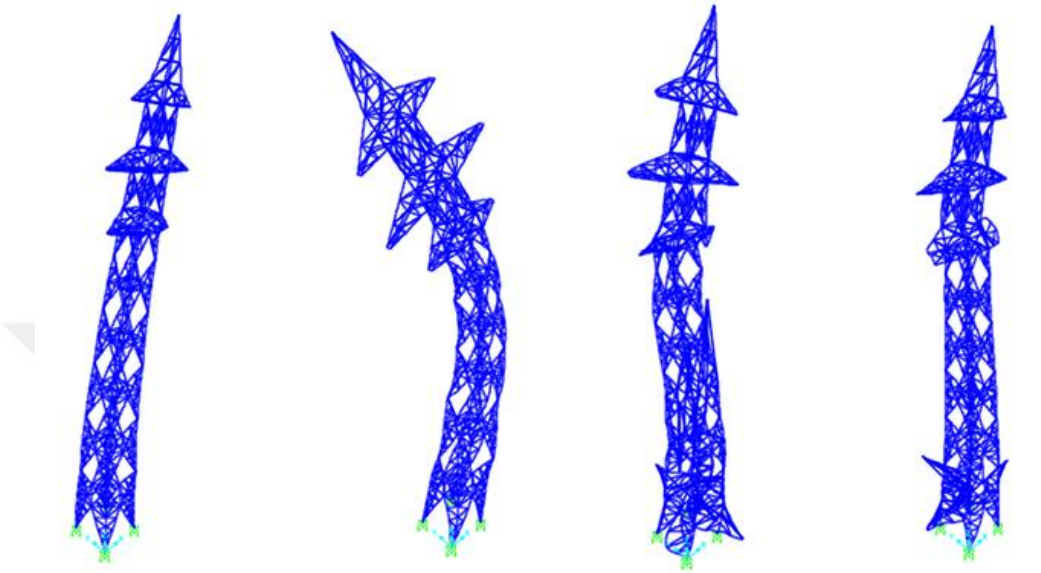


**Figure 4.3.a: Mode 2 – frequency = 2.500 Hz**

**Figure 4.3.b: Mode 6 – frequency = 8.756Hz**

**Figure 4.3.c: Mode 20– frequency = 16.521 Hz**

**Figure 4.3.e: Mode 25 - frequency= 16.852 Hz**

**Figure 4.3: Mode number and frequency of the TL tower**

## 4.3 Earthquake time history

As discussed in Chapter III, TL tower studied herein (Fig. 3.4) was subjected at their foundation to earthquake activity in the transversal direction. The 10 earthquake ground motions were utilized in this thesis are shown in Table 3.7 of Chapter III.

The seismic activity of the towers is measured by the method of time history (TH) analysis. Ten time-history of ground motions were arbitrarily chosen from the Strong Motion database of the Pacific Earthquake Engineering Reseach Center (PEER, 2014).

## 4.4 Time History Analysis Results

### 4.4.1 Horizontal displacement – SAP2000 dynamic loading

Time history analysis is conducted for every single of the 10 ground motions. For the 154 KV tower angle-type, the main components exceed the limit of yield or buckling before the bracing members have any damage under an earthquake. To take into account large limits within which ground motion can be effective. Figure 4.7 displays the time histories for the lateral displacement for the peak node in the electrical transmission towers.

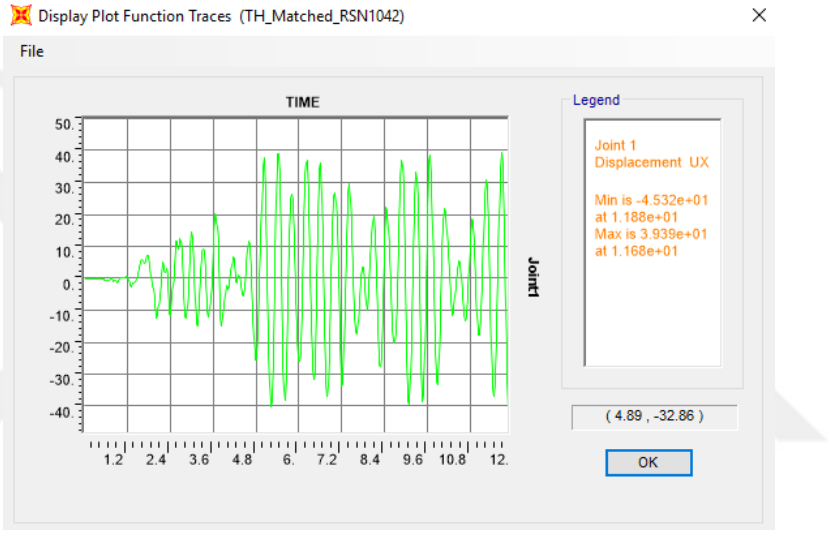



**Figure 4. 4: Time histories of the horizontal displacement of the top node of the transmission towers**

The time intervals are used for the TL tower's structural steel elements. As with all dynamically loaded modules, results do have the highest and lowest load values as a result of the variable nature of loads.

### 4.4.2 Foundation reactions – SAP2000 dynamic loading

Table 4.24 presents the results of the dynamically loaded model from SAP2000 with greatest values for the maximum and minimum force in each direction acting on the foundations.

**Table 4. 24: Foundation reactions from SAP2000 dynamic loading (Earthquake time history load)**

| Earthquake | Foundation No. | Max./ Min. [-] | Long.Force [KN] | Tran.Force [KN] | Vert.Force [KN] |
|---|---|---|---|---|---|

| | | | | | |
|---|---|---|---|---|---|
| Landers earthquake | 1 | Max. | 6.18 | 164.29 | 12.36 |
| | | Min. | -6.56 | -170.98 | -12.88 |
| | 2 | Max. | 6.562 | 170.64 | 12.41 |
| | | Min. | -6.23 | -164.06 | -12.93 |
| | 3 | Max. | 6.30 | 171.68 | 12.40 |
| | | Min. | -6.67 | -164.91 | -12.98 |
| | 4 | Max. | 6.65 | 164.747 | 12.53 |
| | | Min. | -6.30 | -171.31 | -13.06 |

It is obvious the greatest foundation reaction in the model loaded dynamically is lower than the static load. In aging, isolate the legs in compression, the maximum uplift force to be 171.68 KN in the foundation number 3, which represents 6.14% of the corresponding foundation load modeled during static analysis by the SAP2000 model.

Figure 4.8 displays time-series for base joint foundation 3 through uplift conditions, moreover with the greatest value existing at approximately 11.88 seconds corresponded to that demonstrated in Figure 4.8.

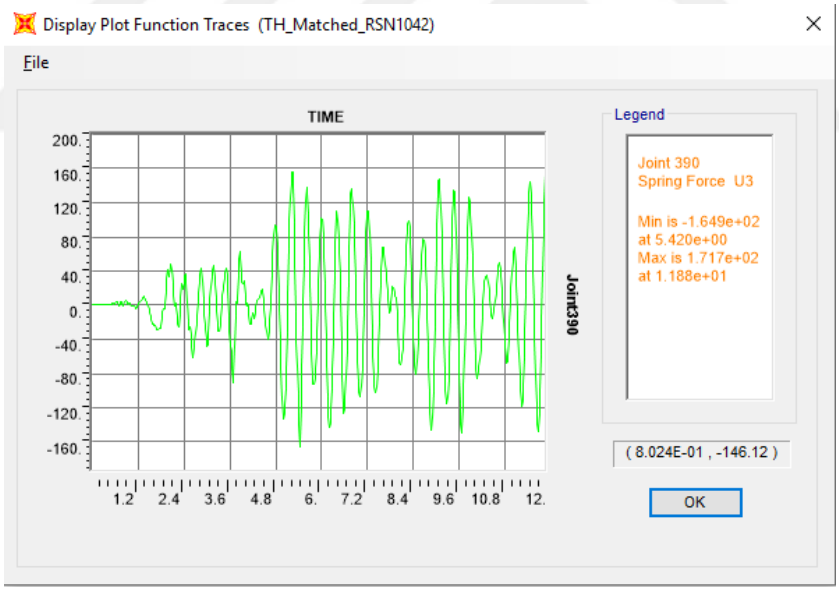



**Figure 4.5: Time history for transverse reaction of foundation number 3**

To compare the nodes undergoing maximum displacement, Table 4.25 presents the results for the highest nodes in the tower, including the maximum loads with seismic ground motion.

**Table 4. 25: SAP2000 key joint displacements dynamic loading for load case High wind 0°**

| Joint Label [-] | Max./Min. [-] | Displ. Long. [mm]U2 | Displ. Tran. [mm]U1 | Displ. Vert. [mm]U3 |
|---|---|---|---|---|
| J1 | Max. | 0.108 | 95.63 | 0.003 |
| | Min. | -0.116 | -82.01 | -0.003 |
| A1 | Max. | 0.108 | 89.21 | 4.00 |
| | Min. | -0.101 | -74.98 | -4.51 |
| A2 | Max. | 0.109 | 89.21 | 4.52 |
| | Min. | -0.108 | -74.09 | -3.99 |
| B1 | Max. | 0.101 | 83.82 | 5.82 |
| | Min. | -0.095 | -62.47 | -6.58 |
| B2 | Max. | 0.103 | 83.82 | 6.58 |
| | Min. | -0.108 | -67.47 | -5.82 |
| C1 | Max. | 0.069 | 78.67 | 4.06 |
| | Min. | -0.064 | -64.19 | -4.61 |
| C2 | Max. | 0.074 | 78.67 | 4.61 |
| | Min. | -0.073 | -64.19 | -4.06 |

There is a comparatively large difference between both the two models in the peak displacement at these nodes. The model loaded dynamically has peak values corresponding to 13.94 % of the model that loaded statically.

## 4.5 Designing of the transmission tower using AISC 360-16 code

If the analysis with SAP2000 is to be performed, you can make the necessary combinations anywhere in the world and you can make the analysis as you want. In this sense, the AISC360-16 code which is the most suitable for Turkey in terms of design has been used. As for the 2018 regulation. The design is very close to the AISC360-16.

A load cases is set of loads and boundary conditions used to define a particular loading conditions. In the study the load cases which have been used to study the linear response of a structure subjected to different loading condions have been taken from Turkey Electricity Distribution (Tedaş). There are 20 load cases illustrated in Appendex 1.

### 4.5.1 Design with the same secions which have been taken from Tedas

During the design we chceked if the section passed and safe. As displayed in Figure 4.6 we can see several sections have not passed. There are 18 steel frames failed stress/capacity check. We can see all the section in Table 4.26 Summary Data of steel design- AISC360-16 (Albayrak, and Morshid, 2020).

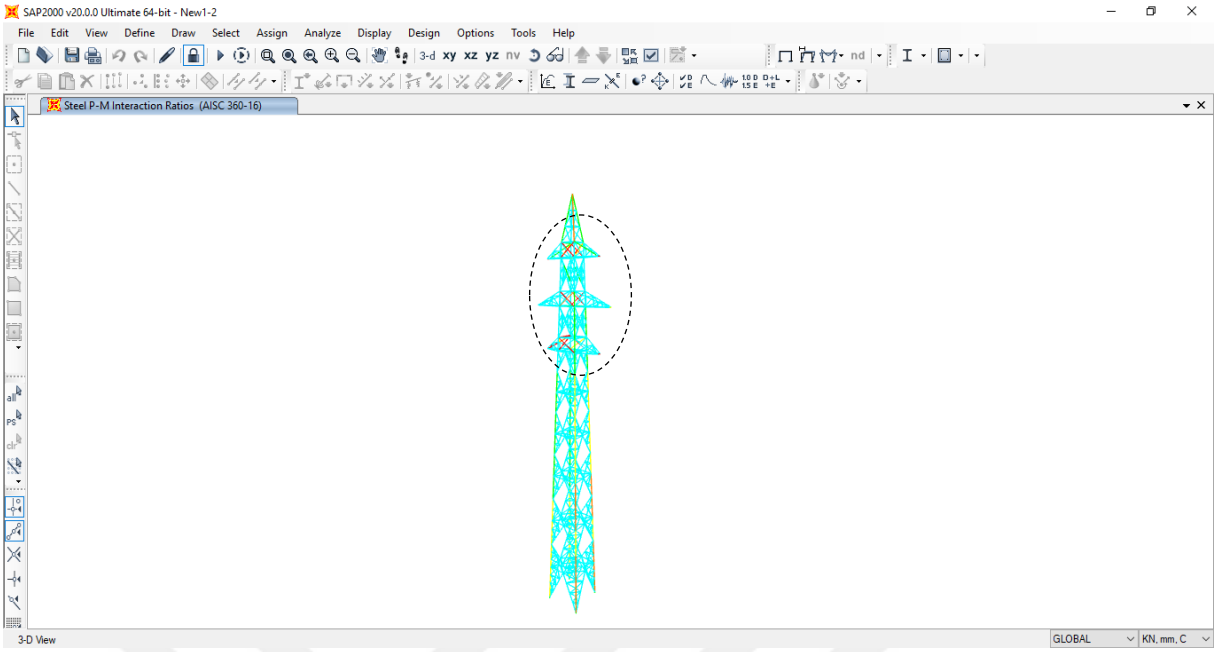



**Figure 4. 6*:* The designed secions of TL tower**

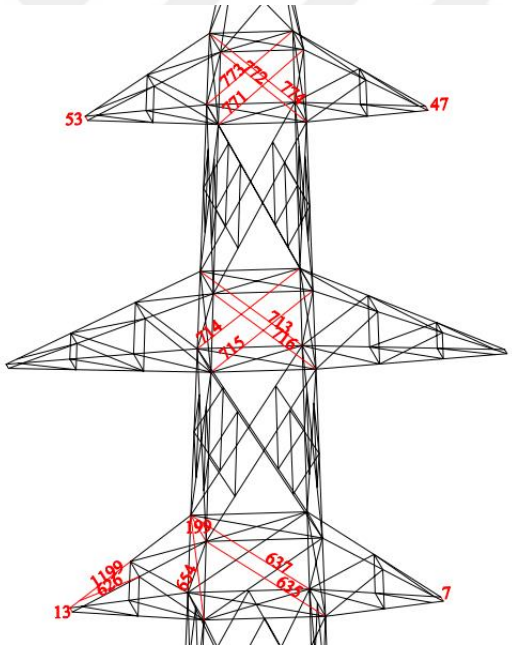



**Figure 4. 7: The failed sections**

## 4.6 Modeling and parametric analysis of bolted connections on retrofitted transmission tower members

The useful retrofitting method for attaching parallel reinforcement components to critical members (Fig.4.8.a) has been commonly used on transmission line towers in Turkey and elsewhere.



**(a) Method of retrofitting**



**(b) Connection of Cruciform**



**(c) Splice joint**

**Figure 4.8 : Connections of transmission tower**

**Table 4.26: Overstressed sections - AISC 360-16**

| No. | **Frame** | **Design Section** | **Design Type** | **Status** | **Ratio** | **Combo** |
|---|---|---|---|---|---|---|
| | Text | Text | Text | Text | Unitless | Text |
| 1 | 7 | L80X7 | Beam | overstressed | 1.82 | COMB1 |
| 2 | 13 | L80X7 | Beam | overstressed | 1.98 | COMB2 |
| 3 | 47 | L80X10 | Beam | overstressed | 1.35 | COMB1 |
| 4 | 53 | L80X10 | Beam | overstressed | 1.76 | COMB2 |
| 5 | 199 | L70X7 | Beam | overstressed | 1.15 | COMB11 |
| 6 | 626 | L60X5 | Brace | overstressed | 1.69 | COMB2 |
| 7 | 635 | L80X7 | Brace | overstressed | 1.08 | COMB1 |
| 8 | 637 | L80X7 | Brace | overstressed | 1.08 | COMB11 |
| 9 | 654 | L80X7 | Brace | overstressed | 1.17 | COMB2 |
| 10 | 713 | L70X7 | Brace | overstressed | 1.41 | COMB14 |
| 11 | 714 | L70X7 | Brace | overstressed | 1.08 | COMB2 |
| 12 | 715 | L70X7 | Brace | overstressed | 0.95 | COMB2 |
| 13 | 716 | L70X7 | Brace | overstressed | 1.43 | COMB10 |
| 14 | 771 | L50X5 | Brace | overstressed | 1.96 | COMB2 |
| 15 | 772 | L50X5 | Brace | overstressed | 2.52 | COMB14 |
| 16 | 773 | L50X5 | Brace | overstressed | 2.11 | COMB2 |
| 17 | 774 | L50X5 | Brace | overstressed | 2.52 | COMB14 |
| 18 | 1199 | L60X6 | Brace | overstressed | 12.73 | COMB2 |

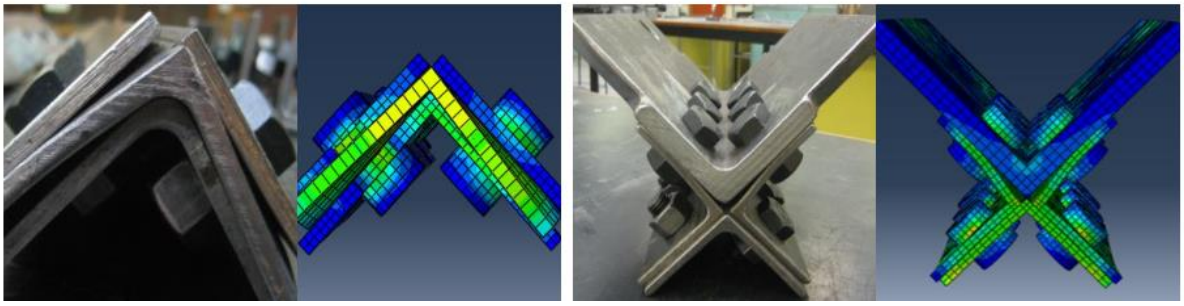
In this approach, critical legs component and parallel reinforcement members are connected by cross-shaped bolt connections (Fig. 4.8.b). The cross-shaped connections transfer large external loads as well from the critically legs member to the reinforcement components so that lesser loads are transported in critically legs and the total load carrying the amount that can be contained is increased. Additionally, splicing joints (Fig.4.8.c) are additionally used in grid transmission towers to connect the critical lengths of leg members. Therefore, cruciform and joint connections are significant factors within the structural behavior of the legs of retrofitted transmission towers.

Experimental investigation of joint connections provided the concept of "slip resistance", relying on a set of affecting factors for instance bolt arrangement, properties of the material surface, material strength, and torque values.

Relying on this study, 'Ungkurapinan et al. (2003)' carried out experimental research on the load transfer behavior of screw connections with the same steel angles. In this work, experimental and theoretical expression of the load shift was developed. This load switching behavior for screw connections was then used in the fault analysis of network towers (Ungkurapinan, Chandrakeerthy and others, 2003).

