FAILURE ANALYSIS OF THREE-LEGGED GUYED TELECOMMUNICATION MAST IN CALABAR AND MINNA, NIGERIA.

BY

UDOFIA, Udeme Mfon
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ABSTRACT

Two cases of telecommunication mast collapse in Calabar and Minna, Nigeria were considered for structural integrity audit to ascertain all the likely causes of the tower collapse. A Collapsed 30 metres three-legged guyed telecommunication mast, by University of Calabar Teaching Hospital, Calabar and a 20 metres three-legged guyed telecommunication mast at Tunga roundabout by David's road, Minna, Niger State, Nigeria was investigated. A typical 30 metres and 20 metres guyed mast of pipe section for the main pole and solid-round high tensile steel for bracing was modelled, analysed and designed using STAAD-Pro V8i software and loadings applicable to Calabar and Minna environment respectively. The result showed that the 30 metres three-legged guyed telecommunication mast, by University of Calabar Teaching Hospital, Calabar and a 20 metres three-legged guyed telecommunication at Tunga roundabout by David's road, Minna, Niger State, Nigeria, collapsed due to insufficient depth of the footing for the guy wires as the mast themselves could not withstand the wind pressure and inadequate sections provided. There was no sufficient space for the guy wire anchorage. It was recommended from the study that; more attention should be paid to guy wire footing. The depth of the guy wires for the collapsed mast was 600mm and the minimum from this research is recommended to be 1200mm for any mast above 15 metres tall. More so, Proper analysis should be carried out on the guy wire in order to determine the initial tension value during guyed mast modelled, analysis and design. While sufficient space should be provided for guy wire anchorage.

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CHAPTER ONE

2.0 INTRODUCTION

1.1 Background to the Study

In the contemporary era, the telecommunication industry plays a great role in human societies and thus much more attention is now being paid to telecommunication towers than it was in the past. At times of occurrence of natural disasters, telecommunication towers have the crucial task of instant transmission of information from the affected areas to the rescue centres. In addition, performance of infrastructure such as dams, electric, gas, and fuel transmission stations, depends extensively on the information being transmitted via these telecommunication towers (Amiri *et al*., 2004).

Military and defence industries, in addition to television, radio, and telecommunication industries are other areas of application for such towers and thus creates the necessity for further research on telecommunication towers. There are three types of steel telecommunication towers mainly known to engineers as guyed towers, self-supporting towers, and monopoles as seen in Figure 1.1. Guyed towers normally provide an economical and efficient solution for tall towers of 150 metres and above, compared to self-supporting towers. Self-supporting towers are categorized into two groups of 4-legged and 3-legged lattice towers. The monopoles are designed for use with cellular, microwave, broadcast, and other applications. Monopoles are most economical for heights under 55 metres and are a viable solution for space limitation problems and rigid zoning codes. Industry separates monopoles from self-supporting towers with the latter being latticed. Most research to date has been performed on 3 & 4- legged self-supporting telecommunication towers. Therefore, in this research, general investigation shall be carried out to obtain detailed information on collapsed mast in Nigeria and some cases outside Nigeria (Amiri *et al*., 2004)

The different types of telecommunication towers are based upon their structural action, cross section and type of sections used. A brief description is as given below:

2.1.1 Type of tower based on cross section

Towers can be classified, based on their cross section, into square, rectangular, triangular, delta, hexagonal and polygonal towers. Open steel lattice towers make the most efficient use of material and enables the construction of extremely light-weight and stiff structures by offering less exposed area to wind loads. Most of the power transmission, telecommunication and broadcasting towers are lattice towers. Triangular Lattice Towers have less weight but offer less stiffness in torsion. With the increase in number of faces, it’s observed that weight of tower increases. If the supporting action of adjacent beams is considered, the expenditure incurred for hexagonal towers is somewhat less (Al-jassani and Al-suraifi, 2017).

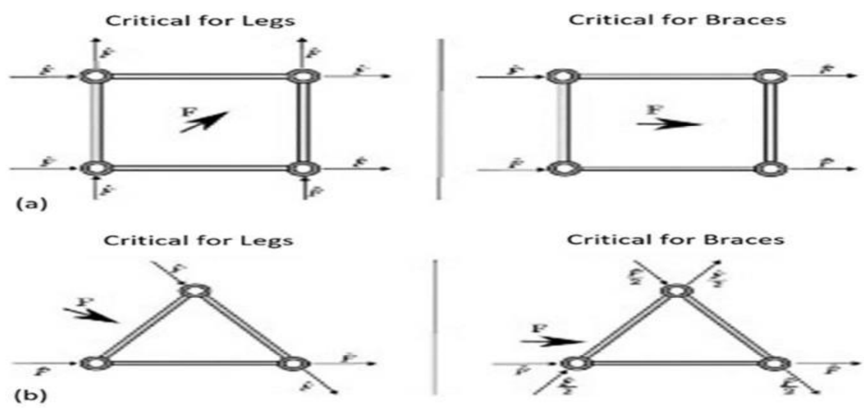


Figure 1.1: Triangular and Square Tower (Al-jassani and Al-suraifi, 2017)

2.1.2 Type of tower based on structural action

Towers are classified into three major groups based on the structural action. They are:

a) Self-supporting towers

b) Monopole

c) Guyed towers

Self-supporting towers

The towers that are supported on ground or on buildings are called as self-supporting towers. Though the weight of these towers is more, they require less base area and are suitable in many situations. Most of the TV, MW, Power transmission, and flood light towers are self-supporting towers, as shown in Figure 1.1.

Monopole towers

It is single self-supporting pole, and is generally placed over roofs of high raised buildings, when number of antennae required is less or height of tower required is less than 9m. It uses minimal space and resemble a single tube, requires one large foundation, typically not exceed 45 m height and the antennas are mounted on the exterior of the tower, as shown in Figure 1.1.

Guyed towers

Guyed towers provide height at a much lower material cost than self-supporting towers due to the efficient use of high-strength steel in the guys. Guyed towers are normally guyed in three directions over an anchor radius of typically 2/3 of the tower height and have a triangular lattice section for the central mast. Tubular masts are also used, especially where icing is very heavy and lattice sections would ice up fully. These towers are much lighter than self-supporting type but require a large free space to anchor guy wires. Whenever large open space is available, guyed towers can be provided. There are other restrictions to mount dish antenna on these towers and require large anchor blocks to hold the ropes, as shown in Figure 1.1. (Al-jassani Al-suraifi, 2017).

Guyed tower benefits

1. Ideal for heights over 60 metres

2. Requires significant installation footprint to accommodate guy anchors
3. Has significant wind-loading capacity.
4. Could be the cheapest choice in case of space availability for so high tower levels (Al-jassani and Al-suraifi, 2017).

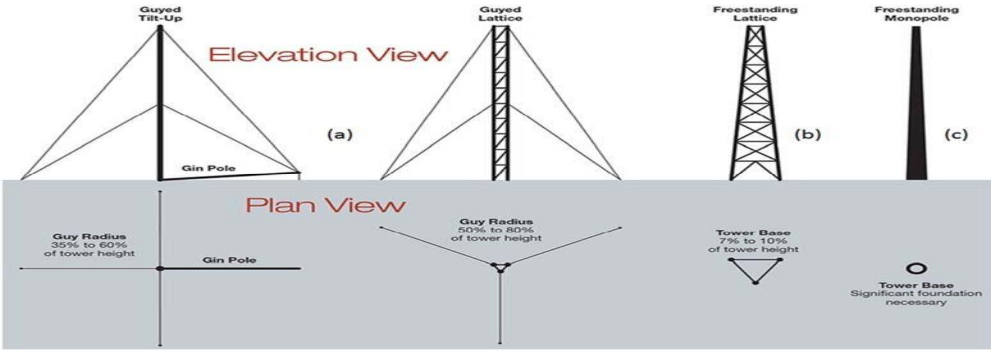


Figure 1.2: Tower Types based on structural action (Al-jassani and Al-suraifi, 2017)

1.1.3 Type of Tower Based on Material Sections

Based on the sections used for fabrication, towers are classified into angular and hybrid towers (With tubular and angle bracings). Lattice towers are usually made of bolted angles. Tubular legs and bracings can be economic, especially when the stresses are low enough to allow relatively simple connections. Towers with tubular members may be less than half the weight of angle towers because of the reduced wind load on circular sections. However the extra cost of the tube and the more complicated connection details can exceed the saving of steel weight and foundations (Al-jassani and Al-suraifi, 2017).

Telecommunication structures are fundamental components of communication and post-disaster networks and their serviceability immediately after a design-level earthquake is essential. In fact accessing to telecommunication and broadcast services is one of the main advantages of using telecommunication masts especially in emergency situations like after a severe earthquake. Telecommunication structures are also used for automatic control of electric power networks, which makes them all the more strategic for lifeline serviceability. Several published studies have used detailed nonlinear dynamic analysis of tall guyed masts using finite element models, either to predict the response of specific structures or to develop simplified analysis procedures more amenable to design practice (Osgoie *et al.*, 2012).

1.2 Statement of the Research Problem

There have been many cases of collapse of telecommunication mast worldwide. One of the significant incidents is the failure of the former 646 metres world's tallest guyed Warsaw Radio mast, at Konstantynow, Gabin, Poland, in 1991 during guy wire replacement (Cindy, 2011).

On January 20th , 2022 it was reported by Sahara Reporters, New York that Two workers of the Nigeria Telecommunication Limited (NITEL) have died in Kastina-Ala Local Government Area of Benue State, five were critically injured. It was learnt that the victim's died after the mast collapsed in the process of dismantling it. Sahara Reporters gathered that the workers were seven in number on top of the mast working around the NITEL premises near Takum Junction in Kastina-Ala when it suddenly collapsed. Confirming the incident, spokesperson for the police in the state, Sewuese Anene, affirmed that two people died in the accident. Chairman of Kastina-Ala Local Government Area, Alfred Atera, while lamenting the tragedy, said, They had loosed one side of the mast when the other part collapsed. Two of them died instantly while five others were taken to the hospital (Sahara Reporters, 2022).

On September 27, 2017, an incident occurred in Miami Gardens, Florida where three construction employees were killed. The employees were engaged in installing a new antenna for a local TV station at the top of a 951-foot tall antenna tower constructed in 2009. The three employees were killed when the gin pole they were using suddenly disengaged from the tower structure plunging several hundred feet to the ground. The employees were tied to the gin pole and fell with it. The cause of the disengagement was the failure of attachment between the gin pole and the tower structure (Mohammad and Bryan, 2018).

A 105 metres high guyed radio transmission tower collapsed during the final phase of its construction on June 6, 1994 at approximately 9:00 am in Selma, Alabama. On that morning, two workers positioned near the top section of the tower, having completed the fastening of the coaxial cable to the top section of the tower, were beginning to lower the erection gin pole from the top section of the tower to the ground. The gin pole suddenly dropped and struck the coaxial cable, followed by the collapse of the tower structure. Both workers, who were tied to the collapsing tower, fell to the ground. The accident resulted in the death of one of the worker and serious injuries to the other Muhammad and Fragrance (1994).

In Minna, Nigeria, there was a collapse of three-legged guyed telecommunication mast of height 20 metres. Also, in Calabar, Cross River Sate, another three-legged telecommunication mast of height 30 metres collapsed in 2020 and 2021 respectively.

Therefore, there is a need to carry out failure analysis of the two collapse telecommunication mast in Nigeria in other to find out the causes and then the solutions to prevent such occurrence in future.

1.3 Aim and Objectives of the Study

The aim of this work is to carry out failure analysis of three-legged guyed telecommunication mast in Calabar and Minna, Nigeria while the objectives are:

1. To identify the causes of collapse of three-legged guyed telecommunication mast.
2. To analyse the two collapsed cases of three-legged guyed telecommunication mast in Calabar and Minna, Nigeria.
3. To design structurally 30 metres and 20 metres three-legged telecommunication mast using STAAD-Pro V8i software and manual approach respectively.

1.4 Justification of the Study

The importance of this research work is to know the causes of mast collapse and the possible solutions in Minna and Calabar. The list of collapsed mast in Nigeria is shown in Table 2.1 which shows just few cases as compared to the numerous cases of mast collapse across Nigeria without any record of those incidence. Collapse of mast causes a lot of casualties, loss to telecommunication industry and destruction of other structures close to the collapsed mast. This study seeks to reduce the rate of its future occurrence. This research is vital as there is no published document of collapsed mast in Nigeria except of news report, when there are so many records of collapsed mast in other countries of the world as seen in Table 2.1. The two cases of collapse considered in this research is of hollow pipe section. Same sections will be considered in this work to make recommendations after due consideration. This will be a guide to practitioners, clients in Nigeria and the world at large.

1.5 Scope of Study

To identify the causes of collapse of three-legged guyed telecommunication mast.

To analyse the two collapsed cases of three-legged guyed telecommunication mast in Calabar and Minna, Nigeria.

To design structurally 30 metres and 20 metres three-legged telecommunication mast using STAAD-Pro V8i software and manual approach respectively.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1.1 Preamble

Over the past 30 years, the growing demand for wireless and broadcast communication has spurred a dramatic increase in communication tower construction and maintenance. Many industries and communications demand towers for variety of purposes. Some of the applications of steel towers are Microwave transmission for communication, Radio transmission, Television transmission, Satellite reception, Air traffic controls, Flood light stands Meteorological measurements, Oil drilling masts, Overhead water tanks, Power transmission lines etc. Fastest growing telecommunication market has increased the demand of steel towers. Failure of such structures is a major concern (Joyson *et al.*, 2019).

2.1.2 Telecommunication Tower

Telecommunication towers, such as the ones used for emergency response systems, require elevated antennas to effectively transmit and receive radio communications. In the absence of tall buildings that antennas can be mounted to, self-supporting (Plate I) and guyed (Plate II) towers tend to be the most economical choice for mounting antennas. These types of towers are generally lightweight in comparison to building a solid structure and are also easier to fabricate and erect. The type of tower used for an application is usually dependent on the design height. “Broadcasting towers generally range from 400 ft to 2,000 ft in height, with those over 600 ft typically being guyed. Towers less than 600 ft will be either self-supporting or guyed, depending on the owner’s preference, budget, and location (Eric and Hani, 2006).

Telecommunication structures are fundamental components of communication and post-disaster networks and their serviceability immediately after a design-level earthquake is essential. In fact accessing to telecommunication and broadcast services is one of the main advantages of using telecommunication masts especially in emergency situations like after a severe earthquake. Telecommunication structures are also used for automatic control of electric power networks, which makes them all the more strategic for lifeline serviceability (Osgoie *et al.*, 2012).

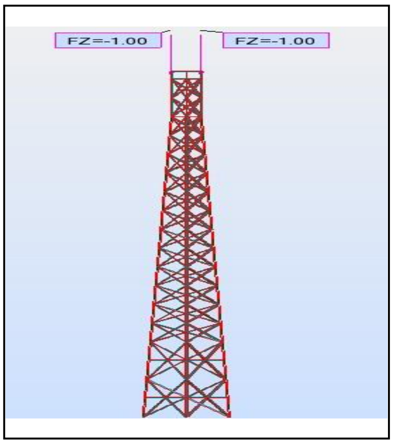
Srikanth & Neelima (2014) analysed a transmission line tower using Indian Standards IS: 875:1987(Wind Load), IS: 802:1995 (Structural steel), IS: 1893:2002 (Earthquake) and dynamic analysis of tower was performed considering ground motion of 2001 Bhuj Earthquake (India). The dynamic analysis was performed considering a tower system consisting two towers spaced 800m apart and 35m height each. This analysis was performed using numerical time stepping finite difference method which is central difference method were employed by a developed MATLAB program to get the normalized ground motion parameters such as acceleration, frequency, velocity which are important in designing the tower. The tower was analyzed using response spectrum analysis. Design and analysis of a steel lattice transmission line towers of a power system located in Delhi and Panjim was done using STAAD.ProV8i.Under the design and analysis of the system, the effect of wind and earthquake loads were studied and the results so obtained were compared for wind zones II and IV (seismic zone IV) for the same configuration of tower. Delhi and Panjim have same seismic zone but there is a lot of difference in the basic wind speed as Panjim is a coastal area. The analysis results was supplied to the management of the considered system for taking appropriate decisions regarding the improvement of power system design. The comparative analysis is carried out with respect to axial force, deflections maximum sectional properties and critical load condition for both locations (Shivam *et al.,* 2016).

Due to the failure of telecommunication structures which is a major concern. A comparative analysis was carried out for different heights of towers using different bracing patterns for Wind zones I to VI and Earthquake zones II to V of India. Gust factor method was used for wind load analysis, modal analysis and response spectrum analysis were used for earthquake loading. The results of displacement at the top of the towers and stresses in the bottom leg of the towers were compared. Displacement increases with the increase in speed of the wind. Results displayed that the increase in the displacement from wind zone I to wind zone VI is maximum for W-Bracing and it is minimum for K-Bracing. For all wind zones tower height between 25m to 35m with different bracing patterns do not show much difference in displacement. For wind zone I to IV, tower height between 35m to 45m having K-Bracing or W-Bracing gives maximum value of displacement and V-Bracing gives minimum value of displacement. For wind zone V and VI tower height between 35m to 45m having W-Bracing gives maximum value of displacement and V-Bracing or XBX -Bracing gives minimum value of displacement (Keshav *et al.,* 2015).

Marcel *et al.* (2007) carried out Structural Analysis of Guyed Steel Telecommunication Towers for Radio Antennas. The Brazilian telecommunication and electrical power transmission systems expansion were the main reasons for efficient and cost-effective transmission and telecommunication steel towers. Steel truss towers have been used to support transmission antennas or to enable electrical power transmission lines to be built, interconnecting the vast Brazilian territory. However, structural collapses, mainly associated with the wind action, are not uncommon to this particular structural solution

(Blessmann, 2001; Carril, 2000). Despite these facts, most of the traditional structural analysis methods for telecommunication and transmission steel towers still assume a simple truss behaviour, where all connections are considered hinged. On the other hand, structural mechanisms, that could compromise the assumed structural response, can be present in various commonly used tower geometries whenever truss type models are adopted (Policani, *et al.*, 2000, Silva *et al*., 2002).

One of the early experimental and theoretical study on the dynamic response of lattice self-supporting telecommunication towers under real and simulated wind forces was done by Chiu and Taoka (1973). In their research, a 3-legged 46-m Y self-supporting telecommunication tower was investigated for its dynamic response under wind loading. The study showed that the tower response to wind-induced forces was dominated by the fundamental mode of vibration. In addition, the average damping for the fundamental mode was obtained to be five percent (0.5%) of the critical viscous damping value, which is considered to be very low. Mikus (1994) carried out investigation of seismic response of six 3-legged self-supporting telecommunication towers with heights ranging from 20 to 90 meters. The selected towers were numerically simulated as bare towers. Three earthquake accelerograms were considered as input in the analysis. It was concluded that modal superposition with the lowest four modes of vibration would ascertain sufficient precision. Konno and Kimura (1973) carried out studies on the effects of earthquake loads on lattice telecommunication towers atop buildings. The objective of their work was to obtain the mode shapes, the natural frequencies, and the damping properties of such structures. Simulation of a stick model of the tower using lumped masses and a viscous damping ratio of 1 % was used in their studies. It was observed that in some of the members, the forces due to earthquake were greater than those due to wind. Jacek *et al.* (2015) carried out a stability analysis of steel telecommunication towers with random parameters to provide a numerical solution to the stability problem of the steel telecommunication tower with some random material and geometrical parameters as given in figure 2.1 below loaded with the vertical unit forces to determine via the generalized perturbation-based Stochastic Finite Element Method up to the fourth order probabilistic characteristics of the critical load multipliers. Computational analysis has been programmed and carried out in the FEM package ROBOT (3D linear elastic model with two-noded 30 beam and 156 space truss finite elements) as well as the mathematical package MAPLE, v. 14. Full determination of probabilistic characteristics for the critical load multipliers enables for reliability index approximation, detection of the output probability density function for critical



forces as well as reliable optimization of this model according to some new possible loadings of the tower (Like solar panels or small windmills). Figure 2.1 shows the 3D FEM model of the steel telecommunication tower.

Figure 2.1: 3D FEM model of the steel telecommunication tower (Jacek *et al.*, 2015)

The telecommunication tower tested was 55, 20 meters high and is divided into nine 6,0 meters high segments, while the cross-section has the triangular shape. The legs are designed as the full round pipes with the diameter decreasing from the bottom as 110, 100, 90 and 80 mm.

A simplified approach was taken for the free vibration analysis of wind turbines taking the effect of foundation into account. The method was based on an Euler-Bernoulli beam-column with elastic end supports. The elastic end-supports are considered to model the flexible nature of the interaction of these systems with the foundation. A closed-form expression of the characteristic equation governing all the natural frequencies of the system has been derived. Theoretical developments are explained by practical numerical examples. Analytical as well as a new experimental approach has been proposed to determine the parameters for the foundation. Some design issues of wind turbine towers are discussed from the point of view of the foundation parameters (Adhikari and Bhattacharya, 2012).

Figure 2.2 shows a typical layout a three-legged telecommunication mast consisting elevation of the mast, generator space and entrance.

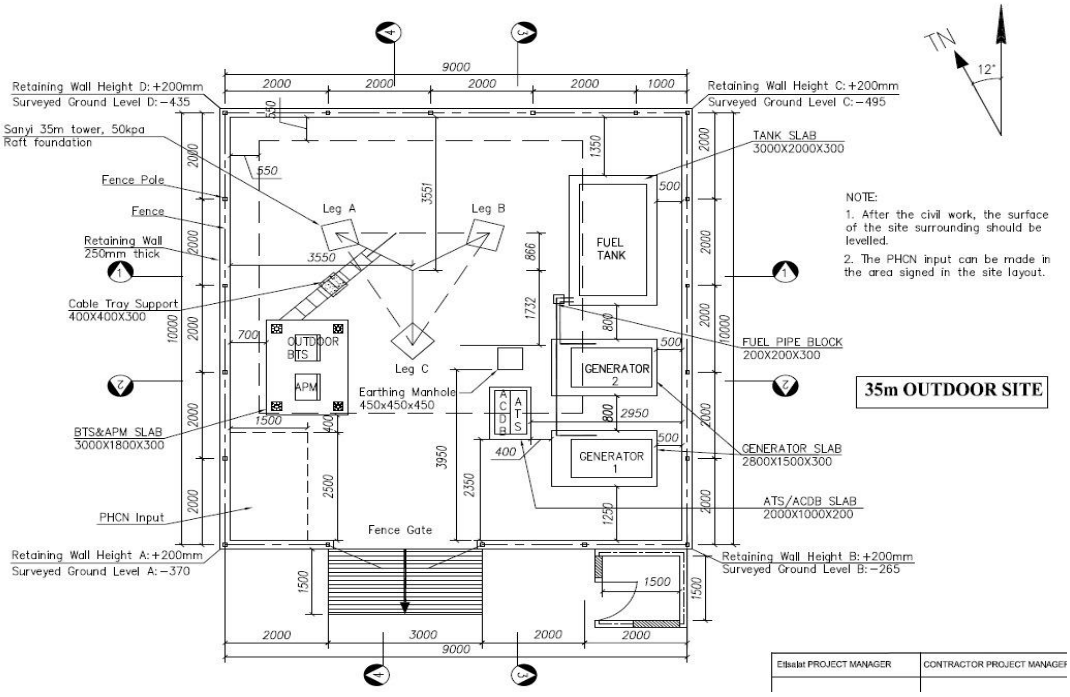


Figure 2.2: Layout of a typical telecommunication site (HIS Towers, 2020)

Table 2.1, Shows some record of tower failures in Nigeria and world over including date of incidence, State, City, country, height of the mast, number of casualty recorded, type of tower and the nature of collapse.

Table 2.1: Some record of tower failures in Nigeria and world over as investigated in the course of this research work

Date	State	City	Country	Heights (m)	Casualty	Tower Type	Extent of Collapse
August 8, 1991	Konstantynow, Voivodeship	Gabin	Poland	646.38	Nil	3-Legged	Total Collapse
June 6, 1994	Alabama	Selma	USA	105	1	3-Legged	Total Collapse
September 4, 2003	Alabama	Huntsville	USA	300	3	3-Legged	Total collapse
December , 2009	New York	New York	USA	114	1	3-Legged	Total collapse
February 1, 2014	Summit Park, Utah	Clarksburg	USA	102	1	3-Legged	Total collapse
September 27, 2017	Florida	Miami Gardens	USA	285.3	3	3-Legged	Total Collapse
April 19, 2018	Missouri	Fordland	USA	567.3	1	3-Legged	Total Collapse
October 17, 2020	Kaduna	Kaduna	Nigeria	46	Nil	3-Legged	Total Collapse
June 15,2020	Sokoto	Nasarawa	Nigeria	55	Nil	3-Legged	Partial Collapse
June 27, 2020	Niger	Minna	Nigeria	25	Nil	3-Legged	Total Collapse
March 13, 2021	Cross River	Calabar	Nigeria	30	Nil	3-Legged	Total Collapse

2.1.3 Guy cable

Mast are usually supported at intervals by guy cables, the lower ends of which are anchored to the ground. For triangular masts, the minimum number of guys at any level is three and for square masts the minimum number of guys at any level is four. The guy cables used are made of either wire rope or wire strand. Wire rope is galvanised and is made in accordance with CSA standard G4-M, ‘’ Steel wire rope for General purpose and for Mine Hoisting and Mine Haulage’’. Seven-wire strand and nineteen-wire strand is made in accordance with CSA standard CAN3-G12-M, ‘’Zinc-coated steel wire strand,’’ using hot, Zinc coated wire. Sometimes bridge strand made in accordance with ANS/ASTM standard A586, ‘’Zinc-coated steel structural strand’’ and aluminium-coated steel wire strand made in accordance with ANSI/ASTM standard A474, ‘’Aluminium-coated steel wire strand’’ are also used for guy cables (Isheke, 1985).

Because the guy cables act as elastic supports for the mast when subjected to lateral wind loads, it is necessary to know the relationships between loads, stresses and deformations for the guy cable. The weight of the guy cable and of a uniform ice distribution deforms the guy cable into a catenary (Isheke , 1985).

