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Advancing Cellular Infrastructure: Design and Analysis of Cell Tower Using Hot-Dip Galvanized Steel Near Don Honorio Ventura State University

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Abstract:

This study provides an innovative process on the design and analysis of cellular infrastructure in Don Honorio Ventura State University, Bacolor, Pampanga, Philippines by utilizing the use of hot-dip galvanized steel (HDGS) as an alternative material in constructing lattice cell towers. The overwhelming user load on the current infrastructure in the vicinity of the university results in poor internet connectivity and data access, this requires the urgency of enhancing cellular infrastructure to boost signal coverage and provide a better education and communication quality. HDGS is a widely used material known for its corrosion resistance and increased mechanical properties ideal to use in order to withstand harsh environments. The research integrates the codes and specifications based on Telecommunications Industry Association (TIA-222-G) and the Load and Resistance Factor Design (LRFD) to achieve optimal results in the design and analysis of the cell tower. The structural analysis of a cell tower designed with hot-dip galvanized steel, using Microsoft Excel and STAAD Pro, revealed critical insights into the stress distribution and resilience of the structure under various load conditions. In conclusion, the use of hot-dip galvanized steel in the design and analysis of the three-legged lattice cell tower guarantees enhanced overall structural stability, and ensures that the design of the cell tower meets industry regulations and safety requirements promoting consistency and reliability in structural performance.

Keywords **—HDGS, TIA-222-G Standards, LRFD, Design, Analysis, Telecommunication,STAAD.Pro 2023, Critical Section, Corrosion**

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I. INTRODUCTION

In today's world, communication has become an important factor in society through the rapid improvement of technology[1]. Cell towers are the backbone of modern communication. These typically range in height from 50 to 200 feet [2]. A cell tower's maximum usable range is typically 25 miles (40 kilometers), and in certain circumstances, radio signals from the tower can travel up to 45 miles (72 kilometers). However, the typical coverage range of a cell tower is limited to 1 to 3 miles (1.6 to 5 kilometers) due to various factors. In densely populated urban areas [3]. The lattice cell tower is a type of cell tower that is commonly known due to its distinct design, which enables it to stand freely without the need for external support or guy wires. The construction of these towers involves the assembly of an interconnected framework of metal sections that form a lattice-like structure [4]. This type of cell tower has a triangular base and height that typically ranges from 100 to 400 feet [5]. The structure is mainly designed to withstand environmental factors while facilitating the transmission of signals across a wide range. The approximate cost of a lattice cell tower is based on several variables, such as the tower's height, geographical placement, foundation type, and the equipment installed on the tower. With the construction of fifty thousand additional cell towers, the mobile network infrastructure of the Philippines will be substantially enhanced. The Department of Information and Communications Technology (DICT) is at the forefront of this undertaking, which strives to resolve the nation's recurrent problem of poor internet connectivity. As of 2022, there are a total of 22,405 cell towers in operation in the country, managed by the three primary telecommunications companies (Smart, Globe, and DITO) [6].

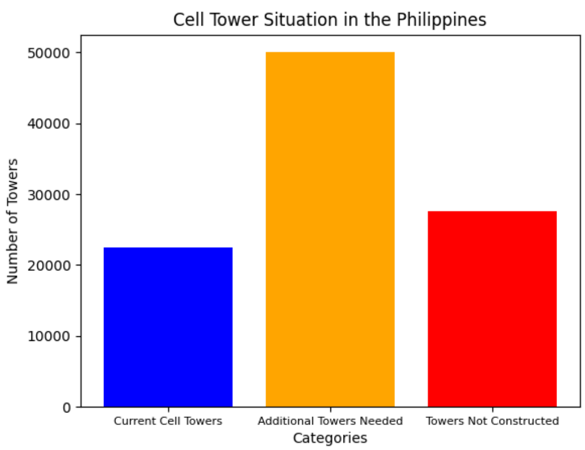

Fig. 1. Cell Tower Situation in the Philippines as of 2022

There are a major number of cell towers located in Pampanga, totalling 475. Even with the large number of mobile towers in Pampanga, there are still certain places where the connection is inconsistent. There are only six cell towers erected in the entire Bacolor area. Only two of the six Bacolor cell towers are located close to DHVSU. During high usage periods, when many people access the network simultaneously, some places may have poor connection quality despite having many cell towers. Cell tower capacity can be overloaded by high demand, resulting in dropped calls, reduced data rates, or trouble establishing connections.

