

CHAPTER ONE

INTRODUCTION

1.1. General Introduction

Cranes are widely used to transport heavy loads and hazardous materials in shipyards, factories, nuclear installations, and high-building construction. They can be classified into two categories based on their configurations; gantry cranes and rotary cranes. Gantry cranes are commonly used in factories; this type of cranes incorporates a trolley, which translates in a horizontal plane. Rotary cranes can be divided into boom and tower cranes; Boom cranes which are commonly used in shipyards and tower cranes which are used in construction, Tower cranes are mounted in tower structure and are used for raising and lowering a load and moving the load horizontally.

Tower cranes are commonly used in construction projects to handling heavy materials in horizontal and vertical direction in the same time the tower cranes are also erected in schemes or public projects which contain huge number of labors. Any failure in tower crane lead to a disastrous accidents .Proper analysis and design insure the safety for the people and the buildings against the failures.

The stability of tower cranes depend on analysis and design specification , which are different from country to another depending on the climate of that regions which the wind speed will be important reason for stability. The design codes of practice for African countries provide approximate schedules for wind load and type of loading in general (Egyptian code). The analysis and design of tower crane depending on the type of the crane and the portions` wind load of the project location. In this work a common type used in Sudan was selected. The analysis of tower crane aided by computer programs will assistant to increase the accuracy of calculations.

The analysis and design of a selected model of tower crane depend on criteria of stability and safety of tower crane and the foundation of the tower crane, In our country, were exported tower crane depending on factors of costing and the value of the scheme, Then the manufacturing companies provide model data sheet to choose a suitable crane for project, in spite of the fact that there are only few number of engineers may design a proper tower crane for scheme as planning or management construction.

The papers interface a guide for analysis and design for tower crane which may improve the techniques of construction in SUDAN, and provides new skills for engineers in analysis and design of non-familiar structure in our country.

1.2. The Research Problem

Now it is ostensible that there is no full study about analysis and design for tower cranes in Sudan, also the nonexistent cognition in tower crane uses and favors, unperceptive of this instrument in projects in workplaces, erection and safety. All these reasons may build the crowd of the problem. Without understanding of tower crane and dealing with it there will not be actual progressing in construction field in Sudan. This research was offer an example of analysis and design of tower crane to illustrate the problem

1.3. Research Objectives:

The objectives of thesis may include the following topics:

1. Acquaint to tower cranes, Types and the selection of suitable tower cranes.
2. Realize to tower cranes management, including site planning, ground conditions, basic principles of loading and a pre-installation checklist.
3. Render background about forces, stresses, and the methods of analysis of tower crane.
4. Familiarize notification in analysis and design of tower crane parts.
5. Expatriate in design of tower crane foundations.

6. Define the Erection, dismantling of tower cranes on site, include the design and safe use of climbing frames.
7. Simplify procedures for security, safety and health for the users of the crane used in various fields, including construction sites and giant infrastructure projects with private and complex construction. These include procedures as wind speed, loading and to the end of the relevant topics.
8. Knowledge for the sides of the administration to tower cranes sites including risk management, evaluation, quality control management, costs management and also including the professional supervision of these cranes, and training programs for human resource development.

1.4. Methodology of the Research

The researcher performed this work by introducing tower cranes in general and in details. The basics of structural analysis and design of the crane. It was assumed suitable Crane close to the exist and suitable for projects and contractors (in Khartoum) .Analysis and design tower crane is carried out to conduct checking or re-designing its member. The discussion of results has been done to fit with the current reality of the Sudan.

1.5. Organization of the Research

This research is divided into Five chapters:

Chapter One contains introduction, the problem, the scope, Research objectives, methodology, and organization of the research. Chapter Two contains an overview of the literature in tower crane in general. Chapter Three presents the introduction in theory of analysis and analysis of tower crane itself. Chapter Four Presents design theory and design of tower crane in study case, and contains the result and discussion of results. Chapter Five presents recommendations and conclusion with suggestion for further projects of the research.

CHAPTER TWO

LITTERATURE REVIEW

2.1. Introduction

Tower Cranes are industrial machines that are mainly used for materials movements in construction sites, production halls, assembly lines, storage areas, power stations and similar places. Material handling is an important part of the delivery process of construction projects, and cranes are the most important resources used in achieving this, especially on a building construction site indicates a typical tower crane.

The tower crane is a modern form of balance crane. Fixed to the ground (and sometimes attached to the sides of structures as well), tower cranes often give the best combination of height and lifting capacity and are used in the construction of tall buildings.

The jib (colloquially, the 'boom') and counter-jib are mounted to the turntable, where the slewing bearing and slewing machinery are located. The counter-jib carries a counterweight, usually of concrete blocks, while the jib suspends the load from the trolley. The Hoist motor and transmissions are located on the mechanical deck on the counter-jib, while the trolley motor is located on the Jib. The crane operator either sits in a cabin at the top of the tower or controls the crane by radio remote control from the ground. In the first case the operator's cabin is most usually located at the top of the tower attached to the turntable, but can be mounted on the jib, or partway down the tower. The lifting hook is operated by using electric motors to manipulate wire rope cables through a system of sheaves. In order to hook and unhook the loads, the operator usually works in conjunction with a signaler (known as a 'rigger' or 'swam per'). They are most often in radio contact, and always use hand signals. The rigger directs the schedule of lifts for the crane, and is responsible for the safety of the rigging and loads. A

tower crane is usually assembled by a telescopic jib (mobile) crane of greater reach (also see "self-erecting crane" below) and in the case of tower cranes that have risen while constructing very tall skyscrapers, a smaller crane (or derrick) will often be lifted to the roof of the completed tower to dismantle the tower crane afterwards.

2.2. History of Tower Crane

In this section, It may be introduced the historical development of tower cranes:

2.2.1. Early Crane Evolution

The earliest recorded version or concept of a crane was called a **Shaduf** and used over 4,000 years by the Egyptians to transport water. The crane consisted of a long pivoting beam balanced on a vertical support with a heavy weight attached at one end of the beam and a bucket on the other. In the first century, cranes were built powered by animals or humans moving on a wheel or treadmill. The crane had a long wooden beam known as a boom and was connected to a base that rotated. The wheel or treadmill was power-driven by a drum with a rope that wound around it. This rope, connected to a pulley at the top of the boom, also had a hook that lifted the weight. During the middle ages the use of cranes to build Europe's massive cathedrals and to load and unload ships in major ports led to advancements in crane design. A horizontal arm was added to the boom. This arm would become known as the jib. This addition to the boom provided cranes with the ability to pivot, thereby increasing the crane's range of motion. By the 16th century, cranes had incorporated two treadmills on each side of a rotating housing holding the boom. Up until the mid-19th century, cranes continued to be dependent on human and animal power; however, this quickly changed with the development of steam engines. At the turn of the century, internal combustion engines and electrical motors powered cranes. Cranes were also being built with cast iron or steel instead of wood.

2.2.2. The First Tower Cranes

Tower cranes first started appearing in Europe in the first half of the 20th century. Streets in European cities were narrow and tall cranes with booms and the operator on the top proved to be more advantageous. As a result, some of the earliest manufacturers of tower cranes originated within Europe. For example, in 1908, Maschinenfabrik Julius Wolff & Co. introduced the first series of tower cranes specifically designed for the construction industry. These first-generation tower cranes mostly appealed to shipbuilders who bought and installed them in shipyards and on docks. Over 10,000 units were built and the basic design of these tower cranes remained in production up until the late 1960s. Other manufacturers like Kaiser and Potion were also developing tower cranes in the early 1930s. Their designs were largely based on dockside and harbor cranes. These cranes were exceptionally heavy made of steel and iron and difficult to set up, dismantle and transport. Even though Wolff's cranes began to be used by the construction industry, in 1948 still there is a need for a fast assembly tower crane.

2.2.3. Hans Liebherr Tower Crane

In 1949, Hans Liebherr realized that fast assembly tower cranes were virtually not existed in the market. He took it upon himself to build a bottom-slewing tower crane with a horizontal jib on top. The crane could also lift material from the ground up, by hoisting it, swinging over, and then dropping the material directly onto the new structure—a feature uncharacteristic of cranes up until this point as materials had to be manually carried from the drop off point. Another defining feature was that the crane could be transported partly assembled and could fully assemble itself. Liebherr presented his first crane, the TK-10, at the Frankfurt Trade Fair in Germany in the fall of 1949. At first, the industry was cautious about Liebherr new crane but eventually the design caught on and Liebherr took the TK-10 into mass production. A whole series of construction

cranes based on the TK-10 design concept came out over the following year. With his design, Liebherr managed to revolutionize the tower crane industry. As the 1950s approached, new ways of using cranes were developing and there were very advanced slewing tower cranes on the market. With a worldwide construction boom occurring during the 1940s and into the 1950s another trend that emerged with tower crane manufacturers was to complement the manufacturing of tower cranes with a combination of other construction equipment like concrete mixing machines. For example, Reich in Ulm, Germany manufactured slewing cranes and advertised concrete mixers as an add-on by matching lifting capacity and working speed. By the 1940s, important slewing tower crane manufacturers included Peschke, Peiner, Wolffe, Weitz, Liebherr, Potain, Boilot, Braud & Faucheux, Campistou, Favellle-Favco from Australia, Ferro, Fiorentini, Fives Lille, Fuochi-Milanesi, and Haulotte.

2.2.4. Tower Cranes Grow to New Heights

The 1950s marked a number of monumental milestones in tower crane design and development. First, multiple manufacturers were began to produce more bottom slewing cranes that had telescoping masts and came to dominate the office and apartment block construction market. The use of cantilever Jib designs were abandoned by a number of leading tower crane manufacturers who switched to luffing jibs as figure 2.2. Shown, the use of luffing jibs eventually became a norm.



Figure 2.1: Typical tower crane.



Figure 2.2: Luffing jibs.

In Europe, other substantial inroads were being made in the design and development of tower cranes. Construction sites were often constricted and using rail systems to move large tower cranes was proving to be too costly and inconvenient. At the same time, a number of manufacturers were offering saddle jib cranes with hook heights of (80 m). These cranes were outfitted with self-climbing mechanisms that enabled sections of mast to be inserted into the crane so it could grow as structures were built upwards. The long jibs on these cranes also covered a larger work area. These developments precipitated the practice of anchoring and erecting cranes inside the building's lift shaft and eventually this method became commonplace in the industry.

From the 1960s, the dominant focus on tower crane development and design would be on covering a bigger job radius, higher load moment, new control systems, climbing mechanisms and technology, and faster erection strategies, with the most important developments being made in drive technology. The market was also becoming increasingly crowded with multiple manufacturers producing a range of tower crane models such as Luffing cranes and saddle jib cranes, as well as branching off in to the development of smaller cranes that could be assembled on site in a matter of a few hours. Much of the drive behind all the improvements and developments made to tower cranes in the 1960s is attributed to the use of mobile cranes and their ever-increasing operating efficiency during this period.

2.2.5. The Tallest Crane in the World

As skyscrapers were being built at record-breaking heights, the need for taller cranes existed. In 1975, the Danish company Kroll became manufacturer of the world's tallest tower crane, the K-10 000. This colossal tower crane has a mast that stands 394 feet (120 m) tall and an extended reach of 295 feet (90 m). Just to grasp the actual size of the K-10000, the crane is five times the size of a standard

tower crane and three times as tall as the Statue of Liberty, with an operating range covering 7.5 acres (3 ha). Due to its massive size, only 20 have ever been built.

2.3. Theory of tower cranes

A tower crane differs from other cranes in the geometry of balancing forces that keep it stable. Each force (either from the crane, the load, or from external factors such as wind or ice) is exactly balanced by a counterforce with a suitable safety margin added. Unlike many other cranes, tower cranes are constant load moment cranes i.e., the load rise multiplied by the distance from the tower remains constant.

2.4. Tower cranes uses

The tower cranes are used for lifting up heavy building materials like concrete slabs, steel structures, bulk sand bags, and machinery equipment's like power generators, cement mixing machines, and many more. They are usually located on top of the building as it is the best suited and safer place from which the raw materials for construction can be handled from. They are suitably fixed on top of the building, so that they can reach any part of the building with ease to lift and drop materials.

2.5. Modern Tower cranes

The Modern Tower Crane With the industrial revolution iron became the basic construction material. From 1850 onwards, crane design began to develop, although large iron cranes do not appear until relatively late in the nineteenth century. Their design developed directly from the ancient tradition of crane construction they were tower cranes. One of the earliest big iron cranes, a sensation in its days was a tracked slew crane nearly 100 feet tall. It was built by Bechem and Keetman for the Vulkan Vegesack yard in Bremen.

2.6. Types of tower crane

The classic distinction between tower cranes concerns the jib (or boom). The Jib is either fixed or putted horizontally with the hook moved in and out by means of a trolley, or it is a luffing (derricking) structure familiar since ancient times.

A second important distinction concerns the point at which slewing Occurs. There are two possibilities; either the tower remains stationary or the jib slews or the whole tower slew together figure 2.3. , 2.4 indicate the slewing in the tower.

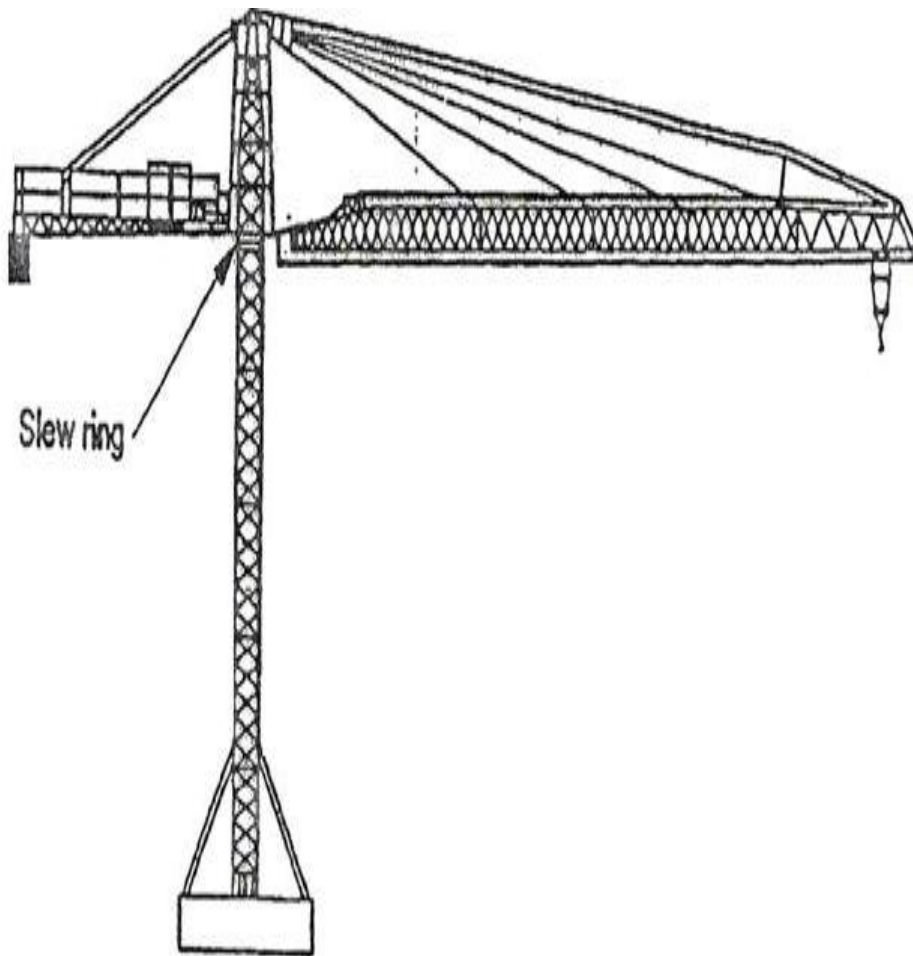


Figure 2.3: The slewing in the top.

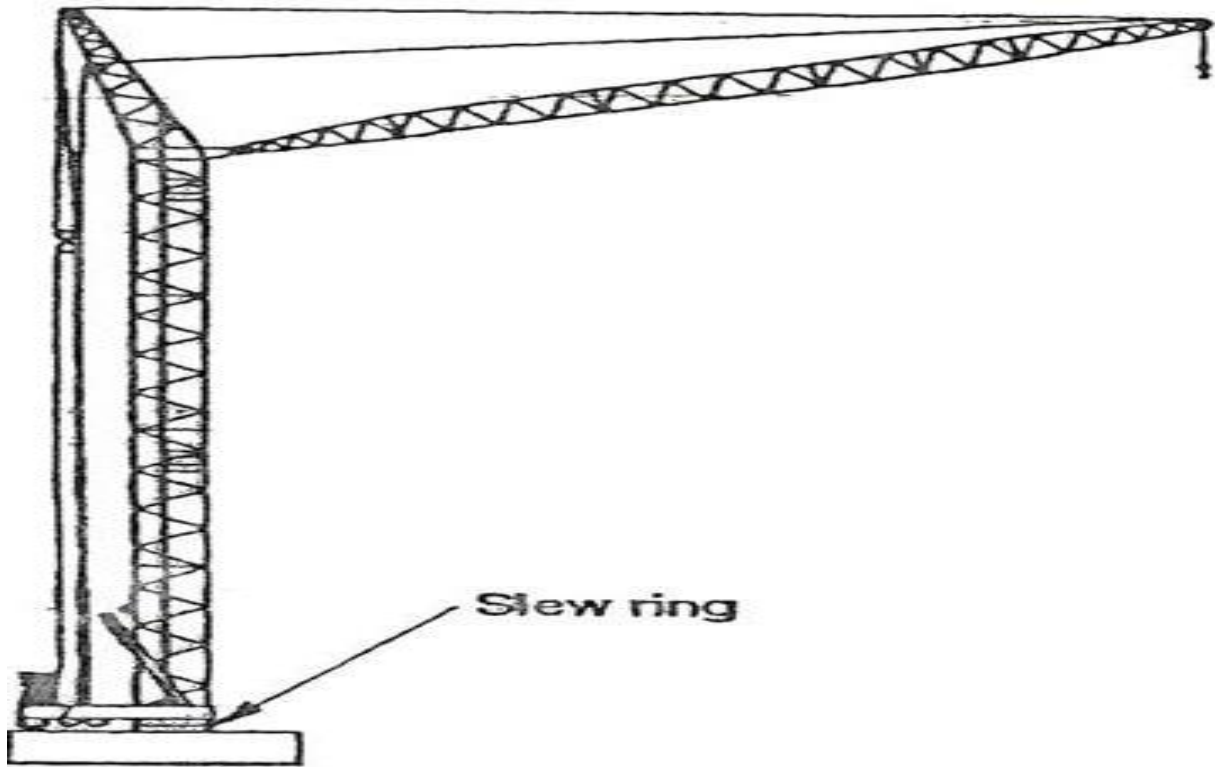


Figure 2.4: The slewing in the bottom.

It may be introduced the main types of tower crane in this section, There are two main types of tower crane in the general use.

2.6. 1. Self-Erect Tower Crane

This is a tower crane that is designed to be easily and rapidly transported and erected. Some of them carry their own generator and are therefore completely self-contained as shown in Figure 2.5.

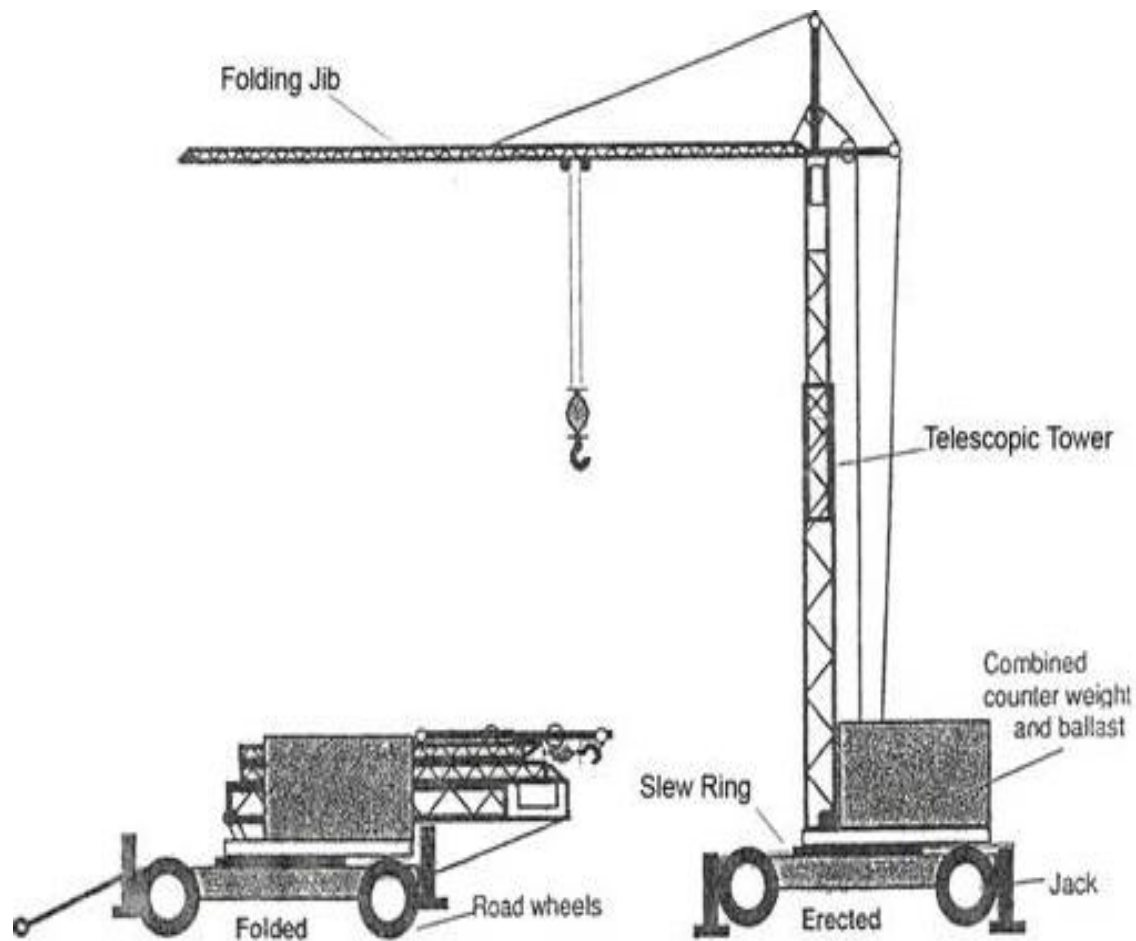


Figure 2.5: Self-Erect Tower Crane.