2.1.4 Wind load on the guy cable

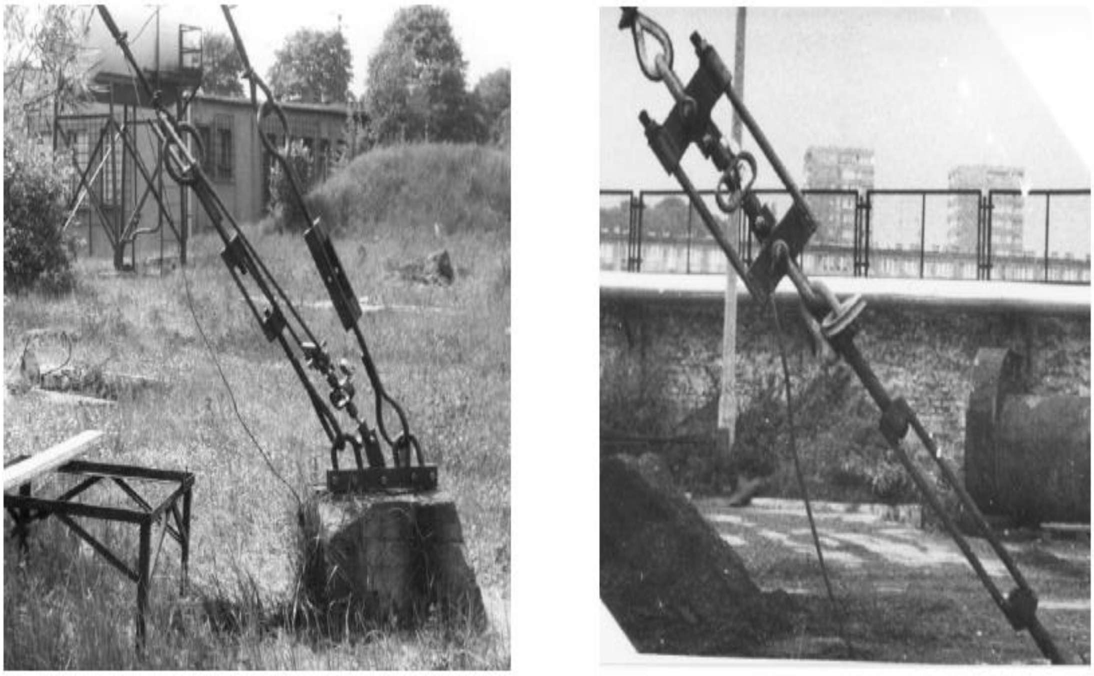
The wind load is assumed to act on the guy cable as a uniform load. It changes the effective load per metre on the guy cables and thus alters the function expressing displacement versus tension as well as the value of the tension in the guy cable before any motion of the tower (Isheke, 1985).

Figure 2.3 shows guy anchorage systems for guyed telecommunication mast consisting of footing, anchorage bolts and nuts.

a) b) c)

Figure 2.3: Guy anchorage systems (Bernard and Janusz (2014)

Figure 2.4 shows guy section close to the foundation for guyed telecommunication mast consisting of footing, anchorage bolts and nuts.



a) b)

. **Figure 2.4.** Guy sections close to the foundation (Bernard and Janusz, 2014)

Jithesh (2014) studied telecommunication towers subjected to seismic and wind loading. In this the displacement due to wind by Gust Factor Method and Seismic effect by modal analysis and response spectrum method at top of the tower for various bracing systems for 30m, 40m, and 50m towers were compared. It is concluded that the joint displacement stress increases as the height of the tower increases and suggested optimum design for various earthquake zones.

In the present study, a detailed analysis has been made on the behaviour of the telecommunication tower subjected to wind and seismic loads with varying the bracing system of towers. Gust factor method is used for wind load analysis. Conducted analytical study on effect of wind on telecommunication towers, for wind speed of 50m/s for four combination of bracing systems; Also studied the effect of earthquake loading on telecommunication towers using Modal analysis and Response Spectrum method, for seismic zones III, IV and V for all the four combination of bracing systems.

Joyson *et al.* (2019) did a detailed analysis on the behaviour of the telecommunication tower subjected to wind and seismic loads with varying the bracing system of towers. Gust factor method was used for wind load analysis. Analytical study on effect of wind on telecommunication towers was conducted for wind speed of 50m/s for four combination of bracing systems. Also studied the effect of earthquake loading on telecommunication towers using Modal analysis and Response Spectrum method, for seismic zones III, IV and V for all the four combination of bracing systems.

The results of displacement at the top of the towers and stresses in the bottom leg of the towers were compared and the optimum bracing system was found.

2.2 Research on collapse of mast

2.2.1 Collapse case in Kaduna

Report of Structural Integrity Audit showed a collapsed case of 46 metres tower at 18 Muhammed Buhari way, City center, Kaduna, Nigeria that happened 2020. Plate I shows the twisted tower due to many loose bolts and lack of proper torqueing/ maintenance on the tower. This resulted in failure of the connecting joints in single/double shear thereby giving rise to high stress ratio at these connections. However, single plate (Outer connector) instead of double (inner and outer) plate were used for the leg joints providing low structural stability at these weak regions. With the application of wind pressure at these connection regions, structural failure is evident which also contributed to the twist experienced on the tower.

Plate I: Mast collapse in Kaduna (HIS Tower, 2020)

2.2.2 Collapse case in Sokoto

Report of Structural Integrity Audit showed a collapsed case of 55 metres tower at Silame Nassarawa, Sokoto State, Nigeria, that happened 2020. From the report, tower twisted due to failure in deflection at tower top and some loose bolts as observed on the tower. This failure is associated with the very low base to height ratio (slender tower) as manufactured and of which will requires huge weight to withstand deflection from wind impact on the tower. However, due to the absence of this required weight, tower bent from the middle of the tower height while the existing foundation remains intact (HIS Tower, 2021).

2.2.3 Collapse case in Poland

Telecommunication systems, such as radio and television broadcasting, require elevated antennas which are most economically supported on monopole, self-supporting, and guyed lattice towers as shown in Plate II. Unfortunately, failures of telecommunication structures due to dynamic effects are high compared with other structures of equal economic and social importance as seen in Plate II. One of the significant incidents is the failure of the former 646 metres world’s tallest guyed Warsaw Radio mast, at Konstantynow, Gabin, Poland, in 1991 during guy wire replacement (Cindy, 2011).

Plate II: Wreckage of the Warsaw Radio mast, at Konstantynow, Gabin, Poland (Source: Cindy, 2011).

2.2.4 Collapse case in New York

In December 2009, a 46 year-old tower technician fell 43 feet to his death when a guyed communication tower collapsed. The 380-foot tall tower was supported by 21 guy wires at seven elevations, three at each height. The lowest three guy wires were at 43 feet. The victim and his co-workers were replacing the guy wires at the time of the incident. The workers first released the lowest three guy wires from the ground anchors. The next set of wires was at 93 feet. The tower immediately bent in response to the removal of the tension in the lowest guy wires. Tension gauge readings indicated that the remaining guy wires were either over-tensioned or tensioned unevenly. The workers adjusted the wires so that the tower was not bent. The victim, who was wearing a safety harness, started climbing the tower to remove the wires at the 43 feet.

As he was climbing, the workers on the ground observed the tower to be moving “like a wet noodle.” The victim dropped the three wires and quickly climbed down. He then climbed to 43 feet to install the new guy wires. He successfully attached two wires before switching to the other side of the tower to attach the third wire. Meanwhile, two workers on the ground picked up one of the wires that was just attached and pulled it hand tight. They took enough slack out of the wire so that it was elevated and not touching the ground. At this moment, the tower start to collapse. The tower reportedly buckled or bent at 43 feet where the victim was. The lower section of the tower (from 43 feet down) fell northwest, while the section above 43 feet fell to southeast (180 degrees from the direction where the lower section fell). The whole tower collapsed. The victim, whose harness was still hooked to the tower, suffered fatal crushing and fall injuries. One worker called 911 and the rest ran to attend the victim. The emergency response staff arrived within minutes. The victim was pronounced dead at the scene (Andrew *et al*., 2009).

2.2.5 Collapse case in Clarksburg

On February 1, 2014, at approximately 11:37 a.m., a 340'-high guyed telecommunication tower (Cell tower), suddenly collapsed during upgrading/construction activities as seen in Plate III. Four employees were working on the tower removing its diagonals. In the process, no temporary supports were installed. As a result of the tower’s collapse, two employees were killed and two others were badly injured. The cell tower fell onto the guy wires of an adjacent smaller cell tower and caused it to collapse, killing a firefighter while he was rescuing the injured employees on the ground. Muhammad and Scott (2014 b).

Plate III: Collapse of a Telecommunication Tower at the Summit Park Community in Clarksburg, Wv (Muhammad and Scott , 2014 a)

2.2.6 Collapse case in Missouri

On April 19, 2018, an incident occurred in Fordland, Missouri where one employee was killed during the reinforcement of the KOZK 1,891-foot-tall guyed communication tower along Highway FF just north of Fordland, Missouri. The cause of the communication tower collapse was the weakening of the compressive strength of the tower legs by removing the bolts at the connection of the diagonals to the horizontal redundant. The compromised redundant effectively doubled the unbraced length of the tower leg which reduced the compressive capacity of the tower leg. The design required for the temporary frame for diagonal replacement above or below a guy level was not provided (Bryan and Mohammad, 2018).

2.2.7 Collapse case in Florida

On September 27, 2017, an incident occurred in Miami Gardens, Florida where three construction employees were killed. The employees were engaged in installing a new antenna for a local TV station at the top of a 951-foot tall antenna tower constructed in 2009. The three employees were killed when the gin pole they were using suddenly disengaged from the tower structure plunging several hundred feet to the ground. The employees were tied to the gin pole and fell with it. The cause of the disengagement was the failure of attachment between the gin pole and the tower structure (Mohammad and Bryan, 2018).

2.2.8 Collapse case in Alabama

A 105 metres high guyed radio transmission tower collapsed during the final phase of its construction on June 6, 1994 at approximately 9:00 am in Selma, Alabama. On that morning, two workers positioned near the top section of the tower, having completed the fastening of the coaxial cable to the top section of the tower, were beginning to lower the erection gin pole from the top section of the tower to the ground. The gin pole suddenly dropped and struck the coaxial cable, followed by the collapse of the tower structure. Both workers, who were tied to the collapsing tower, fell to the ground. The accident resulted in the death of one of the worker and serious injuries to the other Muhammad and Fragrance (1994).

2.2.9 Collapse case in Port Harcourt, Rivers state, Nigeria

On January 24th , 2017 it was reported by PM News that two persons, a 16-year old girl and and 45-year old local football coach are said to have died in the Nkpolu-Orowuoroku area in Mile 3 in Port Harcourt when a telecommunication mast and billboard fell on them during an hour long rain accompanied with thunderstorms. The female victim whose immediate identity remains unknown was said to have been under a giant umbrella assisting her mother to sell her wares when the mast suddenly collapse on a giant billboard and fell on the girl who died immediately. According to a witness, “We were about to start football practice when rain started falling with heavy wind. Suddenly, the telecommunication mast fell on a billboard which fell on her. A pole also fell on the football coach”.

The mother of the girl who was in a state of shock said: “We are selling at Nkpolu here. My daughter was helping me to sell when suddenly the rain started falling with heavy breeze which now fell the mast and the billboard that collapsed on my daughter. The Rivers State government through the Rivers State Signage and Outdoor Advertising Agency has warned that it will prosecute any outdoor advertising agency that erects substandard outdoor advertising billboards in the state. Dimkpa attributed the collapse to lack of maintenance of the billboard and the use of substandard materials for their billboards. He said the rain of yesterday exposed the substandard nature of the billboards erected by the outboard advertising agencies in the state. He said that the agency will start the full implementation of the outdoor advertising law in the state to checkmate excesses of advertising agencies (PM News, 2017).

2.2.10 Collapse case in Benue State

On January 20th , 2022 it was reported by Sahara Reporters, New York that Two workers of the Nigeria Telecommunication Limited (NITEL) have died in Kastina-Ala Local Government Area of Benue State, five were critically injured. It was learnt that the victim's died after the mast collapsed in the process of dismantling it

Sahara Reporters gathered that the workers were seven in number on top of the mast working around the NITEL premises near Takum Junction in Kastina-Ala when it suddenly collapsed. Confirming the incident, spokesperson for the police in the state, Sewuese Anene, affirmed that two people died in the accident. Chairman of Kastina-Ala Local Government Area, Alfred Atera, while lamenting the tragedy, said, They had loosed one side of the mast when the other part collapsed. Two of them died instantly while five others were taken to the hospital (Sahara Reporters, 2022).

Plate IV: Collapse of a Telecommunication Tower near Takum Junction in Kastina-Ala Benue State, Nigeria (Sahara Reporters, 2022)

2.2.11 Collapse case in Bayelsa State

On January 20^{th} , 2022 it was reported by The Nations News that family members in Nange-Ama community of Southern Ijaw Local Government Area of Bayelsa State have escaped death by a whisker following the collapse of a telecommunications mast that destroyed their building. The telecom mast, which is reportedly owned by one of the first generation mobile telecommunications company, fell and destroyed properties worth millions of naira including a building. It was gathered the telecommunications mast, which was erected in a residential area without allegedly considering its radius and reach, collapsed recently.

It was also gathered that several properties were destroyed including a well-furnished six-bedroom bungalow owned by one Mrs. Eva Efere. Mrs Efere was said to be inside the house alongside three others when the unfortunate incident occurred, but no life was lost in the process (The Nation News, 2022).

2.2.12 Collapse case in Jakarta, Indonesia

On August 31st , 2022 it was reported in Featured News by Wireless Estimator Google Maps as Police said at least ten people, including seven children, were killed in Bekasi on the outskirts of Jakarta, Indonesia, in the morning after a truck crashed into a telecommunications tower near a bus stop and toppled the structure in a busy area where school children were on the street during a morning recess. The children's ages ranged from 7 to 11 years old. Police stated that an additional 20 people were injured, many of them children. The structure, which was near an elementary school, was not within the school's compound,

Images from the scene showed the communications tower had fallen across the road outside the school's gates and crashed into the bus stop on the sidewalk. It also fell on top of a truck's cab, reportedly killing the driver.

Authorities have not identified how many fatalities were caused by the falling structure versus those deaths that might have been caused by the truck. The truck driver survived the crash and is now in police custody. Police have not yet determined the cause of the crash, but early signs suggest that the truck experienced brake failure. The truck toppled the tower that fell across the street (Wireless Estimator Google Maps, 2022).

Plate V: Collapse of a Telecommunication Tower Jakarta, Indonesia**.** Wireless Estimator Google Maps screenshot

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials (Design Information)

Materials that were used for this study include the following;

3.2.1 STAAD-Pro V8i

STAAD-Pro V8i is a structural analysis program used to analyse 3 and 4 sided towers or any type of loads. Towers can be either guyed or self-supporting. The program is a compilation of spreadsheets that aid in the modelling of geometry of the tower, and application of external loads such as antennas, dishes and feedlines. STAAD Pro V8i analyses the towers using the TIA-222-G standard or any of the previous versions of the TIA/EIA standards. For steel analysis, the program uses the AISC ASD 9th edition.

Linear and nonlinear (p-delta) analyses can be performed to determine the displacements and forces in the structure. Once analysis has been performed, STAAD Pro V8i creates an extensive report consisting of all inputs into the software and results for the tower. The results include stresses in each member of the tower and whether or not the members fail or pass with respect to the standards and codes that were applied.

The user interface of STAAD Pro V8i is very user friendly. The input menu opens to a page for input of data. Along the top of the menu are tabs for all inputs necessary to create a tower model including Geometry, Guy Data, Discrete Loads, Dishes, etc.

The "Geometry" tab takes the user to the interface that allows the tower model to be created as see in Table 4.2. Here tower type can be chosen depending on if the tower is free standing or guyed, and 3 or 4 sided. The tower height and number of sections can then be defined (Kalamkar *et al.,* 2022).

The "General" tab takes the user to the interface that allow for choice of materials, computation of loads & definition, create supports and choices of section. The

“Analysis/Print” tab takes the user to the interface that allow for analysis before design once all the necessary input has been made, which takes few minutes to process and display the analysis for view minutes in case of any correction to be made. It will run an analysis on the tower and create an output report. The report consists of the inputs for the tower, member stresses due to loading, and a detailed list of whether each member passed or failed with respect to the data. A member is said to pass if it is loaded at less than 100 % of its allowable capacity. Also included in the report is a print out of the model outlining details of the tower. The “Design” tab takes the user to the interface that allow for selection of the design code, design parameter suitable for the design. The “Setup” tab takes the user to the interface that allow for the setup of the title page. The “Report” tab takes the user to the interface that allow for generating of report after design which includes taking of pictures and selecting of the design results to be printed (Kalamkar *et al.,* 2022).

3.2.2 Loadings

There are different types of loads acting on the tower which includes the self-weight of the tower, live load from installed equipment, wind load on the mounted equipment and tower members. The loads acting on the selected tower are derived below.

Self-weight of the tower is automatically generated in STAAD pro by using the summing up the weights of all the sections. The weight obtained is distributed downwardly on all the tower members.

Equipment loads or antenna loads on the tower is calculated by calculating the weight of all installed equipment on the tower as shown below Table 3.2. Thereafter, the load is transferred to STAAD pro and applied to the tower nodes where the equipment is installed.

Characteristics wind pressure

The basic wind speed in Minna was collected from NiMET. BS 5950-1:2000, CP3: (2006) Chapter V: Part 2:, (Buick and Graham, 2012) Steel Designer's Manual was used. Table 3.1 shows the characteristics wind pressure analysis results.

Table 3.1: Characteristics wind Pressure

Storey	Height (m)	Basic wind speed, V(m/s)	S1	S2	S3	Design wind speed, vs (m/s)	Characteristics wind pressure, wk(n/m2)= 0.613vs^2	Wk/1000 (kn/m2)
1	**5**	**45**	**1**	**0.83**	**1**	**37.35**	**855.1487925**	**0.855148793**
2	**10**	**45**	**1**	**0.95**	**1**	**42.75**	**1120.295813**	**1.120295813**
3	**15**	**45**	**1**	**0.99**	**1**	**44.55**	**1216.622633**	**1.216622633**
4	**20**	**45**	**1**	**1.01**	**1**	**45.45**	**1266.275633**	**1.266275633**
5	**25**	**45**	**1**	**1.03**	**1**	**46.35**	**1316.921693**	**1.316921693**
6	**30**	**45**	**1**	**1.05**	**1**	**47.25**	**1368.560813**	**1.368560813**

Vs = V$S_1S_2S_3$ (for Class B, open country with no obstruction), **Vs:** Design speed at any height s in (m/s.), **V :** Basic wind speed in (m/s), $\boldsymbol{S_1}$**:** Multiplying factor relating to topology, $\boldsymbol{S_2}$**:** Multiplying factor relating to height above ground and wind braking, $\boldsymbol{S_3}$**:** Multiplying factor related to life of structure, $\boldsymbol{W_K}$ = 0.613Vs^2 N/m^2, $\boldsymbol{W_K}$**:** Characteristics wind pressure

Loadings

There are different types of loads acting on the mast which includes its self-weight, live load, equipment load and wind load. The loads acting on the mast are seen in Table 3.2.

Table 3.2: Equipment loading

S/N	Description	NO.s	Dia. (m)	Length (mm)	Width (mm)	Thickness(mm)	Weight(kg)	Total weight (kg)	Total weight (kN)
1	GSM	3		1000	170	63	25	75	0.75
2	Microwave	1	0.4	400			14	14	0.14
3	Feeder cables	4					o.2	24	0.24
4	Coaxial cables	4					0.2	24	0.24
5	Live load							100	1

GSM: Radio Frequency Tri-band panel Antenna, **Feeder cables:** 12mm diameter feeder cables, **MW:** 0.4m diameter parabolic Microwave Antenna, **Coaxial cables:** 12mm diameter coaxial cables.

3.2.3 Brief account of BS 5950

BS 5950 is a British standard for the design, fabrication and erection of structural steelwork. It was first published in 1985. BS 5950 replaced BS 449, which used a permissible stress approach and uses a limit state design method. It does not apply to bridges, which are covered by BS 5400. BS5950, the design code for structural steel, has been substantially revised. It was superseded by BS EN 1993 on 30th March 2010 and withdrawn.

3.2.4 Steel designer's manual seventh edition

A remarkable book emerged. Within approximately 900 pages it was possible for the steel designer to find everything necessary to carry out the detailed design of most conventional steelwork. Although not intended as an analytical treatise, the book contained the best summary of methods of analysis then available. The standard solutions, influence lines and formulae for frames could be used by the ingenious designer to disentangle the analysis of the most complex structure. Information on element design was intermingled with guidance on the design of both overall structures and connections. It was a book to dip into rather than read from cover to cover. However well one thought one knew its contents, it was amazing how often a further reading would give some useful insight into current problems. Readers forgave its idiosyncrasies, especially in the order of presentation. How could anyone justify slipping a detailed treatment of angle struts between a very general discussion of space frames and an overall presentation on engineering workshop design? The book was very popular. It ran to four editions with numerous reprints in both hard and soft covers. Special versions were also produced for overseas markets. Each edition was updated by the introduction of new material from a variety of sources. However, the book gradually lost the coherence of its original authorship and it became clear in the 1980s that a more radical revision was required. After 36 very successful years, it was decided to rewrite and reorder the book, while retaining its special character. This decision coincided with the formation of the Steel Construction Institute and it was given the task of co-ordinating this activity. A complete restructuring of the book was undertaken for the fifth edition, with more material on overall design and a new section on construction. The analytical material was condensed because it is now widely available elsewhere, but all the design data were retained in order to maintain the practical usefulness of the book as a day-to-day design manual. Design examples are to the more appropriate of these two codes for each particular application. The fifth edition was published in 1992 and proved to be a very worthy successor to its antecedents. It also ran to several printings in both hard and soft covers; an international edition was also printed and proved to be very popular in overseas markets. The sixth edition of 2003 maintained the broad structure introduced in 1992, reflecting its target readership of designers of structural steelwork of all kinds, and included updates to accommodate changes in the principal design codes required a more radical review of the content (Buick and Graham, 2012).

Figure 3.1 shows the Maximum wind flow map for Nigeria (30 years and above) in m/s used for wind analysis.

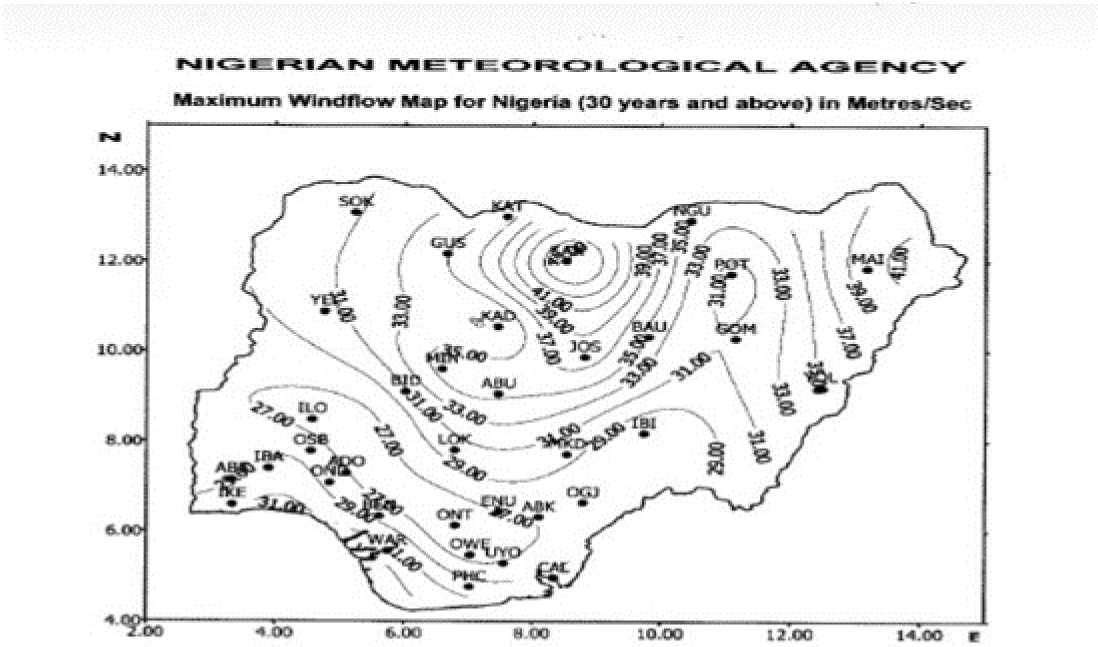


Figure 3.1: Maximum wind flow map for Nigeria (30 years and above) in m/s

Figure 3.2 shows the Multiplying factor chat used for wind analysis. It contains wind data such as characteristic wind pressure, basic wind speed, multiplying factor relating to topology.

Characteristic wind pressure

W_k $0.613 V_s^2$ N/m^2
where:

V_s design wind speed in m/s $= V S_1 S_2 S_3$

V basic wind speed in m/s (read from adjoining map)

S_1 multiplying factor relating to topology

S_2 multiplying factor relating to height above ground and wind braking

S_3 multiplying factor related to life of structure

Relation between design wind speed V_s and characteristic wind pressure w_k

V_s (m/s)	w_k (N/m^2)
10	61
12	88
14	120
16	157
18	199
20	245
22	297
24	353
26	414
28	481
30	552
32	628
34	709
36	794
38	885
40	981
42	1080
44	1190
46	1300
48	1410
50	1530
52	1660
54	1790
56	1920
58	2060
60	2210
62	2360
64	2510
66	2670
68	2830
70	3000

Values of factor S_1

S_1 may generally always be taken as unity except in the following cases:
On sites adversely affected by very exposed hill slopes and crests where wind acceleration is known to occur: $S_1 = 1.1$
On sites in enclosed steep-sided valleys completely sheltered from winds: $S_1 = 0.9$

Values of factor S_3

S_3 is a probability factor relating the likelihood of the design wind speed being exceeded to the probable life of the structure. A value of unity is recommended for general use and corresponds to an excessive speed occurring once in fifty years.