Studies on cross-connections have been carried out. Experimental research showed that the load transfer behavior of cross-connections depends on the screw arrangement. 'Zhuge et al. (2012)' have extended these research results through numerical analysis (Zhuge, Mills and Ma, 2012). 'Mills et al. (2012)' also suggested a retrofitted powerline tower test moreover came to the conclusion that the cross-connection in a transmission tower system has sufficient load transmission capability.

Although, the influencing variables and error paths for the combination of cross and joint connections were not examined. Therefore, the authors have investigated the load transfer behavior of cross-connections and joints using experimental tests as well as compared the results with models that developed in software called ABAQUS. A parametric study was then carried out taking into account friction coefficients, screw numbers and torque values using the confirmed numerical models (Lu, Ma and Mills, 2015).



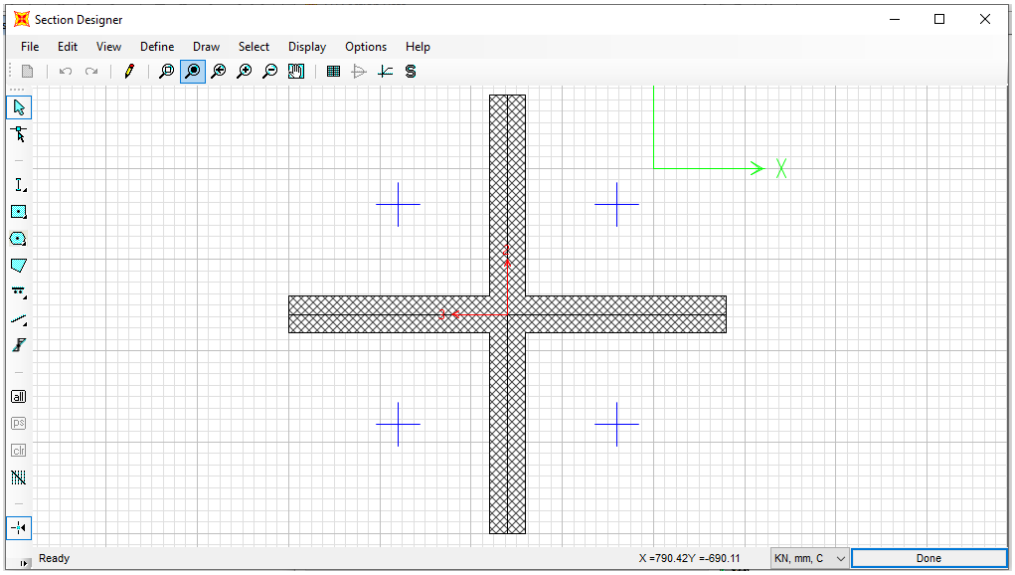
(a) 12 blot cruciform join (b) 12 blot splice joints

**Figure 4. 9: Failure mode of specimens (CTC type)**

C. Lu, X. Ma, and J. Mills presented in their study the load shifting behavior of cross and joint connections on the legs of retrofitted gear towers (Chen, Guo and others, 2014). ABAQUS has been used for designing numerical different models to make a pretense of experimental tests, and In a parametric study, the number model verified was then used. Depending on both experimental and numerical test results, it was found the assembly specification affects the load shifting behavior, Figure 4.9 displayes failure mode of CTC type.

## 4.8 Replace the failed sections in the tower with new sections

In our study we replaced the failed sections with CTC section type (Figure 4.10) using SAP2000 software to design the sections. Table 4.27 shows the comparative of Steel Design -Summary Data - AISC 360-16 (Albayrak, and Morshid, 2020).



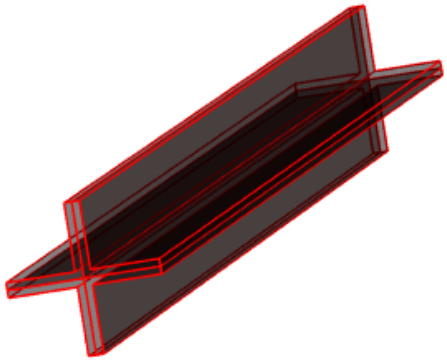


**Figure 4.10: The new designed section**

**Table 4.27: Comparative of Steel Design -Summary Data - AISC 360-16**

| Frame No | Design Section | Ratio | Replaced section | Ratio |
|---|---|---|---|---|
| 7 | L80X7 | 1.82 | CTC 80x7 | 0.58 |
| 13 | L80X7 | 1.98 | CTC 80x7 | 0.56 |
| 47 | L80X10 | 1.35 | CTC 80x10 | 0.41 |
| 53 | L80X10 | 1.76 | CTC 80x10 | 0.61 |
| 199 | L70X7 | 1.15 | CTC 70x7 | 0.10 |
| 626 | L60X5 | 1.69 | CTC 60x5 | 0.21 |
| 635 | L80X7 | 1.08 | CTC 80X7 | 0.10 |
| 637 | L80X7 | 1.08 | CTC 80X7 | 0.10 |
| 654 | L80X7 | 1.17 | CTC 80X7 | 0.10 |
| 713 | L70X7 | 1.41 | CTC 70X7 | 0.10 |
| 714 | L70X7 | 1.08 | CTC 70X7 | 0.10 |
| 715 | L70X7 | 0.95 | CTC 70X7 | 0.50 |
| 716 | L70X7 | 1.43 | CTC 70X7 | 0.08 |
| 771 | L50X5 | 1.96 | CTC 50X5 | 0.10 |
| 772 | L50X5 | 2.52 | CTC 50X5 | 0.09 |

| | | | | |
|---|---|---|---|---|
| 773 | L50X5 | 2.11 | CTC 50X5 | 0.07 |
| 774 | L50X5 | 2.52 | CTC 50X5 | 0.09 |
| 1199 | L60X6 | 12.73 | CTC 60X6 | 0.40 |

## 4.9 Comparative study for different design codes

It has been done a comparative study for the transmission tower when designed using the same sections of Tedas and using new sections. The study shows interesting results as given in Table 4.28. The equal sections to Tedas sections when used ASCE 10-97 are 111 sections, the sections that increased are 427 and the sections that decreased are 158 sections. Similarly, when compared to Eurocode 3-2005. The equal sections are 58, the increased sections are 451 and the decreased sections are 187 sections.

**Table 4.28: Compartion due to the number of sections**

| | ASCE 10-97 | Eurocode 3-2005 |
|---|---|---|
| Equal | 111 | 58 |
| Increased | 427 | 451 |
| Decreased | 158 | 187 |
| Sum of members | 696 | 696 |

In terms of more economy, the part and the total weight of the sections are calculated using Advance Steel software as presented in Appendix-B. The results show that the total weight of the tower when using the sections provided from Tedas is 14682 kilograms, the total weight of the tower model with new angle sections using ASCE 10-97 and Eurocode 3-2005 is 15791 and 16590 kilograms, respectively. The results show the tower with Tedas sections is low-cost.

# 5 CONCLUSIONS AND SUGGESTIONS

## 5.1 Conclusions

The disparity between the transmission tower modeling using industry-standard static loads and advanced techniques for dynamic loading seems relatively important. However, if the completely static load on the tower is removed. the response that has been found of the dynamic model of the tower alone is compared to the response to the static load which is almost six times less than largely static reactions when considering the foundation reactions. However, it can be more economic if we take the wind load as dynamic loads.

It should also be noted that the maximum nodal displacements of the peak point of the transmission tower of the dynamic model are almost 13.94% lesser compared with the static model.

It has also been presented the dynamic loading process is very random. The foundation reactions happened for a long period of over twelve minutes. This is significant because it demonstrates that the greatest force cannot be used for an extended period so that the designer can be confident that the design through the specified load conditions would have to be conservative in most cases.Therefore, it would be better to run a different set of time series simulated of equal duration to get statistics on the greatest dynamic model response.

Due to the complexity, time, and expense of designing high towers like those discussed in this study, it would also make sense to allocate comparatively small additional resources to dynamic load examination throughout the design phase, thus significantly reducing the cost of materials and labor under construction.

With the growth of requirements as well as software updates for existing industry programmers such as SAP2000, designers should be able to perform a comprehensive FEM dynamic analysis for overhead transmission tower lines as efficiently and quickly as they do with existing design practices. There is as well no cause to assume that the dynamic load effect will be smaller for small towers that are subjected to a higher

proportion of seismic load, although this will require a lot of standard/software modification.

The seismic study of transmission towers over Turkey developed a set of time history analyses using non-linear finite element models on towers and a set of 10 recorded earthquake ground motions. The following conclusions shall be drawn. The transmission tower is not totally safe from an earthquake design in Turkey.

For the 154 kV transmission tower, the buckling developed in the steel members is further probable to occur to steel sections located in the cage (top part) of the tower. A relationship is determined between the transmission tower height and the seismic vulnerability for transmission towers.

The results show that a load of failure after retrofitting increased. The retrofitting method was effective and easy to be conducted in fields.

## 5.2 Suggestions for Future Work

For an additional accurate examination of the seismic performance of the transmission towers, a non-linear time history analysis considering the interaction of soil-structure is required.

It would also be important to move forward in this work, especially applying the principle of the dynamic loading to an entire transmission tower through different ground motions. Of course, seismic loads are not only potential examples of dynamic load forms:. The effect of dynamic winds can save in areas where winds cause storm damage.

More generally, it is often advantageous for design engineers to have as complete an understanding of the design structure as possible. The behavior of the tower under extreme load cases is useful to ensure that a complete set of various design parameters is met.

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# APPENDIX-A

## 1 Load cases

The details of the 20 load cases as combinations of different loads presented in the next pages. The figure1 below shows the load directions for conventions.

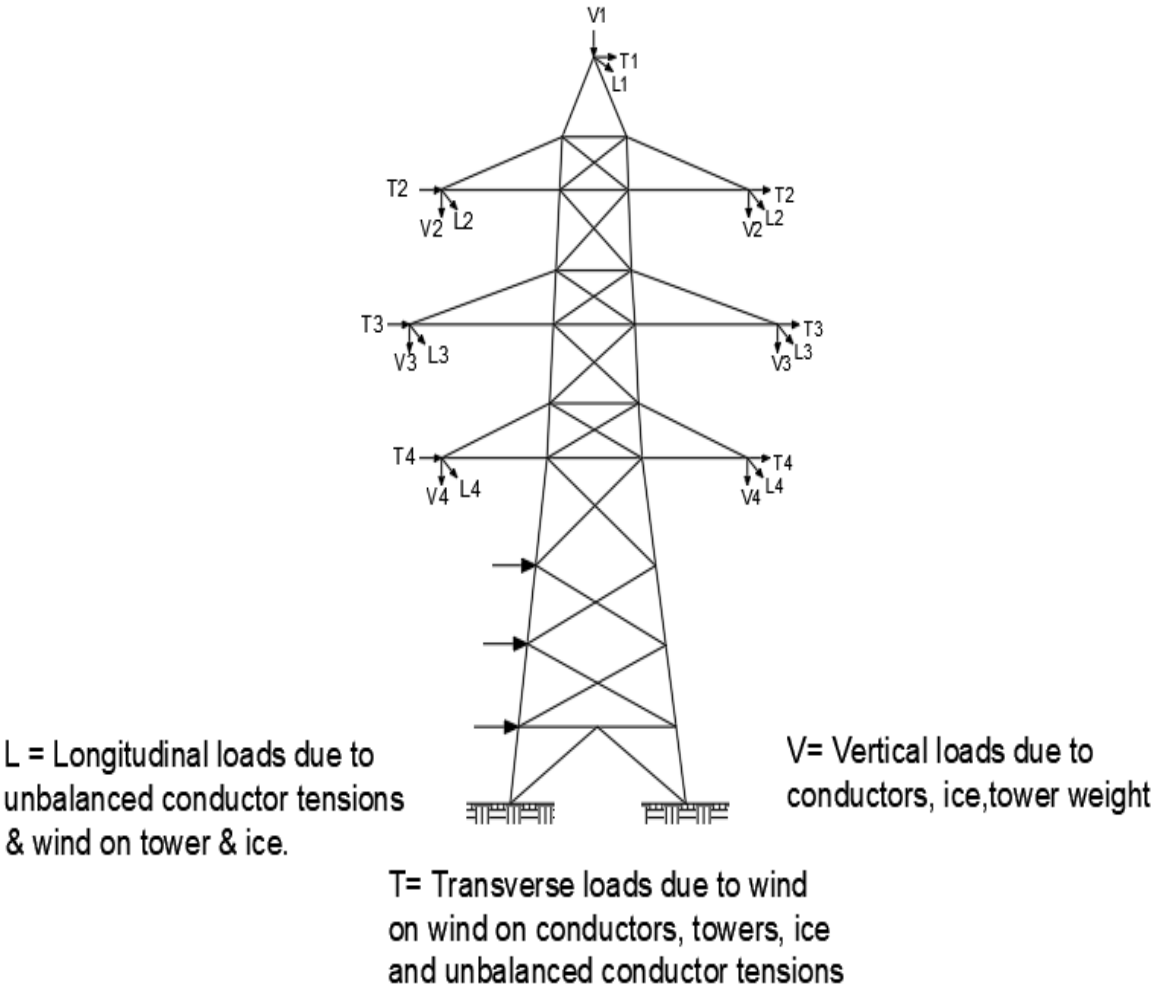
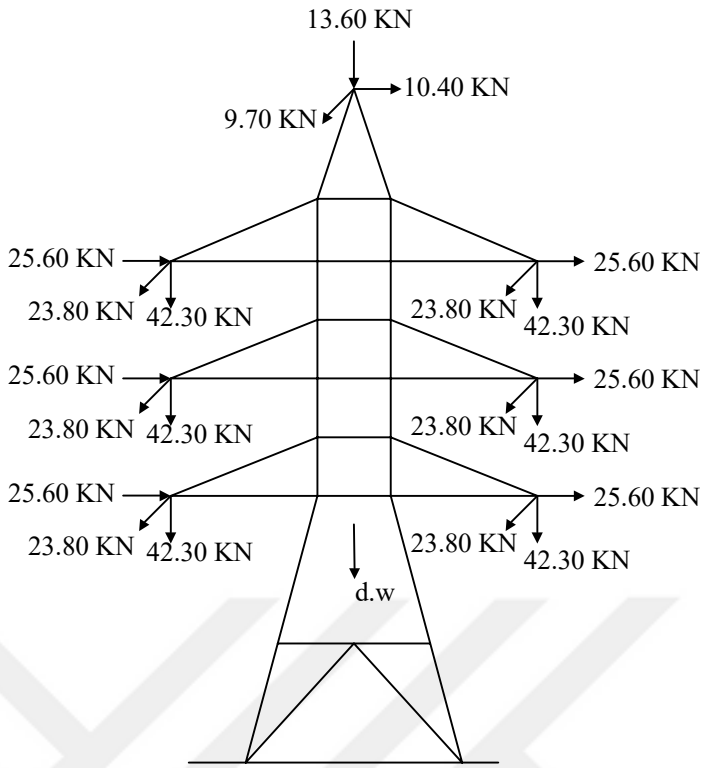
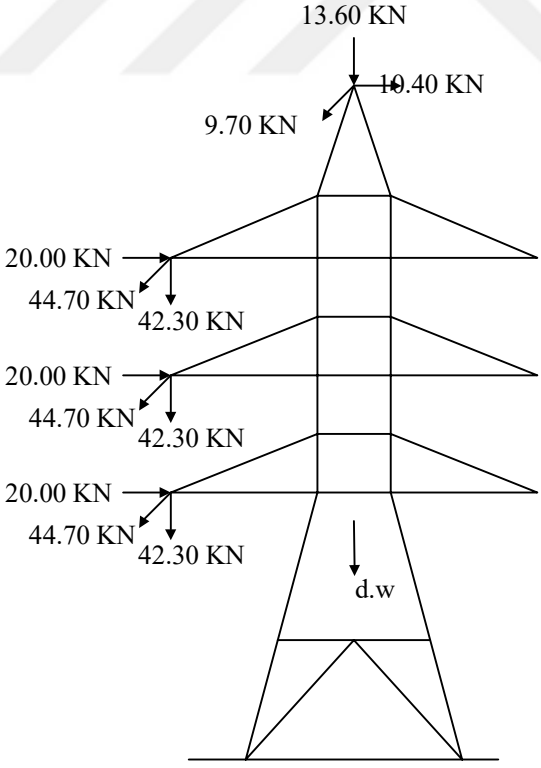



**Figure A1.1: Load direction conventions**

# Load cases of Transmission Tower



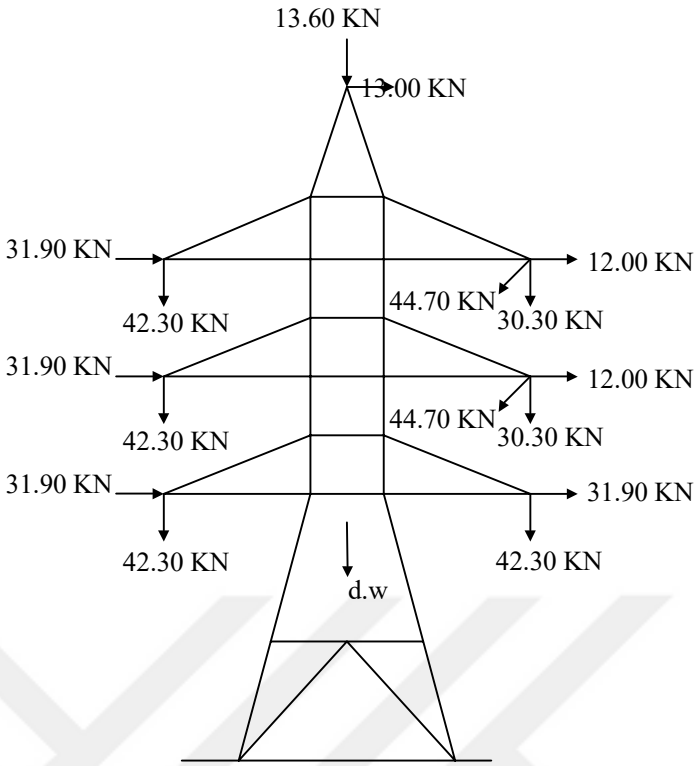

Load case description: 1.UNSTABLE LOADS
Case #: 1



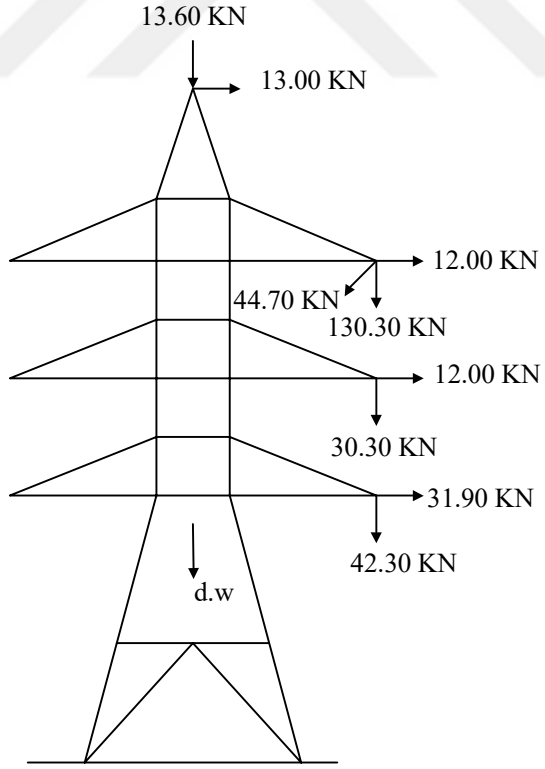

Load case description: 2.UNSTABLE LOADS
Case #: 2

| Desig. | Ref. | Description | Verif. | ESOGU |
|---|---|---|---|---|
| Appendix 1: 01 | Scale: | Comments: 154 kv | | |
| Title: Transmission tower | Review: | | | |
| Date: 29.12.2019 | Student: Loai Morshid | | | |
| Supervisor: DR. ÖĞR. ÜYESİ UĞUR ALBAYRAK | | | | |