2.6.2. Assisted Erect Tower Crane

This type of tower crane is usually larger with a greater lifting capacity than the Self Erect. Its design calls for it to be built on site, piece by piece, often with the assistance of a mobile crane, hence its name ‘Assisted Erect’ as shown in Figure 2.6.

Both types of tower crane can be found in operation with a variety of jib configurations, all designed to provide a specific type of lifting service to sites where the lifting requirements and the environment produce different demands. It may be also introduced three types of jib crane.

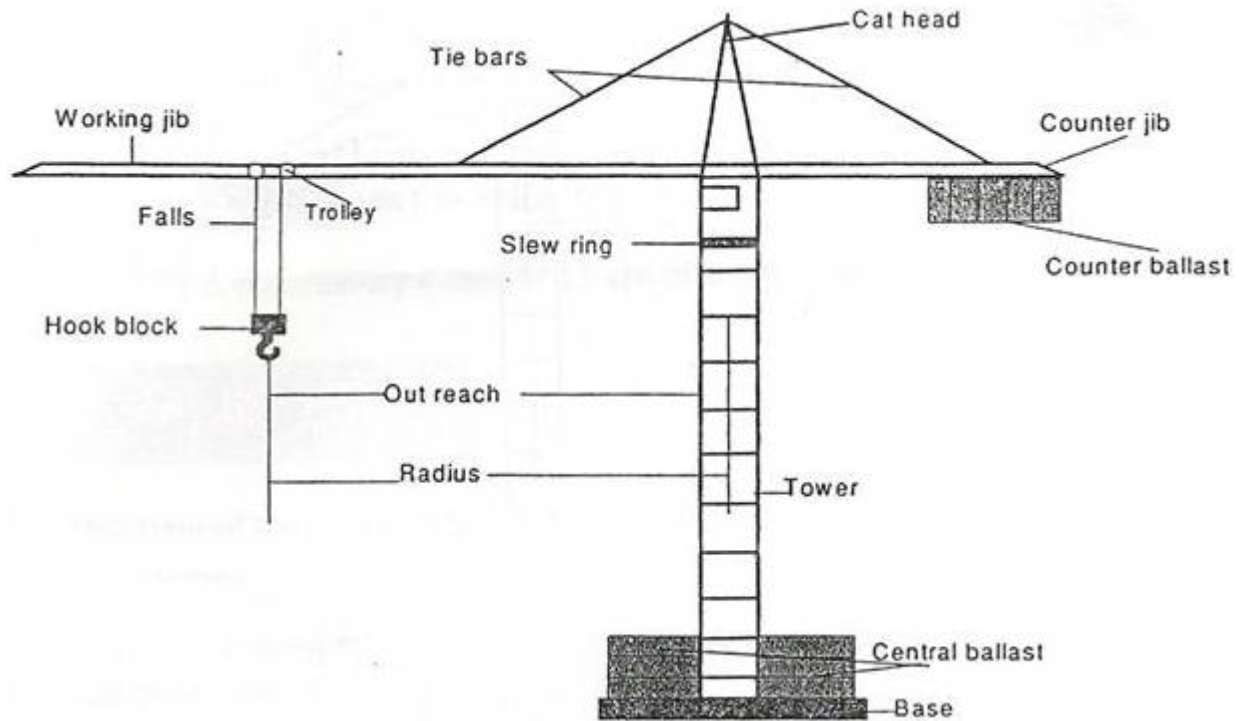


Figure 2.6: Assisted Erect Tower Crane.

2.6.3. Horizontal Jib

This jib takes the form of a simple structure extending from the tower, along which a trolley can travel as shown in Figure 2.7. Trolley Jib Crane carrying the hoist rope and hook assembly to vary radii.



Figure 2.7: Trolley Jib Crane.

2.6.4. Luffing Jib

The luffing jib as shown in Figure 2.8. Has no trolley; the variation of hook radii is achieved by altering the jib angle, the same as with a mobile crane.



Figure2.8: Luffing Jib Crane

2.6.5. Self-erecting crane

A self-assembling tower crane has been demonstrated, which lifts itself off the ground using jacks, allowing the next section of the tower to be inserted at ground level as shown in Figure 2.9. It may be introduced the types of tower cranes mounted as follows.



Figure 2.9: Self-erecting crane

2.6.6. Rail mounted free travelling

The asset with this type of tower crane is that it can travel over any length of straight or curved track to cover greater areas its limitations however are quite severe it can travel freely only when its working height is within certain limits specified by the manufacturer (Maximum free standing height). In addition the rail track must be kept clear at all times, and this requires a certain amount of responsible supervision as shown in Figure 2.10.



Figure 2.10: Rail mounted tower crane.

2.6.7. Lorry mounted

This type of Tower Crane is generally self-erecting, and usually also generates its own power. The crew of two men, working as a team, are usually competent in both crane operating and banks man (slingers) duties. This crane offers greater mobility, i.e. it can be easily transported from one site to another when folded, but when it has been erected to its full operating height this extreme mobility is lost, it can be moved from one part of the site to another only after careful levelling from the ground. Its working height is restricted to within limits specified by the manufacturer as shown in Figure 2.11.



Figure 2.11: Lorry mounted tower crane.

2.6.8. Crawler mounted

This is similar in principle to the lorry mounted tower crane, but with less restriction to working height and freedom of movement. The crawler mounted tower crane usually has some ability to travel unloaded around the site. Great care should be taken to provide a suitable surface to travel on in terms of support and level. Transportation by low loader is required for moving from site to site as shown in Figure 2.12.



Figure 2.12: Crawler tower crane.

2.7. The parts of tower cranes

Generally, all tower cranes consist of the same basic parts as follow:

1. The base is bolted to a large concrete pad that supports the crane.
2. The base connects to the mast (or tower), which gives the tower crane its height.
3. Attached to the top of the mast is the slewing unit (large ring-gear and motor) that allows the crane to rotate.

4. Attached to the slewing unit is the jib (or boom), the machinery arm, the counterweights and, the Operators Cab.

On top of the slewing unit are four parts:

- 1) The long horizontal jib (or working arm) as shown in Figure 2.13, which is the portion of the crane that carries the load. A trolley runs along the jib to move the load in and out from the crane` centre.

The short horizontal machinery arm. As shown in Figure 2.14. which contains the cranes motors, and electronics as well as the large concrete counter weight. The machinery arm contains the winch motor that lifts the load, along with the control electronics that drive it and the cable drum.

- 2) The operators cab as shown in Figure 2.15.
- 3) Base of tower crane as shown in Figures 2.16.a, 2.16.b, 2.16.c. considered to be The first element of the tower crane stability consist from a large concrete pad, which the construction companies pours several weeks before the crane arrives. This pad typically measures square meters and weighs kilos. These are the pad measurements for the crane shown here large anchor bolts embedded deep into this pad support the base of the crane. The mast rises from this firm foundation. The mast is a large, lattice structure. The triangulated cross-members structure gives the mast the strength to remain upright .So these cranes are essentially bolted anchored to the ground to ensure their stability.



Figure 2.13: Jib arm.



Figure 2.14: Counter weight balance.



Figure 2.15: The operators cab.

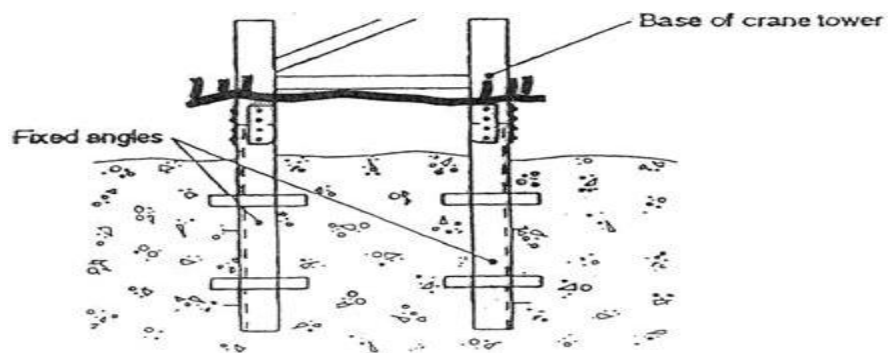


Figure 2.16.a: Section of tower crane base.

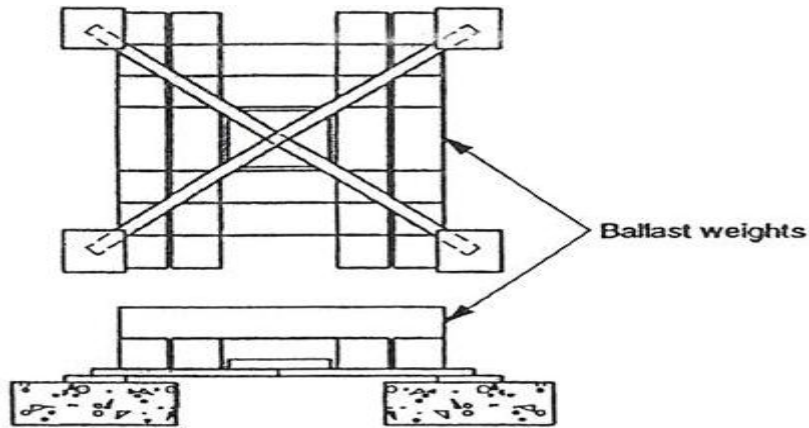


Figure 2.16.b: Layout of tower crane base.

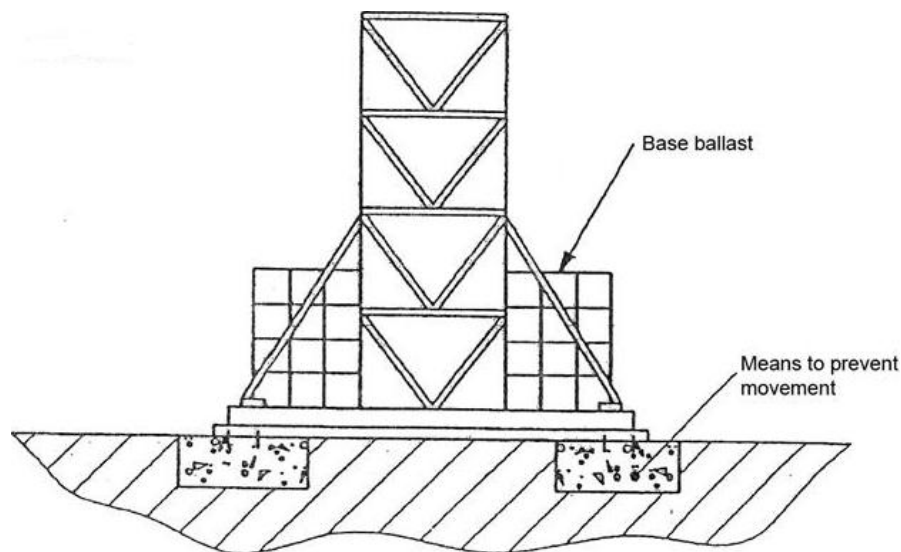


Figure 2.16.c: Foundation details.

2.8. Characteristics of tower cranes

Tower crane model has the following characteristics:

1. The largest non-subsidized rise to (80.9 m).
2. The crane can reach higher than this figure if they were linked with high construction crane on the building.
3. The greatest amount of access to (75 m).
4. Lifting capacity 9.1 tons to the major.
5. The resistance to the weight of 10 tons.

6. Weight over a larger crane can carry to 2.8 tons. Cannot lift the weight, if such a weight has been developed at the end of the arm. Whenever if it was closer to the force of gravity that crane can lift the weight in hands.
 7. The crane use keys (the identification keys) to secure the non-arrival of the weight (the mechanic) to more than the highest weight of the crane.
 8. The key work (the high weight) to check withdrawal cable, and to sure that the weight not increase up to the weight of 9.1 tons.
 9. The key (to the moment of the weight) to make sure that the proportion of (ton - m) of the serried ranks of weight not increase when they are moving through the crane arm.
 10. The head (cat `head) in the management unit to measure the size of the collapse of the crane arm in addition to increasing the sensitivity of the weight. To be sure, this process will be a big problem if one of these things falls down on the site.
- a) Provide basic information to all those involved in the planning and management of tower crane use.
 - b) Enable temporary works design for tower cranes to be standardised and experience shared.

2.9. Health and Safety in Tower Cranes

Some of the safety features that apply to handling tower cranes have already been mentioned. The safety of the structure itself is also worth emphasizing. All industrialized countries have standards to be met by cranes of all types. In Europe, tower cranes have their own standards.

2.9.1. Workplace Health and Safety

The complex, dynamic, and continually changing nature of construction work has been recognized as an important contributor to the high rates of injuries and fatalities in the industry. Cranes are a central component of many construction

operations and are associated with a large fraction of construction deaths; in fact, estimates suggest that cranes are involved in up to one-third of all construction and maintenance fatalities.

Safety and health professionals serving the construction industry need adequate training and knowledge regarding available crane safety devices and procedures so that they may insure these techniques and are effectively utilized during construction operations.

The HSE is issuing a safety alert to the construction industry to remind those working on projects where tower cranes are in use of the importance of the safe erection, operation, maintenance and dismantling of such cranes. This alert has been prompted by a number of serious incidents involving tower cranes in recent years.

2.9.2. The objective of the Workplace Health and Safety

The objective of the Workplace Health and Safety is achieved by preventing or minimising a person's exposure to the risk of death, injury or illness caused by a workplace, by a relevant workplace area, by work activities, or by plant or substances for use at a workplace. Should be based on the installation, operation and maintenance of tower cranes full commitment to follow the technical assets and safety precautions and safety in their respective field of specialization. It also must be available catalogs maintenance and operation of each crane (crane), issued from the manufacturer with the need to see a technical Specialist to guide them in all stages.

2.9.3. Responsibilities in the Tower Crane Site Place

The responsibilities may be concerned by the owner, site supervisor and crane operator as follows:

(1). Responsibilities of the Owner were summarized as follows:

1. Provide safe suitable equipment.

2. Develop qualified operators for cranes.
3. Define equipment management for all parts.
4. provide specific jobs training for crane`s labours.
5. Write the records of cranes processing in the projects.

(2) Responsibilities of the Site Supervisor were summarized as follows:

1. Supervise plans of operations in the site.
2. Should up the responsibility for Lift loads for crane.
3. Guide the operators for the Load Weight Information.
4. Ensure Capability of Rigging Crew.
5. Designate competent signallers.
6. He has overall Safety of job Site.

(3) Responsibilities of the Crane Operator were summarized as follows:

1. Provide crane safety and operation.
2. Know and covering the Crane uses.
3. How to Read Charts.
4. Provide proper maintenance and inspection if needed.
5. Assist manufacturer to the Guidelines.
6. Familiar to the Log Books and write the Records.
7. Familiar to the Load Information data.

2.9.4. The precautions and Regulations of Tower Cranes

The precaution can be taken when choosing installation site, during its installation and operation of tower crane.

2.10. Tower Cranes Accident and Failures

During lifting operations. The results showed the use of mobile cranes with lattice and telescopic booms, truck or crawler mounted, represented over 84 percent of the fatalities in the use of cranes derricks.

Of the cranes that were specified in the fatality, mobile, truck and rail mounted cranes, and overhead cranes represented the type of crane involved for the majority of fatalities. Overhead cranes typically have a hook-and-line mechanism on a horizontal beam that runs along two widely separated rails, whereas mobile cranes are usually cranes that are mounted and travel on top of mobile devices such as trucks or rail cars.

2.10.1. Categories of Crane Accidents:

The crane accidents fall in four categories:

1. Tipping occurs when the operator handles a load that exceeds the stability rating of the machine for a given weight and load radius.
2. Structural failure occurs when a load is lifted that exceeds the crane's structural limitations.
3. Rigging occurs when the item being picked is not properly rigged or connected to the load block or headache ball.
4. Electrocution occurs when the operator allows the load, line or boom to come in contact with an energy source (overhead power line). Most crane accidents are easily prevented.

2.10.2. Accidents of Cranes in Sudan:

In the record history of cranes in Sudan in construction industry areas there were no multiple fatality incidents involving cranes, that may return to lower number of cranes in the country or simplified uses of this crane which refers to poor construction industry .more over there were no specific studies on these field to indicate if it happened or not; or may it happened and there were no recording for these cases.

2.11. Tower Cranes in Sudan:

Tower cranes in **Sudan** are one of modern equipment's, which are intimately linked to developments in the field of architectural installations. However, the

evolution of the facilities and the use of engineering materials in the construction industry more than three times the development of handling equipment and construction in general. Where is the use of tower cranes in charge of the means in the construction industry are not used except in the case of large projects yielding substantial material; so that it covers the cost of this machine. Tower cranes were being used in the early seventies of the last century in the project of building insurance in (KHARTOUM) city, where it imported by a real estate development company; then successively enter cranes to the construction market by different companies, the Sudanese company like Danfodiyo and other companies.

The uses of tower cranes in **Sudan** reveals good indicators function on the rise and progress of the construction industry in the right direction, but that the amount of cranes in the existing facilities is not the right amount to considerable need in the growing market requirements of modern technology to suit the spectacular development. The slowing in the spread of these levers in different work sites refer to many reasons including the high cost of importing such equipment, where Mohamed Abdullah said (who is a pioneer and an expert in the machinery):“the delay in the entry of such equipment to the Sudan to that ignorance on these machines and the lack of sufficient experience which led to the reluctance of contractors and engineering companies to enter into this adventure. Researcher during a visit to many of the workplace became clear that the reasons for lastly the evolution of this technology for the following reasons:

- 1- High costs of purchase or lease or installation.
- 2 - The high value of private insurance when the cranes on-site installation.
- 3 - Not full knowledge of the work of this equipment.
- 4 - Lack of safety factor and the full safety of these facilities.

There are new many tower cranes appeared in the field of real estate and marketing of multi-storey residential buildings, which serves as a catalyst for the acquisition of national experiences of new technologies, if these companies to train manpower in this area.

Notes that the technical condition of the past tower cranes located at the sites considered in the case of medium-or less-than-average, because most of the cranes was either imported or purchased after running out of time to the first company of the concessionaire.

2.12. Marketing and Sales of Tower Crane:

There are many of the construction companies working in the field of construction, architecture and tall buildings to erect tower cranes over these projects to operating the functions of handling of the materials, and transport from one location to another. But for the costs of purchasing may be a barrier to set up the cranes. Therefore, the practice of some manufacturers of these cranes interest to renting side by side with marketing and sales.

However, it was found that the marketing of these cranes holds the biggest side to the most of the manufacturers and this is due to the profitability of sales away from the fast to get involved in maintenance and security of the leased areas that were viewing after the recession of some late models.

CHAPTER THREE

ANALYSIS OF TOWER CRANES

3.1 Introduction

The main purpose of any structure is to carry loads over or round specified spaces and delivers them to the ground. All relevant loads and realistic load combinations have to be considered in design.

Tower crane is steel structure manufacture for handling materials and carry heavy loads from position to another position, due to carrying loads and movement of the machine there will be loads applied to the crane and which changes it to the ground.

3.2 General Loads

ASCE 7 – 10 classifies working loads into the following traditional types:

1. Dead loads due to the weight of the structure materials. Accurate assessment is essential.
2. Imposed loads due to people, furniture, materials stored, snow, erection and maintenance loads. Refer to ASCE 7 – 10.
3. Wind loads. These depend on the location, the building size and height, openings in walls etc. Wind causes external and internal pressures and suctions on building surfaces and the phenomenon of periodic vortex shedding can cause vibration of structures. Wind loads are estimated from maximum wind speeds that can be expected in a 50-year period. They are to be estimated in accordance with ASCE 7 – 10.
4. Dynamic loads are generally caused by cranes. The separate loads are vertical impact and horizontal transverse and longitudinal surge. Wheel loads are rolling loads and must be placed in position to give the maximum moments and shears. Dynamic loads for light and moderate cranes are given in ASCE 7- 10

3.3 Types of Loading in Tower Crane

Loads applied to the tower crane structure consist of those which can be applied when the crane is working, when lifting and moving loads and those that will be imposed even when the crane is not working. The tower crane structure, components and the foundations are all required to safely carry these loads. The crane structure will have been designed to carry these loads, which will include dynamic effects of the load, movement of the crane and wind, within the scope of the prevailing standards for crane design

3.3.1 Structural Loads

The structural loading arises from the weights of the tower crane, its components and loads carried and their position in relation to the tower. Weights carried at the tip of the jib generate much larger overturning moments than those carried close to the axis of the tower. Any non-verticality of the tower may also add to the moment.

3.3.2 Wind Loading

Wind is comprised of a random fluctuating component called turbulence superimposed on a steady mean wind speed. These are summed to give the gust wind speed. Wind speed increases with height above ground. Therefore, what feels like a gentle breeze at ground level will be stronger in the cab of a tower crane? For example in city centre locations the gust wind speed at a height of 100m will be approximately twice as strong as the gust wind speed at pedestrian level (excluding effects from nearby buildings). The occurrence of a particular gust wind speed at a particular location and time is not something that can be predicted. Because of the random nature of the wind all modern wind loading Codes and Standards use a combination of statistical and empirical methods to predict wind speeds for a given probability of exceedance usually presented in terms of a return period. The loading depends on the nature of the disruption to the flow,

which will vary with the shape of the structural element. The wind force on the structure or element is obtained by multiplying the dynamic wind pressure by pressure (or force) coefficients and the area over which the wind load acts.

- The maximum wind speed that the crane is designed to operate in the service position (varying between 14 and 28 m/s).
- the maximum wind speed at which the crane is designed to remain stable in the out of service position (varying between 36 and 47 m/s depending upon height above ground level). The total wind load on the crane structure is calculated from the sum of the loading on each component.

Referring to ASCE 7-10 for simplified procedure, one can notice that the simplified procedure is applicable only to building with mean roof heights less than (9 m), which is not applicable to building of this study. The wind tunnel procedure consists of developing a small scale model of the building for testing in wind tunnel to determine the expected wind pressure etc. It is expensive and may be utilized for difficult or special situations. The analytical procedure is used in most .It is fairly systematic but some that complicated to account for various situations that can occur. Wind velocity will cause pressure on any surface. The velocity pressure depends on the height from the ground level. The following equation is recommend by ASCE 7-10 CODE of practice for calculation the velocity pressure, q_z , resulting from winds:

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

Where:

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

K_d : is directionality factor from Table (3.2)

K_{zt} : is topographic factor

$k_{zt} = 1$ for flat ground

k_z : varies with height z above the ground level obtained from Table (3.4)

I: is the importance factor obtained from Table (3.3)

$P_z = q_z G C_p$ For windward positive pressure

$P_z = q_h G C_p$ For leeward positive pressure

Table 3.1: External pressure coefficient.