Values of factors S_2

Structure		Topo-graphical factor	Height of structure h (m) 5	10	15	20	30	40	50	60	80	100	120	140	160	180	200
Cladding etc.		1	0.88	1.00	1.03	1.06	1.09	1.12	1.14	1.15	1.18	1.20	1.22	1.24	1.25	1.26	1.27
		2	0.79	0.93	1.00	1.03	1.07	1.10	1.12	1.14	1.17	1.19	1.21	1.22	1.24	1.25	1.26
		3	0.70	0.78	0.88	0.95	1.01	1.05	1.08	1.10	1.13	1.16	1.18	1.20	1.21	1.23	1.24
		4	0.60	0.67	0.74	0.79	0.90	0.97	1.02	1.05	1.10	1.13	1.15	1.17	1.19	1.20	1.22
Maximum vertical or maximum horizontal dimension	≯ 50 m	1	0.83	0.95	0.99	1.01	1.05	1.08	1.10	1.12	1.15	1.17	1.19	1.20	1.22	1.23	1.24
		2	0.74	0.88	0.95	0.98	1.03	1.06	1.08	1.10	1.13	1.16	1.18	1.19	1.21	1.22	1.24
		3	0.65	0.74	0.83	0.90	0.97	1.01	1.04	1.06	1.10	1.12	1.15	1.17	1.18	1.20	1.21
		4	0.55	0.62	0.69	0.75	0.85	0.93	0.98	1.02	1.07	1.10	1.13	1.15	1.17	1.19	1.21
	> 50 m	1	0.78	0.90	0.94	0.96	1.00	1.03	1.06	1.08	1.11	1.13	1.15	1.17	1.19	1.20	1.21
		2	0.70	0.83	0.91	0.94	0.98	1.01	1.04	1.06	1.09	1.12	1.14	1.16	1.18	1.19	1.21
		3	0.60	0.69	0.78	0.85	0.92	0.96	1.00	1.02	1.06	1.09	1.11	1.13	1.15	1.17	1.18
		4	0.50	0.58	0.64	0.70	0.79	0.89	0.94	0.98	1.03	1.07	1.10	1.12	1.14	1.16	1.18

Notes

h is height (in metres) above general level of terrain to top of structure or part of structure. Increase to be made for structures on edge of cliff or steep hill.

Topographical factors

1. open country with no obstructions
2. open country with scattered wind-breaks
3. country with many wind-breaks; small towns; suburbs of large cities
4. city centres and other environments with large and frequent obstructions.

Figure 3.2: Multiplying factor chat (CP3, Chapter V: Part 2, 1972)

Plate IV shows pictures of different part of the collapsed 20m Mast in Minna, Nigeria. It seen from plate IV that, the mast fell on a 1- storey building close to the mast location.

a)

b)

c)

Plate VI(a – c): Different part of the collapsed 20m Mast in Minna, Nigeria

Plate IV shows pictures of different part of the collapsed 30m Mast in Calabar, Nigeria. It seen from plate IV that, the mast fell on a 2- storey building close to the mast location.

a)

b)

c)

d)

e)

Plate VII (a -e): Different part of the collapsed 30m mast

3.3 Methods

The following methods were adopted to carry out this research work:

Investigation of the structural causes of a collapsed 30 metres and 20 metres three legged guyed telecommunication mast in Calabar and Minna was done respectively. Other cases of collapse were equally studied within and across Nigeria. A typical of the collapsed mast was modelled, analysed and design with same loading and environmental condition for structural judgement.

3.3.1 Analysis of initial tension forces

The value of initial tension forces was determined by the dynamic method by counting the number of vibration amplitudes in a defined time. By a sharp jerking of the rope near its connection with anchoring, a vertical wave was caused and the amplitude of vibrations counted (full deflection) *N* in time *t* = 10 or 15 s. The rope initial tension at a half of its spread is calculated according to the Eq. (3.1) obtained from the transformation of the formula, defining the circular frequency of vibrations.

$$F_G = \frac{0.4077GLN^2}{t^2} \tag{3.1}$$

Where,
F_G rope tension in kN,

G total rope weight in N,

L rope length in m,

N number of amplitudes in time t,

t time of measuring N vibration amplitudes in s (Bernard and Janusz, 2014).

3.3.2 Analysis of amplitude x sine function (angular frequency x time + phase difference)

$$X = A\sin(\omega t + \varphi) \tag{3.2}$$

Where X = displacement (m)

A = amplitude (m)

ω = angular frequency (radiands/s)

t = time (s)

φ = phase shift (radians)

$$A = \frac{X}{\sin(\omega t + \varphi)} \tag{3.3}$$

Given, X = 4m, φ = 0, t = 4.5 s

$$A = \frac{4}{\sin[(\pi radians/s)(4.5s) + 0)} = \frac{4}{\sin(4.5\pi)} = 4\text{m}$$

A = 4m

Recall

$$F_G = \frac{0.4077GLN^2}{t^2} \qquad = \frac{0.4077\ X\ (0.03X31.05)X\ 31.05\ X\ 4^2}{4.5^2} = 9.317\ \text{kN} \cong 10\text{kN}$$

Therefore, the initial tension on the mast is calculated as F_G = 10kN, (Bernard and Janusz, 2014).

3.4 Tower Analysis and Design using STAAD pro

From the report generated using STAAD pro, the tower can be said to be stable as the stress ratio of all the tower members are less or equal to one. Also, the sizes of the tower members generated due to the present load exerted on the tower are less than the actual tower members. Finally, every failed member identified after the analysis has been provided with a suitable section by the software.

3.5 A Brief Account of Truss Analysis

Firstly, if we plan to design and build a truss structure, such as a tower structure for carrying external loads, we need to find out how much load is carried by each member of the tower. Secondly, in the case of an existing truss structure, we may need to replace one or a few members. In this case, we need to find the internal forces carried by those few members within the truss structure. In both instances, the objective is to figure out and decide whether the members can sustain the forces or not and what size members and what type of cross sections are required.

3.5.1 Types of truss analysis

There are two major methods of analysis for finding the internal forces in members of a truss; the Method of Joints, which is typically used for the case of creating a truss to handle external loads, and the Method of Sections, which is normally used when dealing modifying the internal members of an existing truss. Both methods are based on the assumption that when a structure is in equilibrium, all pieces of the structure are also in equilibrium. While graphical method and triangle are not common commonly used.

3.5.2 Joint method of analysis

Here, it is assumed that all members are in tension reaction. A tension member experiences pull forces at both ends of the bar and usually denoted by positive (+ve) sign. When a member is experiencing a push force at both ends, then the bar is said to be in compression mode and designated as negative (-ve) sign.

In the joints method, a virtual cut is made around a joint and the cut portion is isolated as a Free Body Diagram (FBD). Using the equilibrium equations of $\sum F_x = 0$ and $\sum F_y = 0$, the unknown member forces can be solved. It is assumed that all members are joined together in the form of an ideal pin, and that all forces are in tension (+ve reactions).

An imaginary section may be completely passed around a joint in a truss. The joint has become a free body in equilibrium under the forces applied to it. The equations $\sum H = 0$ and $\sum V = 0$ may be applied to the joint to determine the unknown forces in members meeting there. It is evident that no more than two unknowns can be determined at a joint with these two equations.

3.6 Tower Analysis By Manual Approach

Figure 3.3 shows the cross section of the three-legged telecommunication mast with different wind angle.

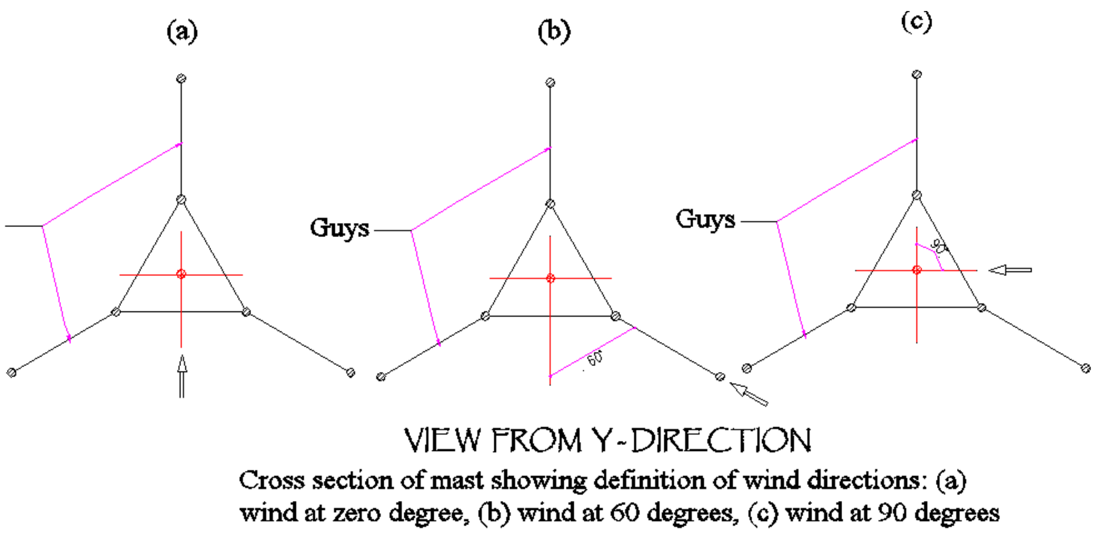


Figure 3.3: Cross Section of the mast view from y-direction

Figure 3.4 shows the elevation of the three-legged telecommunication mast win x-direction.

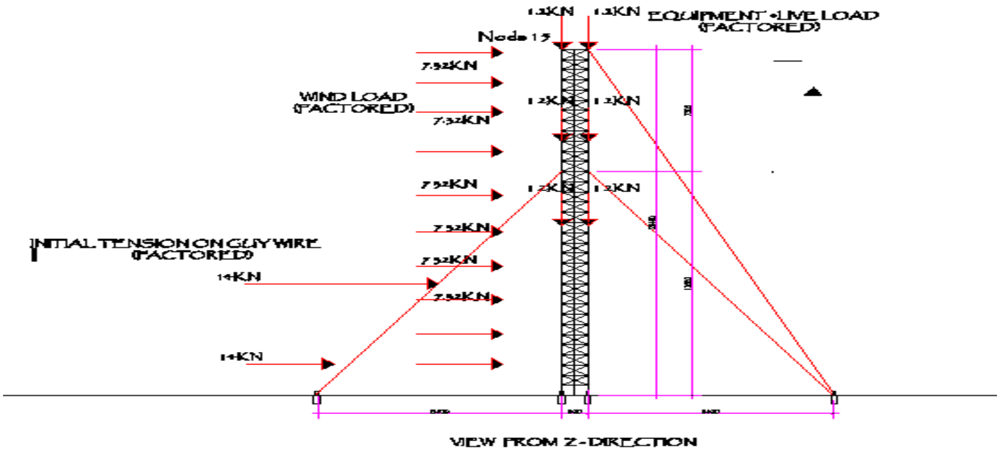


Figure 3.4: View from x-direction.

Figure 3.5 shows the elevation of the three-legged telecommunication mast win z-direction.

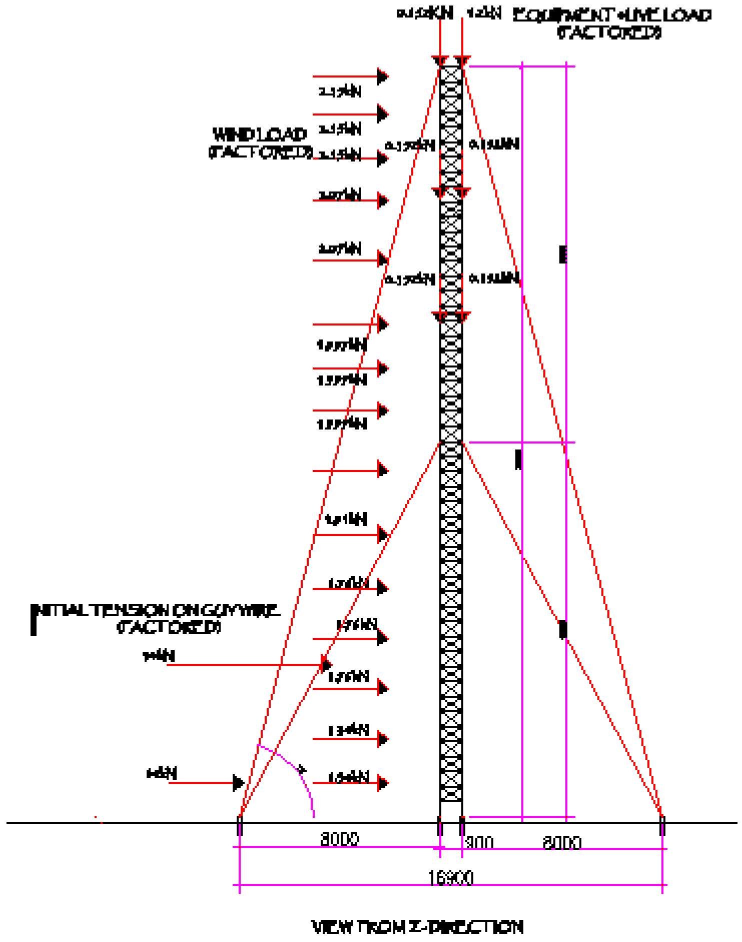


Figure 3.5: View from z-direction.

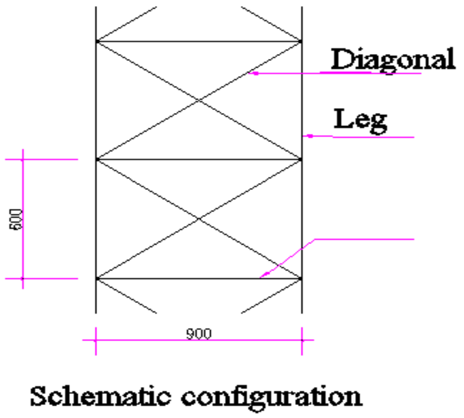
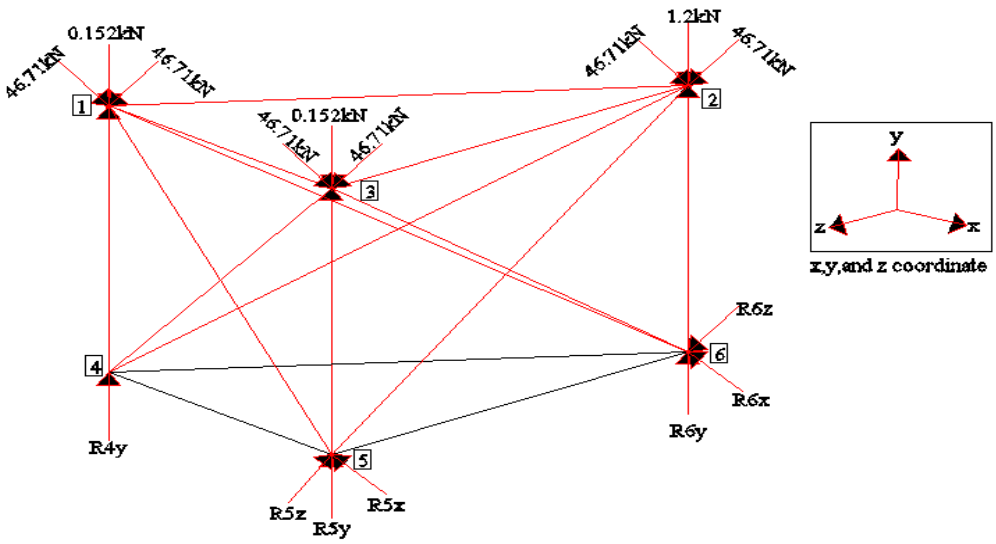


Figure 3.6: Schematic configuration

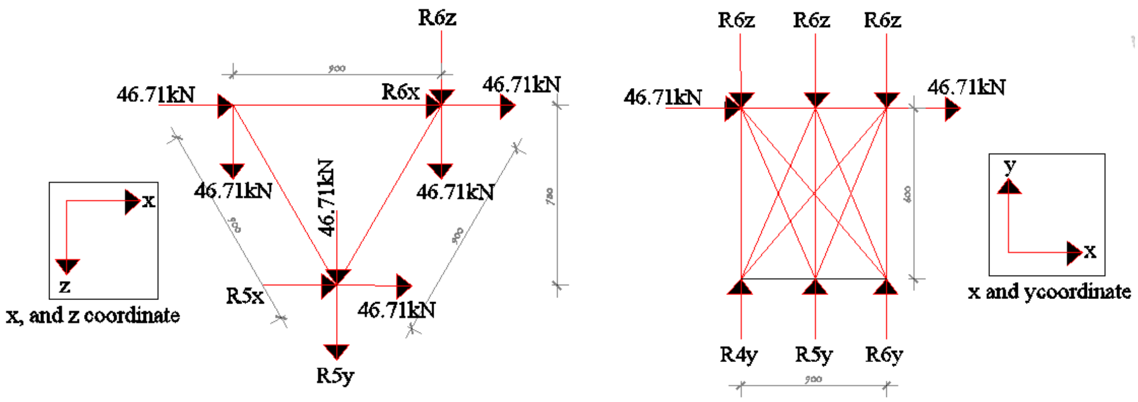
Figure 3.7 shows a 3-dimensional view of a space truss as seen in Figure 3.7a, the plan view in Figure 3.7b and the elevation in Figure 3.7c where the resolution of forces was considered in x, y, and z directions unlike in plannar trusses where the resolution of forces is done in two dorections only. The analysis consist of the computation of wind load, equipment load, dead load and live load application at each nodes.



(a)

Space diagram showing the top level of a 30 meters three legged guyed mast.

(a)



(b) Plan view showing x and z direction

(c) Elevation showing x and y direction

Figure 3.7: a - space diagram of 30 meters three-legged guyed telecommunication mast, b - the plan and c - the elevation

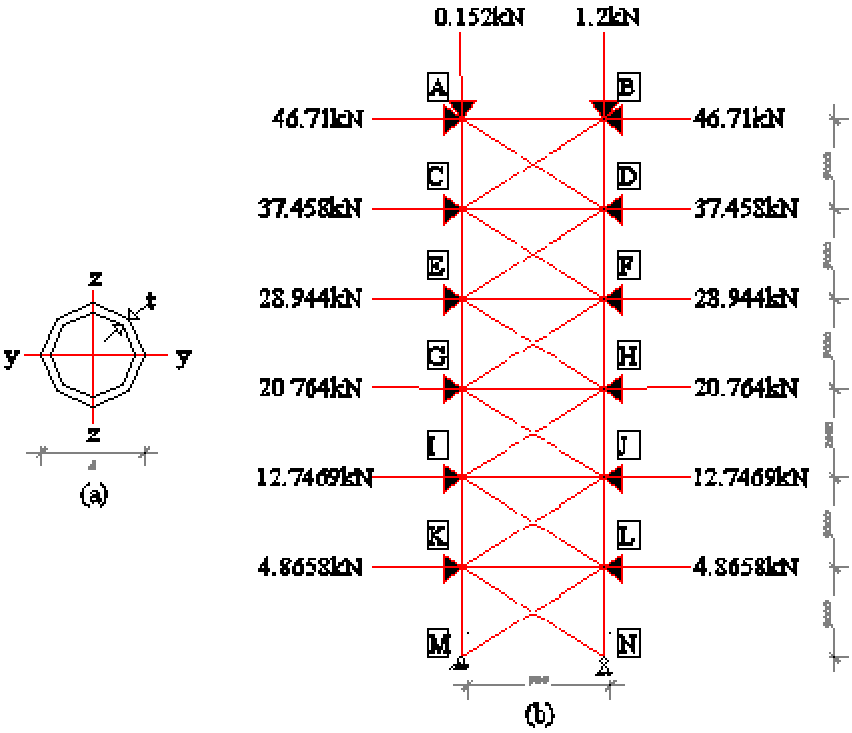


Figure 3.8: a - Hot-Finish circular hollow section of the main poles and b - elevation.

3.6.1 Analysis of the space truss:

Considering 3j = m + r for statically determinacy. From figure 3.3a, j = 6, m = 11, r = 7.

3x6 = 11+7 = 18. Thus, the truss is statically indeterminate.

Equilibrium of an entire space truss or equilibrium of sections of a space truss is described by the six scalar equations. $\Sigma F_x = 0$, $\Sigma F_y = 0$, $\Sigma F_z = 0$, $\Sigma M_{xx} = 0$, $\Sigma M_{yy} = 0$, $\Sigma M_{zz} = 0$

Or in vector form $F_R = 0$; $M_R = 0$. The resultant vectors of F_R and M_R represent three-dimensional force and moment vectors.

Considering the equilibrium equation with only one unknown. The reaction component R_{6y} can be obtained by taking the summation of moments about an x-axis through point 4 and 5.

$[\Sigma Mxx = 0; -\text{ve for clockwise and } +\text{ve for anticlockwise.}]$

$(-1.2x0.9) + (R_{6y} x0.9) = 0$

$-1.08 + 0.9R_{6y} = 0$

$R_{6y} = \frac{1.08}{0.9} = 1.2$ kN

$R_{6y} = 1.2$ kN

$[\Sigma\ Mzz\ =\ 0;\ -\text{ve for clockwise and }+\text{ve for anticlockwise.}]$

$(-1.2x0.9) + (46.71x0.6) + (R_{6y} X0.9) – (0.152X0.45) + (46.71X0.6) + (R_{5Y} x0.45) = 0$

$-1.08 + 28.026 + (0.9x1.2) -0.0684 + 28.026 + 0.45R_{5y} = 0$

$55.9836 + 0.45R_{5y} = 0$

$R_{5y} = \frac{-55.9836}{0.45} = -124.408$ kN

$R_{5y} = -124.408$ kN

Taking the summation of forces in the y-direction and using the above determined values of reaction, we obtain the value of $R_{4y;}$

$[\Sigma\ Fy\ =\ 0;\ -\text{ve for downward forces and }+\text{ve for upward forces.}]$

$R_{4y} -0.152-0.152-124.408-1.2+1.2 = 0$

$R_{4y} -124.408 = 0$

$R_{4y} = 124.408$ kN

The value of R_{5z} can be obtained by taking the summation of moments about a y-axis through point 6.

$[\Sigma\ Mzz\ =\ 0;\ -\text{ve for clockwise and }+\text{ve for anticlockwise.}]$

$(46.71x0.9) + (46.71x0.45) + ((R_{5z} x0.45) = 0$

$63.0585 + 0.45R_{5z} = 0$

$R_{5z} = \frac{-63.0585}{0.45} = -140.13$ kN

$R_{5z} = -140.13$ kN

R_{5x} will be obtained by taking the summation of moments about y-axis through point 6.

$[\Sigma\ Mxx\ =\ 0;\ -\text{ve for clockwise and }+\text{ve for anticlockwise.}]$

$(0.9xR_{5x}) + (0.9x46.71) = 0$

$0.9R_{5x} + 42.039 = 0$

$R_{5x} = \frac{-42.039}{0.9} = -46.71$ kN

$R_{5x} = -46.71$ kN

R_{6z} will be obtained by taking the summation of forces in the z-direction.

$-46.71 -4\ 6.71- (-140.13) - 46.71 - R_{6z} = 0$

$0- R_{6z} = 0$

$R_{6z} = 0$ kN

R_{6x} is then obtained by taking the summation of forces in the x-direction.

$46.71-46.77+46.71+ R_{6x} +46.71 = 0$

$R_{6x} = -93.42$ kN

To obtain the forces on all other members of the space truss, considering from the top of the mast 30 metres to 20 metres level through x-axis.

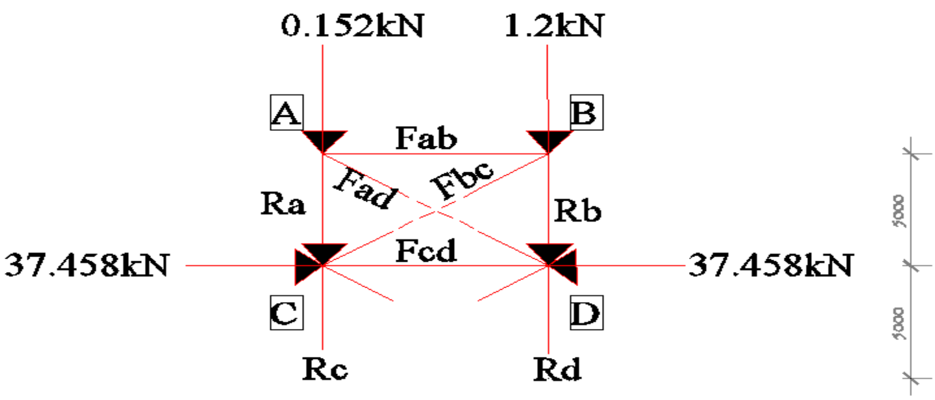
Computing the self-weight of the pole; Mass per meter = 6.82 kg/m;

6.82kg/mx 0.01 = 0.0682 kN/m;

0.0682 KN/m x 5 = 0.341 kN

Therefore, a 60.3mm outside diameter x 5mm thickness of length 5metres weighs 0.341kN as used in this analysis.