The majority of steel structures that are being constructed apply the Load and Resistance Factor Design (LRFD) method. It accounts for uncertainties in loads and material strengths, leading to a more reliable and safer design compared to ASD, which primarily relies on allowable stress limits without explicitly considering variability in loads and materials. Hot-dip galvanized steel is a commonly used material recognized for its resistance to corrosion and its mechanical characteristics. The process of hot-dip galvanization entails submerging iron or steel in a bath of molten zinc to create a corrosion-resistant, multi-layered coating consisting of zinc-iron alloy and zinc metal. This procedure delivers three tiers of corrosion defense to steel: barrier protection, cathodic protection, and zinc patina.it has been discovered that the hot-dipping method may enhance material strength and reduce residual stress, resulting in enhanced mechanical characteristics. The effectiveness of hot-dip galvanized steel arises from zinc's superior corrosion resistance compared to iron in most operational environments [7].

The study aims to examine the application and global significance of the Telecommunications Industry Association Standard 222 Revision G (TIA-222-G) in the design and construction of cell towers to ensure reliable telecommunications infrastructure. It also focuses on analyzing the design of cell towers using hot-dip galvanized steel, evaluating material selection and assembly techniques for optimal performance and longevity. Additionally, the study seeks to integrate Load and Resistance Factor Design (LRFD) principles to enhance the analysis and design process, ensuring standardized safety factors and improved reliability against diverse loads.

II. METHODOLOGY

A. *Load and Resistance Factor Design*

The application of LRFD (Load and Resistance Factor Design) is widely used in the field of structural studies, particularly in lattice cell tower design. The use of this method guarantees the attainment of elevated levels of safety and reliability. Furthermore, it fosters the enhancement of design flexibility, consistency, and efficiency. Additionally, it simplifies the process of complying with industry standards and enables the use of advanced analysis and optimization techniques.

B. *General Design Method and Design Code*

Finite Element Analysis (FEA) software such as STAAD Pro will be applied to create a model and evaluate the behaviour of the cell tower to different types of loads, such as wind, seismic, and equipment loads. The FEA simulations' outcomes will be utilized to validate the design and enhance the stability of the cell tower.

The design code used for this tower is ANSI/TIA 222-G, which stands for the "American National Standards Institute/Telecommunications Industry Association Standard 222 Revision G." It specifically focuses on providing guidelines, specifications, and requirements for the design, analysis, construction, and maintenance of steel antenna towers and their supporting structures. This standard is recognized and adopted by regulatory bodies, engineering firms, and telecommunications industry stakeholders as the authoritative reference for tower design. It utilizes hot-dipped galvanized in accordance with ASTM Standard A123 for structural steel members. It sets forth industry standards, criteria for load combinations, safety factors, material properties, and structural configurations necessary to ensure the safety, reliability, and performance of antenna towers.

C. *Design Parameters*

The ground surface irregularities at the location have been identified as Exposure Category C, indicating open terrain with intermittent obstructions under 30 ft (9.1 m) in height.

The structure is classified under Category 1 in terms of topography, indicating a lack of sudden changes in overall terrain (such as flat or gently sloping land). As a result, there is no need to account for wind speed increase, and terrain characteristics are not taken into consideration.

The importance factor for this building is 1.0, since it falls under the category of Structure II, indicating a significant risk to human life and/or property if it fails, or is utilized for services that could be offered through alternative methods.

The cell tower under consideration has a height of 35 meters, a bottom width of 6 meters, and a top width of 1.6 meters, and it is equipped with 10 panels.