Surface	L/B	C_p
Windward walls	All values	0.8
Leeward walls	0-1	-0.5
	2	-0.3
	≥ 4	-0.2
Side walls	All values	-0.7

Table 3.2: Wind directionality factor k_d .

Structure type	Directionality Factor k_d
Building	
Main wind force resisting system	0.85
Components and cladding	0.85
Arched roofs	0.85
Chimneys, Tanks, and similar Structure	
Square	0.9

Hexagonal	0.95
Round	0.95
Solid sign	0.85
Open sign and lattice formwork	0.85
Trussed Towers	
Triangular , square , rectangular	0.85
All other cross sections	0.95

Table 3.3: Importance factor, I (wind load).

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

Table 3.4: Velocity pressure exposure coefficient K_z .

Velocity Pressure Exposure Coefficients $K_z^{a,b}$				
Height above Ground Level , Z		Exposure Category		
Ft	(m)	B	C	D
0 – 15	0 – 4.6	0.57	0.85	1.03
4	6.1	0.62	0.90	1.08
25	7.6	0.66	0.94	1.12
30	9.1	0.70	0.98	1.16
40	12.2	0.76	1.04	1.22
50	15.2	0.81	1.09	1.27
60	18	0.85	1.13	1.31
70	21.3	0.89	1.17	1.34
80	24.4	0.93	1.21	1.38
90	27.4	0.96	1.24	1.40
100	30.5	0.99	1.26	1.43
120	36.6	1.04	1.31	1.48
140	42.7	1.09	1.36	1.52
160	48.8	1.13	1.39	1.55
180	54.9	1.17	1.43	1.58
200	61	1.2	1.46	1.61
250	76.2	1.28	1.53	1.68
300	91.4	1.35	1.59	1.73
350	106.7	1.41	1.64	1.78
400	121.9	1.47	1.69	1.82
450	137.2	1.52	1.73	1.86
500	152.4	1.56	1.77	1.89

3.3.3. In Service Loading

It may include the following:

- Dead loads - weights of the tower crane components
- imposed loads - weight of the load being lifted
- Live loads - wind loading

Dynamic effects may result in additional loads caused by movements such as:

- hoisting
- slewing
- trolleying
- luffing
- travelling

It may be noticed that affect both dead and live loads are included in the crane manufacturers' calculated sheets data base.

3.3.4. Out of Service Loading

It may include the following:

- Dead loads - weights of the tower crane components
- Live loads - wind loading

The out of service loadings will only be valid for the crane left in the manufacturer's specified out of service condition. This is normally with the crane in the free slew condition so that the jib wills "weathervane" and always presents the minimum wind area, thereby minimising the overturning moment due to wind pressure. On luffing jib cranes it is also important to set the jib radius to the Specified value to ensure that the crane can weathervane. Travelling cranes should be clamped to the rails. In some cases a crane jib may need to be locked for example to prevent weather vanning over a railway; this special condition must be discussed with the crane supplier as it will Cause higher loads than anticipated To the tower crane and its ties and foundations

3.3.5 Foundation Loads That are Supplied With the Crane

When the crane is in service, there will be limitations on the wind speed that can be safely tolerated these will be specified by the crane manufacturer or supplier.

3.3.6 Other Loading

The particular forces applied during erection, reconfiguration or dismantling operations should also be considered when designing the foundation or ties to other structures. These forces may in some circumstances be the highest loads transmitted by the tower crane to its support structures. There will be limits on the weather conditions in which these activities can take place. All tower cranes assembled on site are required to be tested with an overload after erection. The loads applied during this operation, when following the manufacturer's instructions, will have been accounted for in the crane design and loading information supplied for temporary works design. In some locations, for example in high earthquake hazard areas or near to plant that generates significant ground-borne vibration; further loads may be applied that the tower crane and its foundation must resist.

3.4 Loads Applied to the Foundations

Tower crane foundations need to be designed taking into account both in-service and out-of-service loads. These result in forces and moments at the base of the crane tower which must be resisted by the foundation if the crane is to remain upright .

3.5 Determination of load vectors data

A tower crane rests on a foundation. At the point of contact, it is subject to four basic forces:

1. Vertical forces
2. Horizontal forces
3. Forces that result from slewing (v base)

4. Forces that are exerted by the load and that work to “overturn” the crane.

Two other items must also be considered:

- (1). possible tilting of the crane during erection.
- (2). the freedom of the crane free to “wind vane” at all times.

The infrastructure is designing to carry over the loads applied from up mentions vectors with suitable safety margin as shown in figure 3.1. The result is look like downsizing only, but the actually it fixed the crane also from swaying, for that the foundation or the infrastructure are considered to be the key of balancing of the crane.

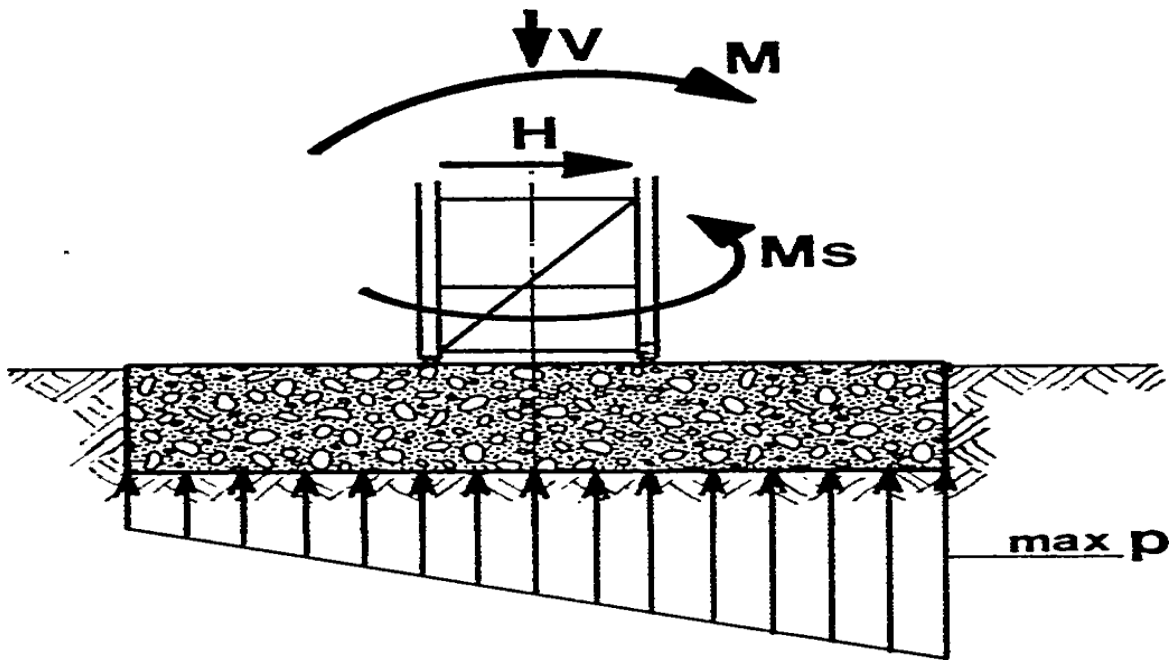


Figure 3.1: Shows the load vectors of tower crane.

3.6 The theory of loading

In practice, the geometry of the crane creates two ranges: the heavy load range and the reduced load range. Within the heavy load range, the capacity of the crane is taken as being Constant. When the rating of a load moment crane is stated, this is its load moment at the outermost radius of the heavy range, the point known as the HV. Figure 3.3. Shows these ranges for a horizontal-jib and a luffing-jib crane.

The load moment are vary from crane to crane depending on the radius of that crane ,also the capacity of crane is variable to positions of loading from the center of crane , in simple way that the capacity of the extreme radius of crane is less than the capacity of close radius .

3.7 Load combinations

The load combinations of crane according to the code American Institute of Steel Construction (ASCE 7 – 10) part as follows:

1. D_L
2. $D_L + L_L$
3. $D_L + 0.75L_L$
4. $D_L + 0.75(0.6W_L)$
5. $0.6D_L + 0.6W_L$

3.8 The impact factor

The impact factor shall apply to the motion of the hook load in a vertical direction and covers inertia forces including shock. In calculating live loads in members of the structure, the hook load shall be multiplied by the impact factor given in Table 3.5 appropriate to the type of crane and its application.

Table 3.5: The impact and duty factors according to crane type and application.

Type and/or application	Impact factor	Duty factor
Normal duty: general use on building sites	1.2	0.95
Medium duty: general use at a permanent location, etc	1.3	0.95

3.9. Design of Tower Crane Component

In this section design of all components of tower cranes is presented in flow chart. The flow charts design for the tension member, compression member, cable connection and base plate were done as shown in Figures 3.2 –3.6.

The excel spread sheets were used in design compression member, tension member, cable and connection.

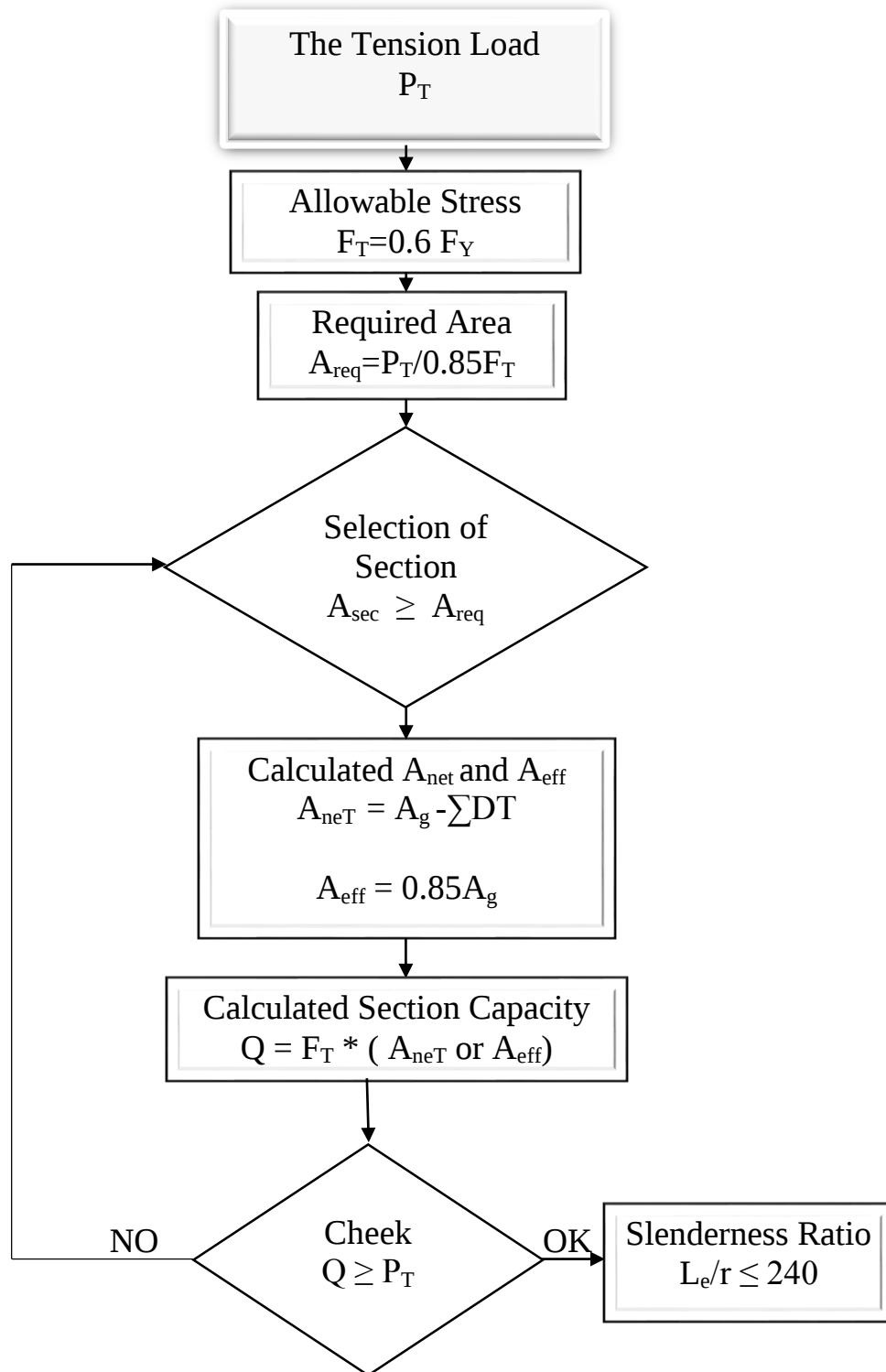


Figure 3.2: Flow chart for Design of Tension members.

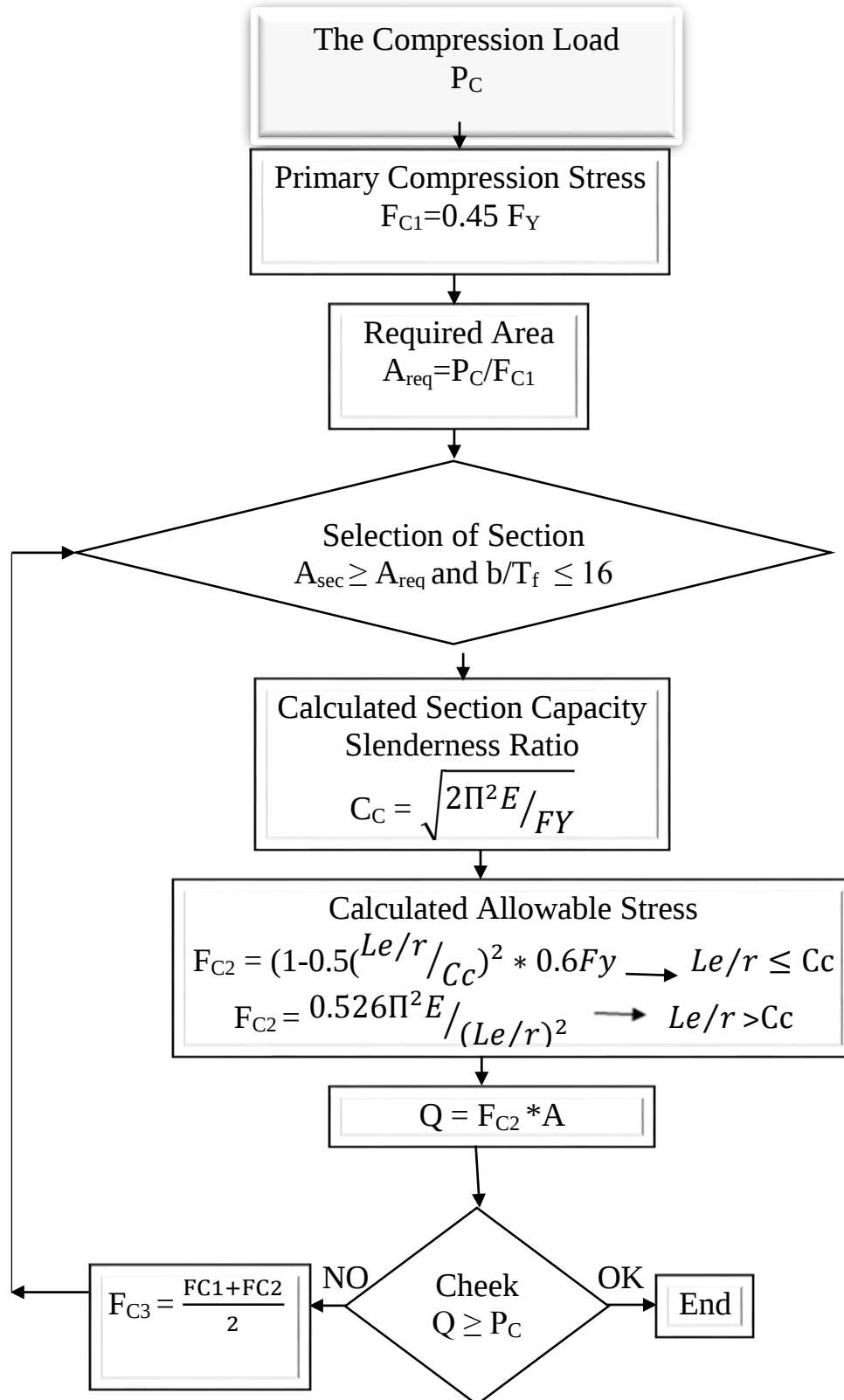


Figure 3.3: Flow chart for Design of Compression members.

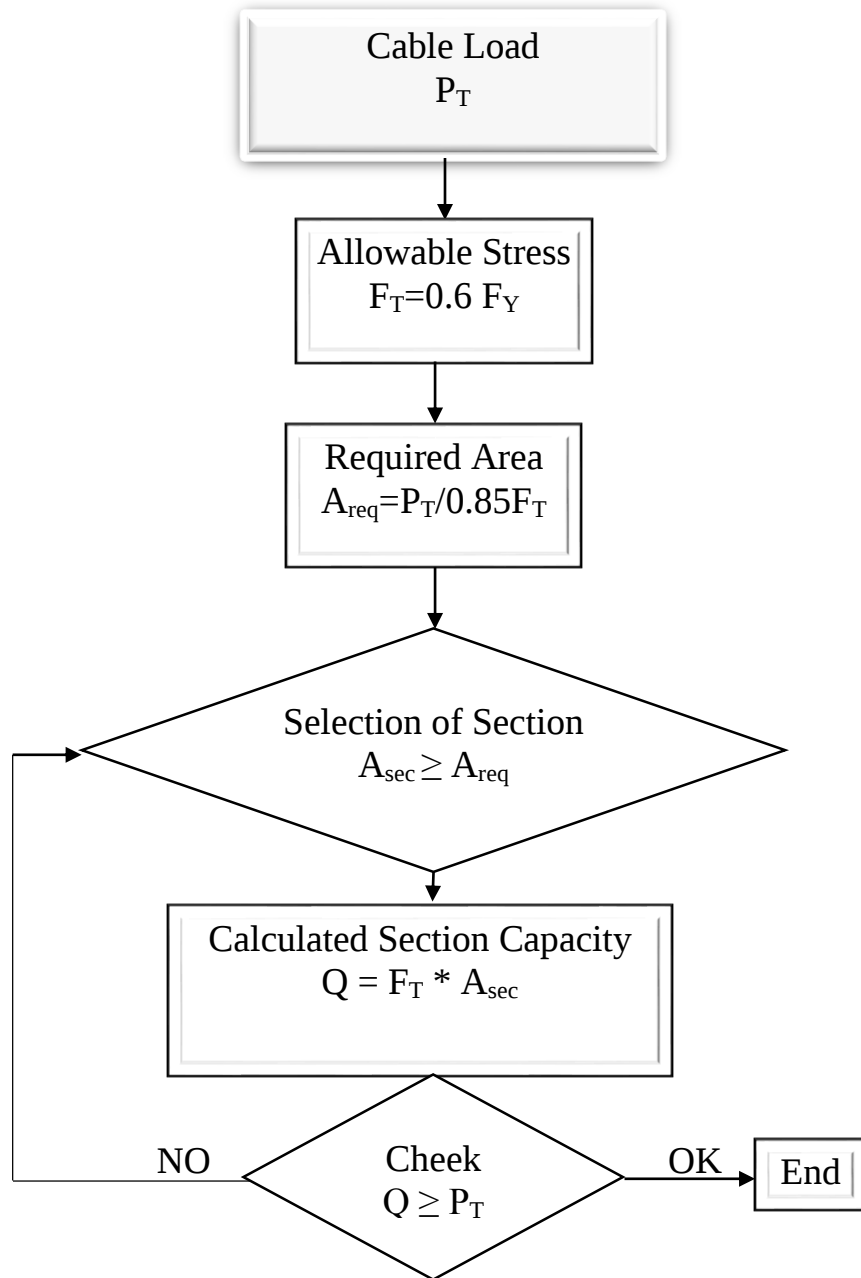


Figure 3.4: Flow chart for Design of Cables.

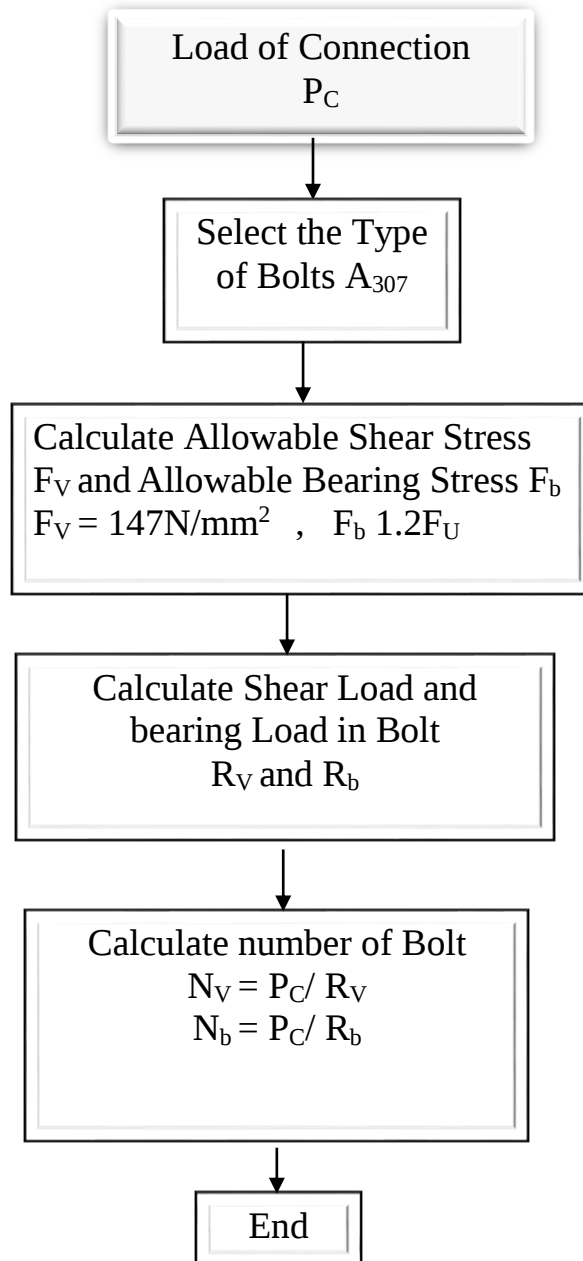


Figure 3.5: Flow chart for Design of Connections.