AT JOINT C:



Taking moment about joint C;

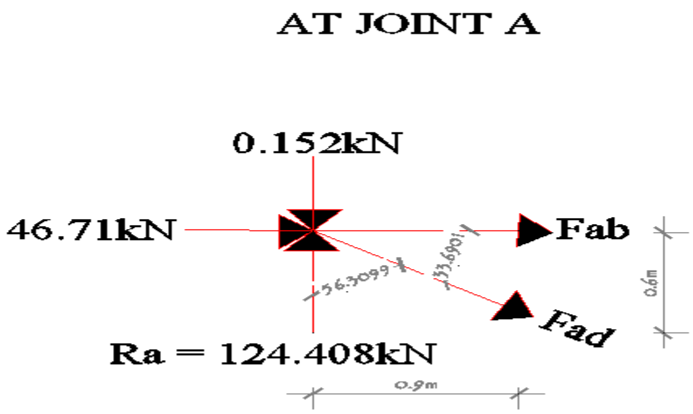
$$[\Sigma \text{ Mc } = 0; \text{ +ve for clockwise and } - \text{ve for anticlockwise.}]$$

$(1.541x0.9) – 0.9R_D = 0$

$1.3869 - 0.9R_D = 0$

$R_D = \frac{1.3869}{0.9} = 1.541 + 0.341$ (self-weight) $= 1.882$

$R_D = 1.882$ kN



$[\Sigma\ Fy\ =\ 0;\ -$ve for downward forces and $+$ ve for upward forces.$]$

$124.408 - 0.152 - F_{AD}\sin 33.6901 = 0$

$124.256 = F_{AD}\sin 33.6901$

$F_{AD} = \frac{124.256}{\sin 33.6901} = 224.01$ kN

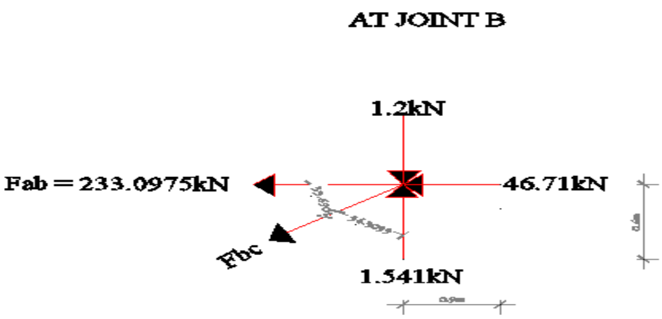
$F_{AD} =\ 224.01$ kN

$[\Sigma\ Fx =\ 0;\ +$ve for eastward forces and $-$ ve for westward forces.$]$

$46.71 + F_{AB} + F_{AB}\cos 33.6901 = 0$

$46.71 + F_{AB} + (224.01 \times \cos 33.6901) = 0$

$F_{AB} = 233.0975$ kN



$[\Sigma\ Fy\ =\ 0;\ -\text{ve for downward forces and } +\text{ve for upward forces.}]$

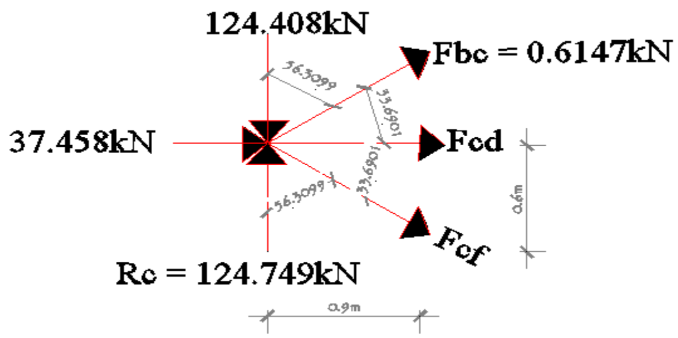
$-1.2 + 1.541 + F_{BC} \sin 33.6901 = 0$

$0.341 + F_{BC} \sin 33.6901 = 0$

$F_{BC} = \frac{-0.341}{\sin 33.6901} = -\ 0.6147\ kN$

$F_{BC} =\ -0.6147\ kN$

AT JOINT C



Taking moment about D

$[\Sigma\ Md\ =\ 0;\ +\text{ve for clockwise and } -\text{ve for anticlockwise.}]$

$(1.541 \times 0.9) - 0.9R_D = 0$

$R_C - 124.749 \times 0.9 = 0$

$R_C = \frac{124.749}{0.9} = 124.749\ kN$

$R_C = 124.749\ kN$

$[\Sigma\ Fy\ =\ 0;\ -\text{ve for downward forces and } +\text{ve for upward forces.}]$

$-124.749 + 124.749 + (0.6147 \times \sin 33.6901) - (F_{CF} \times \sin 33.6901)\ = 0$

$0.34097 - F_{CF} \sin 33.6901 = 0$

$F_{CF} = \frac{0.34097}{\sin 33.6901} = 0.6147\ kN$

$F_{CF} =\ 0.6147\ kN$

$[\Sigma\ Fx =\ 0;\ +\text{ve for eastward forces and } -\text{ve for westward forces.}]$

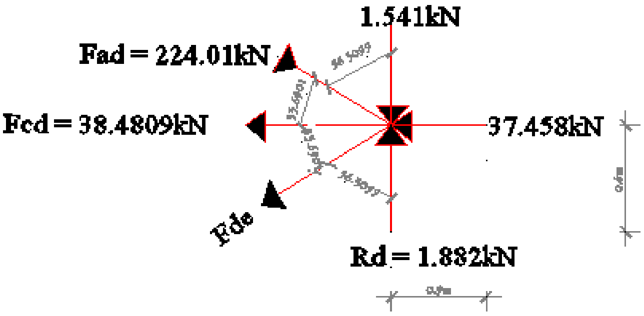
$37.458 + F_{BC} \cos 33.6901 + F_{CF} \cos 33.6901 + F_{CD} = 0$

$37.458 + (0.6147 \times \cos 33.6901) + (0.6147 \times \cos 33.6901) + F_{CD} = 0$

$38.48O9 + F_{CD} = 0$

$F_{CD} = -38.48O9$ kN

AT JOINT D



$[\Sigma Fy = 0; -\text{ve for downward forces and } + \text{ve for upward forces.}]$

$-1.541 + 1.882 + (F_{AD} \times \sin 33.6901) - (F_{DE} \times \sin 33.6901) = 0$

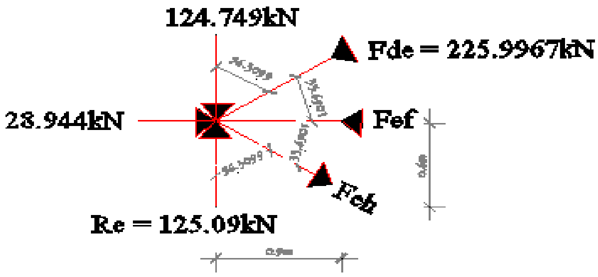
$0.341 + (224.01 \times \sin 33.6901) - (F_{DE} \times \sin 33.6901) = 0$

$135.03 - F_{DE} \sin 33.6901 = 0$

$F_{DE} = \frac{135.03}{\sin 33.6901} = 225.9967$ kN

$F_{DE} = 225.9967$ kN

AT JOINT E



$[\Sigma Fy = 0; -\text{ve for downward forces and } + \text{ve for upward forces.}]$

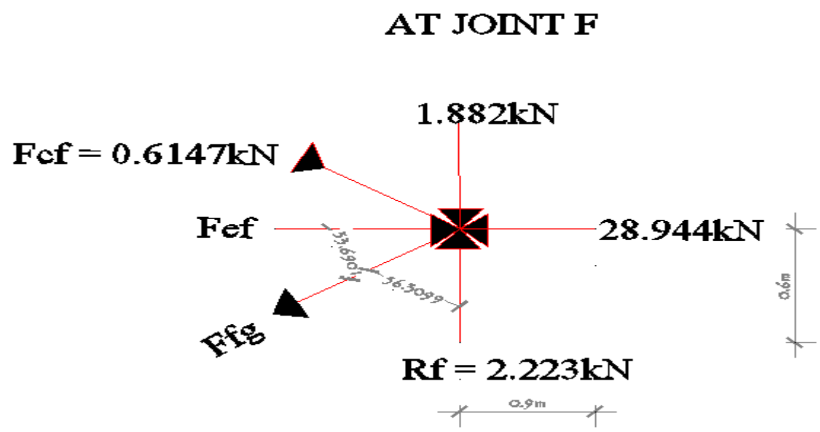
$-124.749 + 125.09 - (F_{AD} \times \sin 33.6901) - (F_{EH} \times \sin 33.6901) = 0$

$-124.749 + 125.09 - (225.9967 \text{ x } \sin 33.6901) - (F_{EH} \text{ x } \sin 33.6901) = 0$

$-125.02 + F_{EH} \sin 33.6901 = 0$

$F_{EH} = \frac{125.02}{\sin 33.6901} = 225.382 \text{ kN}$

$F_{EH} = 225.382 \text{ kN}$



$[\Sigma \text{ Fy} = 0; -\text{ve for downward forces and } +\text{ve for upward forces.}]$

$-1.882 + 2.223 + (F_{CF} \text{ x } \sin 33.6901) - (F_{FG} \text{ x } \sin 33.6901) = 0$

$0.68197 - F_{FG} \sin 33.6901 = 0$

$F_{FG} = \frac{0.68197}{\sin 33.6901} = 1.229 \text{ kN}$

$F_{FG} = 1.229 \text{ kN}$

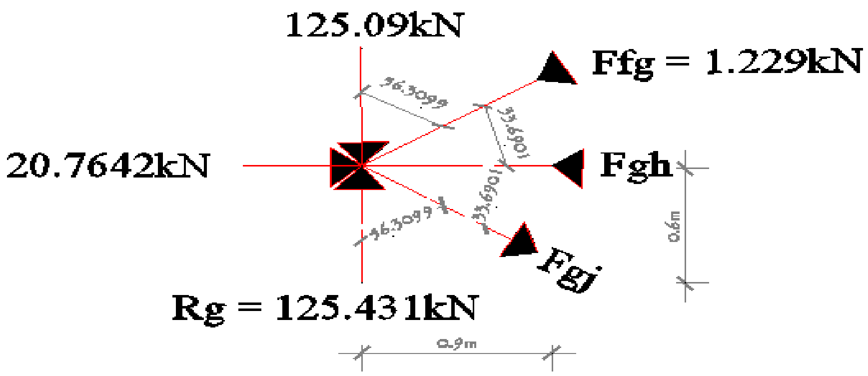
$[\Sigma \text{ Fx} = 0; +\text{ve for eastward forces and } -\text{ve for westward forces.}]$

$F_{EF} - 28.944 - (0.6147 \text{ x } \cos 33.6901) - F_{EG} \cos 33.6901 = 0$

$F_{CD} - 30.4706 = 0$

F_{CD} = 30.4706 kN

AT JOINT G



$[\Sigma\ Fy\ =\ 0;\ -\text{ve for downward forces and } +\text{ve for upward forces.}]$

-125.09 + 125.341 + (F_{FG} x sin33.6901) - (F_{GJ} x sin33.6901) = 0

-125.09 + 125.341 + (1.229 x sin33.6901) - (F_{GJ} x sin33.6901) = 0

0.9327 – F_{GJ} sin33.6901 = 0

$F_{GJ} = \frac{0.9327}{\sin 33.6901}$ = 1.6814 kN

F_{GJ} = 1.6814 kN

$[\Sigma\ Fx\ =\ 0;\ +\text{ve for eastward forces and } -\text{ve for westward forces.}]$

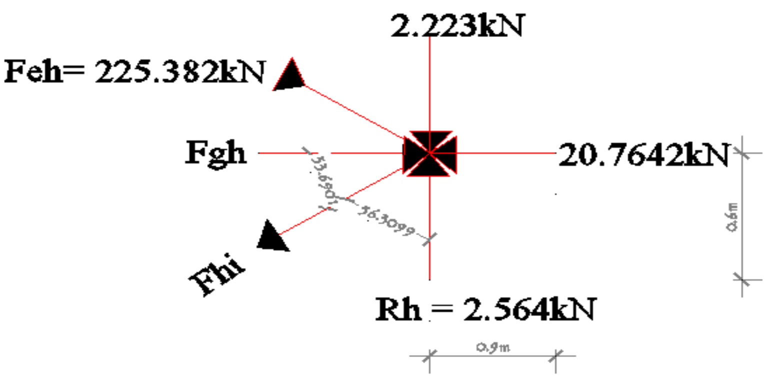
20.7642 – F_{GH} + (F_{FG} x cos33.6901) + F_{GJ} cos33.6901 = 0

20.7642 – F_{GH} + (1.229 x cos33.6901) + 1.6814 cos33.6901 = 0

-F_{GH} + 23.1858 = 0

F_{GH} = 23.1858 kN

AT JOINT H



[Σ Fy = 0; −ve for downward forces and + ve for upward forces.]

-2.223 + 2.564 - (F_{EH} x sin33.6901) - (F_{HI} x sin33.6901) = 0

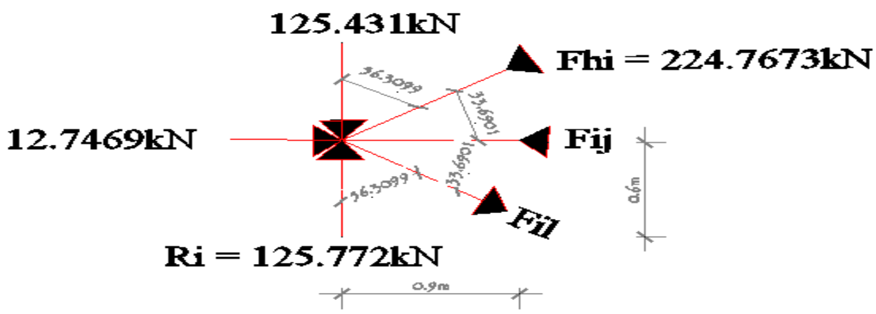
-2.223 + 2.564 - (225.382 x sin33.6901) - (F_{HI} x sin33.6901) = 0

-124.6785 – F_{HI} sin33.6901 = 0

$F_{HI} = \frac{-124.6785}{\sin 33.6901}$ = -224.7673 kN

F_{HI} = -224.7673 kN

AT JOINT I



[Σ Fy = 0; −ve for downward forces and + ve for upward forces.]

-125.431 + 125.772 + (F_{HI} x sin33.6901) - (F_{IL} x sin33.6901) = 0

-125.431 + 125.772 + (224.7673 x sin33.6901) - (F_{IL} x sin33.6901) = 0

125.0196 – F_{IL} sin33.6901 = 0

$F_{IL} = \frac{125.0196}{\sin 33.6901}$ = 225.382 kN

F_{IL} = 225.382 kN

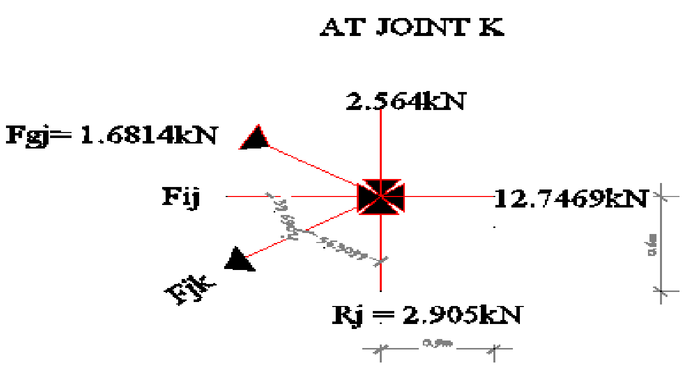
$[\Sigma\ Fx = 0;\ +ve\ for\ eastward\ forces\ and\ -ve\ for\ westward\ forces.]$

12.7469 – F_{IJ} + (F_{IH} x cos33.6901) + F_{IL} cos33.6901 = 0

12.7469 – F_{IJ} + (224.7673 x cos33.6901) + (225.382 cos33.6901) = 0

-F_{IJ} + 387.2936 = 0

F_{IJ} = 387.2936 kN



$[\Sigma\ Fy = 0;\ -ve\ for\ downward\ forces\ and\ +ve\ for\ upward\ forces.]$

-2.564 + 2.905+ (F_{JK} x sin33.6901) - (F_{GJ} x sin33.6901) = 0

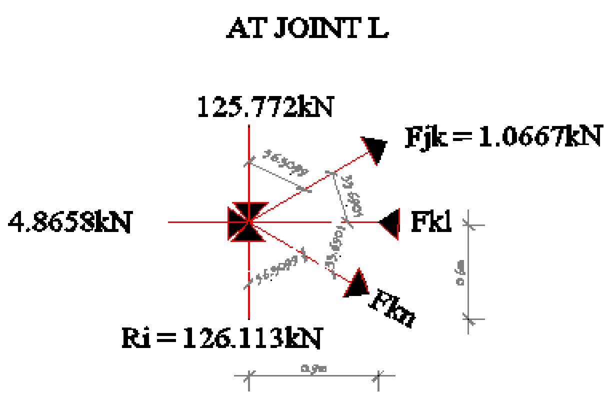
-2.564 + 2.905+ (F_{JK} x sin33.6901) - (1.6814 x sin33.6901) = 0

-0.5917 +F_{JK} sin33.6901 = 0

$F_{JK} = \frac{0.5917}{\sin 33.6901}$ = 1.0667 kN

F_{JK} = 1.0667 kN

$[\Sigma\ Fy = 0;\ -ve\ for\ downward\ forces\ and\ +ve\ for\ upward\ forces.]$



$-125.772 + 126.113 + (F_{JK} \times \sin 33.6901) - (F_{KN} \times \sin 33.6901) = 0$

$-125.772 + 126.113 + (1.0667 \times \sin 33.6901) - (F_{KN} \times \sin 33.6901) = 0$

$0.9327 - F_{KN} \sin 33.6901 = 0$

$F_{KN} = \frac{0.9327}{\sin 33.6901} = 1.6814$ kN

$F_{KN} = 1.6814$ kN

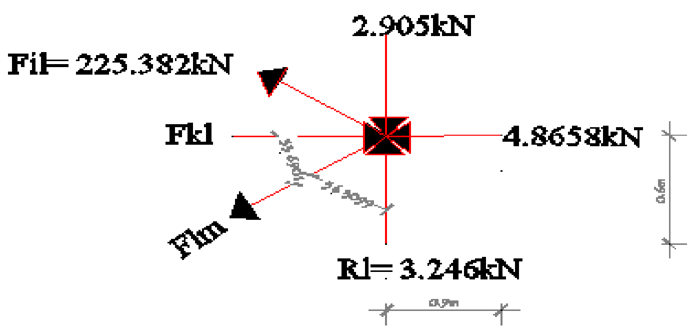
$[\Sigma\, Fx = 0;\ +\text{ve for eastward forces and} - \text{ve for westward forces.}]$

$4.8658 - F_{KL} + (F_{JK} \times \cos 33.6901) + F_{KN} \cos 33.6901 = 0$

$4.8658 - F_{KL} + (1.0667 \times \cos 33.6901) + (1.6814 \cos 33.6901) = 0$

$-F_{KL} + 7.1524 = 0$

AT JOINT M



$F_{KL} = 7.1524$ kN

$[\Sigma\, Fy = 0;\ -\text{ve for downward forces and} + \text{ve for upward forces.}]$

$-2.905 + 3.246 + (F_{IL} \times \sin 33.6901) - (F_{LM} \times \sin 33.6901) = 0$

$-2.905 + 3.246 + (225.382 \times \sin 33.6901) - (F_{LM} \times \sin 33.6901) = 0$

$125.3605 - F_{LM} \sin 33.6901 = 0$

$F_{LM} = \frac{125.3605}{\sin 33.6901} = 225.997$ kN

$F_{LM} = 225.997$ kN

3.7 Tower Design By Manual Approach

Check for crippling:

Recalling Euler's formula for crippling load (P) in columns with both ends fixed. Figure 3.9 shows that the three legs of the mast are fixed at each level of 5 meters long. Euler's formula was used to determine the buckling load for the pole.

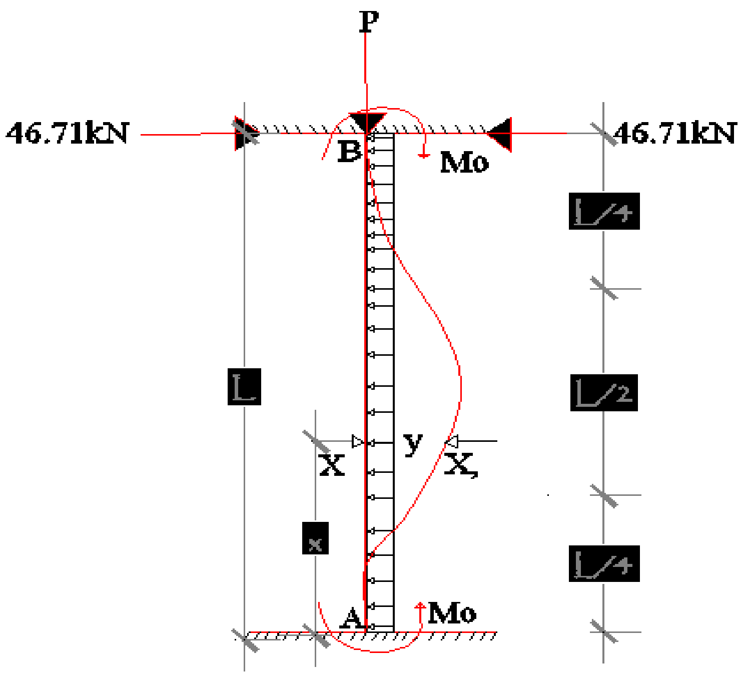


Figure 3.9: Flexural buckling diagram with direction of wind and axial load application on the mast

The relation between equivalent length (L_e) and actual length (L) is $L_e = \frac{L}{2}$

Crippling load (P) $= \frac{\frac{4\pi^2 EI}{L^2} EI}{(\frac{L}{2})^2} = \frac{4\pi^2 EI}{L^2}$

Euler's buckling load (P_E) $= \frac{\pi^2 EI}{Le^2}$

Yield strength $f_y = 275\ N/mm^2$

Compressive force (F) = 124.408 kN

Area (A) = $\frac{Force}{Py}$ = $\frac{124.408\ X\ 10^3}{275}$ = 452.39 mm^2

Area of section (A) = 578.1mm^2 was selected from the steel designers manual, page 1205, Appendix.

Outer diameter (D) = 76.1mm

Internal diameter (d) = 71.1mm

Thickness = 5mm

Mass per metre = 8.77 kg/m

Area of section (A) = $\frac{\pi}{4}[D^2 - d^2]$ = $\frac{\pi}{4}[76.1^2 - 71.1^2]$ = 578.1 mm^2

Moment of inertia (I) = $\frac{\pi}{64}[D^4 - d^4] =$ $\frac{\pi}{64}[76.1^4 - 71.1^4]$ = 391862.89mm^4 ≈ 391.863x10^3 mm^4

Modulus of Elasticity (E) = 205Gpa = 205000 N/mm^2

Check cross-section classification under pure compression. Need only check the section is not class 4 (slender).

Euler's buckling load (P_E) = $\frac{\pi^2 EI}{\mathrm{Le}^2}$ = $\frac{\pi^2\ X\ 205000 X 391863}{2500^2}$ = 126855.1N = 126.9 kN > 124.408 kN. Satisfactory

Compression members:

3.8 Design Statement

Check the ability of a 60.3mm x 5mm Circular Hollow Section (CHS) in grade S275 steel to withstand a design axial compressive load of 124.408 kN over a 5.0m column with fixed ends and intermediate lateral braces provided restraint minor axis buckling at every 0.6m along the column length as seen in Figure 3.10.

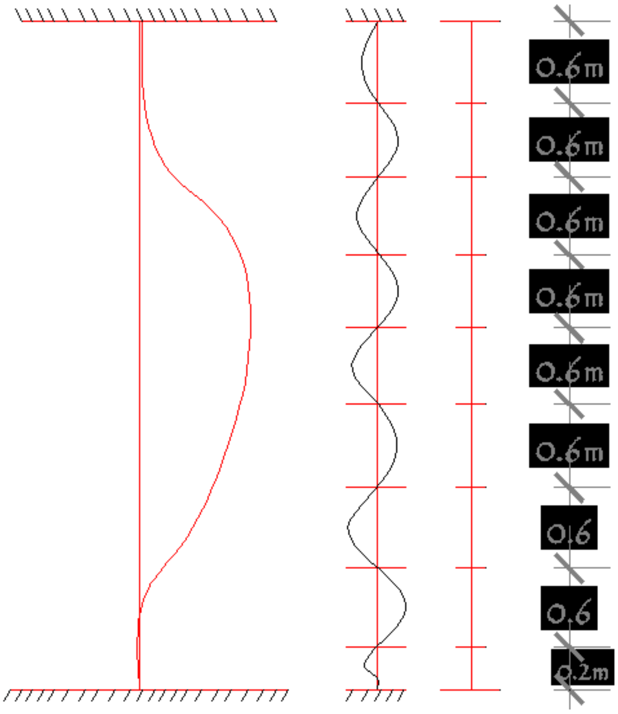


Figure 3.10: Flexural buckling diagram

Manual approach was used to design the three-legged guyed telecommunication mast in Calabar and Minna, Nigeria by Checking the ability of a 60.3mm x 5mm Circular Hollow Section (CHS) in grade S275 steel to withstand a design axial compressive load of 124.408kN over a 5.0m column with fixed ends and intermediate lateral braces provided restraint minor axis buckling at every 0.6m along the column length as seen in figure 3.6.

The result of the manual design is shown in Table 3.3s. From Table 3.3 it can be seen that the members is adequate for shear capacity check, moment capacity check, slenderness check and shear buckling check. Therefore, the design was satisfactory providing 76.1mm x 5mm Circular Hollow Section (CHS) in grade S275 steel against 60.3mm x 5mm used in the collapsed mat.

Table 3.3: Design by manual approach for vertical member

ITEM	CALCULATION	REFERENCES
	Design consideration:	
	Partial factors: $\gamma_{mo} = \mathbf{0.5}$; $\gamma_{m1} = \mathbf{0.5}$;	
	For axial compression, class 3 semi-compact is considered.	BS 5950-1:2000, Table 12, section 3. Structural use of steel work in building.
	Geometric properties:	
	Dimensions and properties:	
	Yield strength $f_y = \mathbf{275N/mm2}$	
	Radius of gyration (ï) = 25.2mm	
	$\varepsilon = \left[\frac{275}{f_y}\right]^{0.5} = \left[\frac{275}{\mathbf{275}}\right]^{0.5} = 1$	
	D/t <$80\varepsilon^2$ For compression due to bending.	
	60.3/5 = 12.06 < $80\varepsilon^2$	
	Section is not class 4.	Wenwei *et al.* (2018) and Steel designers manual.
	Shear capacity	
	Shear force (F_v) = $\frac{Force}{2} = \frac{124.408}{2}$ = 62.204kN	
	F_v = 62.204kN	
	P_v = 0.6 x 275 x 578.1 = 95386.5 = 95.387kN	
	F_v = 95.387KN > 62.204kN OK.	
	Section is satisfactory	
	Moment capacity	
	$Z_x = \frac{D^3-d^3}{6} = \frac{76.1^3-71.1^3}{6}$ = 13547.61mm^3	BS 5950-1: 2000, section 4, page 49
	$P_y = \mathbf{275}N/mm^2$	
	Design moment M = $\frac{WL_e}{8} = \frac{4.8658 \text{ x } 5}{8}$ = 3.04 kN.M	

$M_C = P_y Z_x = \frac{275 \text{ x } 13547.61}{10^6}$ = 3.73kN.M > 3.04kN.M OK.