# Load cases of Transmission Tower



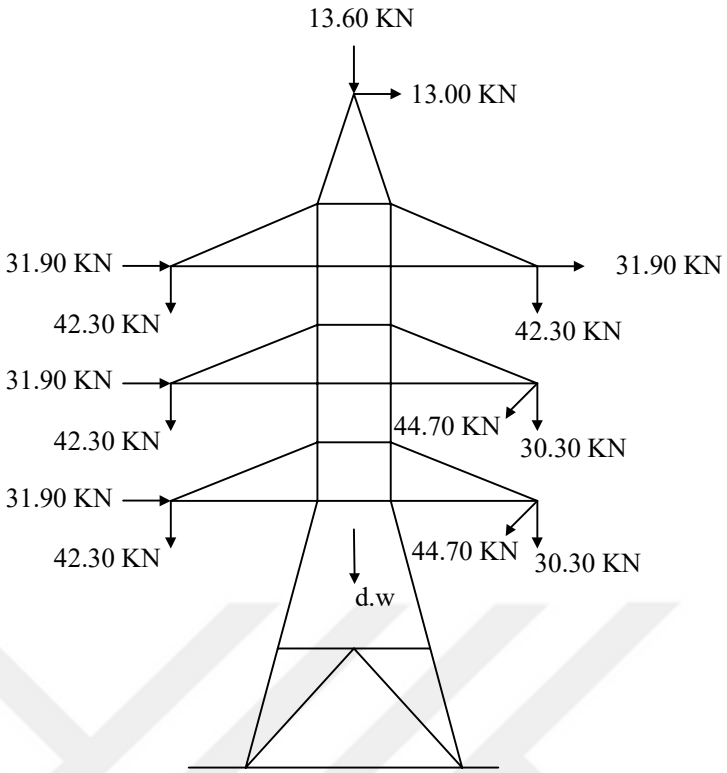

Load case description: RIGHT TOP AND MIDDLE CONDUCTOR COUPLING
Case #: 3



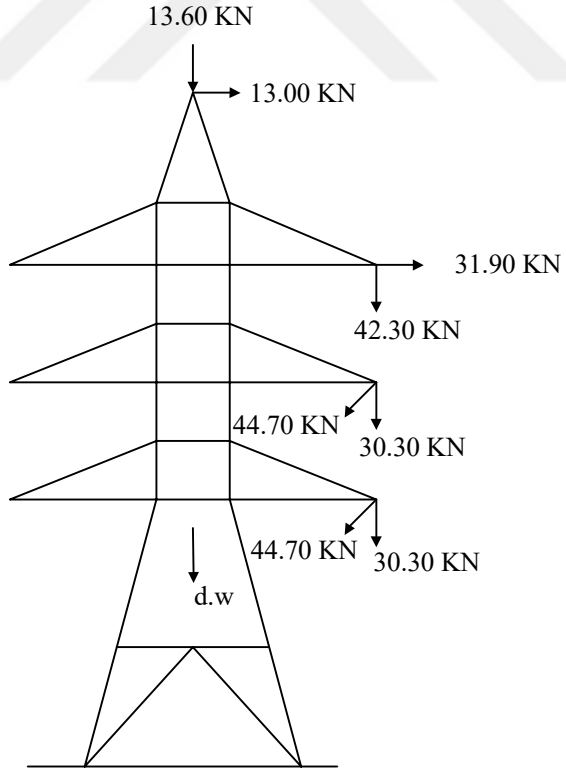

Load case description: RIGHT TOP CONDUCTOR CLOSING SINGLE CIRCUIT
Case #: 4

| Desig. | Ref. | Description | Verif. | ESOGU |
|---|---|---|---|---|
| Appendix 1: 02 | | Scale: | Comments: 154 kv | |
| Title: Transmission tower | | Review: | | |
| Date: 29.12.2019 | | Student: Loai Morshid | | |
| Supervisor: DR. ÖĞR. ÜYESİ UĞUR ALBAYRAK | | | | |

# Load cases of Transmission Tower



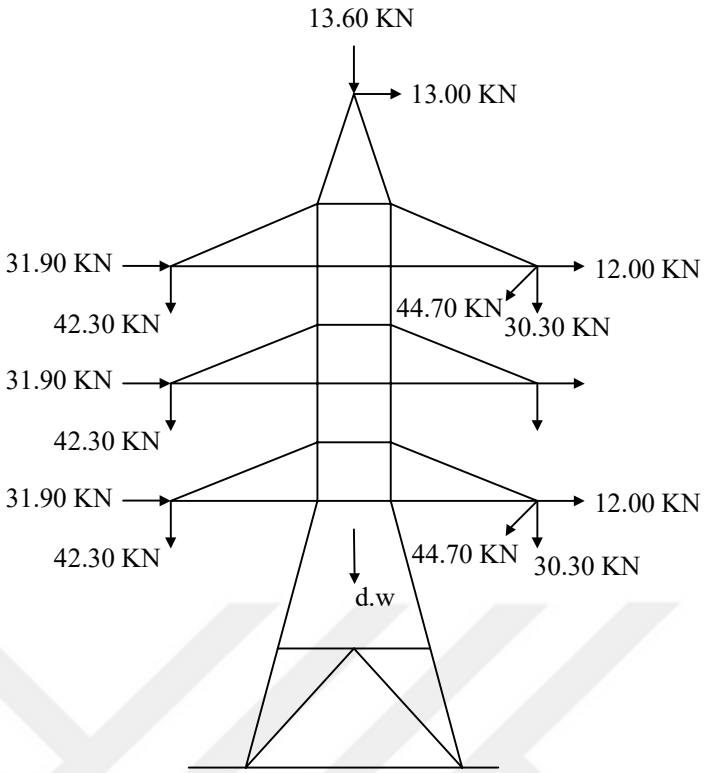

Load case description: RIGHT MIDDLE AND BOTTOM CONDUCTOR COUPLING
Case #: 5



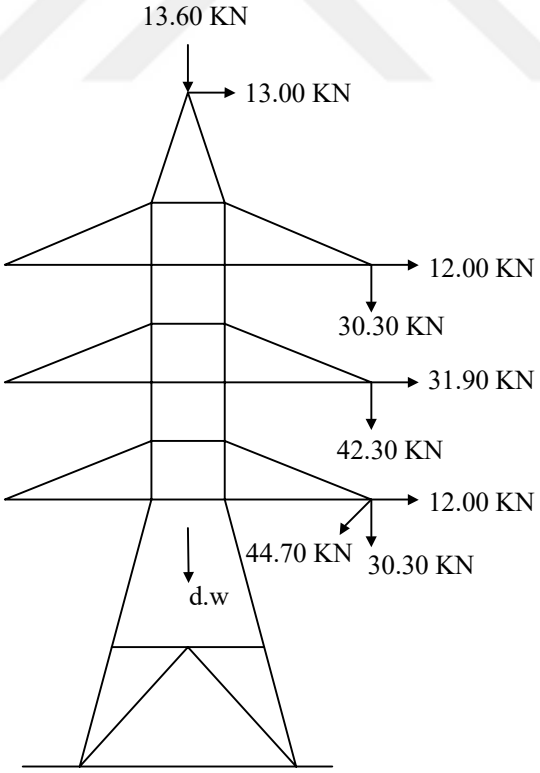

Load case description: RIGHT MIDDLE CONDUCTOR CLOSING SINGLE CIRCUIT
Case #: 6

| Desig. | Ref. | Description | Verif. | ESOGU |
|---|---|---|---|---|
| Appendix 1: 03 | | Scale: | Comments: 154 kv | |
| Title: Transmission tower | | Review: | | |
| Date: 29.12.2019 | | Student: Loai Morshid | | |
| Supervisor: DR. ÖĞR. ÜYESİ UĞUR ALBAYRAK | | | | |

# Load cases of Transmission Tower



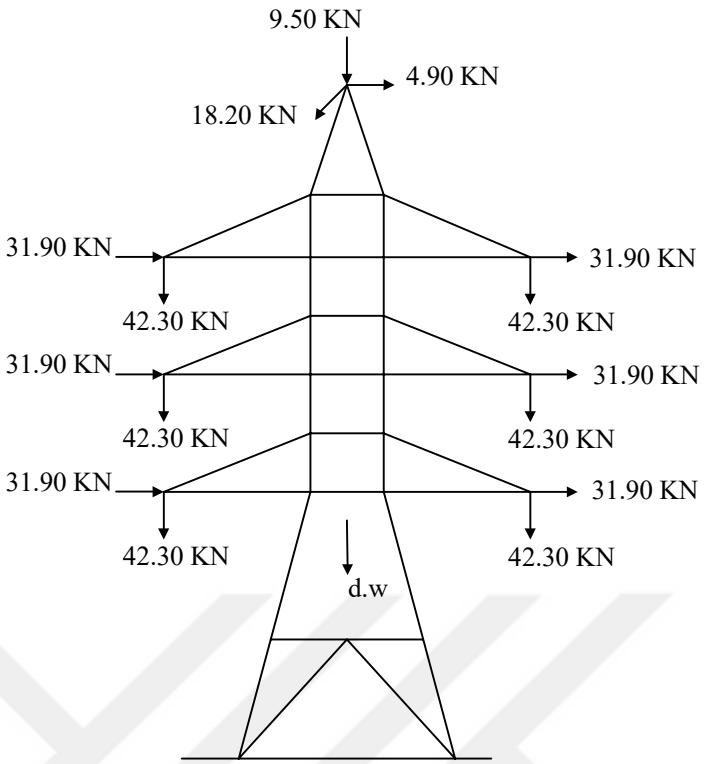

Load case description: RIGHT TOP AND BOTTOM CONDUCTOR COUPLING
Case #: 7




Load case description: RIGHT BOTTOM CONDUCTOR COUPLING SINGLE CIRCUIT
Case #: 8

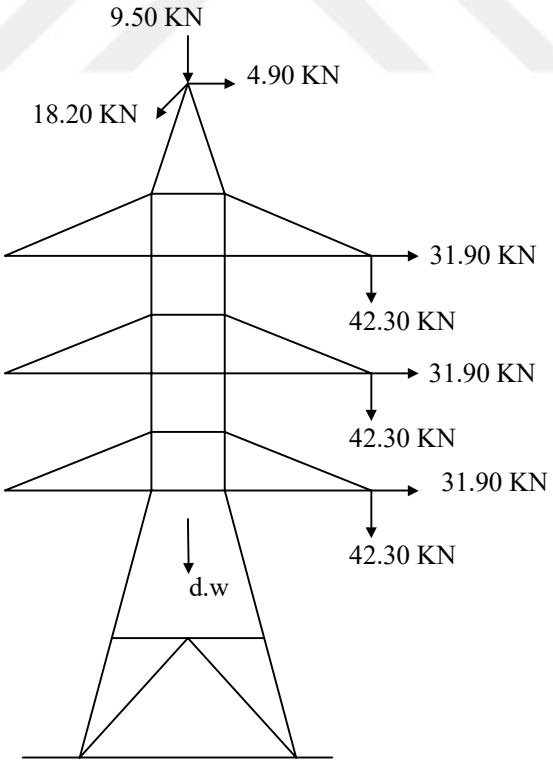
| Desig. | Ref. | Description | Verif. | ESOGU |
|---|---|---|---|---|
| Appendix 1: 04 | | Scale: | Comments: 154 kv | |
| Title: Transmission tower | | Review: | | |
| Date: 29.12.2019 | | Student: Loai Morshid | | |
| Supervisor: DR. ÖĞR. ÜYESİ UĞUR ALBAYRAK | | | | |

# Load cases of Transmission Tower




Load case description: 1.EARTH WIRE BROKEN

Case #: 9

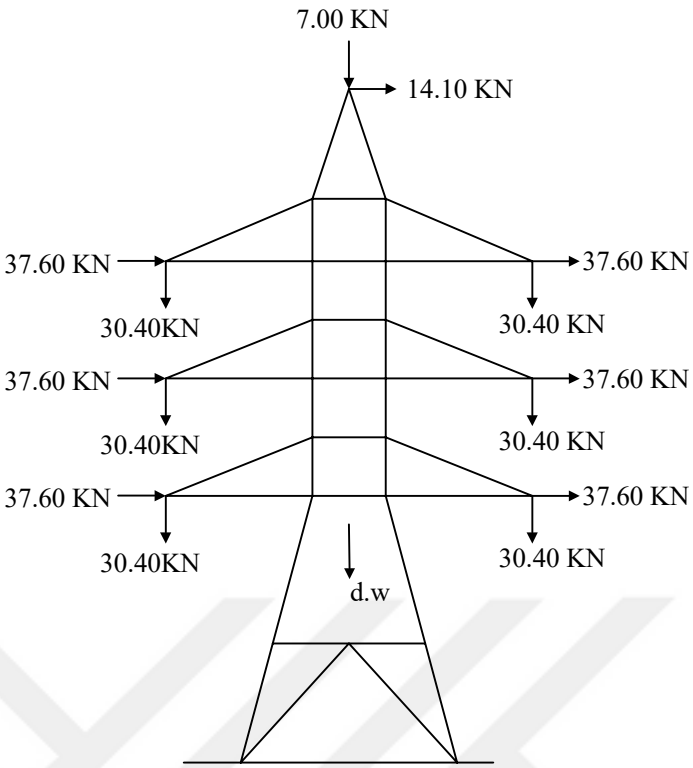



Load case description: 2.EARTH WIRE BROKEN

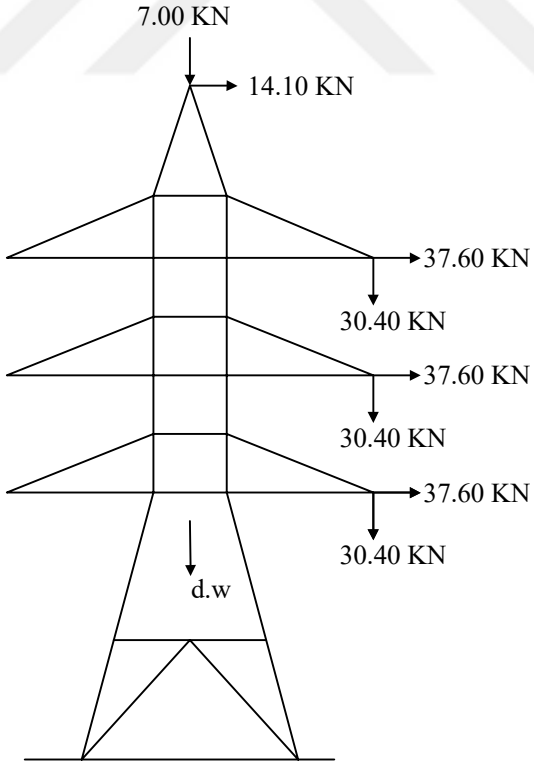
Case #: 10

| Desig. | Ref. | Description | Verif. | ESOGU |
|---|---|---|---|---|
| Appendix 1: 05 | Scale: | Comments: 154 kv | | |
| Title: Transmission tower | Review: | | | |
| Date: 29.12.2019 | Student: Loai Morshid | | | |
| Supervisor: DR. ÖĞR. ÜYESİ UĞUR ALBAYRAK | | | | |

# Load cases of Transmission Tower



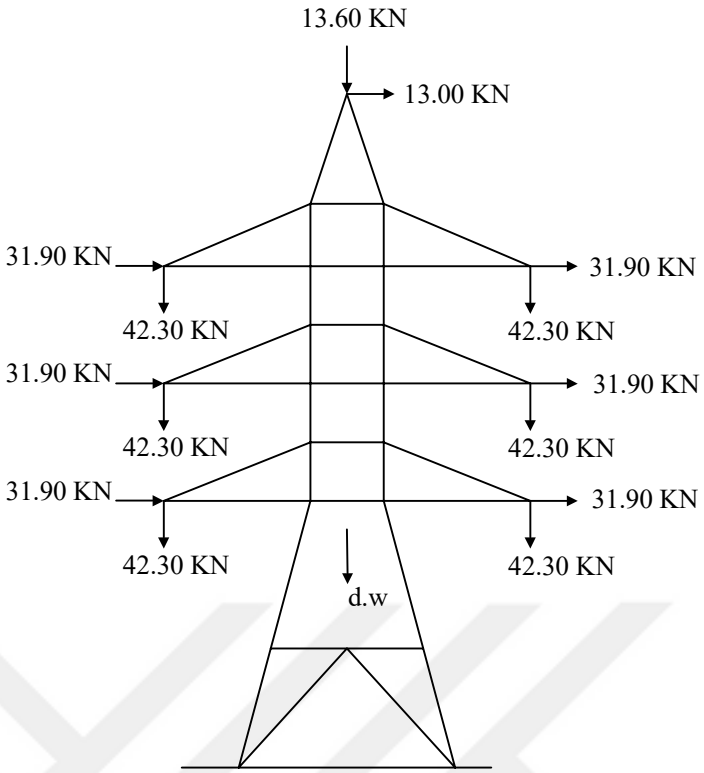

Load case description: EVEN WIND
Case #: 11



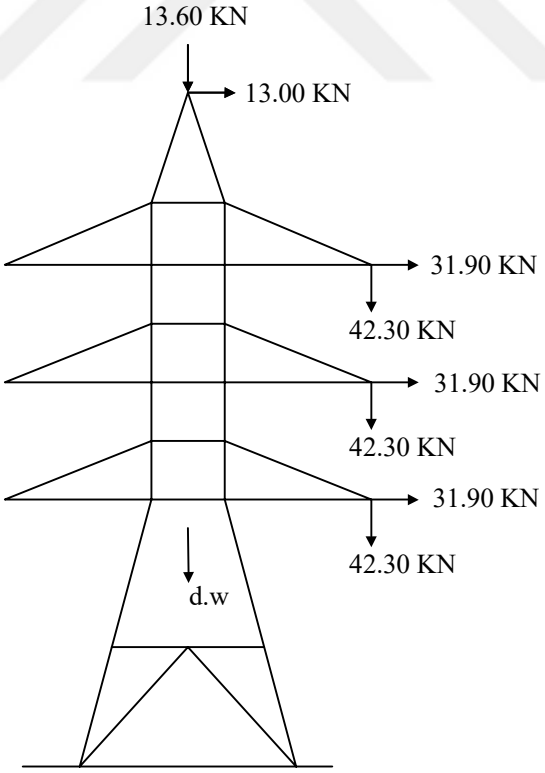

Load case description: ONE VERTICAL WIND SINGLE CIRCUIT
Case #: 12

| Desig. | Ref. | Description | Verif. | ESOGU |
|---|---|---|---|---|
| Appendix 1: 06 | Scale: | Comments: 154 kv | | |
| Title: Transmission tower | Review: | | | |
| Date: 29.12.2019 | Student: Loai Morshid | | | |
| Supervisor: DR. ÖĞR. ÜYESİ UĞUR ALBAYRAK | | | | |