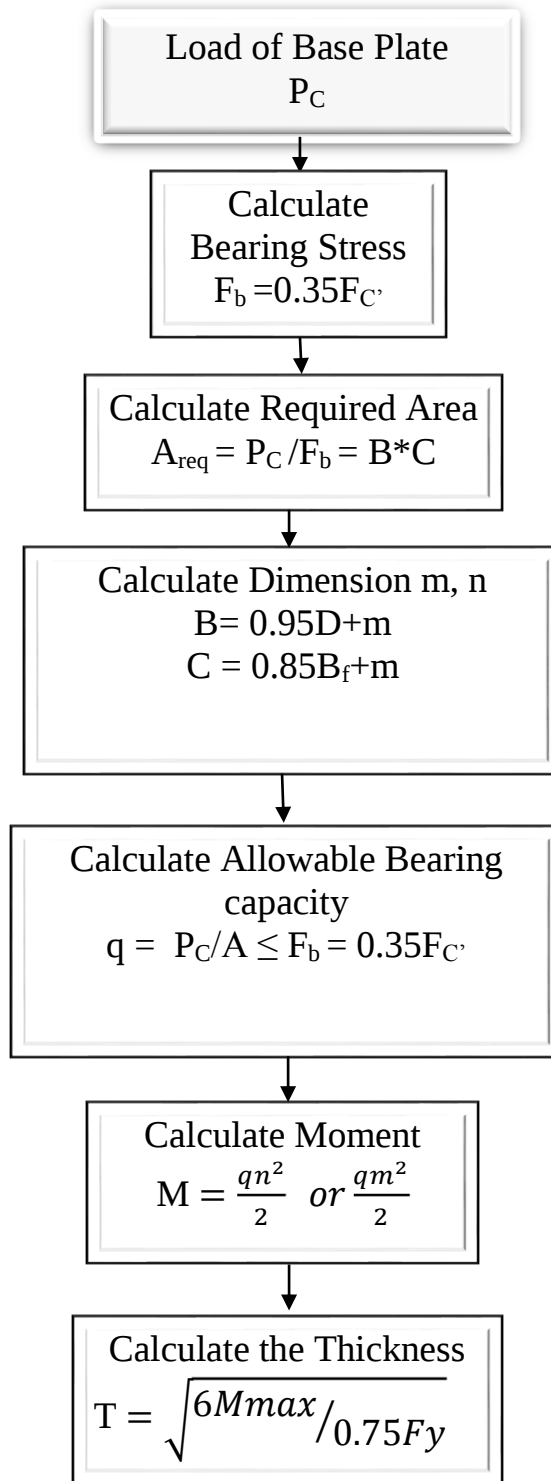


Figure 3.6: flow chart for Design of Base Plate.

3.10. Analysis of the Case study of the Research

In this study the data was collected from previous projects as follows:

- 1- maximum loads hoisting in the projects
- 2- height of the building that may use tower crane
- 3- effects of nearby building around the project and the direction of wind loads
- 4- the diagonal diameter of the building to calculate long arm of crane
- 5- The medium wind speed.

Then the researcher suggested model with suitable dimension and compatible with input data .then the researcher input the data in dialogues box of the program to analysis it in linear analysis for complex tower crane. The main assumptions of analysis tower crane:

1. there is a motor assistant the crane to rotate about Y direction to transit the loading from side to side and floor to other and that may decrease the caring of the effect of deflection in X and Y.
2. The effect of impact load is to be neglected due to valid breaks, which must be checking before starting motors.
3. Live load of the labours and the movement of handling hoist load are less than that value of dead load and the wind load.
4. The calculations of the wind load assume to be in moderate case as the speed of the wind.
5. For that the assumption may differ in worse case like stream or any bad climate.

3. 10.1 Methods of Analysis of Tower Crane

The aim of structural analysis is to evaluate the external reactions, the deformed shape and internal stresses in the structure. Crane is an example of space truss, Figure 3.7. Show space truss in which members may be oriented in any

direction. However, members are subjected to only tensile or compressive stresses.

A space frame classified as structure whose members not all lay in the same plane, tower cranes were fall into this classification. Tower cranes also classified as indeterminate structure apply equally to three dimensional vectors in X, Y and Z.

A space truss is a three –dimensional assemblage of line members, each member being jointed at its ends to the foundation or other member by frictionless ball-and-socket joints. In order to form stable (or rigid) space truss, a sufficient number of members have to be used and these have to be arranged in suitable manner. The simplest stable space truss consists of six members jointed to form a tetrahedron.

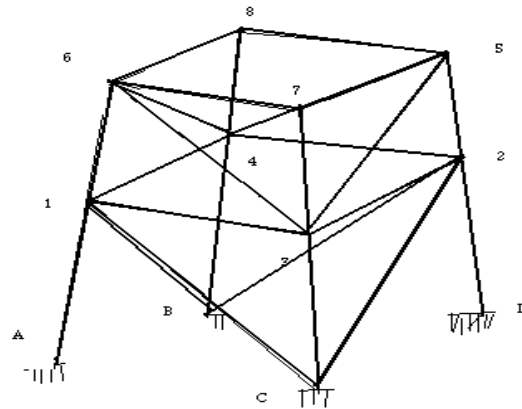
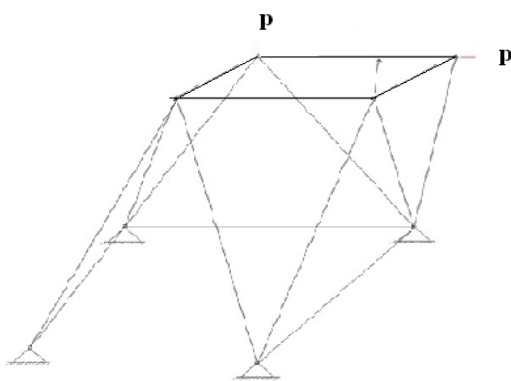


Figure 3.7.a. The forces in space truss Figure 3.7.b. Complex space truss

Space trusses of all types, simple, compound, or complex as shown in Figure 3.9 can be efficiently analyzed by the matrix computer methods. Internal or external in determinacy presents no problem, and unsuitable arrangement of members that lead to instability can be detected. Hence, methods of any analysis of space trusses by hand have little value as practical tools. However, analysis by hand of suitable chosen determinate space trusses inculcates a mastery of principle of statics and an ability to apply them.

All determine space trusses can be analyzed by method of joints. If there are j joints, then since there are three equations:

$$\sum P_x = 0, \sum P_y = 0, \text{ and, } \sum P_z = 0$$

To each joint, there will be a total of three equations, if the truss is rigidly attached to the foundation, then the unknown are the M member forces.

The number of equations will be exactly equal to the number of unknown. Note, however, that it is always possible to set up the three equations and solve them formally; it is rarely desirable to do so. In any case, for a simple space truss it will not be necessary to solve more than three simultaneous equations at a time. By definition, in any simple space truss there is at least one joint and the last joint to be established in accordance with the rule and then working backwards joint by joint, it would be possible to determine all member forces without solving more than three simultaneous equations at a time. For the more complicate case of compound space trusses it may be necessary to solve more than three simultaneous equations at a time; for complex space trusses should in general be solved by computer methods. There are many methods were used in analysis of tower crane depending on the type of software for the program, where the common programs are used finite elements method.

3. 10.2. Short brief about computer aided analysis and design

With the progress in structure engineering in all types of engineering, electrical, mechanical, etc. and so on there appeared computer programming for multi uses like analysis, design, graphics, mapping and other kind of engineering parts. Moreover, from 1930 or before Second World War engineers managed to solve the problems complicated sciences with avoiding mistakes in calculations and provide short time to make decision. Also, briefing of procedures of analysis and design, which may help engineers to compress the stages of projects.

Structural programs are used for two main targets in design process. The first one is to make procedural programming that enables engineers to shorten the time of calculations in a little time by using of CAD features and to minimize the design time. The second step to use computer Intelligence techniques selection and decision making stages of the design process.

Structural programs which use CAD techniques in their process had a wide spread in engineering fields that for simplified uses in steps and learning. Also, powerful of results had merits in hand out sheet for engineers. A famous program is STAAD PRO, ETABS, SAP, SAFE, PROKON, EXCIL SPREAD SHEET and many programs which deferent from country to another depending on standards codes, type of analysis method, units and output of presentation or outlook for interface of the program.

The researcher in this research used SAP2000-v18.0.1 program, which are familiar in engineering fields in SUDAN, easy to learn it and the researcher has an experience in this program.

The uses of structural program mainly not limit in deal with techniques of this types of program but moreover to enables with deferent engineering theorems from understanding elasticity, plasticity, finite element method passing to static and dynamic analysis Finally to the standards codes, units, materials and proprieties of the materials.

3.10.3. Background About SAP2000-v18.0.1 Program

SAP2000-v18.0.1 program is a structural program for analysis and design structures. The idea of program started from drafting module for model generation. It may include:

Gravity load distribution module for the distribution of vertical loads to columns and beams when plate bending floor elements are not provided as a part of the floor system.

Seismic and wind load generation module.
Output display and report generation module.
Steel frame design module.
Concrete frame design module.
Composite beam design module.
Shear wall design module.

Structural Analysis and Design SAP2000-v18.0.1 is a suite of over thirty structural analysis, design and detailing programs. The first **SAP** programs were developed in 1989, and today **SAP** is used worldwide in over eighty countries. The suite is modular in nature, but its true power lies in the tight integration between analysis, design and detailing programs.

Structural Analysis and Design The software provides quick and reliable answers to everyday structural and geotechnical engineering problems such as is developed by a team of professional engineers and aimed for use by structural engineers and technicians. The software provides quick and reliable answers to everyday structural and geotechnical engineering problems such as:

- Frame and finite element analysis
- Steel member design
- Steel connection design
- Reinforced and pre-stress concrete design
- CAD and reinforced concrete detailing
- Timber member design
- Masonry design
- Other structural applications such as section properties calculation and section database

A collection of geotechnical analysis modules is also available as part of the **SAP** suite.

3.10.4 The Loads calculation for Case Study

From the roles mentioned above its clear that the state of crane in service with wind will be a considerable case for this study as follows:

Dead load +Live load +Wind load

The dead load of the whole structure= the weight of the crane +hook load + counter ballast load + Hoist gear unit load

Weight of the crane will be automatic calculated from the program

Hook load according to Liebherr catalogs the weight of hook =0.913 ton = 9kN

The hoist load = 2.8 ton=28kN

The load of the counter ballast in catalogue approximately to 10000 kg and the weight of Hoist gear unit as 5ton. Which it equal to =15 ton =150 kN

The live loads in member including the hoist load multiplied by the impact factor = $28 \times 1.3 = 36.4$ kN

Total load = live load including impact factor + weight of hook = $36.4 + 9 = 45.4$ kN

Wind pressure calculated in both directions:

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

V= wind speed take 47 m/s. For both direction.

$$k_d = 0.85$$

$$I = 1$$

$$k_{zt} = 1$$

For tower crane.

$$V = 47 \text{ m/s}$$

$$q_z = 0.613 * k_z * 1 * 0.85 * 47^2 * 1 = 1150.99 k_z \text{ N/m}^2$$

$$k_z(5.8) = 0.61$$

$$q(5.8) = 1150.99 * 0.61 = 702.1 \text{ N/m}^2$$

$$k_z(80.9) = 1.301$$

$$q(80.9) = 1150.99 * 1.301 = 1497.45 \text{ N/m}^2$$

$$P_z = q_z * G * C_p$$

The gust effect factor for a rigid building or other structure is permitted to be taken as $G = 0.85$.

$C_p = 0.8$ for windward surface.

$$P_z(5.8) = 0.85 * 0.8 * 702.1 = 477.428 \text{ N/m}^2$$

$$P_z(80.9) = 0.85 * 0.8 * 1497.45 = 1018.266 \text{ N/m}^2$$

$C_p = -0.5$ for leeward surface, because $L/B = 1$

$$P_h(5.8) = 0.85 * -0.5 * 702.1 = -298.392 \text{ N/m}^2$$

$$P_h(80.9) = 0.85 * -0.5 * 1497.45 = -636.416 \text{ N/m}^2$$

$$P(5.8) \text{ total} = P_z(5.8) - P_h(5.8)$$

$$P(5.8) \text{ total} = 477.428 - (-298.392) = 775.82 \text{ N/m}^2$$

$$P(80.9) \text{ total} = P_z(80.9) - P_h(80.9)$$

$$P(80.9) \text{ total} = 1018.226 - (-636.416) = 1654.642 \text{ N/m}^2$$

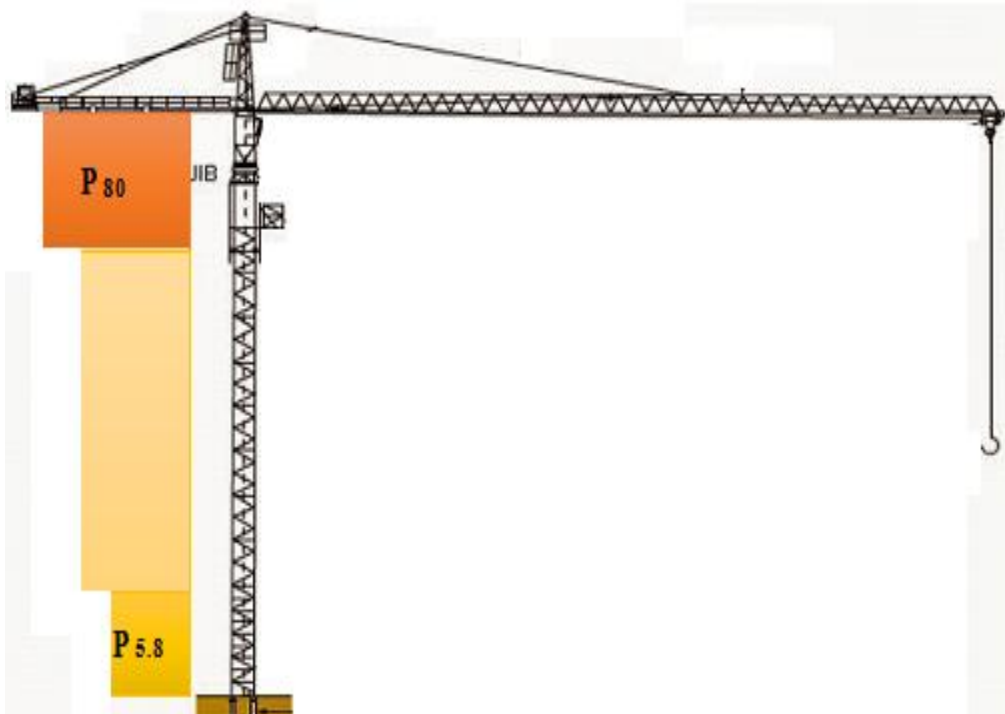


Figure 3.8. The wind pressure on tower cranes.

Table 3.6: wind pressure on tower cranes.

Z (M)	K _Z	P _Z (KN/M ²)	P (KN) Windward in tower crane(1-2)	P (KN) leeward in tower crane (1-2)	P (KN) Windward Tower crane (3)	P (KN) leeward Tower crane(3)
5.8	0.61	0.477	0.564	0.352	0.620	0.387
11.6	0.748	0.585	0.692	0.432	0.760	0.474
17.4	0.841	0.657	0.777	0.486	0.854	0.534
23.2	0.914	0.714	0.845	0.529	0.928	0.581
29	0.975	0.762	0.902	0.563	0.990	0.618
34.8	1.025	0.801	0.948	0.593	1.041	0.651
40.6	1.072	0.838	0.992	0.620	1.089	0.681
46.4	1.114	0.8711	1.031	0.644	1.132	0.707
52.2	1.152	0.900	1.065	0.666	1.170	0.731
58	1.185	0.926	1.096	0.685	1.203	0.752
63.8	1.214	0.949	1.123	0.702	1.233	0.770
69.6	1.245	0.973	1.152	0.719	1.264	0.790
75.4	1.275	0.997	1.180	0.737	1.296	0.809
80.9	1.301	1.017	1.204	0.753	1.322	0.826

3.10.5 Modeling of Tower Crane Geometry:

Before modeling the parameter of the geometry the researcher manage to determine the suitable shape with construction field in Sudan, which were depending on the data collected from different site as the length of arm of crane,

the height of the tower crane, wind speed in the mid of Khartoum and the nature of the general data of project Table 3.8.

Table 3.7: General data of project in tower cranes.

The parameter	Measure
The length of the arm of the Crane	75 m
The length of the counter Jib	22.55 m
The height of the tower crane	80.9 m
Wind load	0.775 -1.654 kN/m ²
Bearing capacity of the soil	200 KN/m ²
Weight of the ballast	10 ton max
Weight of max hoisting load	9.1 ton
weight of hook	0.913 ton
Hoist gear unit	5 ton

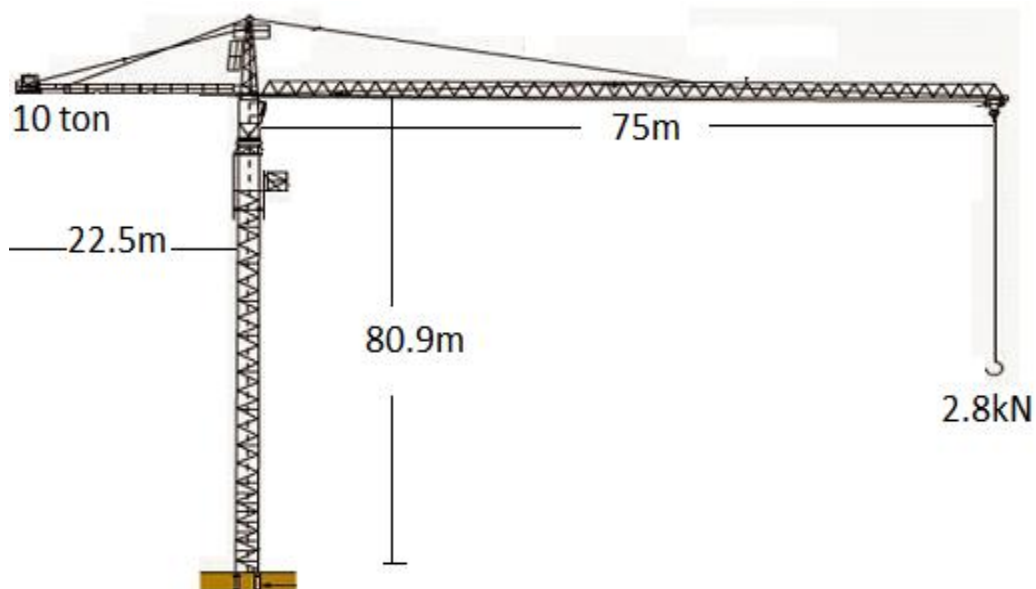


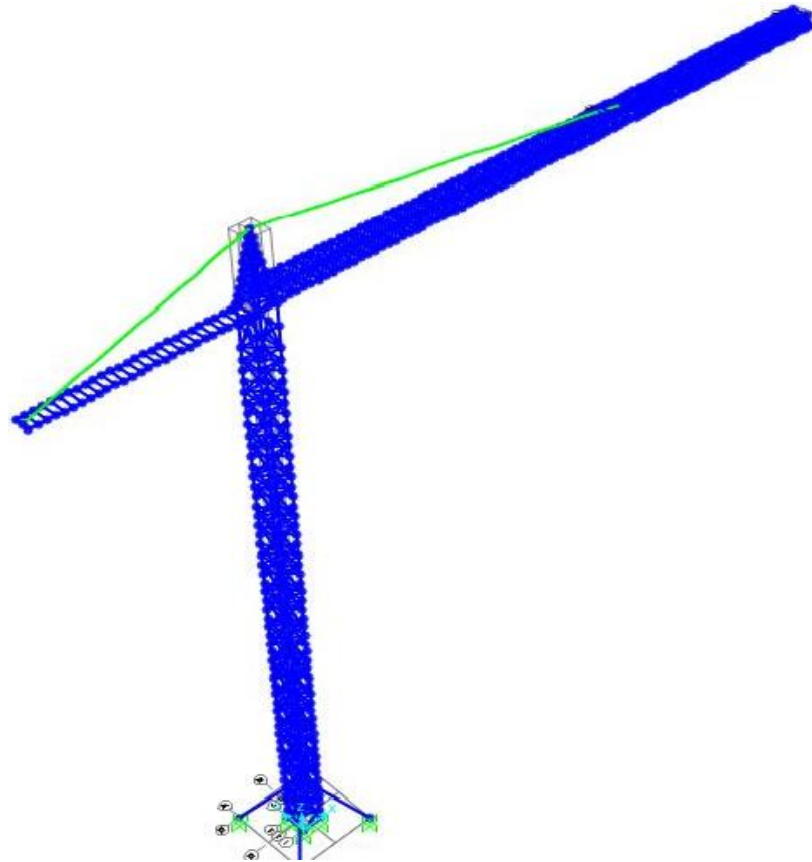
Figure 3.9. General data of project in tower cranes.

Table 3.8: Member types in tower cranes.