Cross-section compression resistance:

$\mathbf{N_{c.Rd}} = \frac{Af_y}{\gamma_{mo}} = \frac{578.1 \, X \, 275}{\mathbf{0.5}} X \, 10^{-3}$ = 317.955kN > 124.408kN OK.

Effective length (L_e) = $\frac{L}{2} = \frac{5000}{2}$ = 2500mm for buckling

Table 16.1, steel designers manual

Non-dimensional slenderness:

$$\lambda = \boldsymbol{\pi} \sqrt{\frac{\mathbf{E}}{\mathbf{f_y}}} = \boldsymbol{\pi} \sqrt{\frac{\mathbf{205000}}{\mathbf{275}}} = \mathbf{85.8}$$

$\bar{\lambda} = \frac{\boldsymbol{\lambda}}{\boldsymbol{\lambda 1}} = \frac{\mathbf{L_e/i}}{\boldsymbol{\lambda 1}} = \frac{\frac{2500}{25.2}}{\mathbf{85.8}} = \mathbf{1.17 < 2.1}$ **Check is Ok for self-weight deflection.**

$\bar{\lambda}$ is the member slenderness or non-dimensional slenderness.

Steel designers manual. Table 16.4

λ is the effective column length divided by the appropriate radius of gyration ï.

λ_1 is the slenderness at which the yield load ($\boldsymbol{Af_y}$) and elastic buckling load are coincident.

Buckling Resistance factor Check:

From buckling curves; buckling reduction factor (χ) is read as 0.4.

$\Phi = 0.5 \; [1 + \propto (\bar{\lambda} - 0.2) + \bar{\lambda}^2] = 0.5 \; [1 + 0.21(1.17 - 0.2) + 1.17^2]$

= 1.75.

$\Phi = 1.75$

$\chi = \frac{1}{\Phi + \sqrt{\Phi^2 - \bar{\lambda}^2}} \leq 1.0 = \frac{1}{1.75 + \sqrt{1.75^2 - 1.49^2}} = 0.37 \leq$

1.0

buckling reduction factor is ok.

Where α is the imperfection factor.

Buckling Resistance Check:

N.Rd = $\frac{XAf_y}{\gamma_{m1}} = \frac{0.37\ X\ 578.1\ X\ 275}{\mathbf{0.5}} X\ 10^{-3} = 92.38\text{kN} >$

62.204kN OK.

Section is satisfactory

Therefore, provide 76.1mm x 5mm Circular Cross Section (CHS) for the main pole.

Area (A) = 578.1mm2

Table 3.4 s c5445cfrhows that 88.9mm x 5mm Circular Hollow Section (CHS) in grade S275 steel is sufficient to carry 387.293kN tensile load. All necessary checks was carry out and was satisfactory.

Table 3.4: Design by manual approach for horizontal member

ITEM	CALCULATION
	Tensile force (F) = 387.293kN
	$P_y = \mathbf{275N/mm2}$
	Length of member = 0.9m
	Area (A) = $\frac{Force}{Py} = \frac{387.293\ X\ 10^3}{275}$ = 1408.34mm2
	Area of section (A) =1630mm^2 was selected from the steel designers manual, page 1205, Appendix.
	Outer diameter (D) = 88.9mm
	Internal diameter (d) = 83.9mm
	Thickness = 5mm
	Shear capacity
	Shear force (F_v) = $\frac{Force}{2} = \frac{387.293}{2}$ = 193.65kN
	F_v = 193.65kN
	P_v = 0.6 x 275 x1630 = 268959 = 268.95kN
	F_v = 2.68.95kN > 193.65kN OK.
	Section is satisfactory
	Cross-section compression resistance:
	$\mathbf{N_{c.Rd}} = \frac{\boldsymbol{Af_y}}{\boldsymbol{\gamma_{mo}}} = \frac{1630\ X\ 275}{\mathbf{0.5}} X\ 10^{-3}$ = 896.500kN > 387.293kN OK.
	Section is satisfactory

Table 3.5 .Shows that 32mm Circular Solid Section (CSS) in grade S275 steel is sufficient to carry 225.9967kN tensile load. All necessary checks was carry out and was satisfactory.

Table 3.5: Design by manual approach for diagonal member

ITEM	CALCULATION
	Tensile force (F) = 225.9967 kN
	$F_y = 460\ N/mm^2$
	Partial factor of safety = 1.15
	Length of member = 1.082m
	Area (A) = $\frac{Force}{Fy}$ = $\frac{225.9967\ X\ 10^3\ x\ 1.15}{460}$ = 564.99mm2
	Area of section (A) =806mm^2 was selected from BS 8110-1:1997
	Steel diameter (D) = 32mm
	Shear capacity
	Shear force (F_v) = $\frac{Force}{2}$ = $\frac{225.9967}{2}$ = 113kN
	F_v = 113kN
	P_v = 0.6 x 275 x804 = 132660N = 132.660kN
	F_v = 132.660kN > 113kN OK.
	Section is satisfactory
	Cross-section compression resistance:
	$N_{c.Rd} = \frac{Af_y}{\gamma_{mo}} = \frac{804X\ 275}{0.5} X\ 10^{-3}$ = 442.2kN > 225.9967kN OK.
	Section is satisfactory

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Manual Structural Analysis Result

Summary of the space truss analysis done in 3.6 shows the truss members, applied load, position of members (vertical, horizontal and diagonal) and nature of force on each members as seen in Table 4.1. From Table 4.1 it can be seen that the highest compressive forces is R5y = 124.408kN (vertical member) which was used for designs and check for shear capacity and shear buckling adequacy for the selected steel section and the highest tensile forces is Fij = 387.293kN which is a horizontal member. From the analysis result in Table 4.1 horizontal member has the highest force because wind load on x and z direction.

Mikus (1994) carried out investigation of seismic response of six 3-legged self-supporting telecommunication towers with heights ranging from 20 to 90 meters. The selected towers were numerically simulated as bare towers. Three earthquake accelerograms were considered as input in the analysis. It was concluded that modal superposition with the lowest four modes of vibration would ascertain sufficient precision. Konno and Kimura (1973) carried out studies on the effects of earthquake loads on lattice telecommunication towers atop buildings. The objective of their work was to obtain the mode shapes, the natural frequencies, and the damping properties of such structures. Simulation of a stick model of the tower using lumped masses and a viscous damping ratio of 1 % was used in their studies. It was observed that in some of the members, the forces due to earthquake were greater than those due to wind.

Jacek *et al.* (2015) carried out a stability analysis of steel telecommunication towers with random parameters to provide a numerical solution to the stability problem of the steel telecommunication tower with some random material and geometrical parameters as given in figure 2.1 below loaded with the vertical unit forces to determine via the generalized perturbation-based Stochastic Finite Element Method up to the fourth order probabilistic characteristics of the critical load multipliers. Computational analysis has been programmed and carried out in the FEM package ROBOT (3D linear elastic model with two-noded 30 beam and 156 space truss finite elements) as well as the mathematical package MAPLE, v. 14. Full determination of probabilistic characteristics for the critical load multipliers enables for reliability index approximation, detection of the output probability density function for critical forces as well as reliable optimization of this model according to some new possible loadings of the tower (like solar panels or small windmills). Figure 2.1 shows the 3D FEM model of the steel telecommunication tower.

Report of Structural Integrity Audit showed a collapsed case of 55 metres tower at Silame Nassarawa, Sokoto State, Nigeria, that happened 2020. From the report, tower twisted due to failure in deflection at tower top and some loose bolts as observed on the tower. This failure is associated with the very low base to height ratio (slender tower) as manufactured and of which will requires huge weight to withstand deflection from wind impact on the tower. However, due to the absence of this required weight, tower bent from the middle of the tower height while the existing foundation remains intact (HIS Tower, 2021)

Table 4.1: Reactions and Member Forces Summary

S/N	MEMBER	LOAD(kN)	POSITION OF MEMBER	NATURE OF FORCE
1	R_{4y}	124.408	VERTICAL	TENSION
2	R_{5y}	-124.408	VERTICAL	COMPRESSION
3	R_{6y}	1.2	VERTICAL	TENSION
4	R_C	124.749	VERTICAL	TENSION
5	R_D	1.882	VERTICAL	TENSION
6	R_E	125.09	VERTICAL	TENSION
7	R_F	2.223	VERTICAL	TENSION
8	R_G	125.431	VERTICAL	TENSION
9	R_H	2.564	VERTICAL	TENSION
10	R_I	125.772	VERTICAL	TENSION
11	R_J	2.905	VERTICAL	TENSION
12	R_K	126.113	VERTICAL	TENSION
13	R_L	3.246	VERTICAL	TENSION
14	R_{5x}	-46.71	HORIZONTAL	COMPRESSION
15	R_{5z}	-140.13	HORIZONTAL	COMPRESSION
16	R_{6x}	-93.42	HORIZONTAL	COMPRESSION
17	R_{6z}	0		COMPRESSION
18	F_{AB}	233.0975	HORIZONTAL	TENSION
19	F_{CD}	-38.4809	HORIZONTAL	COMPRESSION
20	F_{EF}	30.4706	HORIZONTAL	TENSION
21	F_{GH}	23.1858	HORIZONTAL	TENSION
22	F_{IJ}	387.293	HORIZONTAL	TENSION
23	F_{KL}	7.152	HORIZONTAL	TENSION
24	F_{AD}	224.01	DIAGONAL	TENSION
25	F_{BC}	-0.6147	DIAGONAL	COMPRESSION
26	F_{CF}	0.6147	DIAGONAL	TENSION
27	F_{DE}	225.9967	DIAGONAL	TENSION
28	F_{EH}	225.382	DIAGONAL	TENSION
29	F_{FG}	1.229	DIAGONAL	TENSION
30	F_{GJ}	1.6814	DIAGONAL	TENSION
31	F_{HI}	-224.7673	DIAGONAL	COMPRESSION
32	F_{IL}	225.382	DIAGONAL	TENSION
33	F_{JK}	1.0667	DIAGONAL	TENSION
34	F_{KN}	1.6814	DIAGONAL	TENSION
35	F_{LM}	225.997	DIAGONAL	TENSION

4.2 Manual Structural Design Details

As a results of the manual analysis as seen in Table 4.1 and manual design as seen in Table 3.3, 3.4 and 3.5, Figure 4.1 is the details of structural provision suitable to carry the analysed load on the mast. The details can therefore, be used the reconstruction of the collapsed masts. From Figure 4.1, it can be seen that the collapsed mast was under design as the provision in Figure 4.0 is higher that of the collapsed masts.

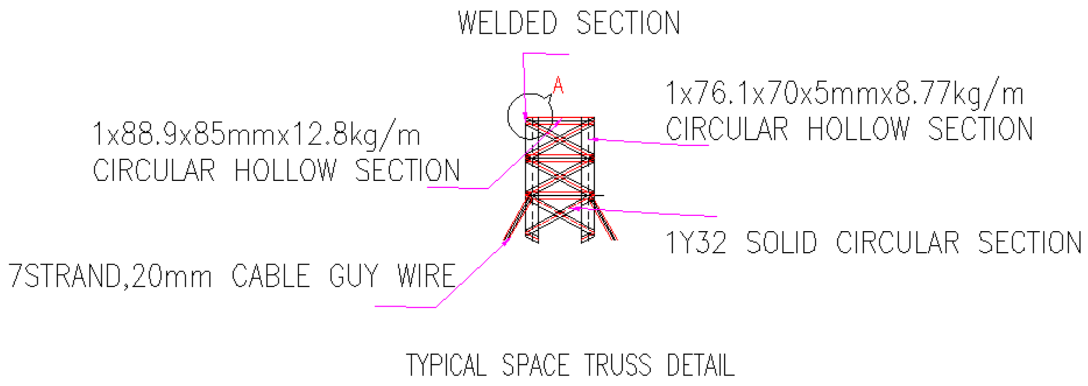


Figure 4.1: Details of 30 meters three-legged guyed telecommunication mast

4.3 Software Structural Analysis and Design results

STAAD-Pro V8i software was used in the course of analysis and design of the collapsed mast to compare with the manual analysis and design result for proper engineering judgement on the causes of the collapse. Software analysis, design and details are contained in the appendix.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

From the failure analysis of a collapFsed 30 metres and 20 metres three-legged guyed Telecommunication Mast in Minna and Calabar respectively. The following conclusions were drawn;

The failure of these structures happened during rainy season with thunderstorm where the soil was saturated with moisture and the guy wires were uprooted since there was a high rate of whirlwind application on the guy wires causing an increase of the initial tension on the guy wires couple with the insufficient depth of the footing for the guy wires as investigated.

The manual and software analysis results shows that most of the sections of the mast failed due to inadequate size which contributes to the collapsed.

From the manual and software design results, it is seen that the mast collapsed as some member failed in design showing that the sections used for the construction was not suitable. It was under designed. The software and manual design provided a suitable section for the failed members in case of reconstruction.

5.2 Recommendations

From the failure analysis of three legged guyed telecommunication mast in Calabar and Minna, Nigeria**.** The following recommendations were given;

1. Regular maintenance should be done in line with telecommunication tower installation guidelines to avoid frequent collapse.
2. Communication tower owners should have a structural analysis completed and the tower structural integrity confirmed before sending contractors to work on a tower.
3. Mast Guy wires should be made from pre-stretched steel only. Guy wires should not be over tightened in the installation of guy towers in order to avoid excessive tension which may cause alignment problems, cable rupture and permanent wrapping of tower structural parts.
4. Communication tower contractors should use temporary guy wires to maintain tower structural integrity when replacing guy wires on a guyed tower.

5.3 Research Contributions to Knowledge

The research considered two cases of 30 metres high and 20 metres 3-legged guyed wired telecommunication masts collapse in Calabar and Minna, Nigeria for structural integrity and audit in order to ascertain the risk of collapse. Manual and software structural designs were carried out to confirm the provisions of structural members. From the findings, a minimum depth of guy wires is recommended to be 1200mm for any 3-legged telecommunication mast above 15 metres height.

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APPENDIX

Job information, load cases and load combination and free body diagram

Software licensed to Hewlett-Packard	Job No	Sheet No 1		Rev
	Part			
Job Title MASTERS THESIS	Ref			
	By Engr Udeme	Date 19/11/2021	Chd Engr Peter	
Client DEPT. OF CIVIL ENGINEERING, FUTMINNA	File 30M THREE-LEGGED G	Date/Time 19-Nov-2021 11:44		

Job Information

	Engineer	Checked	Approved
Name:	Engr Udeme	Engr Peter	Prof Aguwa
Date:	19/11/2021		

Structure Type	SPACE FRAME

Number of Nodes	157	Highest Node	158
Number of Elements	484	Highest Beam	607

Number of Basic Load Cases	5
Number of Combination Load Cases	5

Included in this printout are data for:

All	The Whole Structure

Included in this printout are results for load cases:

Type	L/C	Name
Primary	1	SELF WEIGHT
Primary	2	EQUIPMENT LOAD
Primary	3	LIVE LOAD
Primary	4	WIND LOAD X+
Primary	5	WIND LOAD Z+
Combination	6	GENERATED BRITISH BS 5950 1
Combination	7	GENERATED BRITISH BS 5950 2
Combination	8	GENERATED BRITISH BS 5950 3
Combination	9	GENERATED BRITISH BS 5950 4
Combination	10	GENERATED BRITISH BS 5950 5

Free Body Diagram (Input data was modified after picture taken)

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Section properties, Materials, Supports and Primary load cases

Software licensed to Hewlett-Packard	Job No	Sheet No 20	Rev
	Part		
Job Title MASTERS THESIS	Ref		
	By Engr Udeme	Date 19/11/2021	Chd Engr Peter
Client DEPT. OF CIVIL ENGINEERING, FUTMINNA	File 30M THREE-LEGGED G	Date/Time 19-Nov-2021 11:44	

Section Properties Cont...

Prop	Section	Area (cm^2)	I_{yy} (cm^4)	I_{zz} (cm^4)	J (cm^4)	Material
99	RD18.7	2.750	0.600	0.600	0.005	STEEL
100	RD20.75	3.380	0.910	0.910	0.007	STEEL
101	RD17.5	2.410	0.460	0.460	0.004	STEEL
102	RD20.25	3.220	0.830	0.830	0.007	STEEL
103	RD18.4	2.660	0.560	0.560	0.004	STEEL
104	RD25	4.910	1.920	1.920	0.015	STEEL
105	RD13.75	0.000	0.000	0.000	0.351	STEEL
106	RD20.5	3.300	0.870	0.870	0.007	STEEL
107	RD17.25	2.340	0.430	0.430	0.003	STEEL
108	RD17	2.270	0.410	0.410	0.003	STEEL

Materials

Mat	Name	E (kN/mm^2)	ν	Density (kg/m^3)	α (/°C)
1	STEEL	205.000	0.300	7.83E+3	12E -6
2	STAINLESSSTEEL	197.930	0.300	7.83E+3	18E -6
3	ALUMINUM	68.948	0.330	2.71E+3	23E -6
4	CONCRETE	21.718	0.170	2.4E+3	10E -6

Supports

Node	X (kN/mm)	Y (kN/mm)	Z (kN/mm)	rX (kN·m/deg)	rY (kN·m/deg)	rZ (kN·m/deg)
1	Fixed	Fixed	Fixed	-	-	-
2	Fixed	Fixed	Fixed	-	-	-
4	Fixed	Fixed	Fixed	-	-	-
155	Fixed	Fixed	Fixed	-	-	-
156	Fixed	Fixed	Fixed	-	-	-
158	Fixed	Fixed	Fixed	-	-	-

Releases

There is no data of this type.

Primary Load Cases

Number	Name	Type
1	SELF WEIGHT	Dead
2	EQUIPMENT LOAD	Dead
3	LIVE LOAD	Live
4	WIND LOAD X+	Wind
5	WIND LOAD Z+	Wind

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		Job No	Sheet No 21	Rev
Software licensed to Hewlett-Packard		Part		
Job Title	MASTERS THESIS	Ref		
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Client	DEPT. OF CIVIL ENGINEERING, FUTMINNA	File 30M THREE-LEGGED G	Date/Time 19-Nov-2021 11:44	

Combination Load Cases

Comb.	Combination L/C Name	Primary	Primary L/C Name	Factor
6	GENERATED BRITISH BS 5950 1	1	SELF WEIGHT	1.40
		2	EQUIPMENT LOAD	1.40
		3	LIVE LOAD	1.60
7	GENERATED BRITISH BS 5950 2	1	SELF WEIGHT	1.40
		2	EQUIPMENT LOAD	1.40
		4	WIND LOAD X+	1.40
8	GENERATED BRITISH BS 5950 3	1	SELF WEIGHT	1.40
		2	EQUIPMENT LOAD	1.40
		5	WIND LOAD Z+	1.40
9	GENERATED BRITISH BS 5950 4	1	SELF WEIGHT	1.20
		2	EQUIPMENT LOAD	1.20
		3	LIVE LOAD	1.20
		4	WIND LOAD X+	1.20
10	GENERATED BRITISH BS 5950 5	1	SELF WEIGHT	1.20
		2	EQUIPMENT LOAD	1.20
		3	LIVE LOAD	1.20
		5	WIND LOAD Z+	1.20

Wind Load Definition : Type 1

Intensity (N/mm^2)	Height (m)
0.001	5.000
0.001	10.000
0.001	15.000
0.001	20.000
0.001	25.000
0.001	30.000

Exposure Factor	Range	Nodes / Height Range (m)
1.000	Nodes	5 - 154, 157

1 SELF WEIGHT : Selfweight

Direction	Factor	Assigned Geometry
Y	-1.000	ALL

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Different type of loads on the mast

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	Part		
Job Title MASTERS THESIS	Ref		
	By Engr Udeme	Date 19/11/2021	Chd Engr Peter
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2 EQUIPMENT LOAD : Node Loads

Node	FX (kN)	FY (kN)	FZ (kN)	MX (kNm)	MY (kNm)	MZ (kNm)
125	-	-0.152	-	-	-	-
126	-	-0.152	-	-	-	-
127	-	-0.152	-	-	-	-
140	-	-0.152	-	-	-	-
141	-	-0.152	-	-	-	-
142	-	-0.152	-	-	-	-
152	-	-0.152	-	-	-	-
153	-	-0.152	-	-	-	-
154	-	-0.152	-	-	-	-

3 LIVE LOAD : Node Loads

Node	FX (kN)	FY (kN)	FZ (kN)	MX (kNm)	MY (kNm)	MZ (kNm)
154	-	-1.000	-	-	-	-

4 WIND LOAD X+ : Wind Loading

Direction	Type	Factor
X	1	1.000

5 WIND LOAD Z+ : Wind Loading

Direction	Type	Factor
Z	1	1.000

Node Displacement Summary

	Node	L/C	X (mm)	Y (mm)	Z (mm)	Resultant (mm)	rX (rad)	rY (rad)	rZ (rad)
Max X	154	7:GENERATEL	**380.894**	-14.653	53.298	384.884	0.002	0.132	-0.002
Min X	152	8:GENERATEL	**-71.063**	-2.658	450.545	456.123	0.010	0.007	0.003
Max Y	105	5:WIND LOAD	-19.791	**6.720**	176.438	177.672	0.013	0.007	0.002
Min Y	154	9:GENERATEL	317.290	**-16.737**	76.992	326.926	0.003	0.112	-0.002
Max Z	152	8:GENERATEL	-71.063	-2.658	**450.545**	456.123	0.010	0.007	0.003
Min Z	153	4:WIND LOAD	211.157	-4.429	**-54.615**	218.150	-0.001	0.097	-0.002
Max rX	1	7:GENERATEL	0.000	0.000	0.000	0.000	**0.040**	0.040	0.008
Min rX	2	7:GENERATEL	0.000	0.000	0.000	0.000	**-0.030**	0.044	0.008
Max rY	154	7:GENERATEL	380.894	-14.653	53.298	384.884	0.002	**0.132**	-0.002
Min rY	154	6:GENERATEL	-32.975	-15.417	110.274	116.126	0.004	**-0.006**	0.000
Max rZ	1	7:GENERATEL	0.000	0.000	0.000	0.000	0.040	0.040	**0.008**
Min rZ	4	7:GENERATEL	0.000	0.000	0.000	0.000	0.005	0.043	**-0.048**
Max Rst	152	8:GENERATEL	-71.063	-2.658	450.545	**456.123**	0.010	0.007	0.003

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Beam displacement, Beam end displacement and Beam end force summary

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Job Title MASTERS THESIS	Part		
	Ref		
	By Engr Udeme	Date 19/11/2021	Chd Engr Peter
Client DEPT. OF CIVIL ENGINEERING, FUTMINNA	File 30M THREE-LEGGED G	Date/Time 19-Nov-2021 11:44	

Beam Displacement Detail Summary

Displacements shown in italic indicate the presence of an offset

	Beam	L/C	d (m)	X (mm)	Y (mm)	Z (mm)	Resultant (mm)
Max X	591	7:GENERATEI	0.600	**380.894**	-14.653	53.298	384.884
Min X	589	8:GENERATEI	0.600	**-71.063**	-2.657	450.545	456.123
Max Y	398	5:WIND LOAD	0.600	-19.791	**6.721**	176.438	177.672
Min Y	591	9:GENERATEI	0.600	317.290	**-16.737**	76.992	326.926
Max Z	589	8:GENERATEI	0.600	-71.063	-2.657	**450.545**	456.123
Min Z	590	4:WIND LOAD	0.600	211.157	-4.431	**-54.615**	218.150
Max Rst	589	8:GENERATEI	0.600	-71.063	-2.657	450.545	**456.123**

Beam End Displacement Summary

Displacements shown in italic indicate the presence of an offset

	Beam	Node	L/C	X (mm)	Y (mm)	Z (mm)	Resultant (mm)
Max X	591	154	7:GENERATEI	**380.894**	-14.653	53.298	384.884
Min X	589	152	8:GENERATEI	**-71.063**	-2.657	450.545	456.123
Max Y	398	105	5:WIND LOAD	-19.791	**6.721**	176.438	177.672
Min Y	591	154	9:GENERATEI	317.290	**-16.737**	76.992	326.926
Max Z	589	152	8:GENERATEI	-71.063	-2.657	**450.545**	456.123
Min Z	590	153	4:WIND LOAD	211.157	-4.431	**-54.615**	218.150
Max Rst	589	152	8:GENERATEI	-71.063	-2.657	450.545	**456.123**

Beam End Force Summary

The signs of the forces at end B of each beam have been reversed. For example: this means that the Min Fx entry gives the largest tension value for an beam.