# Load cases of Transmission Tower



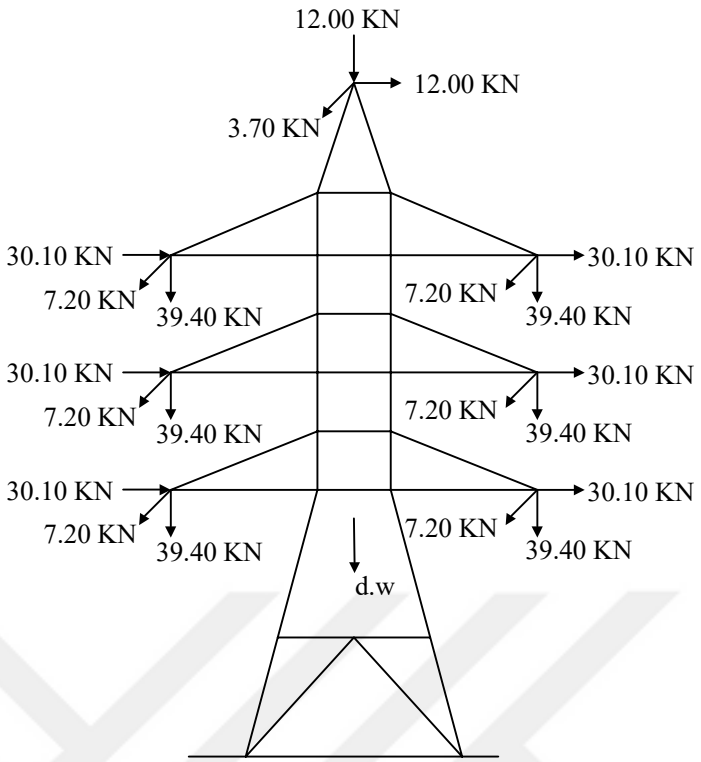

Load case description: 1.MAXIMUM ANGLE DRAWING
Case #: 13



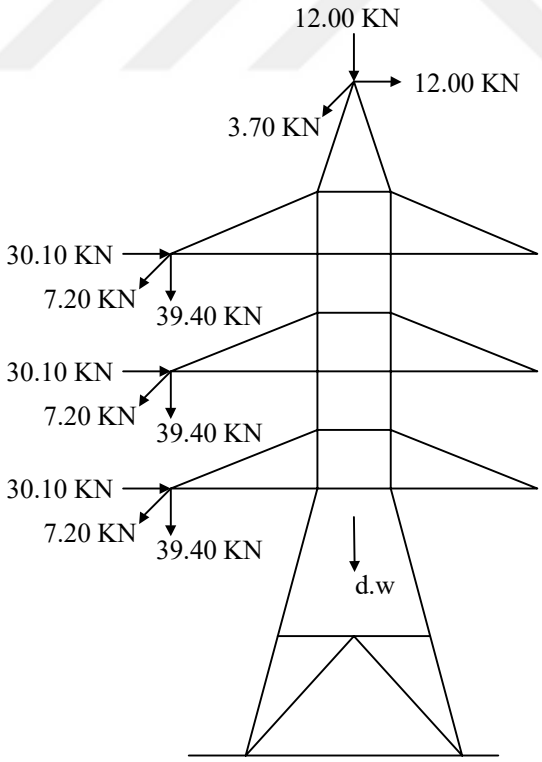

Load case description: 2.MAXIMUM ANGLE DRAWING
Case #: 14

| Desig. | Ref. | Description | Verif. | ESOGU |
|---|---|---|---|---|
| Appendix 1: 07 | Scale: | Comments: 154 kv | | |
| Title: Transmission tower | Review: | | | |
| Date: 29.12.2019 | Student: Loai Morshid | | | |
| Supervisor: DR. ÖĞR. ÜYESİ UĞUR ALBAYRAK | | | | |

# Load cases of Transmission Tower



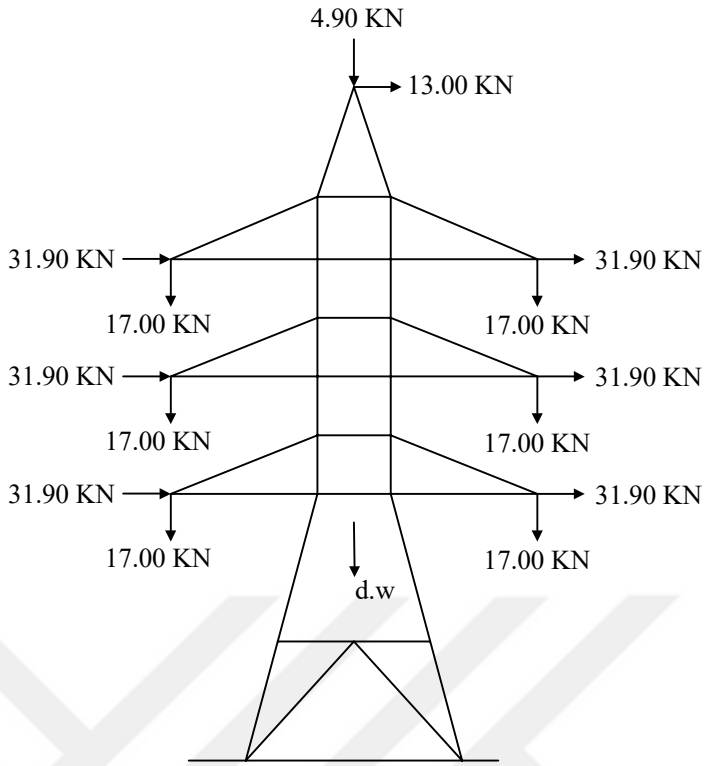

Load case description: 1.UNBALANCED ICING
Case #: 15



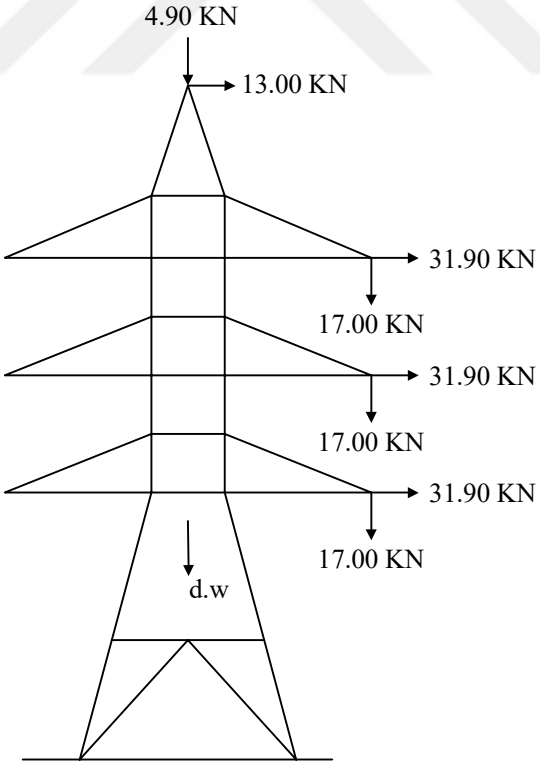

Load case description: 2.UNBALANCED ICING
Case #: 16

| Desig. | Ref. | Description | Verif. | ESOGU |
|---|---|---|---|---|
| Appendix 1: 08 | Scale: | Comments: 154 kv | | |
| Title: Transmission tower | Review: | | | |
| Date: 29.12.2019 | Student: Loai Morshid | | | |
| Supervisor: DR. ÖĞR. ÜYESİ UĞUR ALBAYRAK | | | | |

# Load cases of Transmission Tower



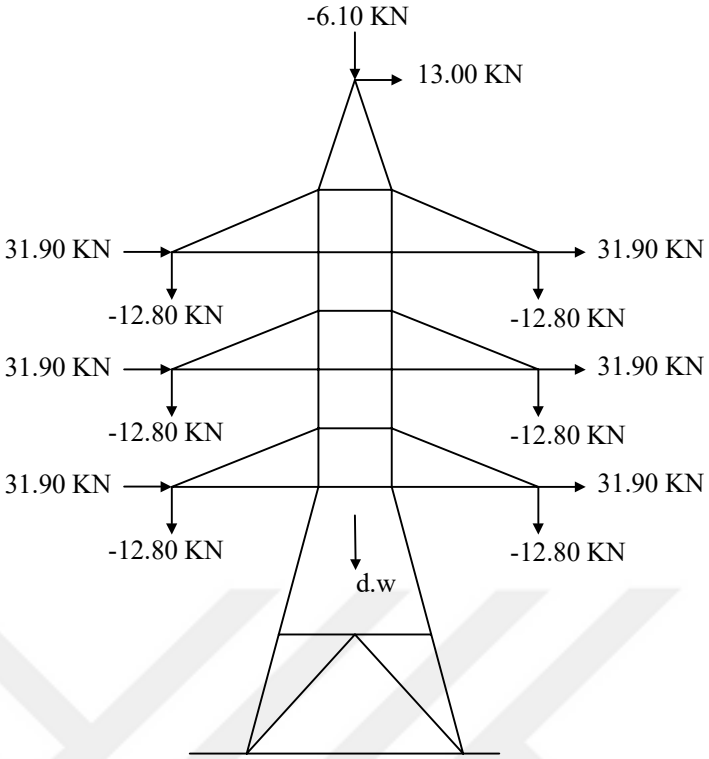

Load case description: 1.DOWN OPENING
Case #: 17



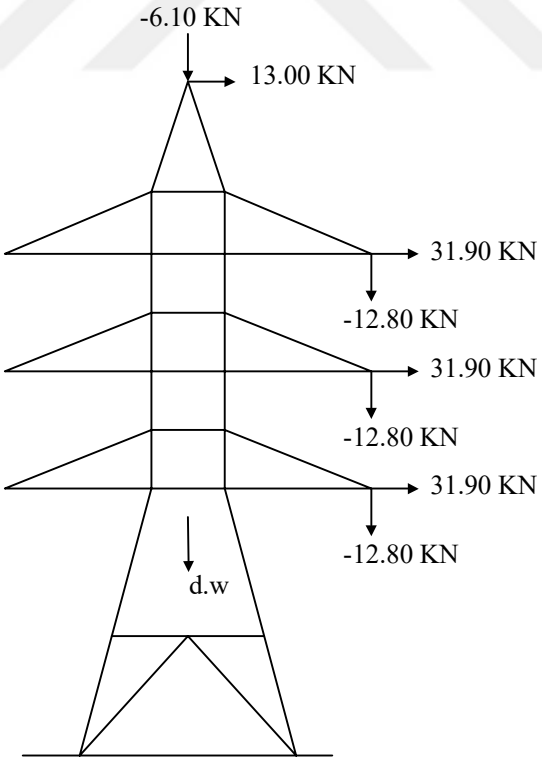

Load case description: 2.DOWN OPENING
Case #: 18

| Desig. | Ref. | Description | Verif. | ESOGU |
|---|---|---|---|---|
| Appendix 1: 09 | Scale: | Comments: 154 kv | | |
| Title: Transmission tower | Review: | | | |
| Date: 29.12.2019 | Student: Loai Morshid | | | |
| Supervisor: DR. ÖĞR. ÜYESİ UĞUR ALBAYRAK | | | | |

# Load cases of Transmission Tower




Load case description: NET UP LIFTING OPENING
Case #: 19




Load case description: DOWN OPENING
Case #: 20

| Desig. | Ref. | Description | Verif. | ESOGU |
|---|---|---|---|---|
| Appendix 1: 10 | Scale: | Comments: 154 kv | | |
| Title: Transmission tower | Review: | | | |
| Date: 29.12.2019 | Student: Loai Morshid | | | |
| Supervisor: DR. ÖĞR. ÜYESİ UĞUR ALBAYRAK | | | | |

# APPENDIX-B

## Table of calculation of quantities of steel materials in Tower

Here we displayed all the sections weight of the three models as Tedaş, ASCE10-97 and Eurocode 3-2005.

### A2.1 The tower model with the sections form Tedas

| Quantity | Mark | Description | Length | Grade | Part weight | Total weight |
|---|---|---|---|---|---|---|
| | | | (mm) | | Kilogram | Kilogram |
| 16 | **B1** | L35X4 | 567 | S355 | 1 | 19 |
| 16 | **B2** | L35X4 | 1.402 | S355 | 3 | 47 |
| 16 | **B3** | L40X4 | 641 | S355 | 2 | 25 |
| 14 | **B4** | L100X8 | 3.207 | S355 | 39 | 548 |
| 14 | **B5** | L40X4 | 722 | S355 | 2 | 24 |
| 8 | **B6** | L100X10 | 3.340 | S355 | 50 | 404 |
| 8 | **B7** | L100X10 | 2.837 | S355 | 43 | 343 |
| 8 | **B8** | L100X10 | 2.637 | S355 | 40 | 319 |
| 8 | **B9** | L100X10 | 2.713 | S355 | 41 | 328 |
| 8 | **B10** | L100X10 | 2.400 | S355 | 36 | 290 |
| 8 | **B11** | L100X12 | 2.334 | S355 | 42 | 332 |
| 8 | **B12** | L100X8 | 3.625 | S355 | 44 | 354 |
| 8 | **B13** | L100X8 | 3.626 | S355 | 44 | 354 |
| 8 | **B14** | L120X11 | 2.223 | S355 | 44 | 354 |
| 8 | **B15** | L120X11 | 2.803 | S355 | 56 | 446 |
| 8 | **B16** | L35X4 | 1.651 | S355 | 3 | 28 |
| 8 | **B17** | L35X4 | 500 | S355 | 1 | 8 |
| 8 | **B18** | L35X4 | 1.356 | S355 | 3 | 23 |
| 8 | **B19** | L35X4 | 1.167 | S355 | 2 | 20 |
| 8 | **B20** | L35X4 | 848 | S355 | 2 | 14 |
| 8 | **B21** | L35X4 | 792 | S355 | 2 | 13 |
| 8 | **B22** | L35X4 | 1.494 | S355 | 3 | 25 |
| 8 | **B23** | L35X4 | 1.082 | S355 | 2 | 18 |
| 8 | **B24** | L35X4 | 544 | S355 | 1 | 9 |

| Quantity | Mark | Description | Length | Grade | Part weight | Total weight |
|---|---|---|---|---|---|---|
| | | | (mm) | | Kilogram | Kilogram |
| 8 | **B25** | L35X4 | 1.200 | S355 | 3 | 20 |
| 8 | **B26** | L35X4 | 751 | S355 | 2 | 13 |
| 8 | **B27** | L35X4 | 1.560 | S355 | 3 | 26 |
| 8 | **B28** | L35X4 | 1.176 | S355 | 2 | 20 |
| 8 | **B29** | L35X4 | 1.461 | S355 | 3 | 25 |
| 8 | **B30** | L35X4 | 1.319 | S355 | 3 | 22 |
| 8 | **B31** | L35X4 | 878 | S355 | 2 | 15 |
| 8 | **B32** | L40X4 | 615 | S355 | 1 | 12 |