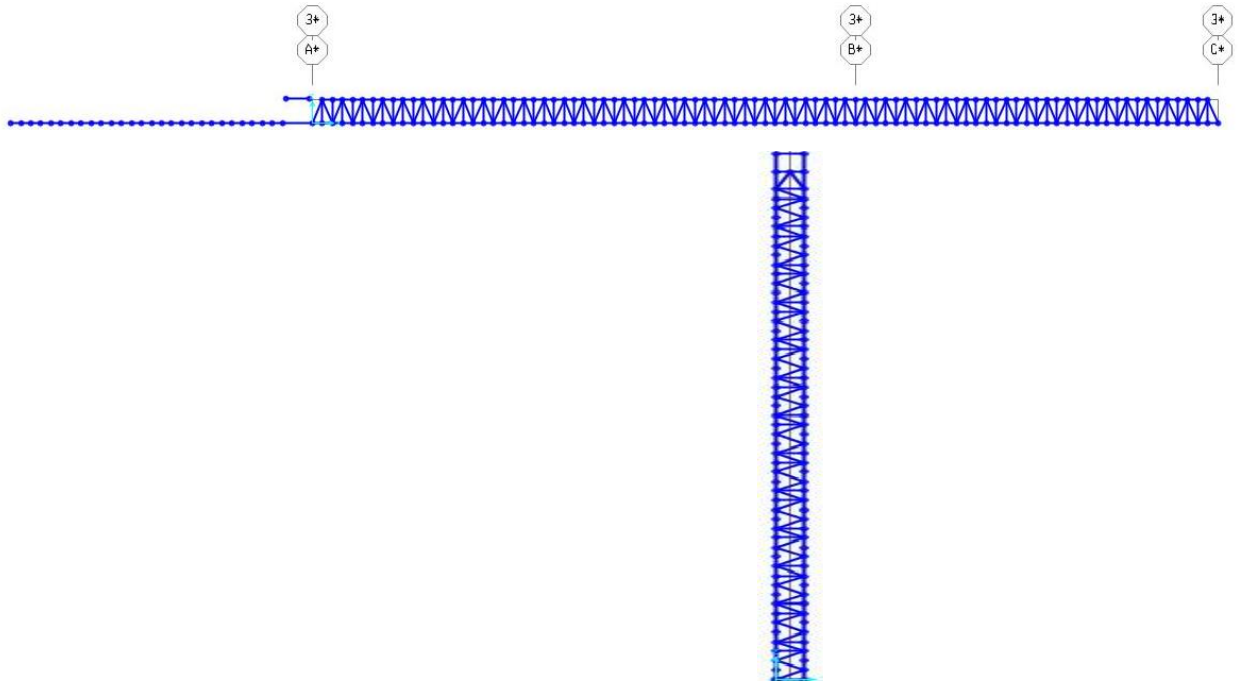
member type	Section
External main crane body	L 4X4X3/4
Internal main crane body	L 2-1/2X2-1/2X3/8
The jib arm	L 2-1/2X2-1/2X3/8
The cable diameter	55 mm

3.10.6. Structural Analysis of tower cranes

In this study, it was considered three models with different configurations and suitable dimensions to be compatible with input data. The linear analysis was carried out using structural analysis program sap 2000. Figures (3.10) - (3.12) show the configurations of tower crane models.

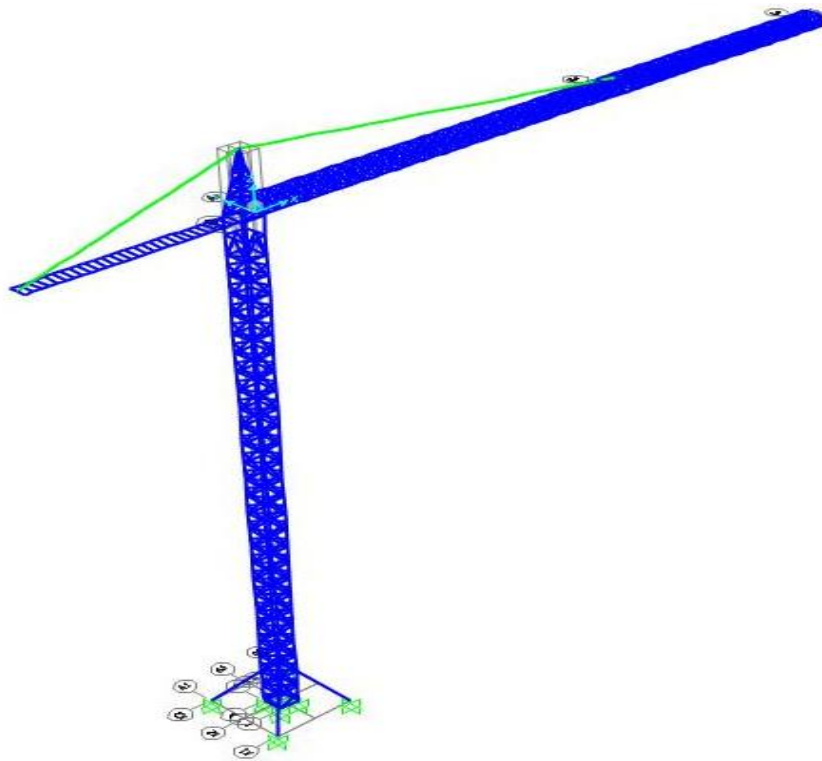


(a) 3D view

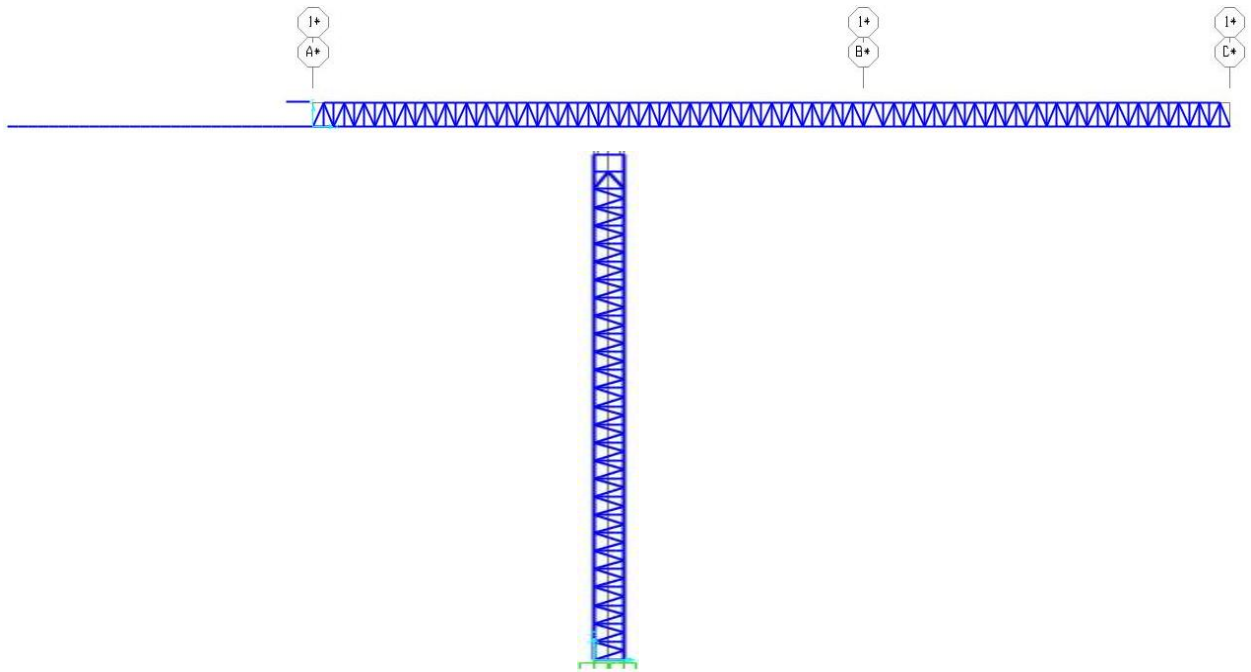


(b)Plane XZ

Figure 3.10. The configuration of tower crane (1)

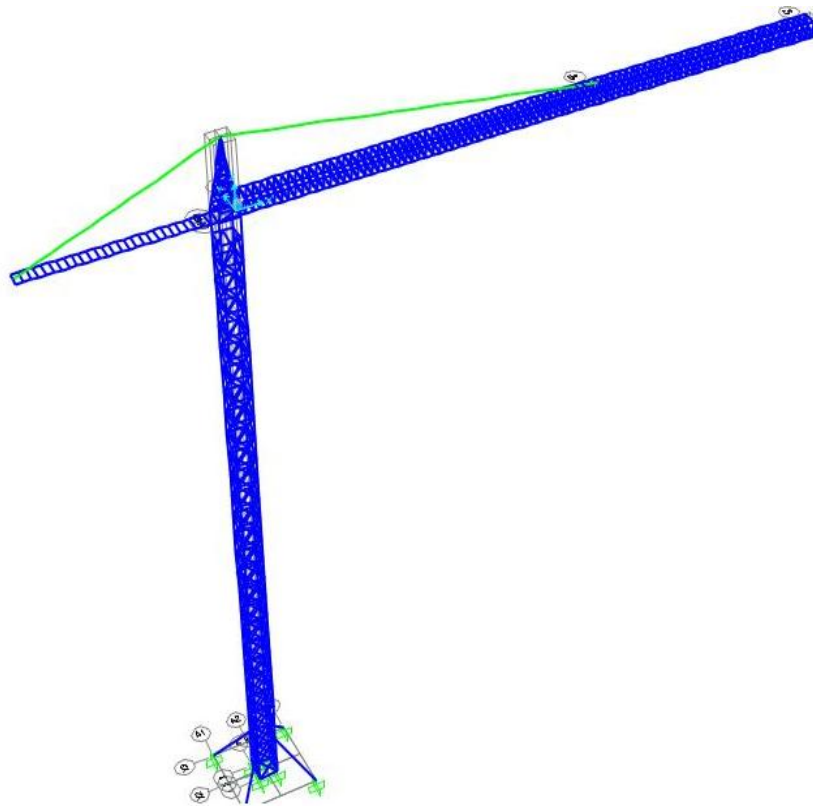


(a)3D view

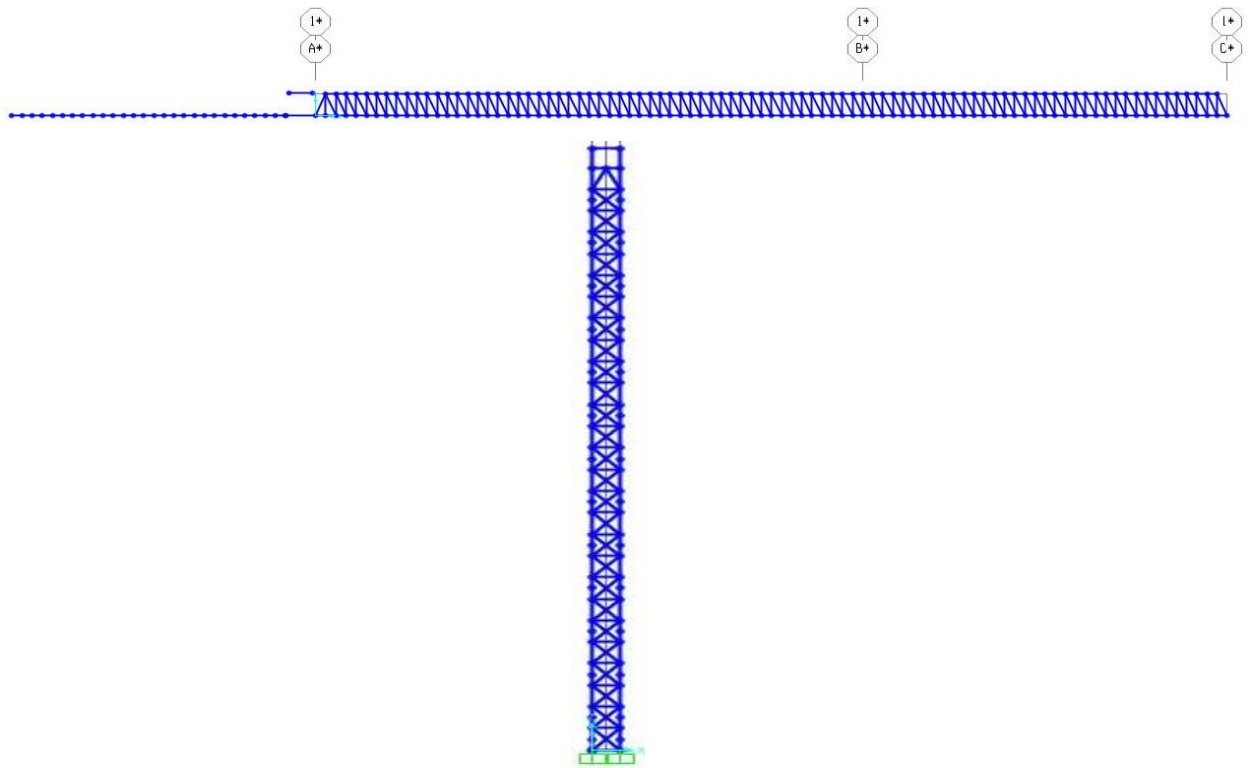


(b)Plane XZ

Figure 3.11. The configuration of tower crane (2).



(a)3D view



(b)Plane XZ

Figure 3.12. The configuration of tower crane (3).

3.10.7. Analysis results of tower cranes

The results of maximum axial forces in tower cranes components and the maximum displacement in X and Y directions and maximum deflection in working jip in tower cranes (1), (2) and (3) respectively.

Table (3. 9): The results of maximum axial forces, displacements in x- and y- directions and jib deflection in all tower cranes components.

Components	Axial force (KN)	Displacement in X direction (m)	Displacement in Y direction (m)	Deflection (m)
Main tower (1)	350.55	0.1027	0.1034	—
Main tower (2)	350.71	0.1284	0.1296	—
Main tower (3)	397.1	0.1423	0.1451	—
Bracing in tower (1)	28.49	—	—	—
Bracing in tower (2)	31.72	—	—	—
Bracing in tower (3)	40.78	—	—	—
Tie rod (1)	132	—	—	—
Tie rod (2)	129.77	—	—	—
Tie rod (3)	90.01	—	—	—
Working jip in tower (1)	222.43	—	—	0.3459
Working jip in tower (2)	229.26	—	—	0.3456
Working jip in tower (3)	282.02	—	—	0.2474

Counter jip (1)	438.87	—	—	0.2746
Counter jip (2)	436.9	—	—	0.2639
Counter jip (3)	573.95	—	—	0.2284
Bracing in working jip (1)	59.45	—	—	—
Bracing in working jip (2)	55.76	—	—	—
Bracing in working jip (3)	56.339	—	—	—
Cable (1)	3826.82	—	—	—
Cable (2)	3828.94	—	—	—
Cable (3)	3840.97	—	—	—

CHAPTER FOUR

THE STRUCTURAL PERFORMANCE AND DESIGN OF TOWER CRANES

4.1. Introduction

There are many codes used in tower crane design, which it different from country to country. The most common code used in wide world is American standard (AISC). In this study, Allowable Stress Design (ASD) is used of the design of the crane towers.

American Institute of Steel Construction (AISC 1997) that is used to design the steel elements of the mast and jibs of the crane.

Specifically for design criteria, stress calculations and specification of classification. It gives tables on how to determine what specification of a crane is needed by taking into account type, cycles, functionality and forces acting on it. This American Institute gives the steps of how to design any crane at any given certain constraints. The American Society of Civil Engineering (ASCE 7-10) is used to calculate the wind load on tower cranes.

American Concrete Institute (ACI310-14) is used in all reinforced concrete elements. This will be closely adhered to in the paramount design of the crane foundation. It will help in finding out the dimensions of the pad foundations and the sizing.

The factors of effect on design crane towers there are many factors effects on processes of design of crane, and must be concerning before the design like the conditions of crane, the shape of crane, size of elements of crane, temperature, wind load, height of crane, length of the jib crane, in –service and out–of service load of crane and the bracing of crane in the sides of cranes. The more important factors are the temperature, middle third rule.

4.2. Design of Components of Tower Crane (1)

In this section, the design of tower crane (1) components was done and the other two tower cranes design were presented in Appendix (A).

The design includes the main tower section, tie rod, bracing, working jib, counter jib, bracing in jib cable, connection and base plate as shown in table 4.1-4.8. The design all tower cranes was presented in Table 4.10.

Table 4.1: Design of Main Tower section.

		Compression				
$F_y (N/mm^2)$	250	K	1	$L(m)$	2.745	
$P_c (kN)$	350.55	$E(N/mm^2)$	200000	$L_e (m)$	2.745	
	$F_{c1}(N/mm^2)$	112.5	$A_{req}(m^2)$	0.003116		
	from AISC tables					
	SECTION DATA USE (ASD)					
USE	Area (m ²)	3.17E-03	$R_x (m)$	3.96E-02	$y(m)$	4.32E-02
AISC L 5*3 1/2*5/8 (Inch)	$D(m)$	1.27E-01	$I_y (m^4)$	2.01E-06	$x(m)$	2.42E-02
	$B_f (m)$	8.89E-02	$S_y (m^3)$	3.11E-05	$R_z(m)$	1.91E-02
	$I_x(m^4)$	5.00E-06	$R_y (m)$	5.59E-02	$T_f(m)$	1.59E-02
	$S_x (m^3)$	5.97E-05	$k(m)$	2.86E-02		
			check $\{B_f / (2 T_f)\} \leq 16$			
		$B_f / (2T_f)$	2.80E+00			
		check	ok			
	L_e/r_{min}	6.93E+01	Cc	125.6		
	$F_{c2}(N/m^2)$	126924989	Q(kN)	4.02E+02		
	check $Q(kN) > P_c (kN)$		ok			

Table 4.2: Design of Tie rod section.

		Tension				
$F_y(N/mm^2)$	250	K	1	$L(m)$	2.45	
$P_t \text{ (kN)}$	132	$E(N/mm^2)$	200000	$L_e \text{ (m)}$	2.45	
	$F_t(N/mm^2)$	150	$A_{req}(m^2)$	0.0010353		
	from AISC tables					
	SECTION DATA USE (ASD)					
USE	$A_{rea} \text{ (m}^2\text{)}$	1.12E-03	$R_x \text{ (m)}$	1.91E-02	$y(m)$	1.94E-02
AISC L2 1/2*2 1/2*3/8 (Inch)	$D(m)$	6.35E-02	$I_y(m^4)$	4.10E-07	$x(m)$	1.94E-02
	$B_f \text{ (m)}$	6.35E-02	$S_y \text{ (m}^3\text{)}$	9.28E-06	$R_z(m)$	1.24E-02
	$I_x(m^4)$	4.10E-07	$R_y \text{ (m)}$	1.91E-02	$T_f(m)$	9.53E-03
	$S_x \text{ (m}^3\text{)}$	9.28E-06	$k(m)$	1.75E-02		
	AXIAL FORCE CHECK					
$d_1(m)$	1.90E-02	n	1	$T(m)$	9.53E-03	
$d_2(m)$	2.20E-02	$A_{net}(m)$	9.06E-04			
		$A_{eff}(m)$	9.49E-04			
		$Q(kN)$	1.36E+02			
	check $Q(kN) \geq P_t(kN)$		ok			
		check $(L_e/r_{min}) \leq 240$				
		$Le/(r_{min})$	1.28E+02			
	d_1 n $d_2(m)=$	diameter of bolt number of bolt $d_1+0.003$				

Table 4.3: Design of Bracing section.

		Compression				
$F_y(N/mm^2)$	250	K	1	$L(m)$	2.847	
$P_c\ (kN)$	28.49	$E(N/mm^2)$	200000	$L_e\ (m)$	2.847	
	$F_{c1}(N/mm^2)$	112.5	$A_{req}(m^2)$	0.000253		
	from AISC tables					
	SECTION DATA USE (ASD)					
USE	Area (m ²)	2.80E-04	$R_x\ (m)$	9.58E-02	$y(m)$	9.68E-02
AISC L1 1/4 *1 1/4 *3/16 (Inch)	D(m)	3.18E-02	$I_y(m4)$	2.54E-08	$x(m)$	9.68E-02
	$B_f\ (m)$	3.18E-02	$S_y\ (m^3)$	1.17E-06	$R_z(m)$	6.20E-02
	$I_x(m4)$	2.54E-08	$R_y\ (m)$	9.58E-02	$T_f(m)$	4.77E-03
	$S_x\ (m^3)$	1.17E-06	$k(m)$	9.52E-02		
	check $\{B_f/(2\ T_f)\} \leq 16$					
		$B_f/(2T_f)$	3.33E+00			
		Check	ok			
	$Le/rmin$	2.97E+01	Cc	125.6		
	$F_{c2}(N/m^2)$	145510173	$Q(kN)$	4.07E+01		
	$check\ Q(kN) > P_c\ (kN)$		ok			

Table 4.4: Design of Working Jib section.

		Compression				
F_y (N/mm ²)	250	K	1	$L(m)$	0.833	
P_c (kN)	222.43	$E(N/mm^2)$	200000	L_e (m)	0.833	
	$F_{c1}(N/mm^2)$	112.5	$A_{req}(m^2)$	0.001977		
	from AISC tables					
	SECTION DATA USE (ASD)					
USE	Area (m ²)	1.99E-03	R_x (m)	3.15E-02	$y(m)$	3.12E-02
AISC L4*3 1/2*7/16 (Inch)	$D(m)$	1.02E-01	$I_y(m4)$	1.42E-06	$x(m)$	2.48E-02
	B_f (m)	8.89E-02	S_y (m ³)	2.21E-05	$R_z(m)$	1.84E-02
	$I_x(m4)$	1.98E-06	R_y (m)	2.67E-02	$T_f(m)$	1.11E-02
	S_x (m ³)	2.82E-05	$k(m)$	2.22E-02		
			check { $B_f/(2 T_f)$ }<=16			
		$B_f/(2T_f)$	4.00E+00			
		Check	ok			
		L_e/r_{min}	3.12E+01	Cc	125.6	
		$F_{c2}(N/m^2)$	145071907	$Q(kN)$	2.89E+02	
		check $Q(kN)>P_c$ (kN)		ok		

Table 4.5: Design of Counter Jib section.

		Compression				
$F_y(N/mm^2)$	250	K	1	$L(m)$	0.833	
$P_c\ (kN)$	438.87	$E(N/mm^2)$	200000	$L_e\ (m)$	0.833	
	$F_{c1}(N/mm^2)$	112.5	$A_{req}(m^2)$	0.003901		
	from AISC tables					
	SECTION DATA USE (ASD)					
USE	Area (m ²)	4.03E-03	$R_x\ (m)$	7.42E-02	$y(m)$	8.41E-02
AISC L9*4*1/2 (Inch)	D(m)	2.29E-02	$I_y(m^4)$	2.88E-06	$x(m)$	2.06E-02
	$B_f\ (m)$	1.02E-02	$S_y\ (m^3)$	3.55E-05	$R_z(m)$	2.17E-02
	$I_x(m^4)$	2.21E-05	$R_y\ (m)$	2.67E-02	$T_f(m)$	1.27E-02
	$S_x\ (m^3)$	1.53E-04	$k(m)$	2.54E-02		
	check $\{B_f/(2\ T_f)\} \leq 16$					
	$B_f/(2T_f)$	4.00E-01				
	check	ok				
	L_e/r_{min}	3.12E+01	Cc	125.6		
	$F_{c2}(N/m^2)$	145071907	Q(kN)	5.85E+02		
	check $Q(kN) > P_c\ (kN)$		ok			

Table 4.6: Design of Bracing in Jib section.