				Axial	Shear		Torsion	Bending	
	Beam	Node	L/C	Fx (kN)	Fy (kN)	Fz (kN)	Mx (kNm)	My (kNm)	Mz (kNm)
Max Fx	3	4	8:GENERATEI	**236.094**	-1.441	-8.120	0.000	0.000	-0.000
Min Fx	2	6	8:GENERATEI	**-126.055**	-0.250	-4.676	0.000	-2.806	0.150
Max Fy	3	4	7:GENERATEI	63.089	**18.804**	-1.777	0.000	0.000	0.000
Min Fy	15	7	7:GENERATEI	64.148	**-18.330**	1.319	0.002	-0.820	-10.900
Max Fz	15	7	8:GENERATEI	223.389	1.639	**8.210**	-0.010	-4.646	0.906
Min Fz	3	4	8:GENERATEI	236.094	-1.441	**-8.120**	0.000	0.000	-0.000
Max Mx	24	8	7:GENERATEI	28.423	-0.225	0.116	**0.054**	-0.030	-0.032
Min Mx	13	5	7:GENERATEI	-87.010	1.104	5.815	**-0.042**	-3.264	0.666
Max My	2	6	7:GENERATEI	221.315	-1.933	7.261	0.000	**4.356**	1.160
Min My	3	7	8:GENERATEI	235.905	-1.441	-8.120	0.000	**-4.872**	0.864
Max Mz	14	6	7:GENERATEI	209.302	2.099	-8.003	-0.001	4.181	**1.179**
Min Mz	3	7	7:GENERATEI	62.900	18.804	-1.777	0.000	-1.066	**-11.283**

Typical steel design of member beam 1

Software licensed to Hewlett-Packard	Job No	Sheet No 522	Rev
	Part		
Job Title MASTERS THESIS	Ref		
	By Engr Udeme	Date 19/11/2021	Chd Engr Peter
Client DEPT. OF CIVIL ENGINEERING, FUTMINNA	File 30M THREE-LEGGED G	Date/Time 19-Nov-2021 11:44	

Steel Design (Track 2) Beam 1 Check 2

```
ALL UNITS ARE - KN   METE (UNLESS OTHERWIS    E Noted)

MEMBER     TABLE       RESULT/   CRITICAL COND/     RATIO/      LOADING/
                         FX            MY             MZ        LOCATION
=======================================================================

     1 ST  RD49          PASS     BS-4.8.2.2         0.999          7
                      107.72 T          0.00           5.75        0.60
=======================================================================
  MATERIAL DATA
     Grade of steel            =  S 275
     Modulus of elasticity     =  205 kN/mm2
     Design Strength  (py)     =  555  N/mm2

  SECTION PROPERTIES (units - cm)
     Member Length =       60.00
     Gross Area =   18.90  Net Area =   18.90  Eff. Area =   18.90

                                  z-z  axis       y-y  axis
     Moment of inertia         :       28.300          28.300
     Plastic modulus           :       11.600          11.600
     Elastic modulus           :       11.551          11.551
     Effective modulus         :       11.551          11.551
     Shear Area                :       11.340          11.340

  DESIGN DATA (units - kN,m)    BS5950-1/2000
     Section Class             :   SLENDER
     Squash Load               :   1048.95
     Axial force/Squash load   :     0.103

                                  z-z  axis       y-y  axis
     Compression Capacity      :        896.9           896.9
     Tension Capacity          :       1048.9          1048.9
     Moment Capacity           :          6.4             6.4
     Reduced Moment Capacity   :          6.4             6.4
     Shear Capacity            :        377.6           377.6

  BUCKLING CALCULATIONS (units - kN,m)
  (axis nomenclature as per design code)
                                   x-x axis        y-y axis
     Slenderness               :       49.033          49.033
     Radius of gyration (cm)   :        1.224           1.224
     Effective Length          :        0.600           0.600

     LTB check unnecessary for this section

  CRITICAL LOADS FOR EACH CLAUSE CHECK (units- kN,m):

   CLAUSE         RATIO  LOAD     FX       VY      VZ      MZ      MY
  BS-4.2.3-(Y)    0.001     9      -       0.4      -       -       -
  BS-4.2.3-(Z)    0.025     7      -        -      9.6      -       -
  BS-4.6    (T)   0.103     7   107.7      -       -       -       -
  BS-4.7    (C)   0.049     6    43.9      -       -       -       -
  BS-4.8.2.2      0.999     7   107.7     0.4     9.6     5.7     0.0
  BS-4.8.2.3      0.896     7   107.7      -       -      5.7     0.0
  BS-4.8.3.2      0.089     6    43.8     0.3     0.4     0.3     0.0
  BS-4.8.3.3.1    0.115     6    43.9      -       -      0.2     0.3
  BS-4.8.3.3.3    0.103     6    43.9      -       -      0.2     0.3
   Torsion and deflections have not been considered in the design.
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Print Time/Date: 19/11/2021 11:53   STAAD.Pro V8i (SELECTseries 6) 20.07.11.33   Print Run 522 of 1965

Typical steel design of member beam 1 continues

Software licensed to Hewlett-Packard	Job No	Sheet No 523	Rev
	Part		
Job Title MASTERS THESIS	Ref		
	By Engr Udeme	Date 19/11/2021	Chd Engr Peter
Client DEPT. OF CIVIL ENGINEERING, FUTMINNA	File 30M THREE-LEGGED G	Date/Time 19-Nov-2021 11:44	

Steel Design (Track 2) Beam 1 Check 3

```
ALL UNITS ARE - KN   METE (UNLESS OTHERWIS     E Noted)

MEMBER     TABLE        RESULT/   CRITICAL COND/     RATIO/     LOADING/
                          FX             MY            MZ       LOCATION
=======================================================================

     1 ST  RD46           PASS     BS-4.8.2.2         0.941         7
                       109.10 T           0.00          4.37       0.60
=======================================================================
  MATERIAL DATA
     Grade of steel           =  S 275
     Modulus of elasticity    =  205 kN/mm2
     Design Strength  (py)    =  555  N/mm2

  SECTION PROPERTIES (units - cm)
     Member Length =      60.00
     Gross Area =    16.60  Net Area =    16.60  Eff. Area =    16.60

                                 z-z  axis        y-y  axis
     Moment of inertia       :     22.000          22.000
     Plastic modulus         :      9.560           9.560
     Elastic modulus         :      9.565           9.565
     Effective modulus       :      9.565           9.565
     Shear Area              :      9.960           9.960

  DESIGN DATA (units - kN,m)   BS5950-1/2000
     Section Class           :   SLENDER
     Squash Load             :   921.30
     Axial force/Squash load :     0.118

                                 z-z  axis        y-y  axis
     Compression Capacity    :      762.2           762.2
     Tension Capacity        :      921.3           921.3
     Moment Capacity         :        5.3             5.3
     Reduced Moment Capacity :        5.3             5.3
     Shear Capacity          :      331.7           331.7

  BUCKLING CALCULATIONS (units - kN,m)
  (axis nomenclature as per design code)
                                  x-x axis         y-y axis
     Slenderness             :     52.119          52.119
     Radius of gyration (cm) :      1.151           1.151
     Effective Length        :      0.600           0.600

     LTB check unnecessary for this section

  CRITICAL LOADS FOR EACH CLAUSE CHECK (units- kN,m):

   CLAUSE         RATIO  LOAD     FX        VY       VZ       MZ       MY
  BS-4.2.3-(Y)    0.002    4       -        0.6      -        -        -
  BS-4.2.3-(Z)    0.022    7       -        -        7.3      -        -
  BS-4.6    (T)   0.118    7   109.1        -        -        -        -
  BS-4.7    (C)   0.031    6    23.6        -        -        -        -
  BS-4.8.2.2      0.941    7   109.1        0.6      7.3      4.4      0.0
  BS-4.8.2.3      0.822    7   109.1        -        -        4.4      0.0
  BS-4.8.3.2      0.079    6    23.4        0.4      0.3      0.3      0.0
  BS-4.8.3.3.1    0.105    6    23.5        -        -        0.2      0.2
  BS-4.8.3.3.3    0.090    6    23.5        -        -        0.2      0.2
   Torsion and deflections have not been considered in the design.
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Print Time/Date: 19/11/2021 11:53 STAAD.Pro V8i (SELECTseries 6) 20.07.11.33 Print Run 523 of 1965

Utilization ratio

Software licensed to Hewlett-Packard		Job No	Sheet No 1955		Rev
		Part			
Job Title MASTERS THESIS		Ref			
		By Engr Udeme	Date 19/11/2021		Chd Engr Peter
Client DEPT. OF CIVIL ENGINEERING, FUTMINNA		File 30M THREE-LEGGED G	Date/Time 19-Nov-2021 11:44		

Utilization Ratio

Beam	Analysis Property	Design Property	Actual Ratio	Allowable Ratio	Ratio (Act./Allow.)	Clause	L/C	Ax (cm^2)	Iz (cm^4)	Iy (cm^4)	Ix (cm^4)
1	PIPBG60.3X	RD46	0.941	1.000	0.941	BS-4.8.2.2	7	16.600	22.000	22.000	44.000
2	PIPBG60.3X	RD51.5	0.901	1.000	0.901	BS-4.8.3.3.1	7	20.800	34.500	34.500	69.000
3	PIPBG60.3X	RD61	0.953	1.000	0.953	BS-4.8.3.3.1	7	29.200	68.000	68.000	136.000
4	RD16	RD15.75	0.979	1.000	0.979	BS-4.8.3.3.1	8	1.950	0.300	0.300	0.600
5	RD16	RD20	0.895	1.000	0.895	BS-4.8.3.3.1	7	3.140	0.790	0.790	1.580
6	RD16	RD8	0.873	1.000	0.873	BS-4.8.2.2	7	0.500	0.020	0.020	0.040
13	PIPBG60.3X	RD44.5	0.997	1.000	0.997	BS-4.8.2.2	7	15.600	19.200	19.200	38.400
14	PIPBG60.3X	RD51	0.894	1.000	0.894	BS-4.8.3.3.1	7	20.400	33.200	33.200	66.400
15	PIPBG60.3X	RD60	0.962	1.000	0.962	BS-4.8.3.3.1	7	28.300	63.600	63.600	127.200
19	RD16	RD20.75	0.948	1.000	0.948	BS-4.8.3.3.1	7	3.380	0.910	0.910	1.820
20	RD16	RD21.7	0.934	1.000	0.934	BS-4.8.3.3.1	8	3.700	1.090	1.090	2.180
21	RD16	RD27.25	0.928	1.000	0.928	BS-4.8.3.3.1	7	5.830	2.710	2.710	5.420
22	RD16	RD12	0.888	1.000	0.888	BS-4.8.3.3.1	6	1.130	0.100	0.100	0.200
23	RD16	RD10	0.903	1.000	0.903	BS-4.8.2.2	7	0.790	0.049	0.049	0.098
24	RD16	RD27.25	0.913	1.000	0.913	BS-4.8.3.3.1	7	5.830	2.710	2.710	5.420
25	PIPBG60.3X	RD24	0.992	1.000	0.992	BS-4.8.2.2	7	4.520	1.630	1.630	3.260
26	PIPBG60.3X	RD35.5	0.878	1.000	0.878	BS-4.8.3.3.1	7	9.900	7.800	7.800	15.600
27	PIPBG60.3X	RD35	0.883	1.000	0.883	BS-4.8.3.3.1	8	9.620	7.370	7.370	14.740
31	RD16	RD16.5	0.955	1.000	0.955	BS-4.8.3.3.1	7	2.140	0.360	0.360	0.720
32	RD16	RD17	0.975	1.000	0.975	BS-4.8.3.3.1	8	2.270	0.410	0.410	0.820
33	RD16	RD21.7	0.950	1.000	0.950	BS-4.8.3.3.1	7	3.700	1.090	1.090	2.180
34	RD16	RD9	0.839	1.000	0.839	BS-4.8.3.3.1	6	0.640	0.032	0.032	0.064
35	RD16	RD7	0.891	1.000	0.891	BS-4.8.2.2	7	0.380	0.012	0.012	0.024
36	RD16	RD20.75	0.934	1.000	0.934	BS-4.8.3.3.1	7	3.380	0.910	0.910	1.820
37	PIPBG60.3X	RD18.25	0.969	1.000	0.969	BS-4.8.3.3.1	6	2.620	0.540	0.540	1.080
38	PIPBG60.3X	RD32	0.921	1.000	0.921	BS-4.8.3.3.1	7	8.040	5.150	5.150	10.300
39	PIPBG60.3X	RD31.3	0.965	1.000	0.965	BS-4.8.3.3.1	8	7.690	4.710	4.710	9.420
43	RD16	RD17	0.874	1.000	0.874	BS-4.8.3.3.1	7	2.270	0.410	0.410	0.820
44	RD16	RD17.5	0.948	1.000	0.948	BS-4.8.3.3.1	8	2.410	0.460	0.460	0.920
45	RD16	RD21.25	0.938	1.000	0.938	BS-4.8.3.3.1	7	3.550	1.000	1.000	2.000
46	RD16	RD11.5	0.947	1.000	0.947	BS-4.8.3.3.1	6	1.040	0.086	0.086	0.172
47	RD16	RD6.5	0.890	1.000	0.890	BS-4.8.2.2	7	0.330	0.009	0.009	0.018
48	RD16	RD21.7	0.968	1.000	0.968	BS-4.8.3.3.1	7	3.700	1.090	1.090	2.180
49	PIPBG60.3X	RD13.75	0.998	1.000	0.998	BS-4.8.2.2	7	1.480	0.180	0.180	0.360
50	PIPBG60.3X	RD31	0.891	1.000	0.891	BS-4.8.3.3.1	7	7.550	4.530	4.530	9.060
51	PIPBG60.3X	RD31	0.946	1.000	0.946	BS-4.8.3.3.1	8	7.550	4.530	4.530	9.060
55	RD16	RD17.25	0.946	1.000	0.946	BS-4.8.3.3.1	7	2.340	0.430	0.430	0.860
56	RD16	RD17.5	0.943	1.000	0.943	BS-4.8.3.3.1	8	2.410	0.460	0.460	0.920
57	RD16	RD21.25	0.979	1.000	0.979	BS-4.8.3.3.3	7	3.550	1.000	1.000	2.000
58	RD16	RD9	0.984	1.000	0.984	BS-4.8.3.3.1	10	0.640	0.032	0.032	0.064
59	RD16	RD6.5	0.951	1.000	0.951	BS-4.8.2.2	7	0.330	0.009	0.009	0.018
60	RD16	RD21.25	0.961	1.000	0.961	BS-4.8.3.3.1	7	3.550	1.000	1.000	2.000
61	PIPBG60.3X	RD18.5	0.984	1.000	0.984	BS-4.8.3.3.1	6	2.690	0.570	0.570	1.140
62	PIPBG60.3X	RD29.6	0.968	1.000	0.968	BS-4.8.3.3.1	7	6.880	3.770	3.770	7.540
63	PIPBG60.3X	RD31	0.875	1.000	0.875	BS-4.8.3.3.1	10	7.550	4.530	4.530	9.060
64	RD16	RD9	0.989	1.000	0.989	BS-4.7 (C)	5	0.640	0.032	0.032	0.064
65	RD16	RD9.5	0.880	1.000	0.880	BS-4.8.3.3.1	4	0.710	0.040	0.040	0.080
66	RD16	RD5.5	0.219	1.000	0.219	BS-4.7 (C)	5	0.240	0.004	0.004	0.008
67	RD16	RD16.5	0.927	1.000	0.927	BS-4.8.3.3.1	7	2.140	0.360	0.360	0.720

Print Time/Date: 19/11/2021 11:53 STAAD.Pro V8i (SELECTseries 6) 20.07.11.33 Print Run 1955 of 1965

Utilization ratio continues

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Job No	Sheet No 1956	Rev	
Part			
Job Title MASTERS THESIS	Ref		
By Engr Udeme	Date 19/11/2021	Chd Engr Peter	

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Job No	Sheet No 1955	Rev	
Part			
Job Title MASTERS THESIS	Ref		
By Engr Udeme	Date 19/11/2021	Chd Engr Peter	
Client DEPT. OF CIVIL ENGINEERING, FUTMINNA	File 30M THREE-LEGGED G	Date/Time 19-Nov-2021 11:44	

Utilization Ratio

Beam	Analysis Property	Design Property	Actual Ratio	Allowable Ratio	Ratio (Act./Allow.)	Clause	L/C	Ax (cm^2)	Iz (cm^4)	Iy (cm^4)	Ix (cm^4)
1	PIPBG60.3X	RD46	0.941	1.000	0.941	BS-4.8.2.2	7	16.600	22.000	22.000	44.000
2	PIPBG60.3X	RD51.5	0.901	1.000	0.901	BS-4.8.3.3.1	7	20.800	34.500	34.500	69.000
3	PIPBG60.3X	RD61	0.953	1.000	0.953	BS-4.8.3.3.1	7	29.200	68.000	68.000	136.000
4	RD16	RD15.75	0.979	1.000	0.979	BS-4.8.3.3.1	8	1.950	0.300	0.300	0.600
5	RD16	RD20	0.895	1.000	0.895	BS-4.8.3.3.1	7	3.140	0.790	0.790	1.580
6	RD16	RD8	0.873	1.000	0.873	BS-4.8.2.2	7	0.500	0.020	0.020	0.040
13	PIPBG60.3X	RD44.5	0.997	1.000	0.997	BS-4.8.2.2	7	15.600	19.200	19.200	38.400
14	PIPBG60.3X	RD51	0.894	1.000	0.894	BS-4.8.3.3.1	7	20.400	33.200	33.200	66.400
15	PIPBG60.3X	RD60	0.962	1.000	0.962	BS-4.8.3.3.1	7	28.300	63.600	63.600	127.200
19	RD16	RD20.75	0.948	1.000	0.948	BS-4.8.3.3.1	7	3.380	0.910	0.910	1.820
20	RD16	RD21.7	0.934	1.000	0.934	BS-4.8.3.3.1	8	3.700	1.090	1.090	2.180
21	RD16	RD27.25	0.928	1.000	0.928	BS-4.8.3.3.1	7	5.830	2.710	2.710	5.420
22	RD16	RD12	0.888	1.000	0.888	BS-4.8.3.3.1	6	1.130	0.100	0.100	0.200
23	RD16	RD10	0.903	1.000	0.903	BS-4.8.2.2	7	0.790	0.049	0.049	0.098
24	RD16	RD27.25	0.913	1.000	0.913	BS-4.8.3.3.1	7	5.830	2.710	2.710	5.420
25	PIPBG60.3X	RD24	0.992	1.000	0.992	BS-4.8.2.2	7	4.520	1.630	1.630	3.260
26	PIPBG60.3X	RD35.5	0.878	1.000	0.878	BS-4.8.3.3.1	7	9.900	7.800	7.800	15.600
27	PIPBG60.3X	RD35	0.883	1.000	0.883	BS-4.8.3.3.1	8	9.620	7.370	7.370	14.740
31	RD16	RD16.5	0.955	1.000	0.955	BS-4.8.3.3.1	7	2.140	0.360	0.360	0.720
32	RD16	RD17	0.975	1.000	0.975	BS-4.8.3.3.1	8	2.270	0.410	0.410	0.820
33	RD16	RD21.7	0.950	1.000	0.950	BS-4.8.3.3.1	7	3.700	1.090	1.090	2.180
34	RD16	RD9	0.839	1.000	0.839	BS-4.8.3.3.1	6	0.640	0.032	0.032	0.064
35	RD16	RD7	0.891	1.000	0.891	BS-4.8.2.2	7	0.380	0.012	0.012	0.024
36	RD16	RD20.75	0.934	1.000	0.934	BS-4.8.3.3.1	7	3.380	0.910	0.910	1.820
37	PIPBG60.3X	RD18.25	0.969	1.000	0.969	BS-4.8.3.3.1	6	2.620	0.540	0.540	1.080
38	PIPBG60.3X	RD32	0.921	1.000	0.921	BS-4.8.3.3.1	7	8.040	5.150	5.150	10.300
39	PIPBG60.3X	RD31.3	0.965	1.000	0.965	BS-4.8.3.3.1	8	7.690	4.710	4.710	9.420
43	RD16	RD17	0.874	1.000	0.874	BS-4.8.3.3.1	7	2.270	0.410	0.410	0.820
44	RD16	RD17.5	0.948	1.000	0.948	BS-4.8.3.3.1	8	2.410	0.460	0.460	0.920
45	RD16	RD21.25	0.938	1.000	0.938	BS-4.8.3.3.1	7	3.550	1.000	1.000	2.000
46	RD16	RD11.5	0.947	1.000	0.947	BS-4.8.3.3.1	6	1.040	0.086	0.086	0.172
47	RD16	RD6.5	0.890	1.000	0.890	BS-4.8.2.2	7	0.330	0.009	0.009	0.018
48	RD16	RD21.7	0.968	1.000	0.968	BS-4.8.3.3.1	7	3.700	1.090	1.090	2.180
49	PIPBG60.3X	RD13.75	0.998	1.000	0.998	BS-4.8.2.2	7	1.480	0.180	0.180	0.360
50	PIPBG60.3X	RD31	0.891	1.000	0.891	BS-4.8.3.3.1	7	7.550	4.530	4.530	9.060
51	PIPBG60.3X	RD31	0.946	1.000	0.946	BS-4.8.3.3.1	8	7.550	4.530	4.530	9.060
55	RD16	RD17.25	0.946	1.000	0.946	BS-4.8.3.3.1	7	2.340	0.430	0.430	0.860
56	RD16	RD17.5	0.943	1.000	0.943	BS-4.8.3.3.1	8	2.410	0.460	0.460	0.920
57	RD16	RD21.25	0.979	1.000	0.979	BS-4.8.3.3.3	7	3.550	1.000	1.000	2.000
58	RD16	RD9	0.984	1.000	0.984	BS-4.8.3.3.1	10	0.640	0.032	0.032	0.064
59	RD16	RD6.5	0.951	1.000	0.951	BS-4.8.2.2	7	0.330	0.009	0.009	0.018
60	RD16	RD21.25	0.961	1.000	0.961	BS-4.8.3.3.1	7	3.550	1.000	1.000	2.000
61	PIPBG60.3X	RD18.5	0.984	1.000	0.984	BS-4.8.3.3.1	6	2.690	0.570	0.570	1.140
62	PIPBG60.3X	RD29.6	0.968	1.000	0.968	BS-4.8.3.3.1	7	6.880	3.770	3.770	7.540
63	PIPBG60.3X	RD31	0.875	1.000	0.875	BS-4.8.3.3.1	10	7.550	4.530	4.530	9.060
64	RD16	RD9	0.989	1.000	0.989	BS-4.7 (C)	5	0.640	0.032	0.032	0.064
65	RD16	RD9.5	0.880	1.000	0.880	BS-4.8.3.3.1	4	0.710	0.040	0.040	0.080
66	RD16	RD5.5	0.219	1.000	0.219	BS-4.7 (C)	5	0.240	0.004	0.004	0.008
67	RD16	RD16.5	0.927	1.000	0.927	BS-4.8.3.3.1	7	2.140	0.360	0.360	0.720

Print Time/Date: 19/11/2021 11:53 STAAD.Pro V8i (SELECTseries 6) 20.07.11.33 Print Run 1955 of 1965

Utilization ratio continues

Software licensed to Hewlett-Packard	Job No	Sheet No 1957	Rev
	Part		
Job Title MASTERS THESIS	Ref		
	By Engr Udeme	Date 19/11/2021	Chd Engr Peter
Client DEPT. OF CIVIL ENGINEERING, FUTMINNA	File 30M THREE-LEGGED G	Date/Time 19-Nov-2021 11:44	

Utilization Ratio Cont...

Beam	Analysis Property	Design Property	Actual Ratio	Allowable Ratio	Ratio (Act./Allow.)	Clause	L/C	Ax (cm^2)	Iz (cm^4)	Iy (cm^4)	Ix (cm^4)
129	RD16	RD21.5	0.961	1.000	0.961	BS-4.8.3.3.1	7	3.630	1.050	1.050	2.100
130	RD16	RD11.5	0.895	1.000	0.895	BS-4.8.3.3.1	6	1.040	0.086	0.086	0.172
131	RD16	RD7	0.973	1.000	0.973	BS-4.8.3.3.1	6	0.380	0.012	0.012	0.024
132	RD16	RD21	0.955	1.000	0.955	BS-4.8.3.3.1	7	3.460	0.950	0.950	1.900
133	PIPBG60.3X	RD19.5	0.986	1.000	0.986	BS-4.8.3.3.1	6	2.990	0.710	0.710	1.420
134	PIPBG60.3X	RD26	0.976	1.000	0.976	BS-4.8.3.3.1	7	5.310	2.240	2.240	4.480
135	PIPBG60.3X	RD27	0.934	1.000	0.934	BS-4.8.3.3.1	10	5.730	2.610	2.610	5.220
139	RD16	RD17.9	0.951	1.000	0.951	BS-4.8.3.3.1	7	2.520	0.500	0.500	1.000
140	RD16	RD17.25	0.982	1.000	0.982	BS-4.8.3.3.1	8	2.340	0.430	0.430	0.860
141	RD16	RD21.5	0.940	1.000	0.940	BS-4.8.3.3.1	7	3.630	1.050	1.050	2.100
142	RD16	RD11.5	0.947	1.000	0.947	BS-4.8.3.3.1	6	1.040	0.086	0.086	0.172
143	RD16	RD7	0.862	1.000	0.862	BS-4.8.2.2	7	0.380	0.012	0.012	0.024
144	RD16	RD20.75	0.952	1.000	0.952	BS-4.8.3.3.1	7	3.380	0.910	0.910	1.820
145	PIPBG60.3X	RD19.7	0.986	1.000	0.986	BS-4.8.3.3.1	6	3.050	0.740	0.740	1.480
146	PIPBG60.3X	RD25.5	0.976	1.000	0.976	BS-4.8.3.3.1	7	5.110	2.080	2.080	4.160
147	PIPBG60.3X	RD26	0.959	1.000	0.959	BS-4.8.3.3.1	10	5.310	2.240	2.240	4.480
151	RD16	RD17	0.966	1.000	0.966	BS-4.8.3.3.1	7	2.270	0.410	0.410	0.820
152	RD16	RD17	0.928	1.000	0.928	BS-4.8.3.3.1	8	2.270	0.410	0.410	0.820
153	RD16	RD20.5	0.969	1.000	0.969	BS-4.8.3.3.1	7	3.300	0.870	0.870	1.740
154	RD16	RD10.5	0.818	1.000	0.818	BS-4.8.3.3.1	10	0.870	0.060	0.060	0.120
155	RD16	RD6	0.906	1.000	0.906	BS-4.8.2.2	7	0.280	0.006	0.006	0.012
156	RD16	RD21.7	0.955	1.000	0.955	BS-4.8.3.3.1	7	3.700	1.090	1.090	2.180
157	PIPBG60.3X	RD20	0.950	1.000	0.950	BS-4.8.3.3.1	9	3.140	0.790	0.790	1.580
158	PIPBG60.3X	RD24.75	0.977	1.000	0.977	BS-4.8.3.3.1	7	4.810	1.840	1.840	3.680
159	PIPBG60.3X	RD25.5	0.930	1.000	0.930	BS-4.8.3.3.1	10	5.110	2.080	2.080	4.160
163	RD16	RD18.25	0.964	1.000	0.964	BS-4.8.3.3.1	7	2.620	0.540	0.540	1.080
164	RD16	RD17	0.932	1.000	0.932	BS-4.8.3.3.1	8	2.270	0.410	0.410	0.820
165	RD16	RD21.25	0.957	1.000	0.957	BS-4.8.3.3.1	7	3.550	1.000	1.000	2.000
166	RD16	RD11.5	0.934	1.000	0.934	BS-4.8.3.3.1	6	1.040	0.086	0.086	0.172
167	RD16	RD6.5	0.962	1.000	0.962	BS-4.8.2.2	7	0.330	0.009	0.009	0.018
168	RD16	RD20.25	0.969	1.000	0.969	BS-4.8.3.3.1	7	3.220	0.830	0.830	1.660
169	PIPBG60.3X	RD21	0.950	1.000	0.950	BS-4.8.3.3.1	9	3.460	0.950	0.950	1.900
170	PIPBG60.3X	RD24.5	0.970	1.000	0.970	BS-4.8.3.3.1	7	4.710	1.770	1.770	3.540
171	PIPBG60.3X	RD24.75	0.969	1.000	0.969	BS-4.8.3.3.1	10	4.810	1.840	1.840	3.680
175	RD16	RD17.5	0.951	1.000	0.951	BS-4.8.3.3.1	7	2.410	0.460	0.460	0.920
176	RD16	RD16.5	0.946	1.000	0.946	BS-4.8.3.3.1	8	2.140	0.360	0.360	0.720
177	RD16	RD20.25	0.967	1.000	0.967	BS-4.8.3.3.3	7	3.220	0.830	0.830	1.660
178	RD16	RD10	0.938	1.000	0.938	BS-4.8.3.3.1	10	0.790	0.049	0.049	0.098
179	RD16	RD5.5	0.998	1.000	0.998	BS-4.8.2.2	7	0.240	0.004	0.004	0.008
180	RD16	RD21.5	0.946	1.000	0.946	BS-4.8.3.3.1	7	3.630	1.050	1.050	2.100
181	PIPBG60.3X	RD21.85	0.963	1.000	0.963	BS-4.8.3.3.1	9	3.750	1.120	1.120	2.240
182	PIPBG60.3X	RD24	0.953	1.000	0.953	BS-4.8.3.3.1	7	4.520	1.630	1.630	3.260
183	PIPBG60.3X	RD24.25	0.957	1.000	0.957	BS-4.8.3.3.1	9	4.620	1.700	1.700	3.400
184	RD16	RD8	0.840	1.000	0.840	BS-4.7 (C)	5	0.500	0.020	0.020	0.040
185	RD16	RD10.5	0.965	1.000	0.965	BS-4.8.3.3.1	7	0.870	0.060	0.060	0.120
186	RD16	RD7.5	0.968	1.000	0.968	BS-4.7 (C)	5	0.440	0.016	0.016	0.032
187	RD16	RD18.7	0.939	1.000	0.939	BS-4.8.3.3.1	7	2.750	0.600	0.600	1.200
188	RD16	RD16.5	0.974	1.000	0.974	BS-4.8.3.3.1	8	2.140	0.360	0.360	0.720
189	RD16	RD21	0.952	1.000	0.952	BS-4.8.3.3.1	7	3.460	0.950	0.950	1.900

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Utilization ratio continues

Software licensed to Hewlett-Packard	Job No	Sheet No 1958	Rev
	Part		
Job Title MASTERS THESIS	Ref		
	By Engr Udeme	Date 19/11/2021	Chd Engr Peter
Client DEPT. OF CIVIL ENGINEERING, FUTMINNA	File 30M THREE-LEGGED G	Date/Time 19-Nov-2021 11:44	

Utilization Ratio Cont...