The tower model with the sections from Tedas (continued)

| | | | | | | |
|---|---|---|---|---|---|---|
| 8 | **B33** | L40X4 | 817 | S355 | 2 | 16 |
| 8 | **B34** | L45X4 | 1.089 | S355 | 3 | 24 |
| 8 | **B35** | L80x7 | 3.199 | S355 | 27 | 218 |
| 8 | **B36** | L80x7 | 462 | S355 | 4 | 31 |
| 8 | **B37** | L80x7 | 1.449 | S355 | 12 | 99 |
| 8 | **B38** | L80x7 | 923 | S355 | 8 | 63 |
| 8 | **B39** | L80x7 | 1.769 | S355 | 15 | 121 |
| 8 | **B40** | L80x7 | 1.224 | S355 | 10 | 84 |
| 8 | **B41** | L80x7 | 1.385 | S355 | 12 | 94 |
| 7 | **B42** | L100X10 | 5.009 | S355 | 76 | 529 |
| 7 | **B43** | L35X4 | 1.244 | S355 | 3 | 18 |
| 7 | **B44** | L35X4 | 1.652 | S355 | 3 | 24 |
| 7 | **B45** | L45X4 | 1.231 | S355 | 3 | 24 |
| 4 | **B46** | L100X8 | 1.725 | S355 | 21 | 84 |
| 4 | **B47** | L120X11 | 1.301 | S355 | 26 | 104 |
| 4 | **B48** | L120X11 | 1.201 | S355 | 24 | 96 |
| 4 | **B49** | L150X14 | 4.155 | S355 | 131 | 525 |
| 4 | **B50** | L150X14 | 1.952 | S355 | 62 | 247 |
| 4 | **B51** | L150X14 | 1.301 | S355 | 41 | 165 |
| 4 | **B52** | L180X16 | 4.695 | S355 | 204 | 817 |
| 4 | **B53** | L180X18 | 5.306 | S355 | 258 | 1.032 |

| Quantity | Mark | Description | Length | Grade | Part weight | Total weight |
|---|---|---|---|---|---|---|
| | | | (mm) | | Kilogram | Kilogram |
| 4 | **B54** | L200X18 | 5.997 | S355 | 326 | 1.302 |
| 4 | **B55** | L200X20 | 4.595 | S355 | 275 | 1.101 |
| 4 | **B56** | L200X20 | 3.184 | S355 | 191 | 763 |
| 4 | **B57** | L35X4 | 457 | S355 | 1 | 4 |
| 4 | **B58** | L35X4 | 1.696 | S355 | 4 | 14 |
| 4 | **B59** | L35X4 | 1.221 | S355 | 3 | 10 |
| 4 | **B60** | L35X4 | 868 | S355 | 2 | 7 |
| 4 | **B61** | L35X4 | 651 | S355 | 1 | 5 |
| 4 | **B62** | L35X4 | 601 | S355 | 1 | 5 |
| 4 | **B63** | L35X4 | 1.276 | S355 | 3 | 11 |
| 4 | **B64** | L35X4 | 1.429 | S355 | 3 | 12 |
| 4 | **B65** | L40X4 | 913 | S355 | 2 | 9 |
| 4 | **B66** | L40X4 | 802 | S355 | 2 | 8 |
| 4 | **B67** | L40X4 | 707 | S355 | 2 | 7 |
| 4 | **B68** | L45X4 | 1.155 | S355 | 3 | 13 |
| 4 | **B69** | L45X4 | 2.043 | S355 | 6 | 22 |
| 4 | **B70** | L45X4 | 1.022 | S355 | 3 | 11 |
| 4 | **B71** | L45X4 | 907 | S355 | 2 | 10 |
| 4 | **B72** | L50X4 | 2.611 | S355 | 8 | 32 |
| 4 | **B73** | L50X4 | 2.310 | S355 | 7 | 28 |
| 4 | **B74** | L50X4 | 1.814 | S355 | 6 | 22 |
| 4 | **B75** | L50X5 | 1.852 | S355 | 7 | 28 |
| 4 | **B76** | L50X5 | 1.605 | S355 | 6 | 24 |
| 4 | **B77** | L50X5 | 1.414 | S355 | 5 | 21 |
| 4 | **B78** | L60X5 | 1.275 | S355 | 6 | 23 |
| 4 | **B79** | L60X5 | 2.490 | S355 | 11 | 46 |
| 4 | **B80** | L60X5 | 2.550 | S355 | 12 | 47 |
| 4 | **B81** | L60X5 | 2.270 | S355 | 10 | 41 |

The tower model with the sections from Tedas (continued)

| | | | | | | |
|---|---|---|---|---|---|---|
| 4 | **B82** | L60X5 | 2.890 | S355 | 13 | 53 |

| Quantity | Mark | Description | Length | Grade | Part weight | Total weight |
|---|---|---|---|---|---|---|
| | | | (mm) | | Kilogram | Kilogram |
| 4 | **B83** | L60X5 | 3.692 | S355 | 17 | 67 |
| 4 | **B84** | L65X7 | 2.349 | S355 | 16 | 64 |
| 4 | **B85** | L65X7 | 2.593 | S355 | 18 | 71 |
| 4 | **B86** | L65X7 | 1.180 | S355 | 8 | 32 |
| 4 | **B87** | L70X6 | 2.566 | S355 | 16 | 65 |
| 4 | **B88** | L70X6 | 3.266 | S355 | 21 | 83 |
| 4 | **B89** | L70X7 | 2.126 | S355 | 16 | 63 |
| 4 | **B90** | L80X10 | 2.153 | S355 | 26 | 102 |
| 4 | **B91** | L80X10 | 1.913 | S355 | 23 | 91 |
| 4 | **B92** | L80x7 | 2.219 | S355 | 19 | 76 |
| 4 | **B93** | L80x7 | 2.000 | S355 | 17 | 68 |
| 3 | **B94** | L45X4 | 1.305 | S355 | 4 | 11 |
| 2 | **B95** | L100X10 | 722 | S355 | 11 | 22 |
| 2 | **B96** | L100X10 | 3.325 | S355 | 50 | 100 |
| 2 | **B97** | L100X10 | 3.327 | S355 | 50 | 100 |
| 2 | **B98** | L100X10 | 300 | S355 | 5 | 9 |
| 2 | **B99** | L100X10 | 3.207 | S355 | 48 | 97 |
| 2 | **B100** | L100X8 | 1.638 | S355 | 20 | 40 |
| 2 | **B101** | L35X4 | 1.391 | S355 | 3 | 6 |
| 2 | **B102** | L35X4 | 434 | S355 | 1 | 2 |
| 2 | **B103** | L45X4 | 1.150 | S355 | 3 | 6 |
| 2 | **B104** | L50X4 | 1.135 | S355 | 3 | 7 |
| 2 | **B105** | L50X4 | 1.000 | S355 | 3 | 6 |
| 2 | **B106** | L50X5 | 1.370 | S355 | 5 | 10 |
| 2 | **B107** | L50X5 | 1.633 | S355 | 6 | 12 |
| 2 | **B108** | L50X5 | 1.445 | S355 | 5 | 11 |
| 2 | **B109** | L50X5 | 1.283 | S355 | 5 | 10 |
| 2 | **B110** | L50X5 | 1.391 | S355 | 5 | 10 |
| 2 | **B111** | L50X5 | 2.052 | S355 | 8 | 15 |

| Quantity | Mark | Description | Length | Grade | Part weight | Total weight |
|---|---|---|---|---|---|---|
| | | | (mm) | | Kilogram | Kilogram |
| 2 | **B112** | L50X5 | 1.937 | S355 | 7 | 15 |
| 2 | **B113** | L60X5 | 1.559 | S355 | 7 | 14 |
| 2 | **B114** | L60X5 | 875 | S355 | 4 | 8 |
| 2 | **B115** | L60X5 | 1.155 | S355 | 5 | 11 |
| 2 | **B116** | L60X5 | 1.642 | S355 | 8 | 15 |
| 2 | **B117** | L60X5 | 835 | S355 | 4 | 8 |
| 2 | **B118** | L60X5 | 1.638 | S355 | 7 | 15 |
| 2 | **B119** | L60X5 | 1.846 | S355 | 8 | 17 |
| 2 | **B120** | L60X5 | 434 | S355 | 2 | 4 |
| 2 | **B121** | L60X5 | 2.705 | S355 | 12 | 25 |
| 2 | **B122** | L65X7 | 1.528 | S355 | 10 | 21 |
| 2 | **B123** | L65X7 | 1.058 | S355 | 7 | 14 |
| 2 | **B124** | L65X7 | 1.477 | S355 | 10 | 20 |

The tower model with the sections from Tedas (continued)

| | | | | | | |
|---|---|---|---|---|---|---|
| 2 | **B125** | L65X7 | 1.949 | S355 | 13 | 27 |
| 2 | **B126** | L65X7 | 1.106 | S355 | 8 | 15 |
| 2 | **B127** | L65X7 | 1.451 | S355 | 10 | 20 |
| 2 | **B128** | L65X7 | 1.250 | S355 | 9 | 17 |
| 2 | **B129** | L65X7 | 1.192 | S355 | 8 | 16 |
| 2 | **B130** | L65X7 | 1.116 | S355 | 8 | 15 |
| 2 | **B131** | L65X7 | 2.440 | S355 | 17 | 33 |
| 2 | **B132** | L65X7 | 2.317 | S355 | 16 | 32 |
| 2 | **B133** | L70X6 | 3.603 | S355 | 23 | 46 |
| 2 | **B134** | L70X6 | 1.056 | S355 | 7 | 13 |
| 2 | **B135** | L70X6 | 1.160 | S355 | 7 | 15 |
| 2 | **B136** | L70X6 | 3.602 | S355 | 23 | 46 |
| 2 | **B137** | L80X10 | 300 | S355 | 4 | 7 |
| 2 | **B138** | L80x7 | 300 | S355 | 3 | 5 |
| 2 | **B139** | L80x7 | 1.879 | S355 | 16 | 32 |
| 2 | **B140** | L80x7 | 1.450 | S355 | 12 | 25 |

| Quantity | Mark | Description | Length | Grade | Part weight | Total weight |
|---|---|---|---|---|---|---|
| | | | (mm) | | Kilogram | Kilogram |
| 2 | **B141** | L80x7 | 1.370 | S355 | 12 | 23 |
| 1 | **B142** | L100X10 | 1.652 | S355 | 25 | 25 |
| 1 | **B143** | L100X10 | 1.231 | S355 | 19 | 19 |
| 1 | **B144** | L100X10 | 1.305 | S355 | 20 | 20 |
| 1 | **B145** | L130X12 | 5.009 | S355 | 118 | 118 |
| 1 | **B146** | L45X4 | 1.244 | S355 | 3 | 3 |
| 1 | **B147** | L50X5 | 1.843 | S355 | 7 | 7 |
| 1 | **B148** | L50X5 | 1.841 | S355 | 7 | 7 |
| 1 | **B149** | L60X5 | 746 | S355 | 3 | 3 |
| 1 | **B150** | L60X5 | 775 | S355 | 4 | 4 |
| 1 | **B151** | L65X7 | 1.263 | S355 | 9 | 9 |
| 1 | **B152** | L65X7 | 1.264 | S355 | 9 | 9 |
| 1 | **B153** | L65X7 | 775 | S355 | 5 | 5 |
| 1 | **B154** | L65X7 | 746 | S355 | 5 | 5 |
| 1 | **B155** | L65X7 | 1.841 | S355 | 13 | 13 |
| 1 | **B156** | L65X7 | 1.843 | S355 | 13 | 13 |
| | | **TOTAL QUANTITY** | | 696 | | |
| | | **TOTAL WEIGHT** | | 14,682 | Kilogram | |

## A2.2 The tower model with new angle sections using ASCE 10-97

| Quantity | Mark | Description | Length (mm) | Grade | Part weight kilogram | Total weight kilogram |
|---|---|---|---|---|---|---|
| 16 | **B1** | L35X4 | 722 | S355 | 2 | 24 |
| 16 | **B2** | L35X4 | 641 | S355 | 1 | 22 |
| 16 | **B3** | L35X4 | 567 | S355 | 1 | 19 |
| 14 | **B4** | L40X4 | 1.402 | S355 | 3 | 47 |
| 10 | **B5** | L100X8 | 3.207 | S355 | 39 | 391 |
| 8 | **B6** | L150X14 | 5.009 | S355 | 158 | 1.266 |
| 8 | **B7** | L35X4 | 1.224 | S355 | 3 | 21 |
| 8 | **B8** | L35X4 | 1.176 | S355 | 2 | 20 |
| 8 | **B9** | L35X4 | 1.082 | S355 | 2 | 18 |
| 8 | **B10** | L35X4 | 544 | S355 | 1 | 9 |
| 8 | **B11** | L35X4 | 817 | S355 | 2 | 14 |
| 8 | **B12** | L35X4 | 1.319 | S355 | 3 | 22 |
| 8 | **B13** | L35X4 | 792 | S355 | 2 | 13 |
| 8 | **B14** | L35X4 | 500 | S355 | 1 | 8 |
| 8 | **B15** | L35X4 | 848 | S355 | 2 | 14 |
| 8 | **B16** | L35X4 | 878 | S355 | 2 | 15 |
| 8 | **B17** | L35X4 | 462 | S355 | 1 | 8 |
| 8 | **B18** | L35X4 | 923 | S355 | 2 | 16 |
| 8 | **B19** | L35X4 | 615 | S355 | 1 | 10 |
| 8 | **B20** | L35X4 | 1.244 | S355 | 3 | 21 |
| 8 | **B21** | L35X4 | 1.167 | S355 | 2 | 20 |
| 8 | **B22** | L35X4 | 1.200 | S355 | 3 | 20 |
| 8 | **B23** | L35X4 | 751 | S355 | 2 | 13 |
| 8 | **B24** | L45X4 | 1.652 | S355 | 5 | 36 |

| Quantity | Mark | Description | Length (mm) | Grade | Part weight kilogram | Total weight kilogram |
|---|---|---|---|---|---|---|
| 7 | **B25** | L50X4 | 1.385 | S355 | 4 | 30 |
| 6 | **B26** | L40X4 | 1.449 | S355 | 4 | 21 |
| 6 | **B27** | L40X4 | 1.089 | S355 | 3 | 16 |
| 6 | **B28** | L40X4 | 1.356 | S355 | 3 | 20 |
| 6 | **B29** | L40X4 | 1.494 | S355 | 4 | 22 |
| 6 | **B30** | L40X4 | 1.461 | S355 | 4 | 21 |
| 6 | **B31** | L45X4 | 1.231 | S355 | 3 | 20 |
| 6 | **B32** | L45X4 | 1.651 | S355 | 5 | 27 |
| 6 | **B33** | L45X4 | 1.560 | S355 | 4 | 26 |
| 6 | **B34** | L50X4 | 1.769 | S355 | 5 | 32 |
| 6 | **B35** | L80X10 | 300 | S355 | 4 | 21 |
| 4 | **B36** | L100X8 | 3.199 | S355 | 39 | 156 |
| 4 | **B37** | L100X8 | 2.611 | S355 | 32 | 127 |
| 4 | **B38** | L100X8 | 3.626 | S355 | 44 | 177 |
| 4 | **B39** | L130X12 | 3.340 | S355 | 79 | 315 |
| 4 | **B40** | L130X12 | 3.207 | S355 | 76 | 303 |
| 4 | **B41** | L35X4 | 913 | S355 | 2 | 8 |
| 4 | **B42** | L35X4 | 457 | S355 | 1 | 4 |
| 4 | **B43** | L35X4 | 1.221 | S355 | 3 | 10 |
| 4 | **B44** | L35X4 | 1.180 | S355 | 2 | 10 |
| 4 | **B45** | L35X4 | 434 | S355 | 1 | 4 |
| 4 | **B46** | L35X4 | 868 | S355 | 2 | 7 |

The tower model with new angle sections using ASCE 10-97 (continued)

| | | | | | | |
|---|---|---|---|---|---|---|
| 4 | **B47** | L35X4 | 601 | S355 | 1 | 5 |
| 4 | **B48** | L35X4 | 651 | S355 | 1 | 5 |
| 4 | **B49** | L35X4 | 907 | S355 | 2 | 8 |
| 4 | **B50** | L35X4 | 802 | S355 | 2 | 7 |
| 4 | **B51** | L35X4 | 707 | S355 | 1 | 6 |
| 4 | **B52** | L40X4 | 1.429 | S355 | 3 | 14 |
| 4 | **B53** | L40X4 | 1.022 | S355 | 2 | 10 |

| Quantity | Mark | Description | Length | Grade | Part weight | Total weight |
|---|---|---|---|---|---|---|
| | | | (mm) | | kilogram | kilogram |
| 4 | **B54** | L40X4 | 1.391 | S355 | 3 | 13 |
| 4 | **B55** | L45X4 | 1.155 | S355 | 3 | 13 |
| 4 | **B56** | L50X4 | 1.305 | S355 | 4 | 16 |
| 4 | **B57** | L60X5 | 1.605 | S355 | 7 | 29 |
| 4 | **B58** | L65X7 | 1.814 | S355 | 12 | 50 |
| 4 | **B59** | L75X6 | 2.043 | S355 | 14 | 56 |
| 3 | **B60** | L100X8 | 2.310 | S355 | 28 | 85 |
| 3 | **B61** | L100X8 | 3.625 | S355 | 44 | 133 |
| 3 | **B62** | L100X8 | 1.301 | S355 | 16 | 48 |
| 3 | **B63** | L130X12 | 3.626 | S355 | 86 | 257 |
| 3 | **B64** | L130X12 | 3.625 | S355 | 86 | 257 |
| 3 | **B65** | L150X14 | 2.593 | S355 | 82 | 246 |
| 3 | **B66** | L35X4 | 1.276 | S355 | 3 | 8 |
| 3 | **B67** | L60X5 | 1.852 | S355 | 8 | 25 |
| 3 | **B68** | L60X5 | 1.451 | S355 | 7 | 20 |
| 3 | **B69** | L60X5 | 2.890 | S355 | 13 | 40 |
| 3 | **B70** | L60X5 | 3.266 | S355 | 15 | 45 |
| 3 | **B71** | L80x7 | 1.301 | S355 | 11 | 33 |
| 2 | **B72** | L100X10 | 3.199 | S355 | 48 | 97 |
| 2 | **B73** | L100X10 | 2.637 | S355 | 40 | 80 |
| 2 | **B74** | L100X10 | 3.625 | S355 | 55 | 109 |
| 2 | **B75** | L100X10 | 2.400 | S355 | 36 | 72 |
| 2 | **B76** | L100X12 | 3.207 | S355 | 57 | 114 |
| 2 | **B77** | L100X8 | 3.340 | S355 | 41 | 82 |
| 2 | **B78** | L100X8 | 2.837 | S355 | 35 | 69 |
| 2 | **B79** | L100X8 | 2.713 | S355 | 33 | 66 |
| 2 | **B80** | L100X8 | 2.637 | S355 | 32 | 64 |
| 2 | **B81** | L100X8 | 2.223 | S355 | 27 | 54 |
| 2 | **B82** | L100X8 | 2.440 | S355 | 30 | 60 |

| Quantity | Mark | Description | Length | Grade | Part weight | Total weight |
|---|---|---|---|---|---|---|
| | | | (mm) | | kilogram | kilogram |
| 2 | **B83** | L100X8 | 2.334 | S355 | 28 | 57 |
| 2 | **B84** | L100X8 | 2.317 | S355 | 28 | 57 |
| 2 | **B85** | L130X12 | 3.327 | S355 | 79 | 157 |
| 2 | **B86** | L130X12 | 2.490 | S355 | 59 | 118 |
| 2 | **B87** | L150X14 | 2.153 | S355 | 68 | 136 |
| 2 | **B88** | L150X14 | 2.219 | S355 | 70 | 140 |
| 2 | **B89** | L150X14 | 3.184 | S355 | 101 | 201 |
| 2 | **B90** | L150X14 | 3.602 | S355 | 114 | 228 |
| 2 | **B91** | L150X14 | 5.996 | S355 | 189 | 379 |
| 2 | **B92** | L150X14 | 5.306 | S355 | 168 | 335 |