		Compression				
$F_y(N/mm^2)$	250	K	1	$L(m)$	2.1298	
$P_c (kN)$	59.45	$E(N/mm^2)$	200000	$L_e (m)$	2.1298	
	$F_{c1}(N/mm^2)$	112.5	$A_{req}(m^2)$	0.000528		
	from AISC tables					
	SECTION DATA USE (ASD)					
USE	Area (m²)	1.05E-03	$R_x (m)$	2.38E-02	$y(m)$	2.37E-02
AISC L3*2 1/2*5/16 (Inch)	D(m)	7.62E-02	$I_y(m4)$	3.74E-07	$x(m)$	1.74E-02
	$B_f (m)$	6.35E-02	$S_y (m^3)$	8.10E-06	$R_z(m)$	1.33E-02
	$I_x(m4)$	5.91E-07	$R_y (m)$	1.89E-02	$T_f(m)$	7.94E-03
	$S_x (m^3)$	1.13E-05	$k(m)$	1.75E-02		
	check $\{B_f / (2 T_f)\} \leq 16$					
	$B_f / (2T_f)$	4.00E+00				
	check	ok				
	L_e/r_{min}	1.13E+02	Cc	125.6		
	$F_{c2}(N/m^2)$	89449038	Q(kN)	9.35E+01		
	check $Q(kN) > P_c (kN)$		ok			

Table 4.7: Design of Cable section.

		Cable				
		Tension				
F_y (N/mm ²)	420	K	1	$L(m)$	46.77165	
P_t (kN)	3826.82	$E(N/mm^2)$	200000	$L_e(m)$	46.77165	
		$F_t(N/mm^2)$	252	$A_{req}(m^2)$	0.017866	
		$D_{req}(m)$		0.15086		
from AISC tables						
SECTION DATA USE (ASD)						
USE	Area (m ²)	1.89E-02	$R_x(m)$	7.75E-02	$y(m)$	—
cable	$D(m)$	1.55E-01	$I_y(m^4)$	2.83E-05	$x(m)$	—
	$B_f(m)$	—	$S_y(m^3)$	3.66E-04	Rz	—
	$I_x(m^4)$	2.83E-05	$R_y(m)$	7.75E-02		
	$S_x(m^3)$	3.66E-04	$k(m)$	—		
	AXIAL FORCE CHECK					
		n	0	t(m)	0	
		$A_{net}(m)$	1.89E-02			
		$A_{eff}(m)$	1.60E-02			
		Q(kN)	4.04E+03			
		ok				

Table 4.8.a: Design of Connection.

CONNECTION DESIGN					
		Using A307 bolts			
Pc (kN)	350.53	FV(Mpa)	147	Fu (Mpa)	406
D (mm)	19	Ab (mm2)	283.528498	Fb (kN)	487.2
Rb (kN)		138.135084	Rv kN)	83.35737827	
Nb		2.5375885	Nv	4.20514665	
Use 6 bolts					
THE DISTANCE BETWEEN HOLES CENTRE (mm)					
		Tp (mm)	16		
		DBHC (max)	117.43103		
		DBHC (min)	57		
		use 100 (mm)			

Table 4.8.b: Design of Connection.

CONNECTION DESIGN					
		Using A ₃₀₇ bolts			
P _c (kN)	28.49	F _v (Mpa)	147	F _u (Mpa)	406
D (mm)	19	Ab (mm2)	283.528498	F _b (kN)	487.2
R _b (kN)		138.135084	R _v (kN)	83.35737827	
N _b		0.2062474	N _v	0.34178138	
Use 1 bolt					
THE DISTANCE BETWEEN HOLES CENTRE (mm)					
		T _p (mm)	16		
		DBHC (max)	18.271552		
		DBHC (min)	57		
		use 50 (mm)			

Table 4.8.c: Design of Connection.

CONNECTION DESIGN					
	Using A307 bolts				
Pc (KN)	10.67	FV(Mpa)	147	Fu (Mpa)	406
D (mm)	19	Ab (mm2)	283.528498	Fb (KN)	487.2
	Rb (KN)	138.135084	Rv (KN)	83.35737827	
	Nb	0.0772432	Nv	0.12800307	
	Use 1 bolt				
	THE DISTANCE BETWEEN HOLES CENTRE (mm)				
	Tp (mm)		16		
	DBHC (max		12.785099		
	DBHC (min)		57		
	use 50 (mm)				

4.3. Design of Base Plate in Tower Crane.

$$P_c = 152 \text{ kN} \quad D = 127 \text{ mm} \quad B_f = 88.9 \text{ mm} \quad F_c = 30 \text{ N/mm}^2$$

$$F_b = 0.35 \cdot F_c = 10.5 \text{ N/mm}^2$$

$$A_{\text{Base}} = P_c / F_b = 152000 / 10.5 = 14476.19 \text{ mm}^2$$

$$A_{\text{Bas}} = (0.95 \cdot D + 2m) \cdot (0.8 \cdot B_f + 2n) = B \cdot C$$

$$14476.19 = (0.95 \cdot 127 + 2m) \cdot (0.8 \cdot 88.9 + 2n)$$

$$14476.19 = (120.65 + 2m) \cdot (71.12 + 2n)$$

Say $m = n$

$$m = 13.47 \text{ mm}$$

$$B = 120.65 + 2 \cdot 13.47 = 147.59 \approx 150 \text{ mm}$$

$$C = 71.12 + 2 \cdot 13.47 = 98.06 \approx 100 \text{ mm}$$

$$q = P_c / B \cdot C = 152000 / 100 \cdot 150 = 10.13 < F_b = 10.5 \text{ N/mm}^2$$

Say $A_{\text{Bas}} = 200 \cdot 200$

$$200 = 120.65 + 2m$$

$$m = 39.675 \text{ mm}$$

$$200 = 71.12 + 2n$$

$$n = 64.44 \text{ mm}$$

$$q = 152000 / 200 \times 200 = 3.8 \text{ N/mm}^2 < F_b = 10.5 \text{ N/mm}^2$$

$$M_{\max} = q \cdot n^2 / 2 = 3.8 \times 64.44^2 / 2 = 7889.775 \text{ N.mm/mm}$$

$$T = \sqrt{\frac{6 \cdot M_{\max}}{0.75 \cdot F_y}} = \sqrt{\frac{6 \cdot 7889.775}{0.75 \cdot 250}} = 15.88 \approx 20 \text{ mm}$$

Use 200*200*20

4.4. Design of Tower crane foundation

The steps of tower crane design are in three steps, corresponding to three possible modes of failure:

(1) **Stability-Check for Overturning:** the factor of safety against overturning about the tone—that is, about point C may be expressed as

$$FS_{\text{overturning}} = \sum MR / \sum MO$$

$\sum MR$ = sum of the moment of force tending to overturning about point c

$\sum MO$ = sum of the moment of force tending to resist overturning about point c

The usual minimum desirable value of the factor of safety with respect to overturning is 2 to 3.

(2) **Geotechnical capacity:** check bearing pressure, using an allowable stress method with working load

(3) **Structural design:** reinforced concrete design to ACI 318 -14 using factored loads. Site investigation report supplied allowable soil bearing pressure (allowable increase in bearing pressure) for shallow foundation as 200kN/m² and the ground water level is 10m.

4.4.1. Stability of Tower Crane

Check for Overturning:

With neglected the self-weight

(I) Out of service

From Table (3.9)

$$M = 4.3 \cdot 80.9 + 4.2 \cdot 75.4 + 4.1 \cdot 69.6 + 4 \cdot 63.8 + 3.9 \cdot 58 + 3.8 \cdot 52.2 + 3.6 \cdot 46.4 + 3.5 \cdot 40.6 + 3.3 \cdot 34.8 + 3.2 \cdot 29 + 3 \cdot 23.2 + 2.7 \cdot 17.4 + 2.4 \cdot 11.6 + 2 \cdot 5.8 = 2302.47 \text{ kN.m}$$

$$M_R = 150 \cdot 29.775 + 2 \cdot 2 \cdot 2 \cdot 1.3 \cdot 24 \cdot 11 + 4 \cdot 4 \cdot 1.3 \cdot 24 \cdot 6 + 2 \cdot 2 \cdot 2 \cdot 1.3 \cdot 24 \cdot 1$$

$$M_R = 10456.65 \text{ kN.m}$$

$$FS_{\text{overturning}} = \sum 10456.65 / \sum 2302.47 = 4.54 > 2 \text{ OK}$$

(II) In service

$$M_O = 1151.235 + 45.4 \cdot 70.225 = 4339.45 \text{ kN.m}$$

$$M_R = 10456.65 \text{ kN.m}$$

$$FS_{\text{overturning}} = \sum 10456.65 / \sum 4339.45 = 2.4 > 2 \text{ OK}$$

4.4.2. Geotechnical capacity of Tower Crane

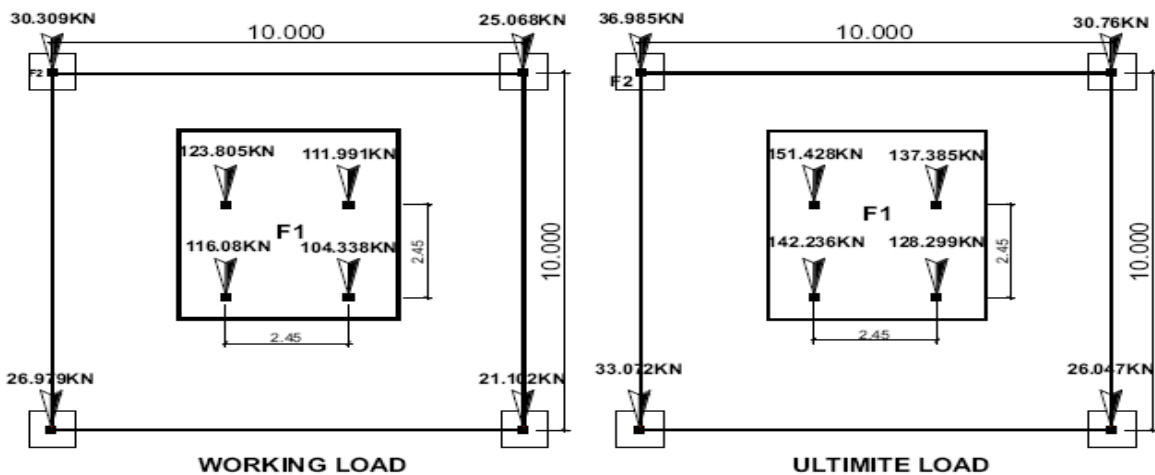


Figure 4.1. Loading on Foundation.

(I) Check bearing pressure for F_1

Total working load in F_1

$$P_w = 111.991 + 123.805 + 116.08 + 104.338 = 456.214 \text{ kN}$$

According to ACI 318-10, the factored load $P_u = 1.2 \cdot D + 1.6 \cdot L$

$$\text{Total } P_u = 137.385 + 151.428 + 142.236 + 128.299 = 559.348 \text{ kN}$$

$$q_{\text{all}} = 200 \text{ kN/m}^2, \text{ and } \gamma_{\text{soil}} = 19 \text{ kN/m}^3$$

$$q_{\text{all}(\text{net})} = 200 - 19 \cdot 0.7 - 24 \cdot 1.3 = 155.5 \text{ kN/m}^2$$

$$A_{F1} = \frac{PW}{q_{\text{all}(\text{net})}} = \frac{456.214}{155.5} = 2.933 \text{ m}^2 \text{ say } 16 \text{ m}^2$$

$$I_X = I_Y = \frac{4 \cdot 4^3}{12} = 21.33 \text{ m}^4$$

$$\text{Also } \sum MY' = 0$$

$$456.214 \cdot X' = (111.991 + 104.338) \cdot 2.45 \text{ or } X' = 1.16 \text{ m}$$

$$\text{And } e_x = 1.16 - 2.45/2 = -0.065 \text{ m}$$

$$\text{Similarly } \sum Mx' = 0$$

$$456.124 \cdot Y' = (123.805 + 111.991) \cdot 2.45 \text{ or } Y' = 1.292 \text{ m}$$

$$\text{And } e_y = 1.292 - 2.45/2 = 0.067 \text{ m}$$

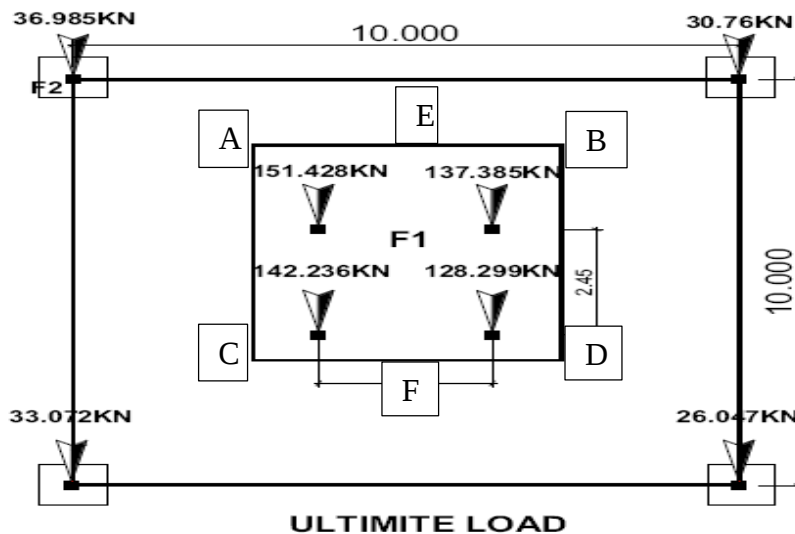


Figure 4.2. The strip of F_1 .

$$M_X = Q_u \cdot e_y = 559.348 \cdot 0.067 = 37.476 \text{ kN.m}$$

$$M_Y = Q_u * e_x = 559.348 * -0.065 = -36.357 \text{ kN.m}$$

$$q = \frac{Q}{A} \pm \frac{My * X}{IX} \pm \frac{Mx * Y}{IY} = \frac{559.348}{4 * 4} \pm \frac{(-36.357) * X}{21.333} \pm \frac{37.476 * Y}{21.333}$$

$$q = 34.959 \pm (-1.7X) \pm 1.576Y$$

Table (4.9): The soil pressures at any point.

Point	$\frac{Q}{A}$ (kN/m ²)	X (M)	1.7X	Y(M)	1.576Y	q (kN/m ²)
A	34.959	-2	3.4	2	3.152	41.511
E	34.959	0	0	2	3.152	38.111
B	34.959	2	-3.4	2	3.152	34.711
C	34.959	-2	3.4	-2	-3.152	35.207
F	34.959	0	0	-2	-3.152	31.807
D	34.959	2	-3.4	-2	-3.152	28.407

The soil pressures at all point less than the given value of $q_{all(net)} = 155.5 \text{ kN/m}^2$

(II) Check bearing pressure for F_2

$$A_{F2} = \frac{QW}{q_{all(net)}}$$

$$A_{F2} = \frac{30.309}{155.5} = 0.194 \text{ m}^2, \text{ say } 4 \text{ m}^2$$

$$q_u = \frac{Qu}{A} = \frac{36.985}{4} = 9.24 \text{ kN/m}^2$$

$$q_u < q_{all(net)} = 155.5 \text{ kN/m}^2 \text{ OK}$$

4.4.3. Structural design of foundation in Tower Crane (3):

(I) Structural design of F_1

From ACI318-10

$$\phi V_c = \phi * 0.33 * \sqrt{F_c'} * b * d$$

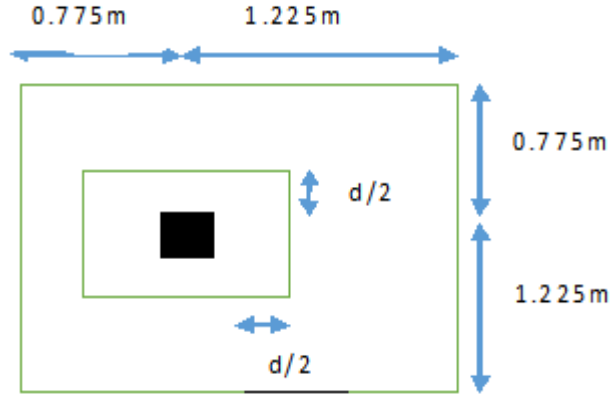


Figure 4.3. The punching shear of F_1 .

Thickness of mat = 1.3m

$$d = h - \text{cover} - 0.5\phi$$

$$d = 1300 - 50 - 0.5 * 16 = 1242\text{mm}$$

$$\phi V_c = 0.75 * 0.33 * \sqrt{25} * \frac{(4 * 1242) * 1242}{1000} = 8865.27\text{kN}$$

$$\phi V_c \gg P_c = 151.428\text{kN}$$

$$q_1 = \frac{qA + qE}{2} = \frac{41.511 + 38.111}{2} = 39.811\text{kN/m}^2$$

$$q_2 = \frac{qC + qF}{2} = \frac{35.207 + 31.807}{2} = 33.507\text{kN/m}^2$$

$$q_3 = \frac{qE + qB}{2} = \frac{38.111 + 34.711}{2} = 36.411\text{kN/m}^2$$

$$q_4 = \frac{qF + qD}{2} = \frac{31.807 + 28.407}{2} = 30.257\text{kN/m}^2$$

Check for $\sum FV = 0$

$$\text{Soil reaction for strip AECF} = 0.5 * (39.811 + 33.507) * 2 * 4 = 293.272\text{kN}$$

$$\text{Soil reaction for strip EBFD} = 0.5 * (36.411 + 30.257) * 2 * 4 = 266.672\text{kN}$$

$$\sum \text{Soil reaction} = 559.944\text{kN} \approx \sum \text{column load} = 559.348\text{kN} \quad \text{OK}$$

For strip AECF

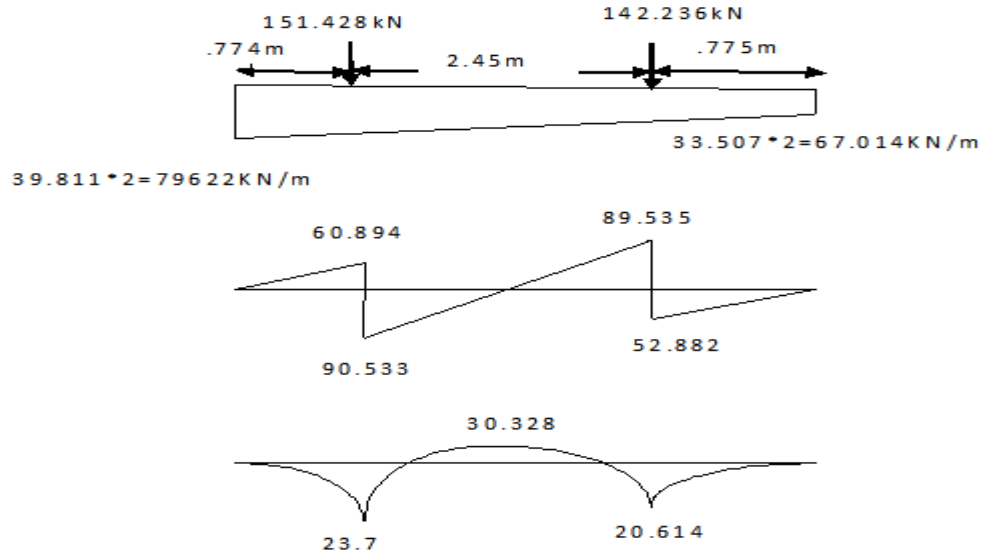


Figure 4.4. Shear and moment force diagram for strip AECF.

$$M_u = 30.328 \text{ kN.m}$$

Thickness resist for moment

$$\rho_b = 0.85 * \frac{F_c'}{F_y} * B * \frac{600}{600 + F_y}$$

$$\rho_b = 0.85 * \frac{25}{420} * 0.85 * \frac{600}{600 + 420} = 0.0253$$

$$\rho_{max} = 0.75 * \rho_b = 0.0189$$

$$\rho = 0.5 * \rho_{max} = 0.0094$$

$$R_u = \rho * F_y * (1 - \frac{\rho m}{2}), m = \frac{F_y}{0.85 F_c'} = 19.764$$

$$R_u = 3.581 \text{ N/mm}^2$$

$$d = \sqrt{\frac{M_u}{\phi * b * R_u}} = \sqrt{\frac{30.328 * 10^6}{0.9 * 2000 * 3.581}}$$

$$d = 68.59 \text{ mm}, d \ll 1242 \text{ mm} \quad \text{OK.}$$

Reinforcements

$$R_{u_{rev}} = \frac{M_u}{\phi * b * d^2} = \frac{30.328 * 10^6}{0.9 * 2000 * 1242^2} = 0.01 \text{ N/mm}^2$$

$$\rho_{rev} = \frac{1}{m} * \left\{ 1 - \sqrt{1 - \frac{2Ru m}{Fy}} \right\}$$

$$\rho_{rev} = \frac{1}{19.7647} * \left(1 - \sqrt{1 - \frac{2*0.01*19.7647}{420}} \right) = 0.0000238$$

$$\rho_{min} = 0.0018 \gg 0.0000238$$

use ρ_{min}

$$As = \rho_{min} * B * d$$

$$As = 0.0018 * 2000 * 1242$$

$$As = 4471.2 \text{ mm}^2$$

$$\text{use } \emptyset 20 \text{ mm} \quad A_b = 314 \text{ mm}^2$$

$$n = \frac{A_s}{A_b} = \frac{4471.2}{314} = 14.24 \text{ bars}$$

$$S = \frac{2000}{14.24} = 140.45 \approx 140 \text{ mm}$$

use $\emptyset 20 \text{ mm}$ @ 140 mm c/c BW top and bottom

Check for bearing $N_u = \emptyset * 0.85 * Fc' * Ac$

$$N_u = \frac{0.65 * 0.85 * 25 * 200 * 200}{1000} = 552.5 \text{ kN}$$

$$N_u > P_U \text{ OK}$$

(II) Structural design of F_2

Thickness of $F_2 = 1.3 \text{ m}$

$$\emptyset V_c = 0.75 * 0.33 * \sqrt{25} * (4 * 1442) * \frac{1242}{1000} = 8865.271 \text{ kN} > P_U = 36.985 \text{ kN}$$

$$M_U = \frac{qu * B * (L - h)^2}{8} = \frac{9.24 * 2 * (2 - 0.2)^2}{8} = 7.4844 \text{ kN.M}$$

use ρ_{min}

$$As = \rho_{min} * B * d = 0.0018 * 2000 * 1242 = 4471.2 \text{ mm}^2$$

$$\text{use } \emptyset 20 \text{ mm} \quad A_b = 314 \text{ mm}^2$$

$$n = \frac{A_s}{A_b} = \frac{4471.2}{314} = 14.24 \text{ bars}$$

$$S = \frac{2000}{14.24} = 140.45 \approx 140 \text{ mm}$$

use $\varnothing 20 \text{ mm}$ @ 140 mm c/c BW

Check for bearing

$$N_u = \varnothing * 0.85 * F_c' * A_c = \frac{0.65 * 0.85 * 25 * 200 * 200}{1000} = 552.5 \text{ kN}$$

$N_u > P_U$ OK

Table 4.10: The design results of tower cranes components.