Beam	Analysis Property	Design Property	Actual Ratio	Allowable Ratio	Ratio (Act./Allow.)	Clause	L/C	Ax (cm^2)	Iz (cm^4)	Iy (cm^4)	Ix (cm^4)
190	RD16	RD11.5	0.951	1.000	0.951	BS-4.8.3.3.1	6	1.040	0.086	0.086	0.172
191	RD16	RD7	0.814	1.000	0.814	BS-4.8.3.3.1	6	0.380	0.012	0.012	0.024
192	RD16	RD20.25	0.960	1.000	0.960	BS-4.8.3.3.1	7	3.220	0.830	0.830	1.660
193	PIPBG60.3X	RD22.5	0.949	1.000	0.949	BS-4.8.3.3.1	9	3.980	1.260	1.260	2.520
194	PIPBG60.3X	RD23.5	0.964	1.000	0.964	BS-4.8.3.3.1	9	4.340	1.500	1.500	3.000
195	PIPBG60.3X	RD24.5	0.926	1.000	0.926	BS-4.8.3.3.3	9	4.710	1.770	1.770	3.540
199	RD16	RD18.7	0.956	1.000	0.956	BS-4.8.3.3.1	7	2.750	0.600	0.600	1.200
200	RD16	RD16.2	0.993	1.000	0.993	BS-4.8.3.3.1	8	2.060	0.340	0.340	0.680
201	RD16	RD21	0.947	1.000	0.947	BS-4.8.3.3.1	7	3.460	0.950	0.950	1.900
202	RD16	RD12	0.895	1.000	0.895	BS-4.8.3.3.1	6	1.130	0.100	0.100	0.200
203	RD16	RD7.5	0.783	1.000	0.783	BS-4.8.3.3.1	6	0.440	0.016	0.016	0.032
204	RD16	RD20.25	0.942	1.000	0.942	BS-4.8.3.3.1	7	3.220	0.830	0.830	1.660
205	PIPBG60.3X	RD23	0.940	1.000	0.940	BS-4.8.3.3.1	9	4.150	1.370	1.370	2.740
206	PIPBG60.3X	RD23.5	0.946	1.000	0.946	BS-4.8.3.3.1	9	4.340	1.500	1.500	3.000
207	PIPBG60.3X	RD23.5	0.977	1.000	0.977	BS-4.8.3.3.1	9	4.340	1.500	1.500	3.000
211	RD16	RD18.25	0.951	1.000	0.951	BS-4.8.3.3.1	7	2.620	0.540	0.540	1.080
212	RD16	RD16	0.951	1.000	0.951	BS-4.8.3.3.1	8	2.010	0.320	0.320	0.640
213	RD16	RD20	0.924	1.000	0.924	BS-4.8.3.3.1	7	3.140	0.790	0.790	1.580
214	RD16	RD9	0.855	1.000	0.855	BS-4.8.3.3.1	10	0.640	0.032	0.032	0.064
215	RD16	RD5.5	0.953	1.000	0.953	BS-4.8.2.2	7	0.240	0.004	0.004	0.008
216	RD16	RD21	0.964	1.000	0.964	BS-4.8.3.3.1	7	3.460	0.950	0.950	1.900
217	PIPBG60.3X	RD23	0.950	1.000	0.950	BS-4.8.3.3.1	9	4.150	1.370	1.370	2.740
218	PIPBG60.3X	RD22.75	0.971	1.000	0.971	BS-4.8.3.3.1	9	4.060	1.310	1.310	2.620
219	PIPBG60.3X	RD23.5	0.951	1.000	0.951	BS-4.8.3.3.1	9	4.340	1.500	1.500	3.000
223	RD16	RD19	0.975	1.000	0.975	BS-4.8.3.3.1	7	2.840	0.640	0.640	1.280
224	RD16	RD16	0.933	1.000	0.933	BS-4.8.3.3.1	10	2.010	0.320	0.320	0.640
225	RD16	RD20.75	0.946	1.000	0.946	BS-4.8.3.3.1	7	3.380	0.910	0.910	1.820
226	RD16	RD12	0.900	1.000	0.900	BS-4.8.3.3.1	6	1.130	0.100	0.100	0.200
227	RD16	RD7	0.740	1.000	0.740	BS-4.8.3.3.1	6	0.380	0.012	0.012	0.024
228	RD16	RD19.7	0.973	1.000	0.973	BS-4.8.3.3.1	7	3.050	0.740	0.740	1.480
229	PIPBG60.3X	RD23.5	0.938	1.000	0.938	BS-4.8.3.3.1	9	4.340	1.500	1.500	3.000
230	PIPBG60.3X	RD22.75	0.982	1.000	0.982	BS-4.8.3.3.1	9	4.060	1.310	1.310	2.620
231	PIPBG60.3X	RD24	0.950	1.000	0.950	BS-4.8.3.3.1	9	4.520	1.630	1.630	3.260
235	RD16	RD18.7	0.932	1.000	0.932	BS-4.8.3.3.1	7	2.750	0.600	0.600	1.200
236	RD16	RD15.5	0.935	1.000	0.935	BS-4.8.3.3.1	8	1.890	0.280	0.280	0.560
237	RD16	RD19.5	0.964	1.000	0.964	BS-4.8.3.3.1	7	2.990	0.710	0.710	1.420
238	RD16	RD8.5	0.847	1.000	0.847	BS-4.8.3.3.1	10	0.570	0.026	0.026	0.052
239	RD16	RD5.5	0.896	1.000	0.896	BS-4.8.2.2	7	0.240	0.004	0.004	0.008
240	RD16	RD20.75	0.944	1.000	0.944	BS-4.8.3.3.1	7	3.380	0.910	0.910	1.820
241	PIPBG60.3X	RD24	0.941	1.000	0.941	BS-4.8.3.3.1	9	4.520	1.630	1.630	3.260
242	PIPBG60.3X	RD22.5	0.972	1.000	0.972	BS-4.8.3.3.1	9	3.980	1.260	1.260	2.520
243	PIPBG60.3X	RD23.65	0.954	1.000	0.954	BS-4.8.3.3.1	9	4.390	1.540	1.540	3.080
244	RD16	RD8.5	0.852	1.000	0.852	BS-4.7 (C)	5	0.570	0.026	0.026	0.052
245	RD16	RD10	0.944	1.000	0.944	BS-4.8.3.3.1	7	0.790	0.049	0.049	0.098
246	RD16	RD7.5	0.813	1.000	0.813	BS-4.7 (C)	5	0.440	0.016	0.016	0.032
247	RD16	RD19.5	0.943	1.000	0.943	BS-4.8.3.3.1	7	2.990	0.710	0.710	1.420
248	RD16	RD15.5	0.963	1.000	0.963	BS-4.8.3.3.1	10	1.890	0.280	0.280	0.560
249	RD16	RD20.25	0.968	1.000	0.968	BS-4.8.3.3.1	7	3.220	0.830	0.830	1.660
250	RD16	RD12	0.947	1.000	0.947	BS-4.8.3.3.1	6	1.130	0.100	0.100	0.200

Print Time/Date: 19/11/2021 11:53 STAAD.Pro V8i (SELECTseries 6) 20.07.11.33 Print Run 1958 of 1965

Software licensed to Hewlett-Packard	Job No	Sheet No 1959	Rev
	Part		
Job Title MASTERS THESIS	Ref		
	By Engr Udeme	Date 19/11/2021	Chd Engr Peter
Client DEPT. OF CIVIL ENGINEERING, FUTMINNA	File 30M THREE-LEGGED G	Date/Time 19-Nov-2021 11:44	

Utilization Ratio Cont...

Beam	Analysis Property	Design Property	Actual Ratio	Allowable Ratio	Ratio (Act./Allow.)	Clause	L/C	Ax (cm^2)	Iz (cm^4)	Iy (cm^4)	Ix (cm^4)
251	RD16	RD7	0.950	1.000	0.950	BS-4.8.3.3.1	6	0.380	0.012	0.012	0.024
252	RD16	RD19.7	0.953	1.000	0.953	BS-4.8.3.3.1	7	3.050	0.740	0.740	1.480
253	PIPBG60.3X	RD24.25	0.941	1.000	0.941	BS-4.8.3.3.1	9	4.620	1.700	1.700	3.400
254	PIPBG60.3X	RD22.5	0.962	1.000	0.962	BS-4.8.3.3.1	9	3.980	1.260	1.260	2.520
255	PIPBG60.3X	RD23.75	0.950	1.000	0.950	BS-4.8.3.3.1	9	4.430	1.560	1.560	3.120
259	RD16	RD19.25	0.941	1.000	0.941	BS-4.8.3.3.1	7	2.910	0.670	0.670	1.340
260	RD16	RD15.75	0.956	1.000	0.956	BS-4.8.3.3.1	10	1.950	0.300	0.300	0.600
261	RD16	RD20	0.975	1.000	0.975	BS-4.8.3.3.1	7	3.140	0.790	0.790	1.580
262	RD16	RD9.5	0.914	1.000	0.914	BS-4.8.3.3.1	6	0.710	0.040	0.040	0.080
263	RD16	RD6.5	0.968	1.000	0.968	BS-4.8.3.3.1	6	0.330	0.009	0.009	0.018
264	RD16	RD19.5	0.952	1.000	0.952	BS-4.8.3.3.1	7	2.990	0.710	0.710	1.420
265	PIPBG60.3X	RD24.25	0.936	1.000	0.936	BS-4.8.3.3.1	9	4.620	1.700	1.700	3.400
266	PIPBG60.3X	RD22.75	0.953	1.000	0.953	BS-4.8.3.3.1	9	4.060	1.310	1.310	2.620
267	PIPBG60.3X	RD23	0.971	1.000	0.971	BS-4.8.3.3.1	9	4.150	1.370	1.370	2.740
271	RD16	RD19.5	0.976	1.000	0.976	BS-4.8.3.3.1	7	2.990	0.710	0.710	1.420
272	RD16	RD15	0.845	1.000	0.845	BS-4.8.3.3.1	8	1.770	0.250	0.250	0.500
273	RD16	RD19.25	0.942	1.000	0.942	BS-4.8.3.3.1	7	2.910	0.670	0.670	1.340
274	RD16	RD12.5	0.876	1.000	0.876	BS-4.8.3.3.1	10	1.230	0.120	0.120	0.240
275	RD16	RD5.5	0.824	1.000	0.824	BS-4.8.2.2	7	0.240	0.004	0.004	0.008
276	RD16	RD20.25	0.955	1.000	0.955	BS-4.8.3.3.1	7	3.220	0.830	0.830	1.660
277	PIPBG60.3X	RD24	0.970	1.000	0.970	BS-4.8.3.3.1	9	4.520	1.630	1.630	3.260
278	PIPBG60.3X	RD22.5	0.952	1.000	0.952	BS-4.8.3.3.1	9	3.980	1.260	1.260	2.520
279	PIPBG60.3X	RD23	0.951	1.000	0.951	BS-4.8.3.3.1	9	4.150	1.370	1.370	2.740
283	RD16	RD19.5	0.946	1.000	0.946	BS-4.8.3.3.1	7	2.990	0.710	0.710	1.420
284	RD16	RD15.5	0.953	1.000	0.953	BS-4.8.3.3.1	10	1.890	0.280	0.280	0.560
285	RD16	RD20	0.932	1.000	0.932	BS-4.8.3.3.3	7	3.140	0.790	0.790	1.580
286	RD16	RD8.5	0.796	1.000	0.796	BS-4.8.3.3.1	6	0.570	0.026	0.026	0.052
287	RD16	RD7	0.819	1.000	0.819	BS-4.8.3.3.1	6	0.380	0.012	0.012	0.024
288	RD16	RD19	0.949	1.000	0.949	BS-4.8.3.3.1	7	2.840	0.640	0.640	1.280
289	PIPBG60.3X	RD24	0.952	1.000	0.952	BS-4.8.3.3.1	9	4.520	1.630	1.630	3.260
290	PIPBG60.3X	RD23	0.932	1.000	0.932	BS-4.8.3.3.1	9	4.150	1.370	1.370	2.740
291	PIPBG60.3X	RD23.25	0.953	1.000	0.953	BS-4.8.3.3.1	9	4.250	1.430	1.430	2.860
295	RD16	RD20	0.952	1.000	0.952	BS-4.8.3.3.1	7	3.140	0.790	0.790	1.580
296	RD16	RD13.4	0.981	1.000	0.981	BS-4.8.3.3.1	8	1.410	0.160	0.160	0.320
297	RD16	RD18.7	0.972	1.000	0.972	BS-4.8.3.3.1	7	2.750	0.600	0.600	1.200
298	RD16	RD13	0.987	1.000	0.987	BS-4.8.3.3.1	10	1.330	0.140	0.140	0.280
299	RD16	RD5.5	0.762	1.000	0.762	BS-4.8.2.2	7	0.240	0.004	0.004	0.008
300	RD16	RD20	0.948	1.000	0.948	BS-4.8.3.3.1	7	3.140	0.790	0.790	1.580
301	PIPBG60.3X	RD24.5	0.936	1.000	0.936	BS-4.8.3.3.3	9	4.710	1.770	1.770	3.540
302	PIPBG60.3X	RD22.75	0.964	1.000	0.964	BS-4.8.3.3.3	9	4.060	1.310	1.310	2.620
303	PIPBG60.3X	RD23	0.956	1.000	0.956	BS-4.8.3.3.3	9	4.150	1.370	1.370	2.740
304	RD16	RD5.5	0.423	1.000	0.423	BS-4.8.2.2	9	0.240	0.004	0.004	0.008
305	RD16	RD13.4	0.954	1.000	0.954	BS-4.8.3.3.1	8	1.410	0.160	0.160	0.320
306	RD16	RD14	0.963	1.000	0.963	BS-4.8.3.3.1	8	1.540	0.190	0.190	0.380
307	RD16	RD19.5	0.972	1.000	0.972	BS-4.8.3.3.1	7	2.990	0.710	0.710	1.420
308	RD16	RD15.5	0.911	1.000	0.911	BS-4.8.3.3.1	10	1.890	0.280	0.280	0.560
309	RD16	RD19.5	0.968	1.000	0.968	BS-4.8.3.3.1	7	2.990	0.710	0.710	1.420
310	RD16	RD6	0.868	1.000	0.868	BS-4.8.2.2	7	0.280	0.006	0.006	0.012
311	RD16	RD9	0.862	1.000	0.862	BS-4.8.3.3.1	10	0.640	0.032	0.032	0.064

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Utilization ratio continues

Software licensed to Hewlett-Packard	Job No	Sheet No 1960	Rev
	Part		
Job Title MASTERS THESIS	Ref		
	By Engr Udeme	Date 19/11/2021	Chd Engr Peter
Client DEPT. OF CIVIL ENGINEERING, FUTMINNA	File 30M THREE-LEGGED G	Date/Time 19-Nov-2021 11:44	

Utilization Ratio Cont...

Beam	Analysis Property	Design Property	Actual Ratio	Allowable Ratio	Ratio (Act./Allow.)	Clause	L/C	Ax (cm^2)	Iz (cm^4)	Iy (cm^4)	Ix (cm^4)
312	RD16	RD19	0.924	1.000	0.924	BS-4.8.3.3.1	7	2.840	0.640	0.640	1.280
313	PIPBG60.3X	RD18.25	0.938	1.000	0.938	BS-4.8.3.3.3	6	2.620	0.540	0.540	1.080
314	PIPBG60.3X	RD25.5	0.979	1.000	0.979	BS-4.8.3.3.1	7	5.110	2.080	2.080	4.160
315	PIPBG60.3X	RD25.65	0.960	1.000	0.960	BS-4.8.3.3.1	8	5.170	2.120	2.120	4.240
319	RD16	RD5.5	0.363	1.000	0.363	BS-4.8.2.2	7	0.240	0.004	0.004	0.008
320	RD16	RD17.9	0.971	1.000	0.971	BS-4.8.3.3.1	8	2.520	0.500	0.500	1.000
321	RD16	RD18.7	0.971	1.000	0.971	BS-4.8.3.3.1	7	2.750	0.600	0.600	1.200
322	RD16	RD15.75	0.938	1.000	0.938	BS-4.8.3.3.1	7	1.950	0.300	0.300	0.600
323	RD16	RD5.5	0.761	1.000	0.761	BS-4.8.2.2	7	0.240	0.004	0.004	0.008
324	RD16	RD19	0.943	1.000	0.943	BS-4.8.3.3.1	7	2.840	0.640	0.640	1.280
325	PIPBG60.3X	RD18	0.954	1.000	0.954	BS-4.8.3.3.1	6	2.540	0.520	0.520	1.040
326	PIPBG60.3X	RD24.75	0.949	1.000	0.949	BS-4.8.3.3.1	7	4.810	1.840	1.840	3.680
327	PIPBG60.3X	RD24.5	0.967	1.000	0.967	BS-4.8.3.3.1	10	4.710	1.770	1.770	3.540
331	RD16	RD8.5	0.862	1.000	0.862	BS-4.8.3.3.1	10	0.570	0.026	0.026	0.052
332	RD16	RD16.2	0.974	1.000	0.974	BS-4.8.3.3.1	8	2.060	0.340	0.340	0.680
333	RD16	RD17.7	0.976	1.000	0.976	BS-4.8.3.3.1	7	2.460	0.480	0.480	0.960
334	RD16	RD15.5	0.935	1.000	0.935	BS-4.8.3.3.1	7	1.890	0.280	0.280	0.560
335	RD16	RD5.5	0.762	1.000	0.762	BS-4.8.2.2	7	0.240	0.004	0.004	0.008
336	RD16	RD18.25	0.977	1.000	0.977	BS-4.8.3.3.1	7	2.620	0.540	0.540	1.080
337	PIPBG60.3X	RD17.9	0.973	1.000	0.973	BS-4.8.3.3.1	6	2.520	0.500	0.500	1.000
338	PIPBG60.3X	RD23.25	0.992	1.000	0.992	BS-4.8.3.3.1	7	4.250	1.430	1.430	2.860
339	PIPBG60.3X	RD23.5	0.980	1.000	0.980	BS-4.8.3.3.1	10	4.340	1.500	1.500	3.000
343	RD16	RD5.5	0.286	1.000	0.286	BS-4.8.2.2	7	0.240	0.004	0.004	0.008
344	RD16	RD17.25	0.967	1.000	0.967	BS-4.8.3.3.1	8	2.340	0.430	0.430	0.860
345	RD16	RD18.25	0.981	1.000	0.981	BS-4.8.3.3.1	7	2.620	0.540	0.540	1.080
346	RD16	RD15.5	0.921	1.000	0.921	BS-4.8.3.3.1	7	1.890	0.280	0.280	0.560
347	RD16	RD5.5	0.667	1.000	0.667	BS-4.8.2.2	7	0.240	0.004	0.004	0.008
348	RD16	RD18.5	0.978	1.000	0.978	BS-4.8.3.3.1	7	2.690	0.570	0.570	1.140
349	PIPBG60.3X	RD18	0.948	1.000	0.948	BS-4.8.3.3.1	6	2.540	0.520	0.520	1.040
350	PIPBG60.3X	RD22.25	0.989	1.000	0.989	BS-4.8.3.3.1	7	3.890	1.200	1.200	2.400
351	PIPBG60.3X	RD22.75	0.983	1.000	0.983	BS-4.8.3.3.1	10	4.060	1.310	1.310	2.620
355	RD16	RD5.5	0.285	1.000	0.285	BS-4.8.2.2	7	0.240	0.004	0.004	0.008
356	RD16	RD16	0.945	1.000	0.945	BS-4.8.3.3.1	8	2.010	0.320	0.320	0.640
357	RD16	RD17.5	0.923	1.000	0.923	BS-4.8.3.3.1	7	2.410	0.460	0.460	0.920
358	RD16	RD15	0.834	1.000	0.834	BS-4.8.3.3.1	7	1.770	0.250	0.250	0.500
359	RD16	RD5.5	0.697	1.000	0.697	BS-4.8.2.2	7	0.240	0.004	0.004	0.008
360	RD16	RD17.9	0.959	1.000	0.959	BS-4.8.3.3.1	7	2.520	0.500	0.500	1.000
361	PIPBG60.3X	RD17.9	0.977	1.000	0.977	BS-4.8.3.3.1	6	2.520	0.500	0.500	1.000
362	PIPBG60.3X	RD21	0.988	1.000	0.988	BS-4.8.3.3.1	7	3.460	0.950	0.950	1.900
363	PIPBG60.3X	RD21.7	0.965	1.000	0.965	BS-4.8.3.3.1	10	3.700	1.090	1.090	2.180
364	RD16	RD6	0.731	1.000	0.731	BS-4.7 (C)	5	0.280	0.006	0.006	0.012
365	RD16	RD5.5	0.106	1.000	0.106	BS-4.8.2.2	7	0.240	0.004	0.004	0.008
366	RD16	RD5.5	0.080	1.000	0.080	BS-4.8.2.2	9	0.240	0.004	0.004	0.008
367	RD16	RD5.5	0.241	1.000	0.241	BS-4.8.2.2	7	0.240	0.004	0.004	0.008
368	RD16	RD17	0.907	1.000	0.907	BS-4.8.3.3.1	8	2.270	0.410	0.410	0.820
369	RD16	RD17.9	0.951	1.000	0.951	BS-4.8.3.3.1	7	2.520	0.500	0.500	1.000
370	RD16	RD15	0.856	1.000	0.856	BS-4.8.3.3.1	7	1.770	0.250	0.250	0.500
371	RD16	RD5.5	0.606	1.000	0.606	BS-4.8.2.2	7	0.240	0.004	0.004	0.008
372	RD16	RD18.25	0.977	1.000	0.977	BS-4.8.3.3.1	7	2.620	0.540	0.540	1.080

Print Time/Date: 19/11/2021 11:53 STAAD.Pro V8i (SELECTseries 6) 20.07.11.33 Print Run 1960 of 1965

Software licensed to Hewlett-Packard	Job No	Sheet No 1961	Rev
	Part		
Job Title MASTERS THESIS	Ref		
	By Engr Udeme	Date 19/11/2021	Chd Engr Peter
Client DEPT. OF CIVIL ENGINEERING, FUTMINNA	File 30M THREE-LEGGED G	Date/Time 19-Nov-2021 11:44	

Utilization Ratio Cont...