The tower model with new angle sections using ASCE 10-97 (continued)

| | | | | | | |
|---|---|---|---|---|---|---|
| 2 | **B93** | L180X16 | 3.325 | S355 | 145 | 289 |
| 2 | **B94** | L180X16 | 4.155 | S355 | 181 | 361 |
| 2 | **B95** | L180X18 | 4.695 | S355 | 228 | 456 |
| 2 | **B96** | L200X24 | 4.595 | S355 | 327 | 653 |
| 2 | **B97** | L200X24 | 3.184 | S355 | 226 | 453 |
| 2 | **B98** | L200X24 | 5.997 | S355 | 426 | 853 |
| 2 | **B99** | L35X4 | 1.696 | S355 | 4 | 7 |
| 2 | **B100** | L35X4 | 875 | S355 | 2 | 4 |
| 2 | **B101** | L35X4 | 1.449 | S355 | 3 | 6 |
| 2 | **B102** | L35X4 | 1.231 | S355 | 3 | 5 |
| 2 | **B103** | L35X4 | 1.769 | S355 | 4 | 7 |
| 2 | **B104** | L35X4 | 1.494 | S355 | 3 | 6 |
| 2 | **B105** | L35X4 | 1.461 | S355 | 3 | 6 |
| 2 | **B106** | L35X4 | 1.651 | S355 | 3 | 7 |
| 2 | **B107** | L35X4 | 1.560 | S355 | 3 | 7 |
| 2 | **B108** | L35X4 | 1.356 | S355 | 3 | 6 |
| 2 | **B109** | L35X4 | 1.089 | S355 | 2 | 5 |
| 2 | **B110** | L35X4 | 1.402 | S355 | 3 | 6 |
| 2 | **B111** | L40X4 | 746 | S355 | 2 | 4 |

| Quantity | Mark | Description | Length | Grade | Part weight | Total weight |
|---|---|---|---|---|---|---|
| | | | (mm) | | kilogram | kilogram |
| 2 | **B112** | L40X4 | 1.000 | S355 | 2 | 5 |
| 2 | **B113** | L45X4 | 1.192 | S355 | 3 | 7 |
| 2 | **B114** | L45X4 | 775 | S355 | 2 | 4 |
| 2 | **B115** | L45X4 | 1.642 | S355 | 4 | 9 |
| 2 | **B116** | L45X4 | 1.135 | S355 | 3 | 6 |
| 2 | **B117** | L45X4 | 1.250 | S355 | 3 | 7 |
| 2 | **B118** | L45X4 | 1.528 | S355 | 4 | 8 |
| 2 | **B119** | L50X4 | 1.696 | S355 | 5 | 10 |
| 2 | **B120** | L50X4 | 1.370 | S355 | 4 | 8 |
| 2 | **B121** | L50X4 | 1.283 | S355 | 4 | 8 |
| 2 | **B122** | L50X4 | 1.843 | S355 | 6 | 11 |
| 2 | **B123** | L50X5 | 2.566 | S355 | 10 | 19 |
| 2 | **B124** | L60X5 | 1.559 | S355 | 7 | 14 |
| 2 | **B125** | L60X5 | 1.949 | S355 | 9 | 18 |
| 2 | **B126** | L60X5 | 1.638 | S355 | 7 | 15 |
| 2 | **B127** | L60X5 | 3.692 | S355 | 17 | 34 |
| 2 | **B128** | L60X5 | 1.633 | S355 | 7 | 15 |
| 2 | **B129** | L60X5 | 1.445 | S355 | 7 | 13 |
| 2 | **B130** | L60X5 | 1.477 | S355 | 7 | 13 |
| 2 | **B131** | L65X7 | 1.275 | S355 | 9 | 17 |
| 2 | **B132** | L65X7 | 1.056 | S355 | 7 | 14 |
| 2 | **B133** | L65X7 | 1.725 | S355 | 12 | 24 |
| 2 | **B134** | L65X7 | 2.550 | S355 | 17 | 35 |
| 2 | **B135** | L65X7 | 2.270 | S355 | 16 | 31 |
| 2 | **B136** | L65X7 | 2.566 | S355 | 18 | 35 |
| 2 | **B137** | L65X7 | 3.692 | S355 | 25 | 50 |
| 2 | **B138** | L65X7 | 1.846 | S355 | 13 | 25 |
| 2 | **B139** | L65X7 | 1.414 | S355 | 10 | 19 |
| 2 | **B140** | L65X7 | 1.841 | S355 | 13 | 25 |

The tower model with new angle sections using ASCE 10-97 (continued)

| Quantity | Mark | Description | Length | Grade | Part weight | Total weight |
|---|---|---|---|---|---|---|
| | | | (mm) | | kilogram | kilogram |
| 2 | **B141** | L65X7 | 1.201 | S355 | 8 | 16 |
| 2 | **B142** | L70X6 | 1.937 | S355 | 12 | 25 |
| 2 | **B143** | L75X6 | 2.052 | S355 | 14 | 28 |
| 2 | **B144** | L80X10 | 2.153 | S355 | 26 | 51 |
| 2 | **B145** | L80X10 | 2.223 | S355 | 26 | 53 |
| 2 | **B146** | L80X10 | 2.803 | S355 | 33 | 67 |
| 2 | **B147** | L80x7 | 2.126 | S355 | 18 | 36 |
| 2 | **B148** | L80x7 | 1.058 | S355 | 9 | 18 |
| 2 | **B149** | L80x7 | 1.414 | S355 | 12 | 24 |
| 2 | **B150** | L80x7 | 2.223 | S355 | 19 | 38 |
| 2 | **B151** | L80x7 | 2.334 | S355 | 20 | 40 |
| 2 | **B152** | L80x7 | 2.400 | S355 | 20 | 41 |
| 2 | **B153** | L80x7 | 2.803 | S355 | 24 | 48 |
| 1 | **B154** | L100X10 | 2.349 | S355 | 35 | 35 |
| 1 | **B155** | L100X10 | 2.219 | S355 | 34 | 34 |
| 1 | **B156** | L100X10 | 2.000 | S355 | 30 | 30 |
| 1 | **B157** | L100X10 | 2.334 | S355 | 35 | 35 |
| 1 | **B158** | L100X10 | 2.223 | S355 | 34 | 34 |
| 1 | **B159** | L100X10 | 3.626 | S355 | 55 | 55 |
| 1 | **B160** | L100X10 | 2.713 | S355 | 41 | 41 |
| 1 | **B161** | L100X10 | 2.837 | S355 | 43 | 43 |
| 1 | **B162** | L100X10 | 2.705 | S355 | 41 | 41 |
| 1 | **B163** | L100X12 | 1.952 | S355 | 35 | 35 |
| 1 | **B164** | L100X12 | 4.155 | S355 | 74 | 74 |
| 1 | **B165** | L100X12 | 2.837 | S355 | 51 | 51 |
| 1 | **B166** | L100X12 | 2.713 | S355 | 48 | 48 |
| 1 | **B167** | L100X12 | 2.400 | S355 | 43 | 43 |
| 1 | **B168** | L100X12 | 2.223 | S355 | 40 | 40 |
| 1 | **B169** | L100X12 | 1.301 | S355 | 23 | 23 |

| Quantity | Mark | Description | Length | Grade | Part weight | Total weight |
|---|---|---|---|---|---|---|
| | | | (mm) | | kilogram | kilogram |
| 1 | **B170** | L100X8 | 1.913 | S355 | 23 | 23 |
| 1 | **B171** | L100X8 | 3.603 | S355 | 44 | 44 |
| 1 | **B172** | L100X8 | 1.952 | S355 | 24 | 24 |
| 1 | **B173** | L100X8 | 2.400 | S355 | 29 | 29 |
| 1 | **B174** | L100X8 | 2.705 | S355 | 33 | 33 |
| 1 | **B175** | L100X8 | 2.803 | S355 | 34 | 34 |
| 1 | **B176** | L120X11 | 4.695 | S355 | 93 | 93 |
| 1 | **B177** | L130X12 | 3.199 | S355 | 75 | 75 |
| 1 | **B178** | L130X12 | 2.349 | S355 | 55 | 55 |
| 1 | **B179** | L130X12 | 4.155 | S355 | 98 | 98 |
| 1 | **B180** | L130X12 | 2.837 | S355 | 67 | 67 |
| 1 | **B181** | L130X12 | 2.713 | S355 | 64 | 64 |
| 1 | **B182** | L130X12 | 2.637 | S355 | 62 | 62 |
| 1 | **B183** | L130X12 | 2.334 | S355 | 55 | 55 |
| 1 | **B184** | L150X14 | 3.340 | S355 | 106 | 106 |
| 1 | **B185** | L150X14 | 4.595 | S355 | 145 | 145 |
| 1 | **B186** | L150X14 | 4.695 | S355 | 148 | 148 |
| 1 | **B187** | L150X14 | 1.952 | S355 | 62 | 62 |

The tower model with new angle sections using ASCE 10-97 (continued)

| | | | | | | |
|---|---|---|---|---|---|---|
| 1 | **B188** | L150X14 | 1.301 | S355 | 41 | 41 |
| 1 | **B189** | L180X16 | 4.595 | S355 | 200 | 200 |
| 1 | **B190** | L200X18 | 5.306 | S355 | 288 | 288 |
| 1 | **B191** | L200X20 | 5.306 | S355 | 318 | 318 |
| 1 | **B192** | L250X24 | 2.593 | S355 | 233 | 233 |
| 1 | **B193** | L250X24 | 2.219 | S355 | 200 | 200 |
| 1 | **B194** | L35X4 | 1.160 | S355 | 2 | 2 |
| 1 | **B195** | L35X4 | 835 | S355 | 2 | 2 |
| 1 | **B196** | L35X4 | 1.264 | S355 | 3 | 3 |
| 1 | **B197** | L35X4 | 1.385 | S355 | 3 | 3 |
| 1 | **B198** | L35X4 | 2.310 | S355 | 5 | 5 |

| Quantity | Mark | Description | Length | Grade | Part weight | Total weight |
|---|---|---|---|---|---|---|
| | | | (mm) | | kilogram | kilogram |
| 1 | **B199** | L40X4 | 1.160 | S355 | 3 | 3 |
| 1 | **B200** | L40X4 | 835 | S355 | 2 | 2 |
| 1 | **B201** | L40X4 | 1.276 | S355 | 3 | 3 |
| 1 | **B202** | L40X4 | 1.106 | S355 | 3 | 3 |
| 1 | **B203** | L40X4 | 1.725 | S355 | 4 | 4 |
| 1 | **B204** | L45X4 | 3.199 | S355 | 9 | 9 |
| 1 | **B205** | L45X4 | 1.150 | S355 | 3 | 3 |
| 1 | **B206** | L45X4 | 1.116 | S355 | 3 | 3 |
| 1 | **B207** | L50X4 | 3.266 | S355 | 10 | 10 |
| 1 | **B208** | L50X5 | 1.116 | S355 | 4 | 4 |
| 1 | **B209** | L50X5 | 1.370 | S355 | 5 | 5 |
| 1 | **B210** | L50X5 | 2.270 | S355 | 9 | 9 |
| 1 | **B211** | L50X5 | 1.201 | S355 | 5 | 5 |
| 1 | **B212** | L60X5 | 1.275 | S355 | 6 | 6 |
| 1 | **B213** | L60X5 | 1.150 | S355 | 5 | 5 |
| 1 | **B214** | L60X5 | 1.370 | S355 | 6 | 6 |
| 1 | **B215** | L60X5 | 2.270 | S355 | 10 | 10 |
| 1 | **B216** | L60X5 | 2.550 | S355 | 12 | 12 |
| 1 | **B217** | L60X5 | 2.803 | S355 | 13 | 13 |
| 1 | **B218** | L65X7 | 3.340 | S355 | 23 | 23 |
| 1 | **B219** | L65X7 | 1.852 | S355 | 13 | 13 |
| 1 | **B220** | L65X7 | 1.106 | S355 | 8 | 8 |
| 1 | **B221** | L65X7 | 1.155 | S355 | 8 | 8 |
| 1 | **B222** | L65X7 | 1.879 | S355 | 13 | 13 |
| 1 | **B223** | L65X7 | 1.913 | S355 | 13 | 13 |
| 1 | **B224** | L65X7 | 1.450 | S355 | 10 | 10 |
| 1 | **B225** | L65X7 | 2.890 | S355 | 20 | 20 |
| 1 | **B226** | L65X7 | 2.000 | S355 | 14 | 14 |
| 1 | **B227** | L65X7 | 2.803 | S355 | 19 | 19 |

| Quantity | Mark | Description | Length | Grade | Part weight | Total weight |
|---|---|---|---|---|---|---|
| | | | (mm) | | kilogram | kilogram |
| 1 | **B228** | L70X6 | 1.275 | S355 | 8 | 8 |
| 1 | **B229** | L70X6 | 2.126 | S355 | 14 | 14 |
| 1 | **B230** | L70X6 | 1.879 | S355 | 12 | 12 |
| 1 | **B231** | L70X6 | 1.913 | S355 | 12 | 12 |
| 1 | **B232** | L70X7 | 1.638 | S355 | 12 | 12 |
| 1 | **B233** | L70X7 | 2.400 | S355 | 18 | 18 |

The tower model with new angle sections using ASCE 10-97 (continued)

| | | | | | | |
|---|---|---|---|---|---|---|
| 1 | **B234** | L75X6 | 2.349 | S355 | 16 | 16 |
| 1 | **B235** | L75X6 | 2.490 | S355 | 17 | 17 |
| 1 | **B236** | L75X6 | 2.550 | S355 | 17 | 17 |
| 1 | **B237** | L75X6 | 2.713 | S355 | 19 | 19 |
| 1 | **B238** | L75X6 | 2.837 | S355 | 19 | 19 |
| 1 | **B239** | L75X6 | 2.637 | S355 | 18 | 18 |
| 1 | **B240** | L75X6 | 2.803 | S355 | 19 | 19 |
| 1 | **B241** | L75X6 | 1.201 | S355 | 8 | 8 |
| 1 | **B242** | L80X10 | 2.126 | S355 | 25 | 25 |
| 1 | **B243** | L80X10 | 1.155 | S355 | 14 | 14 |
| 1 | **B244** | L80X10 | 3.603 | S355 | 43 | 43 |
| 1 | **B245** | L80X10 | 2.400 | S355 | 29 | 29 |
| 1 | **B246** | L80X10 | 2.837 | S355 | 34 | 34 |
| 1 | **B247** | L80X10 | 2.637 | S355 | 31 | 31 |
| 1 | **B248** | L80X10 | 2.334 | S355 | 28 | 28 |
| 1 | **B249** | L80X8 | 1.263 | S355 | 12 | 12 |
| 1 | **B250** | L80X8 | 1.913 | S355 | 18 | 18 |
| 1 | **B251** | L80X8 | 1.725 | S355 | 17 | 17 |
| 1 | **B252** | L80X8 | 2.000 | S355 | 19 | 19 |
| 1 | **B253** | L80X8 | 1.952 | S355 | 19 | 19 |
| 1 | **B254** | L80X8 | 2.334 | S355 | 23 | 23 |
| 1 | **B255** | L80X8 | 2.713 | S355 | 26 | 26 |
| 1 | **B256** | L80x7 | 2.349 | S355 | 20 | 20 |

| Quantity | Mark | Description | Length (mm) | Grade | Part weight kilogram | Total weight kilogram |
|---|---|---|---|---|---|---|
| 1 | **B257** | L80x7 | 2.490 | S355 | 21 | 21 |
| 1 | **B258** | L80x7 | 1.638 | S355 | 14 | 14 |
| 1 | **B259** | L80x7 | 2.000 | S355 | 17 | 17 |
| 1 | **B260** | L80x7 | 2.713 | S355 | 23 | 23 |
| 1 | **B261** | L80x7 | 2.837 | S355 | 24 | 24 |
| 1 | **B262** | L80x7 | 2.637 | S355 | 22 | 22 |
| | | **TOTAL QUANTITY** | | 696 | | |
| | | **TOTAL WEIGHT** | | 15, 791 | kilogram | |

## A2.3 The tower model with new angles sections using Eurocode 3-2005

| Quantity | Mark | Description | Length | Grade | Part weight | Total weight |
|---|---|---|---|---|---|---|
| | | | (mm) | | kilogram | kilogram |
| 16 | **B1** | L35X4 | 1.402 | S355 | 3 | 47 |
| 8 | **B2** | L35X4 | 1.231 | S355 | 3 | 21 |
| 8 | **B3** | L35X4 | 1.089 | S355 | 2 | 18 |
| 8 | **B4** | L35X4 | 792 | S355 | 2 | 13 |
| 8 | **B5** | L35X4 | 1.769 | S355 | 4 | 30 |
| 8 | **B6** | L35X4 | 1.494 | S355 | 3 | 25 |
| 8 | **B7** | L35X4 | 751 | S355 | 2 | 13 |
| 8 | **B8** | L35X4 | 1.385 | S355 | 3 | 23 |
| 8 | **B9** | L35X4 | 1.652 | S355 | 3 | 28 |
| 8 | **B10** | L35X4 | 848 | S355 | 2 | 14 |
| 8 | **B11** | L35X4 | 1.449 | S355 | 3 | 24 |
| 8 | **B12** | L40X4 | 567 | S355 | 1 | 11 |
| 8 | **B13** | L60X5 | 722 | S355 | 3 | 26 |
| 7 | **B14** | L35X4 | 878 | S355 | 2 | 13 |
| 6 | **B15** | L40X4 | 722 | S355 | 2 | 10 |
| 6 | **B16** | L40X4 | 641 | S355 | 2 | 9 |
| 6 | **B17** | L50X5 | 567 | S355 | 2 | 13 |
| 6 | **B18** | L60X5 | 641 | S355 | 3 | 18 |
| 4 | **B19** | L100X10 | 3.207 | S355 | 48 | 194 |
| 4 | **B20** | L130X12 | 3.207 | S355 | 76 | 303 |
| 4 | **B21** | L150X14 | 1.301 | S355 | 41 | 165 |
| 4 | **B22** | L35X4 | 913 | S355 | 2 | 8 |
| 4 | **B23** | L35X4 | 923 | S355 | 2 | 8 |
| 4 | **B24** | L35X4 | 1.167 | S355 | 2 | 10 |