Components	Tower crane (1)	Tower crane (2)	Tower crane (3)
Main tower	L5*3 ½ *5/8	L5*3 ½ *5/8	L5*3 ½ *5/8
Tie rod	L2 ½ *2 ½ *3/8	L2 ½ *2 ½ *3/8	L2½ *2 ½ *3/8
Bracing in tower	L1¼ *1¼ *3/16	L1¼ *1¼ *3/16	L1¼ *1¼*3/16
Working jip	L4*3 ½ *7/16	L4*3 ½ *7/16	L4*3 ½ *7/16
Counter jip	L9*4*1/2	L9*4*1/2	L9*4*1/2
Bracing in jip	L3*2 ½ *5/16	L3*2 ½ *5/16	L3*2 ½ *5/16
Cable diameter	155(mm)	155(mm)	155(mm)

4.5. Structural Performance of Tower Cranes

In order to study the structural performance, the variations of axial forces and displacements with respects to the height of tower cranes were drawing in Figures (4. 5)-(4. 7). It was taken the variation axial forces and deflections with the length of the jip for the three configurations as shown in Figures (4. 8)-(4. 9)

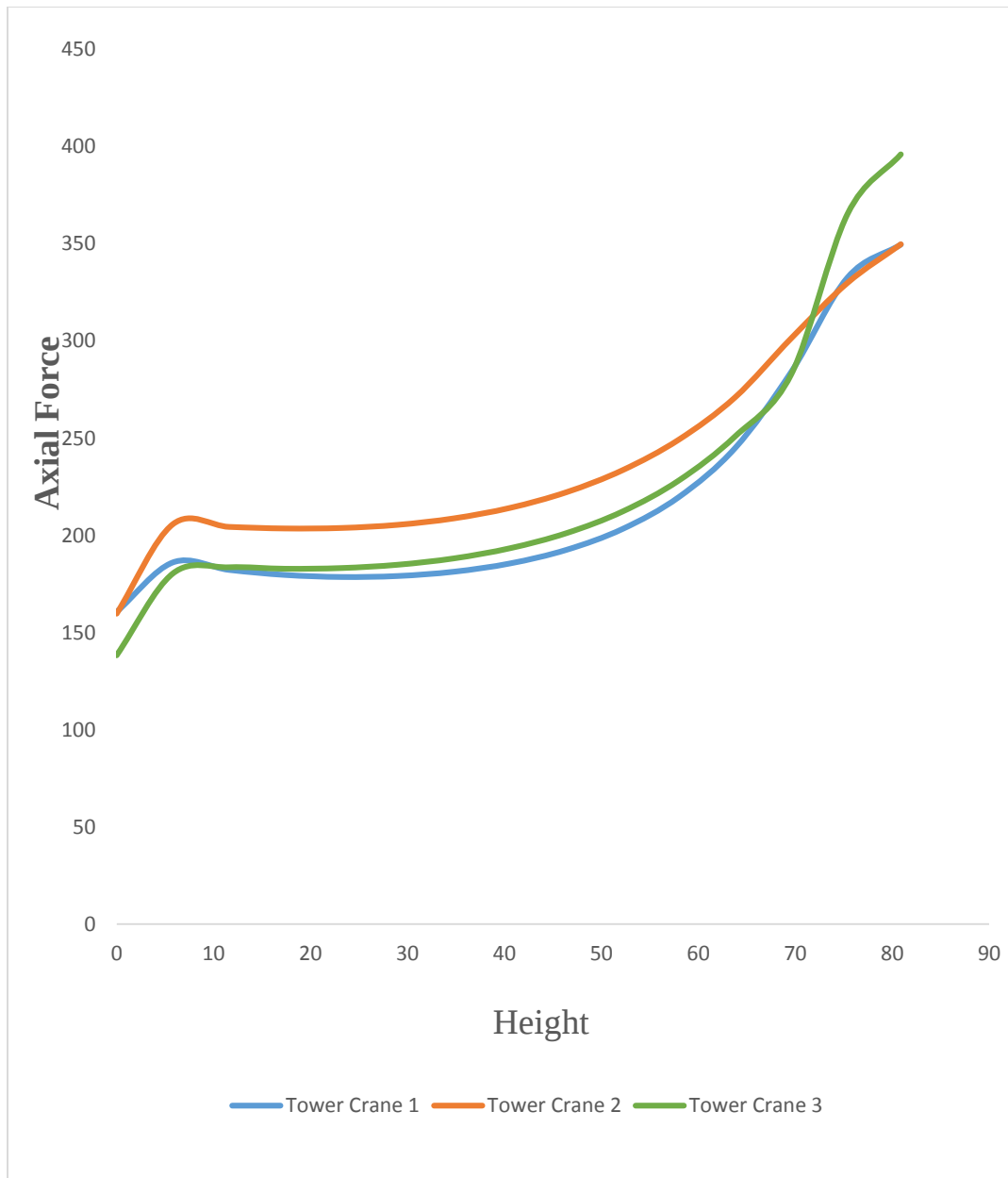


Figure 4.5: Variation of Axial forces with the Height for Tower Cranes.

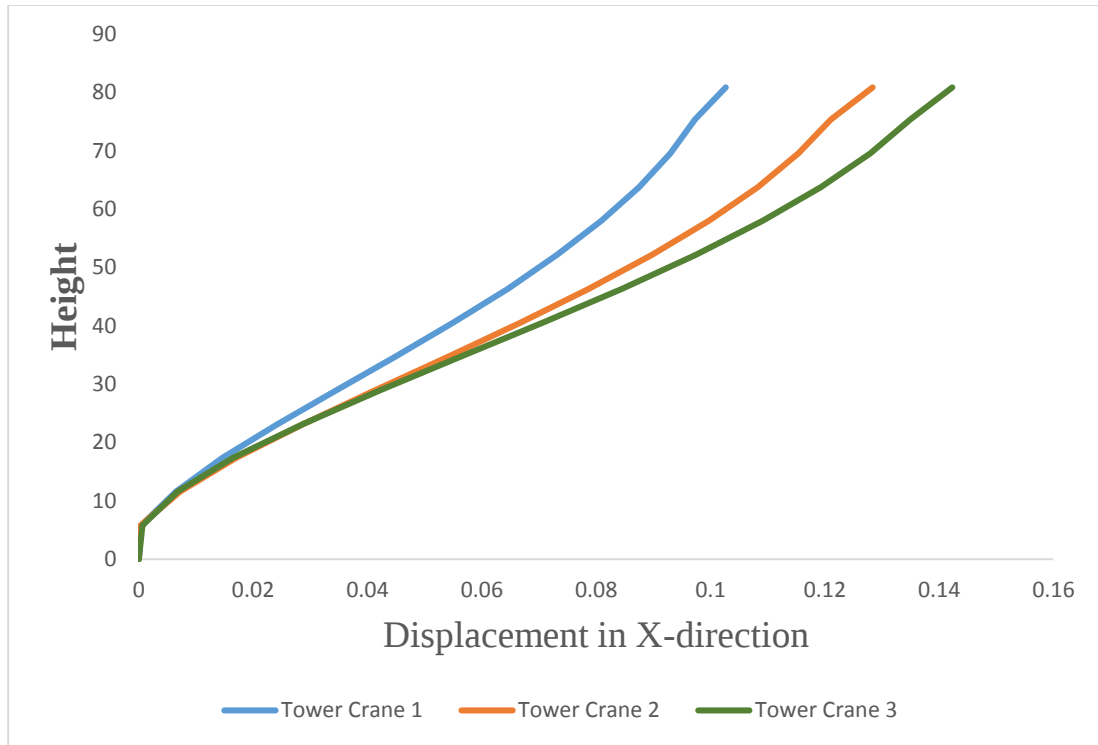


Figure 4.6: Variation of Displacement in X-direction with the Height for Tower Cranes.

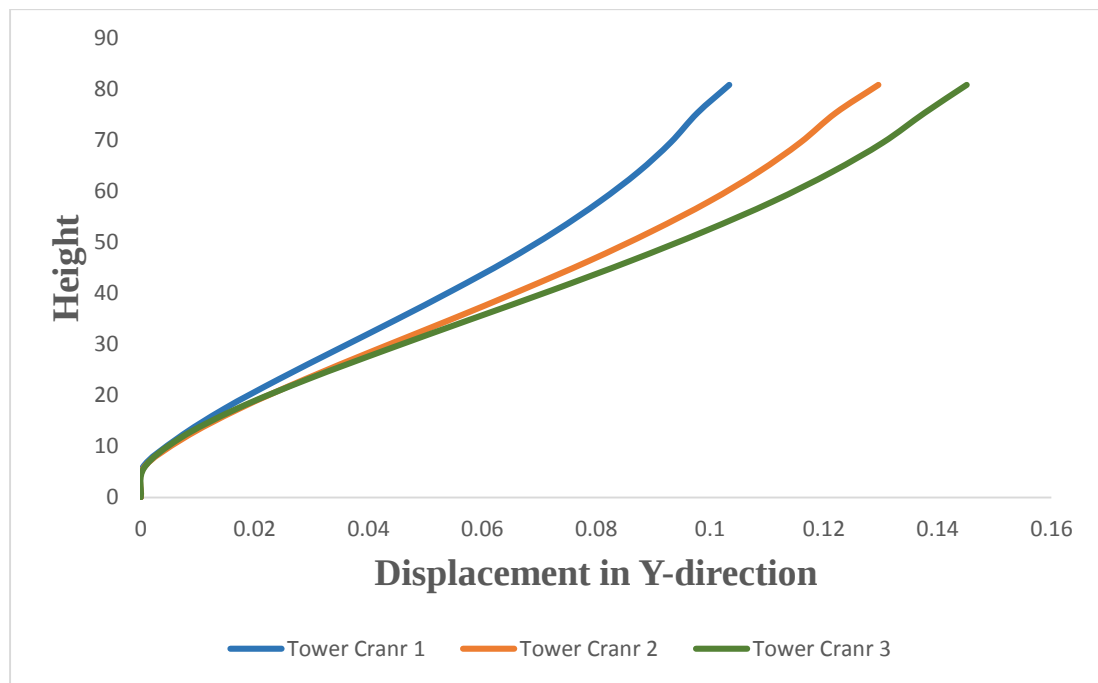


Figure 4.7: Variation of Displacement in Y-direction with the Height for Tower Cranes.

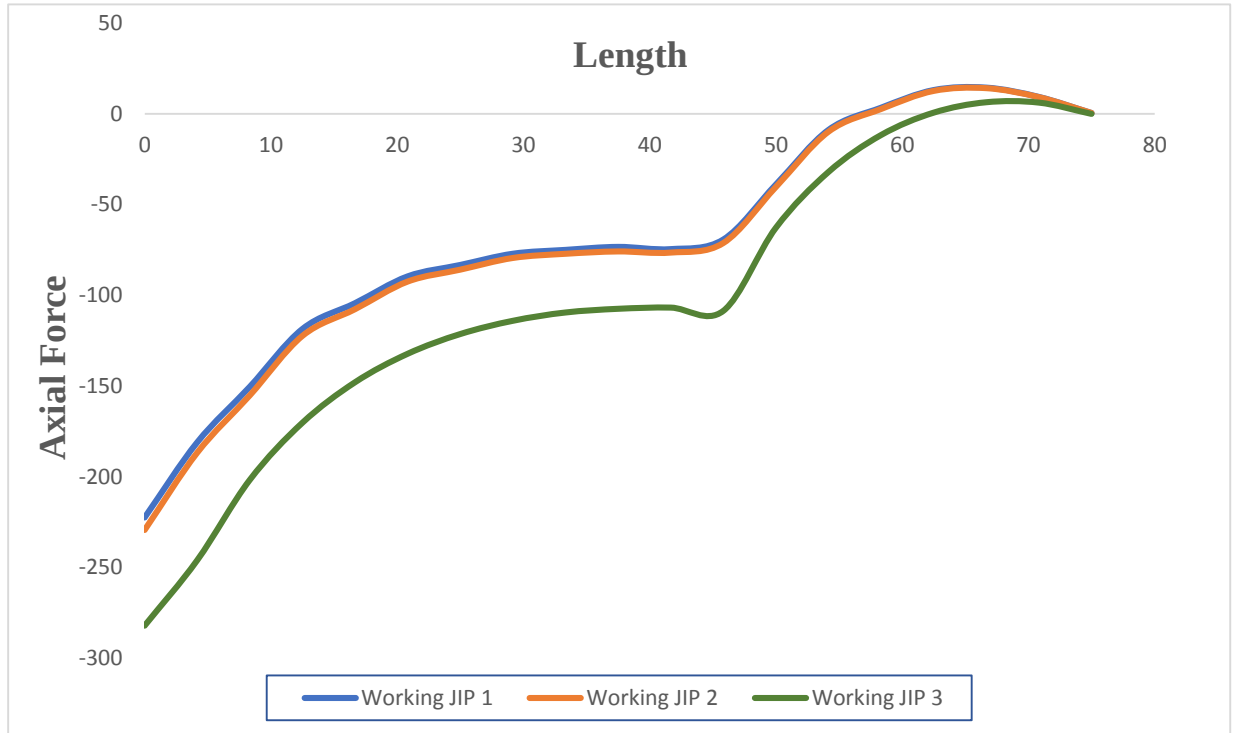


Figure 4.8: Variation of Axial forces with the Length for Working Jip.

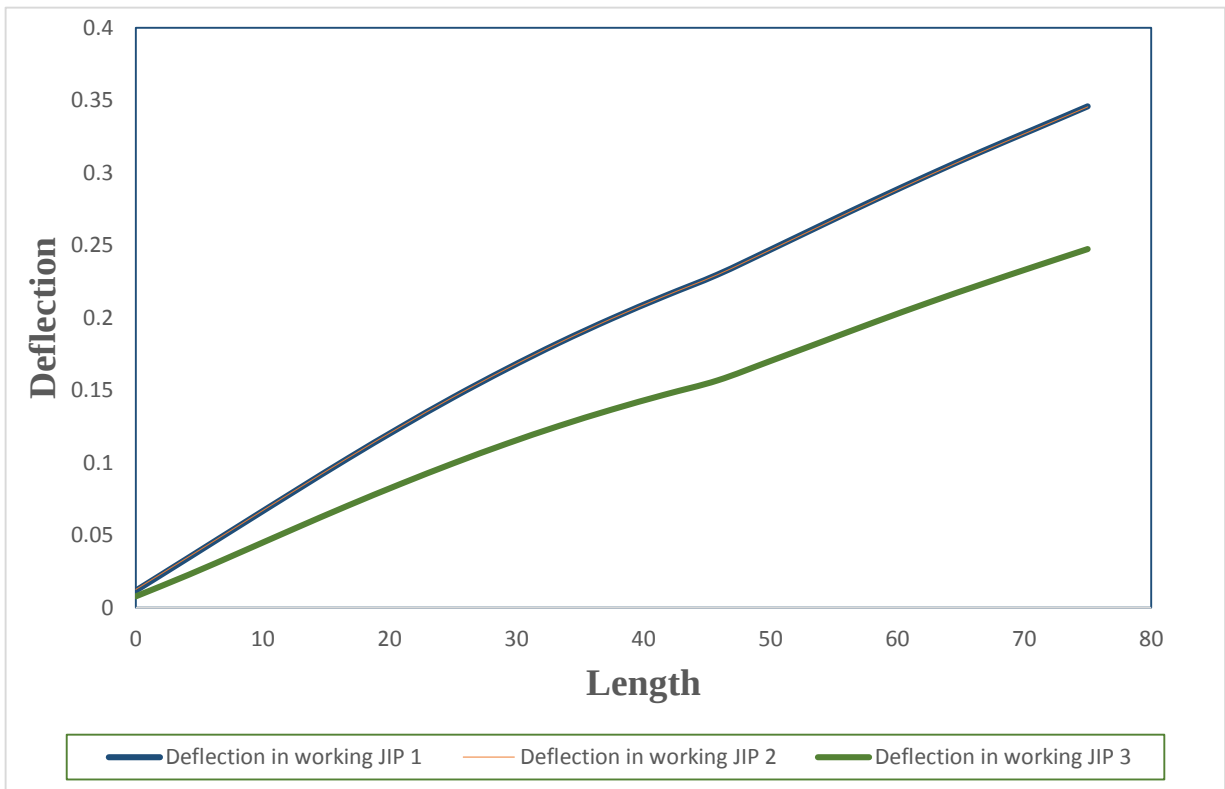


Figure 4.9: Variation of Deflection with the Length for Working Jip.

The variation of three configurations of Tower Cranes shown in table 4.11

Table 4.11: The Difference between the three Tower Cranes.

Type	Tower Crane (1) Design Axial Load (KN)	Tower Crane (2)		Tower Crane (3)	
		Design Axial Load (KN)	Difference %	Design Axial Load (KN)	Difference %
Main Towers	350.55	350.71	0	397.1	13
Working Jip	222.43	229.26	3	282.02	27

4.5. Discussion of Results

Discussion of results was summarized as follows:

- 1- It was noticed that the variation of axial forces with height in tower crane (1) gave minimum values of axial force in comparison with the other two as shown in Figure (4.5).
- 2- It was appear that the variations of displacement in x- and y-directions were increased with respect to height for all tower cranes. The tower crane (1) gave minimum displacement in x- and y-direction with respect to the other configurations of cranes as shown in Figures (4.6)-(4.7).
- 3- It was noticed that axial forces on working jib were varied at the end of jib for all tower cranes. The minimum axial forces distribution along the working jib as shown in Figure (4.8).
- 4- It was appear that the variation of deflection in working jib were increased with respect to the length for all working jip. The working jib (3) gave minimum deflection with respect to the other configuration as shown Figure (4.9).
- 5- It was noticed that the variation of design axial load and difference for all tower cranes. The deference of main tower (2 and 3) equal to (0-13) to comparison in the main tower (1). The deference of working jib (1and 2) equal to (3-27) to comparison in the working jib (1) as shown in Table (4.11).
- 6- From the variation of axial forces, displacement in x- and y- directions, deflection on jib. It was noticed that tower crane (1) is best configuration in comparison with the other two tower cranes (2) and (3). Tower crane type (1) has a self-weight of 1140kN and a number of nodes of 633, type (2) has a self-weight of 1259.31kN and a number of nodes of 667. And type (3) has a self-weight of 1470 kN and a number of nodes 667.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

In this study a model of tower crane was analyzed by using linear analysis and also designed to achieve the stability to insure that it resist the in-service and out-service condition in order to satisfy the functional of uses. Hoist loading were applied to the jib crane to represent the deformation and displacement for each load case.

1. The maximum displacement induced in the jib crane in Z direction was found to be 247.4mm in Tower Crane 3, which is considered acceptable according to the slenderness ratio of crane jib. The maximum axial load of value 350.55kN Tower Crane 1 was carried by highlighted member which transferred to the foundation and used to design it. The maximum torsion moment appears as low value 0.01738kN.m in Tower Crane 1 which can be neglected.
2. It may be concluded that according to the members obtained from design of model compared with the cranes used in Khartoum, that the later are almost safe due to the nature of engineering work in the Sudan which as general can be described of low values of loadings in all types of projects. Effect of the wind loads both at X and Y directions were minimize by tying the crane with the building in order to decrease the sways.
3. The deflections are considered to be acceptable in three configurations of Tower cranes.

5.2. Recommendations

Recommendations may be summarized:

1. This study did not implement the tower crane in Sudan in details, so more studies in this field may be useful for researchers, the libraries, and engineering sciences`.
2. The designer must allow more alternatives for making decision to select tower crane ,moreover he can modify the sections those allowed in the market ,that may done by testing those sections to satisfy the health and safety for both labours and crane structure.
3. The engineers must create more studies in this field so as to catch progressing in constructions methods, as while the tower crane rapid the velocity of the projects and assistant the contractor to do in specific time as it was planned .
4. In updating technology of computer aided design the company manufactured new issues for tower crane analysis and design that may reduce the time of research in coming days; so it wold be advised to enter those programs in the domain of the researches.

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Appendices (Design of Components of Tower Crane 2and 3)

APPENDIX (A)

Design of Components of Tower Crane (2, 3)

Table 5.1: Design of Main Tower section.

		Compression				
$F_y(N/mm^2)$	250	K	1	$L(m)$	2.745	
$P_c \text{ (kN)}$	350.71	$E(N/mm^2)$	200000	$L_e \text{ (m)}$	2.745	
		$F_{c1}(N/mm^2)$	112.5	$A_{req}(m^2)$	0.003117	
from AISC tables						
SECTION DATA USE (ASD)						
USE	Area (m ²)	3.17E-03	$R_x \text{ (m)}$	3.96E-02	$y(m)$	4.32E-02
AISC L 5*3 1/2*5/8 (Inch)	D(m)	1.27E-01	$I_y(m^4)$	2.01E-06	$x(m)$	2.42E-02
	Bf (m)	8.89E-02	$S_y \text{ (m}^3\text{)}$	3.11E-05	$R_z(m)$	1.91E-02
	$I_x(m^4)$	5.00E-06	$R_y \text{ (m)}$	5.59E-02	$T_f(m)$	1.59E-02
	$S_x \text{ (m}^3\text{)}$	5.97E-05	k(m)	2.86E-02		
	check {B _f /(2 T _f)}<=16					
		$B_f/(2T_f)$	2.80E+00			
		check	ok			
L_e/r_{min}		6.93E+01	Cc	125.6		
$F_{c2}(N/m^2)$		126901977	Q(kN)	4.02E+02		
check Q(kN)>P _c (kN)			ok			

Table 5.2: Design of Tie rod section.