Beam	Analysis Property	Design Property	Actual Ratio	Allowable Ratio	Ratio (Act./Allow.)	Clause	L/C	Ax (cm^2)	Iz (cm^4)	Iy (cm^4)	Ix (cm^4)
373	PIPBG60.3X	RD18.25	0.956	1.000	0.956	BS-4.8.3.3.1	9	2.620	0.540	0.540	1.080
374	PIPBG60.3X	RD20	0.928	1.000	0.928	BS-4.8.3.3.1	9	3.140	0.790	0.790	1.580
375	PIPBG60.3X	RD21.25	0.931	1.000	0.931	BS-4.8.3.3.3	9	3.550	1.000	1.000	2.000
379	RD16	RD5.5	0.539	1.000	0.539	BS-4.8.3.3.1	6	0.240	0.004	0.004	0.008
380	RD16	RD16.2	0.957	1.000	0.957	BS-4.8.3.3.1	8	2.060	0.340	0.340	0.680
381	RD16	RD17.5	0.970	1.000	0.970	BS-4.8.3.3.1	7	2.410	0.460	0.460	0.920
382	RD16	RD14	0.983	1.000	0.983	BS-4.8.3.3.1	7	1.540	0.190	0.190	0.380
383	RD16	RD5.5	0.608	1.000	0.608	BS-4.8.2.2	7	0.240	0.004	0.004	0.008
384	RD16	RD17.9	0.965	1.000	0.965	BS-4.8.3.3.1	7	2.520	0.500	0.500	1.000
385	PIPBG60.3X	RD19.7	0.978	1.000	0.978	BS-4.8.3.3.1	9	3.050	0.740	0.740	1.480
386	PIPBG60.3X	RD18.7	0.956	1.000	0.956	BS-4.8.3.3.1	9	2.750	0.600	0.600	1.200
387	PIPBG60.3X	RD20.75	0.967	1.000	0.967	BS-4.8.3.3.1	9	3.380	0.910	0.910	1.820
391	RD16	RD5.5	0.203	1.000	0.203	BS-4.8.2.2	7	0.240	0.004	0.004	0.008
392	RD16	RD15.75	0.979	1.000	0.979	BS-4.8.3.3.1	8	1.950	0.300	0.300	0.600
393	RD16	RD17	0.899	1.000	0.899	BS-4.8.3.3.1	7	2.270	0.410	0.410	0.820
394	RD16	RD13.4	0.880	1.000	0.880	BS-4.8.3.3.1	7	1.410	0.160	0.160	0.320
395	RD16	RD5.5	0.611	1.000	0.611	BS-4.8.2.2	7	0.240	0.004	0.004	0.008
396	RD16	RD17.5	0.919	1.000	0.919	BS-4.8.3.3.1	7	2.410	0.460	0.460	0.920
397	PIPBG60.3X	RD20.75	0.956	1.000	0.956	BS-4.8.3.3.1	9	3.380	0.910	0.910	1.820
398	PIPBG60.3X	RD17.5	0.979	1.000	0.979	BS-4.8.3.3.1	6	2.410	0.460	0.460	0.920
399	PIPBG60.3X	RD20.25	0.994	1.000	0.994	BS-4.8.3.3.1	9	3.220	0.830	0.830	1.660
403	RD16	RD5.5	0.140	1.000	0.140	BS-4.8.2.2	7	0.240	0.004	0.004	0.008
404	RD16	RD15.75	0.943	1.000	0.943	BS-4.8.3.3.1	8	1.950	0.300	0.300	0.600
405	RD16	RD17	0.980	1.000	0.980	BS-4.8.3.3.1	7	2.270	0.410	0.410	0.820
406	RD16	RD13.4	0.883	1.000	0.883	BS-4.8.3.3.1	7	1.410	0.160	0.160	0.320
407	RD16	RD5.5	0.534	1.000	0.534	BS-4.8.2.2	7	0.240	0.004	0.004	0.008
408	RD16	RD17.5	0.946	1.000	0.946	BS-4.8.3.3.1	7	2.410	0.460	0.460	0.920
409	PIPBG60.3X	RD21.7	0.966	1.000	0.966	BS-4.8.3.3.1	7	3.700	1.090	1.090	2.180
410	PIPBG60.3X	RD17.9	0.964	1.000	0.964	BS-4.8.3.3.1	6	2.520	0.500	0.500	1.000
411	PIPBG60.3X	RD20.75	0.954	1.000	0.954	BS-4.8.3.3.1	9	3.380	0.910	0.910	1.820
415	RD16	RD5.5	0.138	1.000	0.138	BS-4.8.2.2	7	0.240	0.004	0.004	0.008
416	RD16	RD15	0.980	1.000	0.980	BS-4.8.3.3.1	8	1.770	0.250	0.250	0.500
417	RD16	RD16.2	0.944	1.000	0.944	BS-4.8.3.3.1	7	2.060	0.340	0.340	0.680
418	RD16	RD12	0.926	1.000	0.926	BS-4.8.3.3.1	7	1.130	0.100	0.100	0.200
419	RD16	RD5.5	0.556	1.000	0.556	BS-4.8.2.2	7	0.240	0.004	0.004	0.008
420	RD16	RD17	0.889	1.000	0.889	BS-4.8.3.3.1	7	2.270	0.410	0.410	0.820
421	PIPBG60.3X	RD22.75	0.959	1.000	0.959	BS-4.8.3.3.1	7	4.060	1.310	1.310	2.620
422	PIPBG60.3X	RD17.9	0.961	1.000	0.961	BS-4.8.3.3.1	6	2.520	0.500	0.500	1.000
423	PIPBG60.3X	RD20.25	0.966	1.000	0.966	BS-4.8.3.3.1	9	3.220	0.830	0.830	1.660
424	RD16	RD5.5	0.046	1.000	0.046	BS-4.8.2.2	8	0.240	0.004	0.004	0.008
425	RD16	RD5.5	0.150	1.000	0.150	BS-4.8.2.2	7	0.240	0.004	0.004	0.008
426	RD16	RD7	0.760	1.000	0.760	BS-4.7 (C)	5	0.380	0.012	0.012	0.024
427	RD16	RD5.5	0.166	1.000	0.166	BS-4.8.3.3.1	6	0.240	0.004	0.004	0.008
428	RD16	RD15.5	0.890	1.000	0.890	BS-4.8.3.3.1	8	1.890	0.280	0.280	0.560
429	RD16	RD16.5	0.965	1.000	0.965	BS-4.8.3.3.1	7	2.140	0.360	0.360	0.720
430	RD16	RD12	0.899	1.000	0.899	BS-4.8.3.3.1	7	1.130	0.100	0.100	0.200
431	RD16	RD5.5	0.465	1.000	0.465	BS-4.8.2.2	7	0.240	0.004	0.004	0.008
432	RD16	RD17.25	0.947	1.000	0.947	BS-4.8.3.3.1	7	2.340	0.430	0.430	0.860
433	PIPBG60.3X	RD23.5	0.937	1.000	0.937	BS-4.8.3.3.1	7	4.340	1.500	1.500	3.000

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Utilization ratio continues

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Job No	Sheet No 1962	Rev
Part		
Ref		
By Engr Udeme	Date 19/11/2021	Chd Engr Peter
File 30M THREE-LEGGED G	Date/Time 19-Nov-2021 11:44	

Job Title MASTERS THESIS

Client DEPT. OF CIVIL ENGINEERING, FUTMINNA

Utilization Ratio Cont...

Beam	Analysis Property	Design Property	Actual Ratio	Allowable Ratio	Ratio (Act./Allow.)	Clause	L/C	Ax (cm^2)	Iz (cm^4)	Iy (cm^4)	Ix (cm^4)
434	PIPBG60.3X	RD18.4	0.975	1.000	0.975	BS-4.8.3.3.1	10	2.660	0.560	0.560	1.120
435	PIPBG60.3X	RD20.25	0.948	1.000	0.948	BS-4.8.3.3.3	9	3.220	0.830	0.830	1.660
439	RD16	RD5.5	0.078	1.000	0.078	BS-4.8.2.2	7	0.240	0.004	0.004	0.008
440	RD16	RD15	0.951	1.000	0.951	BS-4.8.3.3.1	8	1.770	0.250	0.250	0.500
441	RD16	RD16	0.966	1.000	0.966	BS-4.8.3.3.1	7	2.010	0.320	0.320	0.640
442	RD16	RD11	0.854	1.000	0.854	BS-4.8.3.3.1	7	0.950	0.072	0.072	0.144
443	RD16	RD5.5	0.430	1.000	0.430	BS-4.8.2.2	7	0.240	0.004	0.004	0.008
444	RD16	RD17	0.953	1.000	0.953	BS-4.8.3.3.1	7	2.270	0.410	0.410	0.820
445	PIPBG60.3X	RD24	0.960	1.000	0.960	BS-4.8.3.3.1	7	4.520	1.630	1.630	3.260
446	PIPBG60.3X	RD19	0.963	1.000	0.963	BS-4.8.3.3.1	10	2.840	0.640	0.640	1.280
447	PIPBG60.3X	RD20	0.945	1.000	0.945	BS-4.8.3.3.1	9	3.140	0.790	0.790	1.580
451	RD16	RD5.5	0.065	1.000	0.065	BS-4.8.2.2	8	0.240	0.004	0.004	0.008
452	RD16	RD15	0.789	1.000	0.789	BS-4.8.3.3.1	8	1.770	0.250	0.250	0.500
453	RD16	RD15.5	0.970	1.000	0.970	BS-4.8.3.3.1	7	1.890	0.280	0.280	0.560
454	RD16	RD8.5	0.946	1.000	0.946	BS-4.8.3.3.1	7	0.570	0.026	0.026	0.052
455	RD16	RD5.5	0.490	1.000	0.490	BS-4.8.2.2	7	0.240	0.004	0.004	0.008
456	RD16	RD15.75	0.939	1.000	0.939	BS-4.8.3.3.1	7	1.950	0.300	0.300	0.600
457	PIPBG60.3X	RD24	0.992	1.000	0.992	BS-4.8.3.3.1	7	4.520	1.630	1.630	3.260
458	PIPBG60.3X	RD19.5	0.942	1.000	0.942	BS-4.8.3.3.1	10	2.990	0.710	0.710	1.420
459	PIPBG60.3X	RD19.5	0.980	1.000	0.980	BS-4.8.3.3.1	9	2.990	0.710	0.710	1.420
463	RD16	RD9	0.827	1.000	0.827	BS-4.8.3.3.1	7	0.640	0.032	0.032	0.064
464	RD16	RD15	0.775	1.000	0.775	BS-4.8.3.3.1	8	1.770	0.250	0.250	0.500
465	RD16	RD15.5	0.947	1.000	0.947	BS-4.8.3.3.1	7	1.890	0.280	0.280	0.560
466	RD16	RD8.5	0.820	1.000	0.820	BS-4.8.3.3.1	9	0.570	0.026	0.026	0.052
467	RD16	RD5.5	0.373	1.000	0.373	BS-4.8.2.2	7	0.240	0.004	0.004	0.008
468	RD16	RD16.2	0.967	1.000	0.967	BS-4.8.3.3.1	7	2.060	0.340	0.340	0.680
469	PIPBG60.3X	RD24.75	0.958	1.000	0.958	BS-4.8.3.3.1	7	4.810	1.840	1.840	3.680
470	PIPBG60.3X	RD19.7	0.987	1.000	0.987	BS-4.8.3.3.1	10	3.050	0.740	0.740	1.480
471	PIPBG60.3X	RD20	0.921	1.000	0.921	BS-4.8.3.3.1	9	3.140	0.790	0.790	1.580
475	RD16	RD9	0.949	1.000	0.949	BS-4.8.3.3.1	7	0.640	0.032	0.032	0.064
476	RD16	RD13.4	0.924	1.000	0.924	BS-4.8.3.3.1	8	1.410	0.160	0.160	0.320
477	RD16	RD15	0.895	1.000	0.895	BS-4.8.3.3.1	7	1.770	0.250	0.250	0.500
478	RD16	RD5.5	0.664	1.000	0.664	BS-4.8.3.3.1	8	0.240	0.004	0.004	0.008
479	RD16	RD5.5	0.432	1.000	0.432	BS-4.8.2.2	7	0.240	0.004	0.004	0.008
480	RD16	RD15	0.916	1.000	0.916	BS-4.8.3.3.1	7	1.770	0.250	0.250	0.500
481	PIPBG60.3X	RD25	0.976	1.000	0.976	BS-4.8.3.3.1	7	4.910	1.920	1.920	3.840
482	PIPBG60.3X	RD20	0.970	1.000	0.970	BS-4.8.3.3.1	10	3.140	0.790	0.790	1.580
483	PIPBG60.3X	RD19.5	0.938	1.000	0.938	BS-4.8.3.3.1	9	2.990	0.710	0.710	1.420
484	RD16	RD7	0.846	1.000	0.846	BS-4.7 (C)	4	0.380	0.012	0.012	0.024
485	RD16	RD5.5	0.527	1.000	0.527	BS-4.7 (C)	5	0.240	0.004	0.004	0.008
486	RD16	RD7.5	0.974	1.000	0.974	BS-4.7 (C)	4	0.440	0.016	0.016	0.032
487	RD16	RD11	0.982	1.000	0.982	BS-4.8.3.3.1	7	0.950	0.072	0.072	0.144
488	RD16	RD13.75	0.886	1.000	0.886	BS-4.8.3.3.1	10	1.480	0.180	0.180	0.360
489	RD16	RD15	0.843	1.000	0.843	BS-4.8.3.3.1	7	1.770	0.250	0.250	0.500
490	RD16	RD8.5	0.946	1.000	0.946	BS-4.8.3.3.1	10	0.570	0.026	0.026	0.052
491	RD16	RD5.5	0.291	1.000	0.291	BS-4.8.2.2	7	0.240	0.004	0.004	0.008
492	RD16	RD16	0.945	1.000	0.945	BS-4.8.3.3.1	7	2.010	0.320	0.320	0.640
493	PIPBG60.3X	RD25.5	0.935	1.000	0.935	BS-4.8.3.3.1	7	5.110	2.080	2.080	4.160
494	PIPBG60.3X	RD20.25	0.976	1.000	0.976	BS-4.8.3.3.1	10	3.220	0.830	0.830	1.660

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Utilization ratio continues

	Job No	Sheet No 1963	Rev
Software licensed to Hewlett-Packard	Part		
Job Title MASTERS THESIS	Ref		
	By Engr Udeme	Date 19/11/2021	Chd Engr Peter
Client DEPT. OF CIVIL ENGINEERING, FUTMINNA	File 30M THREE-LEGGED G	Date/Time 19-Nov-2021 11:44	

Utilization Ratio Cont...

Beam	Analysis Property	Design Property	Actual Ratio	Allowable Ratio	Ratio (Act./Allow.)	Clause	L/C	Ax (cm^2)	Iz (cm^4)	Iy (cm^4)	Ix (cm^4)
495	PIPBG60.3X	RD19.25	0.953	1.000	0.953	BS-4.8.3.3.3	9	2.910	0.670	0.670	1.340
499	RD16	RD11	0.982	1.000	0.982	BS-4.8.3.3.1	7	0.950	0.072	0.072	0.144
500	RD16	RD13	0.973	1.000	0.973	BS-4.8.3.3.1	10	1.330	0.140	0.140	0.280
501	RD16	RD14	0.976	1.000	0.976	BS-4.8.3.3.1	7	1.540	0.190	0.190	0.380
502	RD16	RD8.5	0.928	1.000	0.928	BS-4.8.3.3.1	10	0.570	0.026	0.026	0.052
503	RD16	RD5.5	0.257	1.000	0.257	BS-4.8.2.2	7	0.240	0.004	0.004	0.008
504	RD16	RD15.75	0.955	1.000	0.955	BS-4.8.3.3.1	7	1.950	0.300	0.300	0.600
505	PIPBG60.3X	RD25.5	0.955	1.000	0.955	BS-4.8.3.3.1	7	5.110	2.080	2.080	4.160
506	PIPBG60.3X	RD20.5	0.977	1.000	0.977	BS-4.8.3.3.1	10	3.300	0.870	0.870	1.740
507	PIPBG60.3X	RD19	0.957	1.000	0.957	BS-4.8.3.3.1	9	2.840	0.640	0.640	1.280
511	RD16	RD13	0.910	1.000	0.910	BS-4.8.3.3.1	7	1.330	0.140	0.140	0.280
512	RD16	RD12.5	0.946	1.000	0.946	BS-4.8.3.3.1	8	1.230	0.120	0.120	0.240
513	RD16	RD13.75	0.896	1.000	0.896	BS-4.8.3.3.1	7	1.480	0.180	0.180	0.360
514	RD16	RD5.5	0.111	1.000	0.111	BS-4.8.2.2	7	0.240	0.004	0.004	0.008
515	RD16	RD5.5	0.363	1.000	0.363	BS-4.8.2.2	7	0.240	0.004	0.004	0.008
516	RD16	RD13.4	0.917	1.000	0.917	BS-4.8.3.3.1	7	1.410	0.160	0.160	0.320
517	PIPBG60.3X	RD25.5	0.950	1.000	0.950	BS-4.8.3.3.1	7	5.110	2.080	2.080	4.160
518	PIPBG60.3X	RD20.75	0.964	1.000	0.964	BS-4.8.3.3.1	10	3.380	0.910	0.910	1.820
519	PIPBG60.3X	RD18.5	0.982	1.000	0.982	BS-4.8.3.3.1	9	2.690	0.570	0.570	1.140
523	RD16	RD13	0.878	1.000	0.878	BS-4.8.3.3.1	7	1.330	0.140	0.140	0.280
524	RD16	RD12	0.977	1.000	0.977	BS-4.8.3.3.1	10	1.130	0.100	0.100	0.200
525	RD16	RD13.4	0.888	1.000	0.888	BS-4.8.3.3.1	7	1.410	0.160	0.160	0.320
526	RD16	RD8.5	0.776	1.000	0.776	BS-4.8.3.3.1	10	0.570	0.026	0.026	0.052
527	RD16	RD5.5	0.212	1.000	0.212	BS-4.8.2.2	7	0.240	0.004	0.004	0.008
528	RD16	RD15	0.877	1.000	0.877	BS-4.8.3.3.1	7	1.770	0.250	0.250	0.500
529	PIPBG60.3X	RD25.5	0.958	1.000	0.958	BS-4.8.3.3.1	7	5.110	2.080	2.080	4.160
530	PIPBG60.3X	RD20.75	0.994	1.000	0.994	BS-4.8.3.3.1	10	3.380	0.910	0.910	1.820
531	PIPBG60.3X	RD18.7	0.952	1.000	0.952	BS-4.8.3.3.1	9	2.750	0.600	0.600	1.200
535	RD16	RD13.75	0.986	1.000	0.986	BS-4.8.3.3.1	7	1.480	0.180	0.180	0.360
536	RD16	RD11	0.863	1.000	0.863	BS-4.8.3.3.1	10	0.950	0.072	0.072	0.144
537	RD16	RD12.5	0.948	1.000	0.948	BS-4.8.3.3.1	4	1.230	0.120	0.120	0.240
538	RD16	RD5.5	0.179	1.000	0.179	BS-4.8.2.2	7	0.240	0.004	0.004	0.008
539	RD16	RD7	0.859	1.000	0.859	BS-4.7 (C)	5	0.380	0.012	0.012	0.024
540	RD16	RD12	0.976	1.000	0.976	BS-4.8.3.3.1	7	1.130	0.100	0.100	0.200
541	PIPBG60.3X	RD25.5	0.962	1.000	0.962	BS-4.8.3.3.1	7	5.110	2.080	2.080	4.160
542	PIPBG60.3X	RD21	0.961	1.000	0.961	BS-4.8.3.3.1	10	3.460	0.950	0.950	1.900
543	PIPBG60.3X	RD18.25	0.958	1.000	0.958	BS-4.8.3.3.1	9	2.620	0.540	0.540	1.080
544	RD16	RD8.5	0.771	1.000	0.771	BS-4.7 (C)	4	0.570	0.026	0.026	0.052
545	RD16	RD7	0.981	1.000	0.981	BS-4.7 (C)	5	0.380	0.012	0.012	0.024
546	RD16	RD7	0.969	1.000	0.969	BS-4.7 (C)	4	0.380	0.012	0.012	0.024
547	RD16	RD13.75	0.972	1.000	0.972	BS-4.8.3.3.1	7	1.480	0.180	0.180	0.360
548	RD16	RD11.5	0.967	1.000	0.967	BS-4.8.3.3.1	6	1.040	0.086	0.086	0.172
549	RD16	RD12	0.888	1.000	0.888	BS-4.8.3.3.1	7	1.130	0.100	0.100	0.200
550	RD16	RD8.5	0.902	1.000	0.902	BS-4.8.3.3.1	10	0.570	0.026	0.026	0.052
551	RD16	RD6	0.901	1.000	0.901	BS-4.7 (C)	5	0.280	0.006	0.006	0.012
552	RD16	RD14	0.971	1.000	0.971	BS-4.8.3.3.1	7	1.540	0.190	0.190	0.380
553	PIPBG60.3X	RD25.5	0.965	1.000	0.965	BS-4.8.3.3.1	7	5.110	2.080	2.080	4.160
554	PIPBG60.3X	RD21	0.976	1.000	0.976	BS-4.8.3.3.1	10	3.460	0.950	0.950	1.900
555	PIPBG60.3X	RD18	0.969	1.000	0.969	BS-4.8.3.3.1	9	2.540	0.520	0.520	1.040

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Utilization ratio continues

Software licensed to Hewlett-Packard	Job No	Sheet No 1964	Rev
	Part		
Job Title MASTERS THESIS	Ref		
	By Engr Udeme	Date 19/11/2021	Chd Engr Peter
Client DEPT. OF CIVIL ENGINEERING, FUTMINNA	File 30M THREE-LEGGED G	Date/Time 19-Nov-2021 11:44	

Utilization Ratio Cont...

Beam	Analysis Property	Design Property	Actual Ratio	Allowable Ratio	Ratio (Act./Allow.)	Clause	L/C	Ax (cm^2)	Iz (cm^4)	Iy (cm^4)	Ix (cm^4)
559	RD16	RD15	0.781	1.000	0.781	BS-4.8.3.3.1	7	1.770	0.250	0.250	0.500
560	RD16	RD10.5	0.953	1.000	0.953	BS-4.8.3.3.1	6	0.870	0.060	0.060	0.120
561	RD16	RD11	0.975	1.000	0.975	BS-4.8.3.3.1	4	0.950	0.072	0.072	0.144
562	RD16	RD10	0.815	1.000	0.815	BS-4.8.3.3.1	10	0.790	0.049	0.049	0.098
563	RD16	RD8.5	0.878	1.000	0.878	BS-4.7 (C)	5	0.570	0.026	0.026	0.052
564	RD16	RD12.5	0.974	1.000	0.974	BS-4.8.3.3.1	7	1.230	0.120	0.120	0.240
565	PIPBG60.3X	RD25.5	0.934	1.000	0.934	BS-4.8.3.3.1	7	5.110	2.080	2.080	4.160
566	PIPBG60.3X	RD21.25	0.954	1.000	0.954	BS-4.8.3.3.1	10	3.550	1.000	1.000	2.000
567	PIPBG60.3X	RD17.9	0.950	1.000	0.950	BS-4.8.3.3.1	9	2.520	0.500	0.500	1.000
571	RD16	RD15.5	0.902	1.000	0.902	BS-4.8.3.3.1	7	1.890	0.280	0.280	0.560
572	RD16	RD11	0.857	1.000	0.857	BS-4.8.3.3.1	6	0.950	0.072	0.072	0.144
573	RD16	RD10.5	0.948	1.000	0.948	BS-4.8.3.3.1	4	0.870	0.060	0.060	0.120
574	RD16	RD5.5	0.266	1.000	0.266	BS-4.8.2.2	7	0.240	0.004	0.004	0.008
575	RD16	RD10	0.838	1.000	0.838	BS-4.8.3.3.1	8	0.790	0.049	0.049	0.098
576	RD16	RD11	0.952	1.000	0.952	BS-4.8.3.3.1	7	0.950	0.072	0.072	0.144
577	PIPBG60.3X	RD25.5	0.914	1.000	0.914	BS-4.8.3.3.1	7	5.110	2.080	2.080	4.160
578	PIPBG60.3X	RD21.25	0.953	1.000	0.953	BS-4.8.3.3.1	10	3.550	1.000	1.000	2.000
579	PIPBG60.3X	RD17.5	0.979	1.000	0.979	BS-4.8.3.3.1	9	2.410	0.460	0.460	0.920
583	RD16	RD15.5	0.917	1.000	0.917	BS-4.8.3.3.1	7	1.890	0.280	0.280	0.560
584	RD16	RD10.5	0.866	1.000	0.866	BS-4.8.3.3.1	6	0.870	0.060	0.060	0.120
585	RD16	RD10	0.841	1.000	0.841	BS-4.8.3.3.1	4	0.790	0.049	0.049	0.098
586	RD16	RD10	0.966	1.000	0.966	BS-4.8.3.3.1	10	0.790	0.049	0.049	0.098
587	RD16	RD10	0.944	1.000	0.944	BS-4.8.3.3.1	8	0.790	0.049	0.049	0.098
588	RD16	RD10.5	0.834	1.000	0.834	BS-4.8.3.3.1	7	0.870	0.060	0.060	0.120
589	PIPBG60.3X	RD25	0.940	1.000	0.940	BS-4.8.3.3.1	7	4.910	1.920	1.920	3.840
590	PIPBG60.3X	RD21.25	0.953	1.000	0.953	BS-4.8.3.3.1	10	3.550	1.000	1.000	2.000
591	PIPBG60.3X	RD17.25	0.965	1.000	0.965	BS-4.8.3.3.1	9	2.340	0.430	0.430	0.860
592	RD16	RD5.5	0.279	1.000	0.279	BS-4.8.2.2	9	0.240	0.004	0.004	0.008
593	RD16	RD9.5	0.962	1.000	0.962	BS-4.8.3.3.1	8	0.710	0.040	0.040	0.080
594	RD16	RD11	0.871	1.000	0.871	BS-4.8.3.3.1	8	0.950	0.072	0.072	0.144
595	RD16	RD15.75	0.959	1.000	0.959	BS-4.8.3.3.1	7	1.950	0.300	0.300	0.600
596	RD16	RD11	0.936	1.000	0.936	BS-4.8.3.3.1	6	0.950	0.072	0.072	0.144
597	RD16	RD9.5	0.994	1.000	0.994	BS-4.7 (C)	5	0.710	0.040	0.040	0.080
598	RD16	RD5.5	0.387	1.000	0.387	BS-4.8.2.2	7	0.240	0.004	0.004	0.008
599	RD16	RD11	0.936	1.000	0.936	BS-4.8.3.3.1	8	0.950	0.072	0.072	0.144
600	RD16	RD10	0.939	1.000	0.939	BS-4.8.3.3.1	7	0.790	0.049	0.049	0.098
601	Cir 0.02	N/A						3.142	0.785	0.785	1.571
602	PIPBG60.3X	RD17	0.950	1.000	0.950	BS-4.8.3.3.1	6	2.270	0.410	0.410	0.820
603	Cir 0.02	N/A						3.142	0.785	0.785	1.571
604	Cir 0.02	N/A						3.142	0.785	0.785	1.571
605	Cir 0.02	N/A						3.142	0.785	0.785	1.571
606	Cir 0.02	N/A						3.142	0.785	0.785	1.571
607	Cir 0.02	N/A						3.142	0.785	0.785	1.571

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