| Quantity | Mark | Description | Length | Grade | Part weight | Total weight |
|---|---|---|---|---|---|---|
| | | | (mm) | | kilogram | kilogram |
| 4 | **B25** | L35X4 | 2.611 | S355 | 5 | 22 |
| 4 | **B26** | L35X4 | 1.305 | S355 | 3 | 11 |
| 4 | **B27** | L35X4 | 2.310 | S355 | 5 | 19 |
| 4 | **B28** | L35X4 | 1.155 | S355 | 2 | 10 |
| 4 | **B29** | L35X4 | 2.043 | S355 | 4 | 17 |
| 4 | **B30** | L35X4 | 1.814 | S355 | 4 | 15 |
| 4 | **B31** | L35X4 | 1.022 | S355 | 2 | 9 |
| 4 | **B32** | L35X4 | 907 | S355 | 2 | 8 |
| 4 | **B33** | L35X4 | 802 | S355 | 2 | 7 |
| 4 | **B34** | L40X4 | 923 | S355 | 2 | 9 |
| 4 | **B35** | L40X4 | 1.356 | S355 | 3 | 13 |
| 4 | **B36** | L40X4 | 1.319 | S355 | 3 | 13 |
| 4 | **B37** | L40X4 | 1.176 | S355 | 3 | 11 |
| 4 | **B38** | L40X4 | 1.167 | S355 | 3 | 11 |
| 4 | **B39** | L40X4 | 500 | S355 | 1 | 5 |
| 4 | **B40** | L45X4 | 868 | S355 | 2 | 10 |
| 4 | **B41** | L45X4 | 1.560 | S355 | 4 | 17 |
| 4 | **B42** | L50X4 | 457 | S355 | 1 | 6 |
| 4 | **B43** | L50X4 | 544 | S355 | 2 | 7 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 4 | **B44** | L50X4 | 1.461 | S355 | 4 | 18 |
| 4 | **B45** | L50X4 | 1.319 | S355 | 4 | 16 |
| 4 | **B46** | L50X4 | 1.082 | S355 | 3 | 13 |
| 4 | **B47** | L60X5 | 817 | S355 | 4 | 15 |
| 4 | **B48** | L60X5 | 1.176 | S355 | 5 | 21 |
| 4 | **B49** | L60X5 | 1.391 | S355 | 6 | 25 |
| 4 | **B50** | L65X7 | 462 | S355 | 3 | 13 |
| 4 | **B51** | L65X7 | 615 | S355 | 4 | 17 |
| 4 | **B52** | L65X7 | 544 | S355 | 4 | 15 |
| 3 | **B53** | L100X10 | 2.803 | S355 | 42 | 127 |

| Quantity | Mark | Description | Length | Grade | Part weight | Total weight |
|---|---|---|---|---|---|---|
| | | | (mm) | | kilogram | kilogram |
| 3 | **B54** | L100X8 | 3.199 | S355 | 39 | 117 |
| 3 | **B55** | L100X8 | 2.334 | S355 | 28 | 85 |
| 3 | **B56** | L130X12 | 3.340 | S355 | 79 | 236 |
| 3 | **B57** | L130X12 | 300 | S355 | 7 | 21 |
| 3 | **B58** | L130X12 | 5.009 | S355 | 118 | 355 |
| 3 | **B59** | L130X12 | 2.713 | S355 | 64 | 192 |
| 3 | **B60** | L130X12 | 2.837 | S355 | 67 | 201 |
| 3 | **B61** | L150X14 | 5.009 | S355 | 158 | 475 |
| 3 | **B62** | L35X4 | 1.651 | S355 | 3 | 10 |
| 3 | **B63** | L35X4 | 1.560 | S355 | 3 | 10 |
| 3 | **B64** | L35X4 | 1.356 | S355 | 3 | 9 |
| 3 | **B65** | L40X4 | 1.651 | S355 | 4 | 12 |
| 3 | **B66** | L40X4 | 1.244 | S355 | 3 | 9 |
| 3 | **B67** | L50X5 | 1.220 | S355 | 5 | 14 |
| 3 | **B68** | L60X5 | 1.852 | S355 | 8 | 25 |
| 3 | **B69** | L60X5 | 1.244 | S355 | 6 | 17 |
| 3 | **B70** | L65X7 | 1.224 | S355 | 8 | 25 |
| 3 | **B71** | L80X10 | 1.276 | S355 | 15 | 46 |
| 3 | **B72** | L80x7 | 1.082 | S355 | 9 | 28 |
| 2 | **B73** | L100X10 | 2.219 | S355 | 34 | 67 |
| 2 | **B74** | L100X10 | 5.009 | S355 | 76 | 151 |
| 2 | **B75** | L100X10 | 3.626 | S355 | 55 | 110 |
| 2 | **B76** | L100X10 | 2.637 | S355 | 40 | 80 |
| 2 | **B77** | L100X12 | 2.593 | S355 | 46 | 92 |
| 2 | **B78** | L100X12 | 2.223 | S355 | 40 | 79 |
| 2 | **B79** | L100X12 | 2.334 | S355 | 42 | 83 |
| 2 | **B80** | L100X12 | 1.301 | S355 | 23 | 46 |
| 2 | **B81** | L100X8 | 3.327 | S355 | 41 | 81 |
| 2 | **B82** | L100X8 | 3.626 | S355 | 44 | 88 |

| Quantity | Mark | Description | Length | Grade | Part weight | Total weight |
|---|---|---|---|---|---|---|
| | | | (mm) | | kilogram | kilogram |
| 2 | **B83** | L100X8 | 2.837 | S355 | 35 | 69 |
| 2 | **B84** | L100X8 | 2.400 | S355 | 29 | 59 |
| 2 | **B85** | L100X8 | 2.223 | S355 | 27 | 54 |
| 2 | **B86** | L100X8 | 3.207 | S355 | 39 | 78 |
| 2 | **B87** | L130X12 | 3.325 | S355 | 78 | 157 |
| 2 | **B88** | L130X12 | 3.602 | S355 | 85 | 170 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 2 | **B89** | L130X12 | 3.625 | S355 | 86 | 171 |
| 2 | **B90** | L130X12 | 2.637 | S355 | 62 | 124 |
| 2 | **B91** | L130X12 | 2.400 | S355 | 57 | 113 |
| 2 | **B92** | L130X12 | 3.626 | S355 | 86 | 171 |
| 2 | **B93** | L130X12 | 2.803 | S355 | 66 | 132 |
| 2 | **B94** | L150X14 | 3.340 | S355 | 106 | 211 |
| 2 | **B95** | L150X14 | 4.155 | S355 | 131 | 263 |
| 2 | **B96** | L150X14 | 5.306 | S355 | 168 | 335 |
| 2 | **B97** | L150X14 | 4.695 | S355 | 148 | 297 |
| 2 | **B98** | L250x25 | 4.595 | S355 | 431 | 861 |
| 2 | **B99** | L35X4 | 1.696 | S355 | 4 | 7 |
| 2 | **B100** | L35X4 | 615 | S355 | 1 | 3 |
| 2 | **B101** | L35X4 | 1.461 | S355 | 3 | 6 |
| 2 | **B102** | L35X4 | 1.200 | S355 | 3 | 5 |
| 2 | **B103** | L35X4 | 500 | S355 | 1 | 2 |
| 2 | **B104** | L35X4 | 1.846 | S355 | 4 | 8 |
| 2 | **B105** | L35X4 | 1.633 | S355 | 3 | 7 |
| 2 | **B106** | L35X4 | 1.605 | S355 | 3 | 7 |
| 2 | **B107** | L35X4 | 1.445 | S355 | 3 | 6 |
| 2 | **B108** | L35X4 | 1.283 | S355 | 3 | 5 |
| 2 | **B109** | L35X4 | 1.135 | S355 | 2 | 5 |
| 2 | **B110** | L35X4 | 1.000 | S355 | 2 | 4 |
| 2 | **B111** | L35X4 | 1.429 | S355 | 3 | 6 |

| Quantity | Mark | Description | Length | Grade | Part weight | Total weight |
|---|---|---|---|---|---|---|
| | | | (mm) | | kilogram | kilogram |
| 2 | **B112** | L40X4 | 1.642 | S355 | 4 | 8 |
| 2 | **B113** | L40X4 | 875 | S355 | 2 | 4 |
| 2 | **B114** | L40X4 | 817 | S355 | 2 | 4 |
| 2 | **B115** | L40X4 | 1.200 | S355 | 3 | 6 |
| 2 | **B116** | L40X4 | 1.461 | S355 | 4 | 7 |
| 2 | **B117** | L40X4 | 1.605 | S355 | 4 | 8 |
| 2 | **B118** | L45X4 | 1.843 | S355 | 5 | 10 |
| 2 | **B119** | L45X4 | 641 | S355 | 2 | 4 |
| 2 | **B120** | L45X4 | 817 | S355 | 2 | 4 |
| 2 | **B121** | L45X4 | 722 | S355 | 2 | 4 |
| 2 | **B122** | L45X4 | 1.200 | S355 | 3 | 7 |
| 2 | **B123** | L45X4 | 1.224 | S355 | 3 | 7 |
| 2 | **B124** | L45X4 | 707 | S355 | 2 | 4 |
| 2 | **B125** | L50X4 | 1.224 | S355 | 4 | 7 |
| 2 | **B126** | L50X4 | 567 | S355 | 2 | 3 |
| 2 | **B127** | L50X4 | 462 | S355 | 1 | 3 |
| 2 | **B128** | L50X4 | 615 | S355 | 2 | 4 |
| 2 | **B129** | L50X4 | 1.200 | S355 | 4 | 7 |
| 2 | **B130** | L50X5 | 1.180 | S355 | 4 | 9 |
| 2 | **B131** | L50X5 | 775 | S355 | 3 | 6 |
| 2 | **B132** | L50X5 | 1.451 | S355 | 5 | 11 |
| 2 | **B133** | L50X5 | 1.370 | S355 | 5 | 10 |
| 2 | **B134** | L50X5 | 3.266 | S355 | 12 | 25 |
| 2 | **B135** | L50X5 | 462 | S355 | 2 | 3 |
| 2 | **B136** | L50X5 | 641 | S355 | 2 | 5 |
| 2 | **B137** | L60X5 | 1.559 | S355 | 7 | 14 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 2 | **B138** | L60X5 | 2.566 | S355 | 12 | 23 |
| 2 | **B139** | L65X7 | 1.841 | S355 | 13 | 25 |
| 2 | **B140** | L65X7 | 835 | S355 | 6 | 11 |

| Quantity | Mark | Description | Length | Grade | Part weight | Total weight |
|---|---|---|---|---|---|---|
| | | | (mm) | | kilogram | kilogram |
| 2 | **B141** | L65X7 | 1.879 | S355 | 13 | 26 |
| 2 | **B142** | L65X7 | 2.270 | S355 | 16 | 31 |
| 2 | **B143** | L65X7 | 2.890 | S355 | 20 | 39 |
| 2 | **B144** | L65X7 | 3.266 | S355 | 22 | 45 |
| 2 | **B145** | L65X7 | 3.692 | S355 | 25 | 50 |
| 2 | **B146** | L65X7 | 1.192 | S355 | 8 | 16 |
| 2 | **B147** | L65X7 | 1.477 | S355 | 10 | 20 |
| 2 | **B148** | L70X6 | 2.566 | S355 | 16 | 33 |
| 2 | **B149** | L75X6 | 2.126 | S355 | 15 | 29 |
| 2 | **B150** | L80X10 | 2.349 | S355 | 28 | 56 |
| 2 | **B151** | L80X10 | 3.207 | S355 | 38 | 76 |
| 2 | **B152** | L80X10 | 3.625 | S355 | 43 | 86 |
| 2 | **B153** | L80X8 | 2.334 | S355 | 23 | 45 |
| 2 | **B154** | L80x7 | 1.056 | S355 | 9 | 18 |
| 2 | **B155** | L80x7 | 2.550 | S355 | 22 | 43 |
| 2 | **B156** | L80x7 | 2.223 | S355 | 19 | 38 |
| 2 | **B157** | L80x7 | 2.400 | S355 | 20 | 41 |
| 1 | **B158** | L100X10 | 3.199 | S355 | 48 | 48 |
| 1 | **B159** | L100X10 | 300 | S355 | 5 | 5 |
| 1 | **B160** | L100X10 | 1.106 | S355 | 17 | 17 |
| 1 | **B161** | L100X10 | 2.153 | S355 | 33 | 33 |
| 1 | **B162** | L100X10 | 1.913 | S355 | 29 | 29 |
| 1 | **B163** | L100X10 | 1.952 | S355 | 29 | 29 |
| 1 | **B164** | L100X10 | 3.625 | S355 | 55 | 55 |
| 1 | **B165** | L100X10 | 2.713 | S355 | 41 | 41 |
| 1 | **B166** | L100X10 | 2.837 | S355 | 43 | 43 |
| 1 | **B167** | L100X10 | 2.705 | S355 | 41 | 41 |
| 1 | **B168** | L100X10 | 1.201 | S355 | 18 | 18 |
| 1 | **B169** | L100X12 | 3.199 | S355 | 57 | 57 |

| Quantity | Mark | Description | Length | Grade | Part weight | Total weight |
|---|---|---|---|---|---|---|
| | | | (mm) | | kilogram | kilogram |
| 1 | **B170** | L100X12 | 2.349 | S355 | 42 | 42 |
| 1 | **B171** | L100X12 | 300 | S355 | 5 | 5 |
| 1 | **B172** | L100X12 | 2.153 | S355 | 38 | 38 |
| 1 | **B173** | L100X12 | 1.106 | S355 | 20 | 20 |
| 1 | **B174** | L100X12 | 1.952 | S355 | 35 | 35 |
| 1 | **B175** | L100X12 | 3.625 | S355 | 65 | 65 |
| 1 | **B176** | L100X12 | 3.207 | S355 | 57 | 57 |
| 1 | **B177** | L100X12 | 2.400 | S355 | 43 | 43 |
| 1 | **B178** | L100X12 | 2.637 | S355 | 47 | 47 |
| 1 | **B179** | L100X12 | 1.201 | S355 | 21 | 21 |
| 1 | **B180** | L100X8 | 2.349 | S355 | 29 | 29 |
| 1 | **B181** | L100X8 | 3.340 | S355 | 41 | 41 |
| 1 | **B182** | L100X8 | 746 | S355 | 9 | 9 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 1 | **B183** | L100X8 | 1.155 | S355 | 14 | 14 |
| 1 | **B184** | L100X8 | 3.603 | S355 | 44 | 44 |
| 1 | **B185** | L100X8 | 2.490 | S355 | 30 | 30 |
| 1 | **B186** | L100X8 | 2.000 | S355 | 24 | 24 |
| 1 | **B187** | L100X8 | 1.058 | S355 | 13 | 13 |
| 1 | **B188** | L100X8 | 2.713 | S355 | 33 | 33 |
| 1 | **B189** | L100X8 | 3.625 | S355 | 44 | 44 |
| 1 | **B190** | L100X8 | 2.637 | S355 | 32 | 32 |
| 1 | **B191** | L100X8 | 2.440 | S355 | 30 | 30 |
| 1 | **B192** | L100X8 | 1.201 | S355 | 15 | 15 |
| 1 | **B193** | L100X8 | 2.803 | S355 | 34 | 34 |
| 1 | **B194** | L120X11 | 1.952 | S355 | 39 | 39 |
| 1 | **B195** | L130X12 | 3.199 | S355 | 75 | 75 |
| 1 | **B196** | L130X12 | 2.219 | S355 | 52 | 52 |
| 1 | **B197** | L130X12 | 4.155 | S355 | 98 | 98 |
| 1 | **B198** | L130X12 | 2.334 | S355 | 55 | 55 |

| Quantity | Mark | Description | Length | Grade | Part weight | Total weight |
|---|---|---|---|---|---|---|
| | | | (mm) | | kilogram | kilogram |
| 1 | **B199** | L130X12 | 2.223 | S355 | 52 | 52 |
| 1 | **B200** | L130X12 | 1.301 | S355 | 31 | 31 |
| 1 | **B201** | L150X14 | 300 | S355 | 9 | 9 |
| 1 | **B202** | L150X14 | 2.219 | S355 | 70 | 70 |
| 1 | **B203** | L150X14 | 2.593 | S355 | 82 | 82 |
| 1 | **B204** | L150X14 | 3.184 | S355 | 101 | 101 |
| 1 | **B205** | L150X14 | 5.996 | S355 | 189 | 189 |
| 1 | **B206** | L150X14 | 1.952 | S355 | 62 | 62 |
| 1 | **B207** | L150X14 | 3.626 | S355 | 115 | 115 |
| 1 | **B208** | L150X14 | 3.625 | S355 | 115 | 115 |
| 1 | **B209** | L150X14 | 3.207 | S355 | 101 | 101 |
| 1 | **B210** | L150X14 | 2.803 | S355 | 89 | 89 |
| 1 | **B211** | L180X16 | 3.184 | S355 | 138 | 138 |
| 1 | **B212** | L180X16 | 2.593 | S355 | 113 | 113 |
| 1 | **B213** | L180X16 | 5.996 | S355 | 261 | 261 |
| 1 | **B214** | L180X16 | 4.695 | S355 | 204 | 204 |
| 1 | **B215** | L180X16 | 4.155 | S355 | 181 | 181 |
| 1 | **B216** | L180X16 | 1.301 | S355 | 57 | 57 |
| 1 | **B217** | L200X18 | 5.306 | S355 | 288 | 288 |
| 1 | **B218** | L200X18 | 4.695 | S355 | 255 | 255 |
| 1 | **B219** | L200X20 | 5.997 | S355 | 359 | 359 |
| 1 | **B220** | L200X24 | 4.595 | S355 | 327 | 327 |
| 1 | **B221** | L200X24 | 3.184 | S355 | 226 | 226 |
| 1 | **B222** | L200X24 | 5.997 | S355 | 426 | 426 |
| 1 | **B223** | L200X24 | 5.306 | S355 | 377 | 377 |
| 1 | **B224** | L250X35 | 4.595 | S355 | 588 | 588 |
| 1 | **B225** | L250x250x25 | | 3.184 | S355 | 298 |
| 1 | **B226** | L35X4 | 651 | S355 | 1 | 1 |
| 1 | **B227** | L35X4 | 601 | S355 | 1 | 1 |

| Quantity | Mark | Description | Length | Grade | Part weight | Total weight |
|---|---|---|---|---|---|---|
| | | | (mm) | | kilogram | kilogram |