		Tension				
$F_y(N/mm^2)$	250	K	1	$L(m)$	2.45	
$P_t \text{ (kN)}$	129.77	$E(N/mm^2)$	200000	$L_e \text{ (m)}$	2.45	
	$F_t(N/mm^2)$	150	$A_{req}(m^2)$	0.0010178		
	from AISC tables					
	SECTION DATA USE (ASD)					
USE	$A_{rea} \text{ (m}^2\text{)}$	1.12E-03	$R_x \text{ (m)}$	1.91E-02	$y(m)$	1.94E-02
AISC L2 ½*2 ½*3/8 (Inch)	$D(m)$	6.35E-02	$I_y(m4)$	4.10E-07	$x(m)$	1.94E-02
	$B_f \text{ (m)}$	6.35E-02	$S_y \text{ (m}^3\text{)}$	9.28E-06	$R_z(m)$	1.24E-02
	$I_x(m4)$	4.10E-07	$R_y \text{ (m)}$	1.91E-02	$T_f(m)$	9.53E-03
	$S_x \text{ (m}^3\text{)}$	9.28E-06	$k(m)$	1.75E-02		
	AXIAL FORCE CHECK					
$d_1(m)$	1.90E-02	n	1	T(m)	9.53E-03	
$d_2(m)$	2.20E-02	$A_{net}(m)$	9.06E-04			
		$A_{eff}(m)$	9.49E-04			
		Q(kN)	1.36E+02			
	check Q(kN)>=Pt(kN)		ok			
		check $(L_e/r_{min}) \leq 240$				
		$Le/(r_{min})$	1.28E+02			
d1		diameter of bolt number of bolt $d_1+0.003$				
n						
$d_2(m)=$						

Table 5.3: Design of Bracing section.

		Compression				
$F_y(N/mm^2)$	250	K	1	$L(m)$	2.847	
$P_c\ (kN)$	31.27	$E(N/mm^2)$	200000	$L_e\ (m)$	2.847	
	$F_{c1}(N/mm^2)$	112.5	$A_{req}(m^2)$	0.000278		
	from AISC tables					
	SECTION DATA USE (ASD)					
USE	Area (m ²)	2.80E-04	$R_x\ (m)$	9.58E-02	y(m)	9.68E-02
AISC L1 1/4 *1 1/4 *3/16 (Inch)	D(m)	3.18E-02	$I_y(m^4)$	2.54E-08	x(m)	9.68E-02
	$B_f\ (m)$	3.18E-02	$S_y\ (m^3)$	1.17E-06	$R_z(m)$	6.20E-02
	$I_x(m^4)$	2.54E-08	$R_y\ (m)$	9.58E-02	$T_f(m)$	4.77E-03
	$S_x\ (m^3)$	1.17E-06	k(m)	9.52E-02		
	check $\{B_f/(2\ T_f)\} \leq 16$					
	$B_f/(2T_f)$		3.33E+00			
	check		ok			
	$Le/rmin$	2.97E+01	Cc	125.6		
	$F_{c2}(N/m^2)$	145510173	Q(kN)	4.07E+01		
	check $Q(kN) > P_c\ (kN)$		ok			

Table 5.4: Design of Working Jib section.

		Compression				
$F_y(N/mm^2)$	250	K	1	$L(m)$	0.833	
$P_c (kN)$	229.26	$E(N/mm^2)$	200000	$L_e (m)$	0.833	
	$F_{c1}(N/mm^2)$	112.5	$A_{req}(m^2)$	0.002038		
	from AISC tables					
	SECTION DATA USE (ASD)					
USE	Area (m ²)	1.99E-03	$R_x (m)$	3.15E-02	$y(m)$	3.12E-02
AISC L4*3 1/2*7/16 (Inch)	D(m)	1.02E-01	$I_y(m4)$	1.42E-06	x(m)	2.48E-02
	$B_f (m)$	8.89E-02	$S_y (m^3)$	2.21E-05	$R_z(m)$	1.84E-02
	$I_x(m4)$	1.98E-06	$R_y (m)$	2.67E-02	$T_f(m)$	1.11E-02
	$S_x (m^3)$	2.82E-05	$k(m)$	2.22E-02		
	check $\{B_f / (2 T_f)\} \leq 16$					
	$B_f / (2T_f)$	4.00E+00				
	check	ok				
	Le/r_{min}	3.12E+01	Cc	125.6		
	$F_{c2}(N/m^2)$	145071907	Q(kN)	2.89E+02		
	check $Q(kN) > P_c (kN)$		ok			

Table 5.5: Design of Counter Jib section.

		Compression				
$F_y(N/mm^2)$	250	K	1	$L(m)$	0.833	
$P_c\ (kN)$	436.9	$E(N/mm^2)$	200000	$L_e\ (m)$	0.833	
	$F_{c1}(N/mm^2)$	112.5	$A_{req}(m^2)$	0.00388		
	from AISC tables					
	SECTION DATA USE (ASD)					
USE	Area (m ²)	4.03E-03	$R_x\ (m)$	7.42E-02	y(m)	8.41E-02
AISC L9*4*1/2 (Inch)	D(m)	2.29E-02	$I_y(m^4)$	2.88E-06	x(m)	2.06E-02
	$B_f\ (m)$	1.02E-02	$S_y\ (m^3)$	3.55E-05	$R_z(m)$	2.17E-02
	$I_x(m^4)$	2.21E-05	$R_y\ (m)$	2.67E-02	$T_f(m)$	1.27E-02
	$S_x\ (m^3)$	1.53E-04	k(m)	2.54E-02		
	check $\{B_f/(2\ T_f)\} \leq 16$					
	$B_f/(2T_f)$		4.00E-01			
	check		ok			
	L_e/r_{min}	3.12E+01	Cc	125.6		
	$F_{c2}(N/m^2)$	145071907	Q(kN)	5.85E+02		
	check $Q(kN) > P_c\ (kN)$		ok			

Table 5.6: Design of Bracing in Jib section.

		Compression				
$F_y(N/mm^2)$	250	K	1	$L(m)$	2.1298	
$P_c\ (kN)$	55.76	$E(N/mm^2)$	200000	$L_e\ (m)$	2.1298	
	$F_{c1}(N/mm^2)$	112.5	$A_{req}(m^2)$	0.000496		
	from AISC tables					
	SECTION DATA USE (ASD)					
USE	Area (m ²)	1.05E-03	$R_x\ (m)$	2.38E-02	$y(m)$	2.37E-02
AISC L3*2 1/2*5/16 (Inch)	D(m)	7.62E-02	$I_y(m4)$	3.74E-07	$x(m)$	1.74E-02
	$B_f\ (m)$	6.35E-02	$S_y\ (m^3)$	8.10E-06	$R_z(m)$	1.33E-02
	$I_x(m4)$	5.91E-07	$R_y\ (m)$	1.89E-02	$T_f(m)$	7.94E-03
	$S_x\ (m^3)$	1.13E-05	$k(m)$	1.75E-02		
	check $\{B_f/(2\ T_f)\} \leq 16$					
	$B_f/(2T_f)$		4.00E+00			
	check		ok			
	L_e/r_{min}	1.13E+02	Cc	125.6		
	$F_{c2}(N/m^2)$	89449038	Q(kN)	9.35E+01		
	check $Q(kN) > P_c\ (kN)$		ok			

Table 5.7: Design of Cable section.

		Cable				
		Tension				
F_y (N/mm ²)	420	K	1	$L(m)$	46.77165	
P_t (kN)	3828.94	$E(N/mm^2)$	200000	L_e (m)	46.77165	
	$F_t(n/mm^2)$	252	$A_{req}(m^2)$	0.017876		
		D_{req} (m)	0.150902			
	from AISC tables					
	SECTION DATA USE (ASD)					
USE	$Area$ (m ²)	1.89E-02	R_x (m)	7.75E-02	$y(m)$	—
cable	$D(m)$	1.55E-01	$I_y(m4)$	2.83E-05	$x(m)$	—
	$B_f(m)$	—	S_y (m ³)	3.66E-04	Rz	—
	$I_x(m4)$	2.83E-05	R_y (m)	7.75E-02		
	S_x (m ³)	3.66E-04	$k(m)$	—		
	AXIAL FORCE CHECK					
		n	0	t(m)	0	
		$A_{net}(m)$	1.89E-02			
		$A_{eff}(m)$	1.60E-02			
		Q(kN)	4.04E+03			
		ok				

Table 5.8.a: Design of Connection (A).

CONNECTION DESIGN					
		Using A307 bolts			
Pc (kN)	350.71	FV(Mpa)	147	Fu (Mpa)	406
D (mm)	19	Ab (mm2)	283.528498	Fb (kN)	487.2
Rb (kN)		138.135084	Rv kN)	83.35737827	
Nb		2.5375885	Nv	4.20514665	
Use 6 bolts					
THE DISTANCE BETWEEN HOLES CENTRE (mm)					
		Tp (mm)	16		
		DBHC (mm)	117.43103		
		DBHC (mm)	57		
		use 100 (mm)			

Table 5.8.b: Design of Connection (B).

CONNECTION DESIGN					
		Using A ₃₀₇ bolts			
P _c (kN)	31.27	F _v (Mpa)	147	F _u (Mpa)	406
D (mm)	19	Ab (mm2)	283.528498	F _b (kN)	487.2
R _b (kN)		138.135084	R _v (kN)	83.35737827	
N _b		0.2263726	N _v	0.37513176	
Use 1 bolts					
THE DISTANCE BETWEEN HOLES CENTRE (mm)					
		T _p (mm)	16		
		DBHC (mm)	19.127463		
		DBHC (mm)	57		
		use 50 (mm)			

Design of Components of Tower Crane (3)

Table 5.9: Design of Main Tower section.

		Compression				
$F_y(N/mm^2)$	250	K	1	$L(m)$	2.745	
$P_c (kN)$	397.1	$E(N/mm^2)$	200000	$L_e (m)$	2.745	
	$F_{c1}(N/mm^2)$	112.5	$A_{req}(m^2)$	0.00353		
	from AISC tables					
	SECTION DATA USE (ASD)					
USE	$Area (m^2)$	3.17E-03	$R_x (m)$	3.96E-02	$y(m)$	4.32E-02
AISC L 5*3 1/2*5/8 (Inch)	$D(m)$	1.27E-01	$I_y(m4)$	2.01E-06	$x(m)$	2.42E-02
	$B_f (m)$	8.89E-02	$S_y (m^3)$	3.11E-05	$R_z(m)$	1.91E-02
	$I_x(m4)$	5.00E-06	$R_y (m)$	5.59E-02	$T_f(m)$	1.59E-02
	$S_x (m^3)$	5.97E-05	$k(m)$	2.86E-02		
	check $\{B_f /(2 T_f)\} \leq 16$					
		$B_f /(2T_f)$	2.80E+00			
		check	ok			
	L_e/r_{min}	6.93E+01	Cc	125.6		
	$F_{c2}(N/m^2)$	126901977	$Q(kN)$	4.02E+02		
	check $Q(kN) > P_c (kN)$		ok			

Table 5.10: Design of Tie rod section.

		Tension				
$F_y(N/mm^2)$	250	K	1	$L(m)$	2.45	
$P_t \text{ (kN)}$	90.01	$E(N/mm^2)$	200000	$L_e \text{ (m)}$	2.45	
	$F_t(N/mm^2)$	150	$A_{req}(m^2)$	0.000706 7		
	from AISC tables					
	SECTION DATA USE (ASD)					
USE	$A_{rea} \text{ (m}^2\text{)}$	7.68E-04	$R_x \text{ (m)}$	1.95E-02	$y(m)$	1.82E-02
AISC	$D(m)$	6.35E-02	$I_y(m^4)$	2.93E-07	$x(m)$	1.82E-02
	L2 ½*2 ½*1/4	$B_f \text{ (m)}$	6.35E-02	$S_y \text{ (m}^3\text{)}$	6.46E-06	$R_z(m)$
(Inch)	$I_x(m^4)$	2.93E-07	$R_y \text{ (m)}$	1.95E-02	$T_f(m)$	6.35E-03
	$S_x \text{ (m}^3\text{)}$	6.46E-06	$k(m)$	1.43E-02		
AXIAL FORCE CHECK						
					6.35E-03	
$d_1(m)$	1.90E-02	n	1	$T(m)$		
$d_2(m)$	2.20E-02	$A_{net}(m)$	6.28E-04			
		$A_{eff}(m)$	6.53E-04			
		Q(kN)	9.42E+01			
check $Q(kN) \geq P_t(kN)$			ok			
		check $(L_e/r_{min}) \leq 240$				
		$Le/(r_{min})$	1.25E+02			
d_1		diameter of bolt number of bolt $d_1+0.003$				
n						
$d_2(m)=$						

Table 5.11.a: Design of Bracing section.

		Compression				
$F_y(N/mm^2)$	250	K	1	$L(m)$	3.79	
$P_c\ (kN)$	40.76	$E(N/mm^2)$	200000	$L_e\ (m)$	3.79	
	$F_{c1}(N/mm^2)$	112.5	$A_{req}(m^2)$	0.000362		
	from AISC tables					
	SECTION DATA USE (ASD)					
USE	Area (m ²)	1.25E-03	$R_x\ (m)$	3.18E-02	y(m)	2.77E-02
AISC L4*4 *1/4 (Inch)	D(m)	1.02E-01	$I_y(m4)$	1.27E-06	x(m)	2.77E-02
	B _f (m)	1.02E-01	S _y (m ³)	1.72E-05	R _z (m)	2.02E-02
	I _x (m4)	1.27E-06	R _y (m)	3.18E-02	T _f (m)	6.35E-03
	S _x (m ³)	1.72E-05	k(m)	1.59E-02		
	check {B _f /(2 T _f)}<=16					
		B _f /(2T _f)	8.00E+00			
		check	ok			
		Le/rmin	1.19E+02	Cc	125.6	
		F _{c2} (N/m ²)	82091488	Q(kN)	1.03E+02	
check Q(kN)>Pc (kN)			ok			

Table 5.11.b: Design of Bracing section.

		Tension				
F _y (N/mm ²)	250	K	1	L(m)	3.79	
P _t (kN)	45.68	E(N/mm ²)	200000	L _e (m)	3.79	
	F _t (N/mm ²)	150	A _{req} (m ²)	0.0003583		
	from AISC tables					
	SECTION DATA USE (ASD)					
USE	A _{rea} (m ²)	1.25E-03	R _x (m)	3.18E-02	y(m)	2.77E-02
AISC	D(m)	1.02E-01	I _y (m4)	1.27E-06	x(m)	2.77E-02
L4*4*1/4	B _f (m)	1.02E-01	S _y (m ³)	1.72E-05	R _z (m)	2.02E-02
(Inch)	I _x (m4)	1.27E-06	R _y (m)	3.18E-02	T _f (m)	6.35E-03
	S _x (m ³)	1.72E-05	k(m)	1.59E-02		
	AXIAL FORCE CHECK					
d ₁ (m)	1.90E-02	n	1	T(m)	6.35E-03	
d ₂ (m)	2.20E-02	A _{net} (m)	1.11E-03			
		A _{eff} (m)	1.06E-03			
			1.60E+0			
		Q(kN)	2			
	check Q(kN)>=Pt(kN)		ok			
		check (L _e /r _{min}) <=240				
		Le/(r _{min})	1.19E+0			
			2			
d1		diameter of bolt				
n		number of bolt				
d ₂ (m)=		d ₁ +0.003				

Table 5.12: Design of Working Jib section.

		Compression				
$F_y(N/mm^2)$	250	K	1	$L(m)$	0.833	
$P_c (kN)$	282.02	$E(N/mm^2)$	200000	$L_e (m)$	0.833	
	$F_{c1}(N/mm^2)$	112.5	$A_{req}(m^2)$	0.002507		
	from AISC tables					
	SECTION DATA USE (ASD)					
USE	Area (m ²)	1.99E-03	$R_x (m)$	3.15E-02	$y(m)$	3.12E-02
AISC L4*3 1/2*7/16 (Inch)	D(m)	1.02E-01	$I_y(m^4)$	1.42E-06	$x(m)$	2.48E-02
	$B_f (m)$	8.89E-02	$S_y (m^3)$	2.21E-05	$R_z(m)$	1.84E-02
	$I_x(m^4)$	1.98E-06	$R_y (m)$	2.67E-02	$T_f(m)$	1.11E-02
	$S_x (m^3)$	2.82E-05	$k(m)$	2.22E-02		
	check $\{B_f / (2 T_f)\} \leq 16$					
	$B_f / (2T_f)$		4.00E+00			
	check		ok			
	Le/r_{min}	3.12E+01	Cc	125.6		
	$F_{c2}(N/m^2)$	145071907	Q(kN)	2.89E+02		
	check $Q(kN) > P_c (kN)$		ok			

Table 5.13: Design of Counter Jib section.

		Compression				
$F_y(N/mm^2)$	250	K	1	$L(m)$	0.833	
$P_c\ (kN)$	573.95	$E(N/mm^2)$	200000	$L_e\ (m)$	0.833	
	$F_{c1}(N/mm^2)$	112.5	$A_{req}(m^2)$	0.005102		
	from AISC tables					
	SECTION DATA USE (ASD)					
USE	$Area\ (m^2)$	4.03E-03	$R_x\ (m)$	7.42E-02	$y(m)$	8.41E-02
AISC L9*4*1/2 (Inch)	$D(m)$	2.29E-02	$I_y(m4)$	2.88E-06	$x(m)$	2.06E-02
	$B_f\ (m)$	1.02E-02	$S_y\ (m^3)$	3.55E-05	$R_z(m)$	2.17E-02
	$I_x(m4)$	2.21E-05	$R_y\ (m)$	2.67E-02	$T_f\ (m)$	1.27E-02
	$S_x\ (m^3)$	1.53E-04	$k(m)$	2.54E-02		
	check $\{B_f/(2\ T_f)\} \leq 16$					
	$B_f/(2T_f)$		4.00E-01			
	check		ok			
	L_e/r_{min}	3.12E+01	Cc	125.6		
	$F_{c2}(N/m^2)$	145071907	$Q(kN)$	5.85E+02		
	check $Q(kN) > P_c\ (kN)$		ok			

Table 5.14: Design of Bracing in Jib section.

		Compression				
$F_y(N/mm^2)$	250	K	1	$L(m)$	2.1298	
$P_c (kN)$	56.39	$E(N/mm^2)$	200000	$L_e (m)$	2.1298	
	$F_{c1}(N/mm^2)$	112.5	$A_{req}(m^2)$	0.000501		
	from AISC tables					
	SECTION DATA USE (ASD)					
USE	Area (m ²)	1.05E-03	$R_x (m)$	2.38E-02	$y(m)$	2.37E-02
AISC L3*2 1/2*5/16 (Inch)	D(m)	7.62E-02	$I_y(m4)$	3.74E-07	$x(m)$	1.74E-02
	$B_f (m)$	6.35E-02	$S_y (m^3)$	8.10E-06	$R_z(m)$	1.33E-02
	$I_x(m4)$	5.91E-07	$R_y (m)$	1.89E-02	$T_f(m)$	7.94E-03
	$S_x (m^3)$	1.13E-05	$k(m)$	1.75E-02		
	check $\{B_f/(2 T_f)\} \leq 16$					
	$B_f/(2T_f)$	4.00E+00				
	check	ok				
	L_e/r_{min}	1.13E+02	Cc	125.6		
	$F_{c2}(N/m^2)$	89449038	Q(kN)	9.35E+01		
	check $Q(kN) > P_c (kN)$		ok			

Table 5.15: Design of Cable section.

		Cable				
		Tension				
$F_y(N/mm^2)$	420	K	1	$L(m)$	46.77165	
$P_t \text{ (kN)}$	3840.97	$E(N/mm^2)$	200000	$L_e \text{ (m)}$	46.77165	
$F_t(N/mm^2)$		252	$A_{req}(m^2)$	0.017932		
		$D_{req} \text{ (m)}$	0.151139			
from AISC tables						
SECTION DATA USE (ASD)						
USE	$Area \text{ (m}^2\text{)}$	1.89E-02	$R_x \text{ (m)}$	7.75E-02	$y(m)$	—
cable	$D(m)$	1.55E-01	$I_y(m4)$	2.83E-05	$x(m)$	—
	$B_f(m)$	—	$S_y \text{ (m}^3\text{)}$	3.66E-04	Rz	—
	$I_x(m4)$	2.83E-05	$R_y \text{ (m)}$	7.75E-02		
	$S_x \text{ (m}^3\text{)}$	3.66E-04	$k(m)$	—		
AXIAL FORCE CHECK						
		n	0	t(m)	0	
		$A_{net}(m)$	1.89E-02			
		$A_{eff}(m)$	1.60E-02			
		Q(kN)	4.04E+03			
		ok				

Table 5.16.a: Design of Connection (A).

CONNECTION DESIGN					
		Using A307 bolts			
Pc (kN)	397.1	FV(Mpa)	147	Fu (Mpa)	406
D (mm)	19	Ab (mm2)	283.528498	Fb (kN)	487.2
Rb (kN)		138.135084	Rv kN)	83.35737827	
Nb		2.8747223	Nv	4.76382545	
Use 6 bolts					
THE DISTANCE BETWEEN HOLES CENTRE (mm)					
		Tp (mm)	16		
		DBHC (mm)	131.75985		
		DBHC (mm)	57		
		use 100 (mm)			

Table 5.16.b: Design of Connection (B).

CONNECTION DESIGN					
		Using A307 bolts			
Pc (KN)	45.68	FV(Mpa)	147	Fu (Mpa)	406
D (mm)	19	Ab (mm2)	283.528498	Fb (KN)	487.2
Rb (KN)		138.135084	Rv (KN)	83.35737827	
Nb		0.3306908	Nv	0.54800188	
Use 6 bolts					
THE DISTANCE BETWEEN HOLES CENTRE (mm)					
		Tp (mm)	16		
		DBHC (mm)	23.564039		
		DBHC (mm)	57		
		use 50 (mm)			