D. *Structural Members*

To optimize the three-legged lattice cell tower, the design focuses on durability, cost-effectiveness, and compliance with Load and Resistance Factor Design (LRFD) specifications. Circular Hollow Sections (CHS) are used for the leg and diagonal members due to their superior stiffness against torsion, lack of a weak axis, and reduced wind resistance. Horizontal members utilize equal angle bars, which provide necessary strength, durability, and excellent connectivity through bolted connections to gusset plates. This combination of CHS for vertical components and angle sections for horizontal components ensures a balanced and efficient tower design that maximizes cost-effectiveness and performance.

E. *Loads*

The following loads are computed using Microsoft Excel:

TABLE I
LOADS OF THE STRUCTURE

Dead Loads, DL	Self-weight Factor	-1.1		
	Nodal	Platform	@ 30.6 m Elev	0.554 kN
		4-Ports Panel Antenna	@ Leg A	0.5 kN
			@ Leg B	0.5 kN
			@ Leg C	0.5 kN
		Microwave Antennas	@ Leg A 1.8 m	2.18 kN
			@ Leg A 1.2 m	1.25 kN
Live Load, LL	Nodal	Platform	@ 30.6 m Elev	0.924 kN

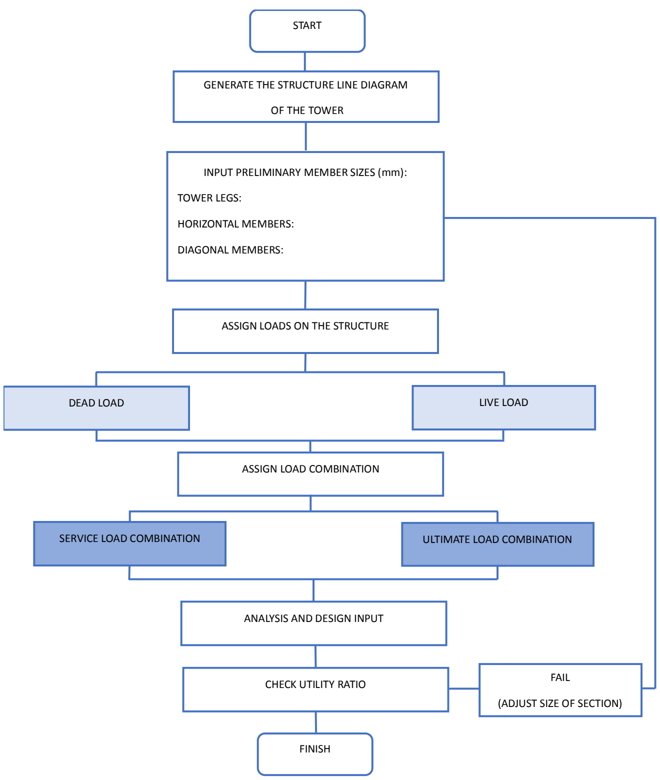

Fig. 1. Analysis Using STAAD.Pro

F. *Wind Load*

The wind load is calculated using the Microsoft Excel Program.