| | | | | | | |
|---|---|---|---|---|---|---|
| 1 | **B228** | L40X4 | 1.429 | S355 | 3 | 3 |
| 1 | **B229** | L40X4 | 601 | S355 | 1 | 1 |
| 1 | **B230** | L40X4 | 1.250 | S355 | 3 | 3 |
| 1 | **B231** | L40X4 | 1.451 | S355 | 4 | 4 |
| 1 | **B232** | L40X4 | 1.725 | S355 | 4 | 4 |
| 1 | **B233** | L40X4 | 1.560 | S355 | 4 | 4 |
| 1 | **B234** | L40X4 | 878 | S355 | 2 | 2 |
| 1 | **B235** | L40X4 | 707 | S355 | 2 | 2 |
| 1 | **B236** | L40X4 | 1.696 | S355 | 4 | 4 |
| 1 | **B237** | L40X4 | 1.937 | S355 | 5 | 5 |
| 1 | **B238** | L45X4 | 601 | S355 | 2 | 2 |
| 1 | **B239** | L45X4 | 3.692 | S355 | 10 | 10 |
| 1 | **B240** | L45X4 | 1.356 | S355 | 4 | 4 |
| 1 | **B241** | L45X4 | 500 | S355 | 1 | 1 |
| 1 | **B242** | L45X4 | 1.651 | S355 | 5 | 5 |
| 1 | **B243** | L45X4 | 1.250 | S355 | 3 | 3 |
| 1 | **B244** | L45X4 | 1.180 | S355 | 3 | 3 |
| 1 | **B245** | L45X4 | 1.429 | S355 | 4 | 4 |
| 1 | **B246** | L45X4 | 1.937 | S355 | 5 | 5 |
| 1 | **B247** | L50X4 | 1.221 | S355 | 4 | 4 |
| 1 | **B248** | L50X4 | 1.150 | S355 | 4 | 4 |
| 1 | **B249** | L50X4 | 1.370 | S355 | 4 | 4 |
| 1 | **B250** | L50X4 | 1.244 | S355 | 4 | 4 |
| 1 | **B251** | L50X4 | 1.651 | S355 | 5 | 5 |
| 1 | **B252** | L50X4 | 500 | S355 | 2 | 2 |
| 1 | **B253** | L50X4 | 707 | S355 | 2 | 2 |
| 1 | **B254** | L50X4 | 1.528 | S355 | 5 | 5 |
| 1 | **B255** | L50X4 | 1.696 | S355 | 5 | 5 |
| 1 | **B256** | L50X5 | 1.275 | S355 | 5 | 5 |

| Quantity | Mark | Description | Length | Grade | Part weight | Total weight |
|---|---|---|---|---|---|---|
| | | | (mm) | | kilogram | kilogram |
| 1 | **B257** | L50X5 | 1.528 | S355 | 6 | 6 |
| 1 | **B258** | L50X5 | 1.150 | S355 | 4 | 4 |
| 1 | **B259** | L50X5 | 1.160 | S355 | 4 | 4 |
| 1 | **B260** | L50X5 | 601 | S355 | 2 | 2 |
| 1 | **B261** | L50X5 | 1.638 | S355 | 6 | 6 |
| 1 | **B262** | L50X5 | 2.890 | S355 | 11 | 11 |
| 1 | **B263** | L50X5 | 3.692 | S355 | 14 | 14 |
| 1 | **B264** | L50X5 | 1.244 | S355 | 5 | 5 |
| 1 | **B265** | L50X5 | 434 | S355 | 2 | 2 |
| 1 | **B266** | L60X5 | 3.199 | S355 | 15 | 15 |
| 1 | **B267** | L60X5 | 1.160 | S355 | 5 | 5 |
| 1 | **B268** | L60X5 | 1.263 | S355 | 6 | 6 |
| 1 | **B269** | L60X5 | 1.913 | S355 | 9 | 9 |
| 1 | **B270** | L60X5 | 1.725 | S355 | 8 | 8 |
| 1 | **B271** | L60X5 | 2.270 | S355 | 10 | 10 |
| 1 | **B272** | L60X5 | 2.890 | S355 | 13 | 13 |
| 1 | **B273** | L60X5 | 1.224 | S355 | 6 | 6 |
| 1 | **B274** | L60X5 | 1.414 | S355 | 6 | 6 |

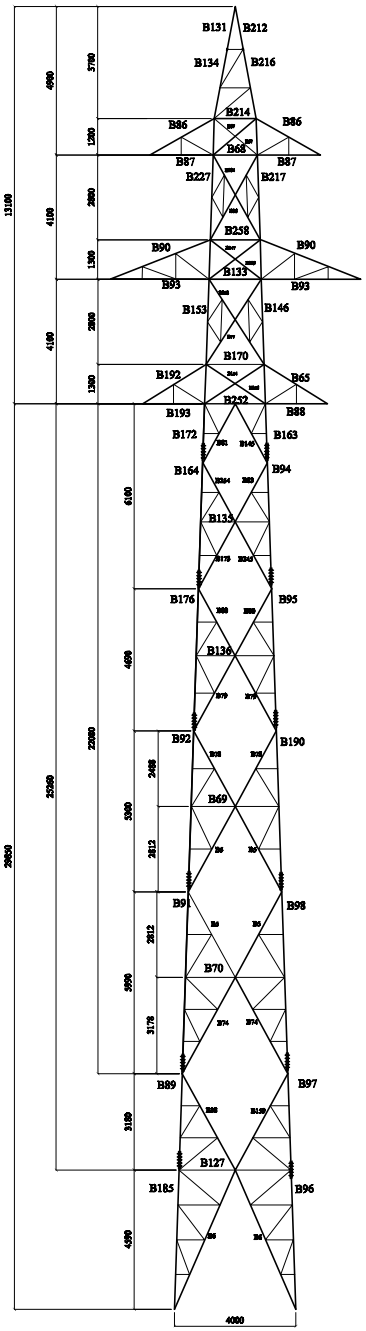
| | | | | | | |
|---|---|---|---|---|---|---|
| 1 | **B275** | L60X5 | 1.180 | S355 | 5 | 5 |
| 1 | **B276** | L60X5 | 2.052 | S355 | 9 | 9 |
| 1 | **B277** | L65X7 | 1.275 | S355 | 9 | 9 |
| 1 | **B278** | L65X7 | 434 | S355 | 3 | 3 |
| 1 | **B279** | L65X7 | 1.949 | S355 | 13 | 13 |
| 1 | **B280** | L65X7 | 651 | S355 | 4 | 4 |
| 1 | **B281** | L65X7 | 2.490 | S355 | 17 | 17 |
| 1 | **B282** | L65X7 | 1.638 | S355 | 11 | 11 |
| 1 | **B283** | L65X7 | 1.725 | S355 | 12 | 12 |
| 1 | **B284** | L65X7 | 1.370 | S355 | 9 | 9 |
| 1 | **B285** | L65X7 | 2.550 | S355 | 17 | 17 |

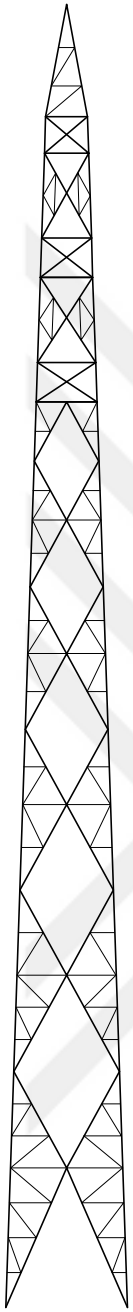
| Quantity | Mark | Description | Length | Grade | Part weight | Total weight |
|---|---|---|---|---|---|---|
| | | | (mm) | | kilogram | kilogram |
| 1 | **B286** | L65X7 | 1.414 | S355 | 10 | 10 |
| 1 | **B287** | L65X7 | 2.317 | S355 | 16 | 16 |
| 1 | **B288** | L70X6 | 1.116 | S355 | 7 | 7 |
| 1 | **B289** | L70X6 | 1.949 | S355 | 12 | 12 |
| 1 | **B290** | L70X6 | 651 | S355 | 4 | 4 |
| 1 | **B291** | L70X6 | 1.264 | S355 | 8 | 8 |
| 1 | **B292** | L70X6 | 1.638 | S355 | 10 | 10 |
| 1 | **B293** | L70X6 | 1.450 | S355 | 9 | 9 |
| 1 | **B294** | L70X6 | 2.550 | S355 | 16 | 16 |
| 1 | **B295** | L70X6 | 2.270 | S355 | 14 | 14 |
| 1 | **B296** | L70X6 | 2.000 | S355 | 13 | 13 |
| 1 | **B297** | L70X6 | 434 | S355 | 3 | 3 |
| 1 | **B298** | L70X6 | 2.051 | S355 | 13 | 13 |
| 1 | **B299** | L70X7 | 2.000 | S355 | 15 | 15 |
| 1 | **B300** | L70X7 | 2.637 | S355 | 19 | 19 |
| 1 | **B301** | L75X6 | 1.275 | S355 | 9 | 9 |
| 1 | **B302** | L75X6 | 3.199 | S355 | 22 | 22 |
| 1 | **B303** | L75X6 | 1.852 | S355 | 13 | 13 |
| 1 | **B304** | L75X6 | 434 | S355 | 3 | 3 |
| 1 | **B305** | L75X6 | 1.913 | S355 | 13 | 13 |
| 1 | **B306** | L75X6 | 1.082 | S355 | 7 | 7 |
| 1 | **B307** | L75X6 | 1.414 | S355 | 10 | 10 |
| 1 | **B308** | L75X6 | 3.626 | S355 | 25 | 25 |
| 1 | **B309** | L75X6 | 3.207 | S355 | 22 | 22 |
| 1 | **B310** | L75X6 | 2.837 | S355 | 19 | 19 |
| 1 | **B311** | L75X6 | 1.201 | S355 | 8 | 8 |
| 1 | **B312** | L80X10 | 3.340 | S355 | 40 | 40 |
| 1 | **B313** | L80X10 | 2.490 | S355 | 30 | 30 |
| 1 | **B314** | L80X10 | 1.058 | S355 | 13 | 13 |

| Quantity | Mark | Description | Length | Grade | Part weight | Total weight |
|---|---|---|---|---|---|---|
| | | | (mm) | | kilogram | kilogram |
| 1 | **B315** | L80X10 | 1.155 | S355 | 14 | 14 |
| 1 | **B316** | L80X10 | 2.153 | S355 | 26 | 26 |
| 1 | **B317** | L80X10 | 1.725 | S355 | 21 | 21 |
| 1 | **B318** | L80X10 | 746 | S355 | 9 | 9 |
| 1 | **B319** | L80X10 | 2.837 | S355 | 34 | 34 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 1 | **B320** | L80X10 | 2.637 | S355 | 31 | 31 |
| 1 | **B321** | L80X10 | 2.713 | S355 | 32 | 32 |
| 1 | **B322** | L80X10 | 2.223 | S355 | 26 | 26 |
| 1 | **B323** | L80X8 | 2.126 | S355 | 21 | 21 |
| 1 | **B324** | L80X8 | 1.276 | S355 | 12 | 12 |
| 1 | **B325** | L80X8 | 1.638 | S355 | 16 | 16 |
| 1 | **B326** | L80X8 | 2.000 | S355 | 19 | 19 |
| 1 | **B327** | L80X8 | 3.603 | S355 | 35 | 35 |
| 1 | **B328** | L80X8 | 651 | S355 | 6 | 6 |
| 1 | **B329** | L80X8 | 3.207 | S355 | 31 | 31 |
| 1 | **B330** | L80X8 | 2.713 | S355 | 26 | 26 |
| 1 | **B331** | L80X8 | 2.400 | S355 | 23 | 23 |
| 1 | **B332** | L80X8 | 2.440 | S355 | 24 | 24 |
| 1 | **B333** | L80X8 | 2.705 | S355 | 26 | 26 |
| 1 | **B334** | L80X8 | 2.803 | S355 | 27 | 27 |
| 1 | **B335** | L80x7 | 1.275 | S355 | 11 | 11 |
| 1 | **B336** | L80x7 | 3.340 | S355 | 28 | 28 |
| 1 | **B337** | L80x7 | 2.126 | S355 | 18 | 18 |
| 1 | **B338** | L80x7 | 2.490 | S355 | 21 | 21 |
| 1 | **B339** | L80x7 | 2.153 | S355 | 18 | 18 |
| 1 | **B340** | L80x7 | 1.913 | S355 | 16 | 16 |
| 1 | **B341** | L80x7 | 1.414 | S355 | 12 | 12 |
| 1 | **B342** | L80x7 | 1.116 | S355 | 10 | 10 |
| 1 | **B343** | L80x7 | 2.713 | S355 | 23 | 23 |

| Quantity | Mark | Description | Length | Grade | Part weight | Total weight |
|---|---|---|---|---|---|---|
| | | | (mm) | | kilogram | kilogram |
| 1 | **B344** | L80x7 | 2.317 | S355 | 20 | 20 |
| | | **TOTAL QUANTITY** | | 696 | | |
| | | **TOTAL WEIGHT** | | 16,590 | kilogram | |



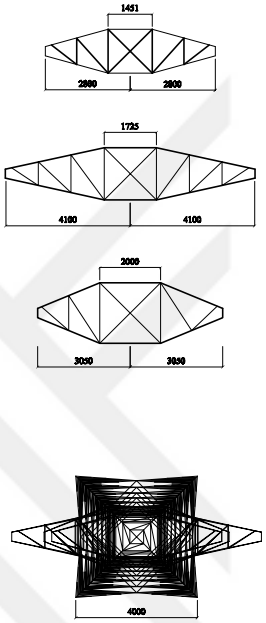



**Table of sections 1-1**

| Mark | Quantity | Description | Length | Grade | Part weight | Total weight |
|---|---|---|---|---|---|---|
| B96 | 2 | L200X24 | 4595 | S355 | 327 | 653 |
| B97 | 2 | L200X24 | 3184 | S355 | 226 | 453 |
| B98 | 2 | L200X24 | 5997 | S355 | 426 | 853 |
| B190 | 1 | L200X18 | 5306 | S355 | 288 | 288 |
| B95 | 2 | L180X18 | 4695 | S355 | 288 | 459 |
| B94 | 2 | L180X16 | 4155 | S355 | 181 | 361 |
| B163 | 1 | L100X12 | 1962 | S355 | 35 | 35 |
| B88 | 2 | L150X14 | 2219 | S355 | 70 | 140 |
| B65 | 3 | L150X14 | 2593 | S355 | 82 | 246 |
| B146 | 2 | L80X10 | 2803 | S355 | 33 | 67 |
| B93 | 2 | L180X16 | 3325 | S355 | 145 | 289 |
| B90 | 2 | L150X14 | 3602 | S355 | 114 | 228 |
| B217 | 1 | L60X5 | 2803 | S355 | 13 | 13 |
| B87 | 2 | L150X14 | 2153 | S355 | 68 | 136 |
| B86 | 2 | L130X12 | 2490 | S355 | 59 | 118 |
| B216 | 1 | L60X5 | 2550 | S355 | 12 | 12 |
| B212 | 1 | L60X5 | 1275 | S355 | 6 | 6 |
| B131 | 2 | L56X7 | 1275 | S355 | 9 | 17 |
| B134 | 2 | L65X7 | 2555 | S355 | 17 | 35 |
| B227 | 1 | L65X7 | 2803 | S355 | 19 | 19 |
| B133 | 2 | L80X7 | 2803 | S355 | 24 | 48 |
| B192 | 1 | L250X24 | 2593 | S355 | 233 | 233 |
| B193 | 1 | L250X24 | 2219 | S355 | 200 | 200 |
| B172 | 1 | L100X8 | 1962 | S355 | 24 | 24 |
| B164 | 1 | L100X12 | 4155 | S355 | 74 | 74 |
| B176 | 1 | L120X11 | 4695 | S355 | 93 | 93 |
| B92 | 2 | L150X14 | 5306 | S355 | 168 | 335 |
| B91 | 2 | L150X14 | 5996 | S355 | 189 | 379 |
| B89 | 2 | L150X14 | 3184 | S355 | 101 | 201 |
| B185 | 1 | L150X14 | 4595 | S355 | 145 | 145 |
| B127 | 2 | L60X5 | 3692 | S355 | 17 | 34 |
| B70 | 3 | L60X5 | 3266 | S355 | 15 | 45 |
| B69 | 3 | L60X5 | 2890 | S355 | 13 | 40 |
| B136 | 2 | L65X7 | 2566 | S355 | 18 | 35 |
| B135 | 2 | L65X7 | 2270 | S355 | 16 | 31 |
| B252 | 1 | L80X8 | 2000 | S355 | 19 | 19 |
| B170 | 1 | L100X8 | 1913 | S355 | 23 | 23 |
| B133 | 2 | L65X7 | 1725 | S355 | 12 | 24 |

**Table of sections 1-2**

| Mark | Quantity | Description | Length | Grade | Part weight | Total weight |
|---|---|---|---|---|---|---|
| B258 | 1 | L90X7 | 1638 | S355 | 14 | 14 |
| B68 | 3 | L60X5 | 1451 | S355 | 7 | 20 |
| B214 | 1 | L60X5 | 1370 | S355 | 6 | 6 |
| B6 | 8 | L150X14 | 5009 | S355 | 158 | 1266 |
| B159 | 1 | L100X10 | 3626 | S355 | 55 | 55 |
| B38 | 4 | L100X8 | 3626 | S355 | 44 | 177 |
| B74 | 2 | L100X10 | 3625 | S355 | 55 | 109 |
| B5 | 10 | L100X8 | 3207 | S355 | 39 | 391 |
| B78 | 2 | L100X8 | 2837 | S355 | 35 | 69 |
| B79 | 2 | L100X8 | 2713 | S355 | 33 | 66 |
| B80 | 2 | L100X8 | 2637 | S355 | 32 | 64 |
| B245 | 1 | L80X10 | 2400 | S355 | 29 | 29 |
| B173 | 1 | L100X8 | 2400 | S355 | 29 | 29 |
| B88 | 1 | L130X12 | 2334 | S355 | 55 | 55 |
| B254 | 1 | L80X8 | 2334 | S355 | 23 | 23 |
| B145 | 2 | L80X10 | 2223 | S355 | 26 | 53 |
| B81 | 2 | L100X8 | 2223 | S355 | 27 | 54 |
| B256 | 1 | L100X10 | 2000 | S355 | 30 | 30 |
| B154 | 1 | L100X10 | 2349 | S355 | 35 | 35 |
| B218 | 1 | L65X7 | 3340 | S355 | 23 | 23 |
| B77 | 2 | L100X8 | 3340 | S355 | 41 | 82 |
| B229 | 1 | L70X6 | 2126 | S355 | 14 | 14 |
| B147 | 1 | L100X8 | 2705 | S355 | 33 | 33 |
| B204 | 1 | L45X4 | 3199 | S355 | 9 | 9 |
| B36 | 4 | L100X8 | 3199 | S355 | 39 | 156 |
| B67 | 3 | L60X5 | 1852 | S355 | 8 | 25 |

| Desig. | Ref. | Description | Verif. | ESOGU |
|---|---|---|---|---|
| Drawing N °: CP 1-00 | | Scale: | Comments: 154 kv | |
| Title: Transmission tower | | Review: | | |
| Date: 29.12.2019 | | Student: Loai Morshid | | |
| Danışman: DR. ÖĞR. ÜYESİ UĞUR ALBAYRAK | | | | |