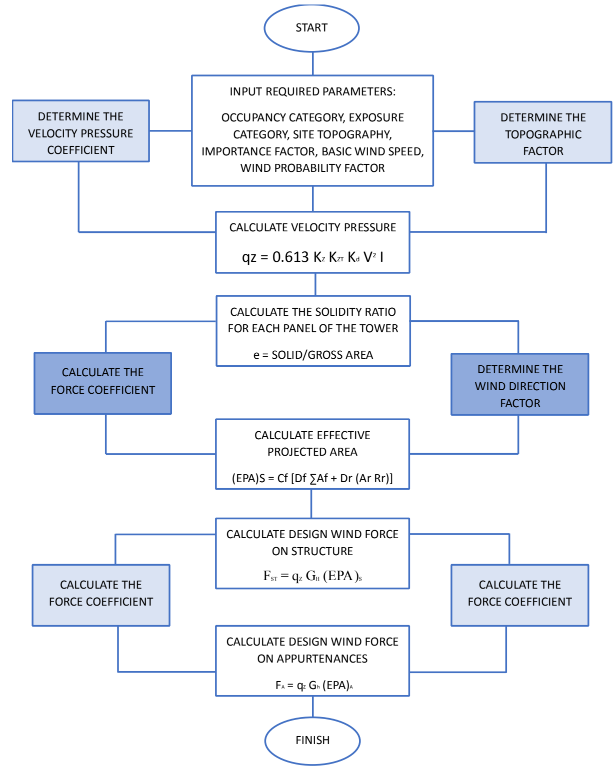

Fig. 2. Design Process of Wind Load Analysis

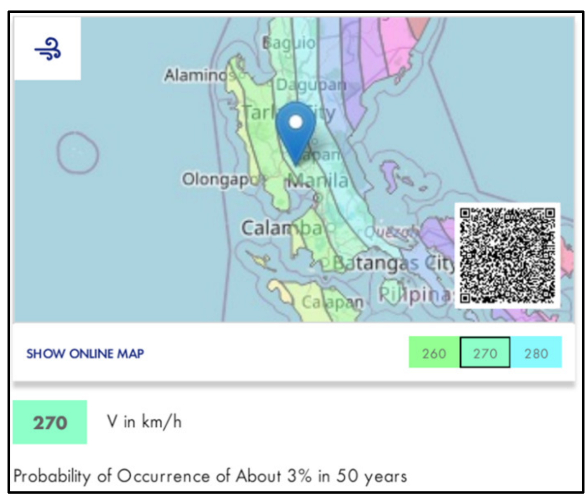

Fig. 3. Wind Speed at Bacolor, Pampanga[8]

G. ***Earthquake Loads***

Seismic load is the force applied to a structure by seismic vibrations, equivalent in design effect to the horizontal and vertical forces caused by ground movement during an earthquake. This load is defined by the National Structural Code of the Philippines (NSCP) 2015, which is based on the Uniform Building Code 1997 (UBC 97). According to NSCP 2015 Figure 208-1, which depicts the "Seismic Zone Map of the Philippines," Cabambangan, Bacolor, Pampanga, falls under Zone 4 and is located 53.5 km from the West Valley Fault.

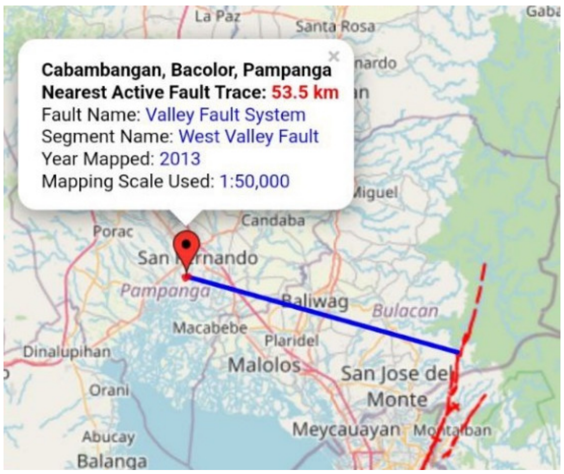

Fig. 4. Valley Fault System using DOST-PHIVOLCS Fault Finder[9]

For a structure with a seismic source type A, located in a seismic zone with a factor of 0.40, and situated on a soft soil profile (type SE), the relevant parameters are as follows: Near-Source Factors Nv and Na are both 1.0, and the structure falls under Class II as per the TIA-222-G classification. The importance factor for the structure is 1.0, and the response modification factor (R) for latticed self-supporting structures is 3.0. These parameters are derived from the respective tables (208-4, 208.4.3, 208-3, 208-5, 208-4, TIA-222-G Table 2-1, and Table 2-3) used for seismic analysis and structural design.

H. ***Design Strength of Structural Steel***

TABLE III
DESIGN PARAMETERS OF MEMBERS

MEMBERS	Fy (MPa)	E (MPa)
Leg Members (Tubular Round)	355	200 000
Diagonal Members (Tubular Round)	235	200 000
Horizontal Members (Angular)	235	200 000

I. ***Design Process for the Structural Members***

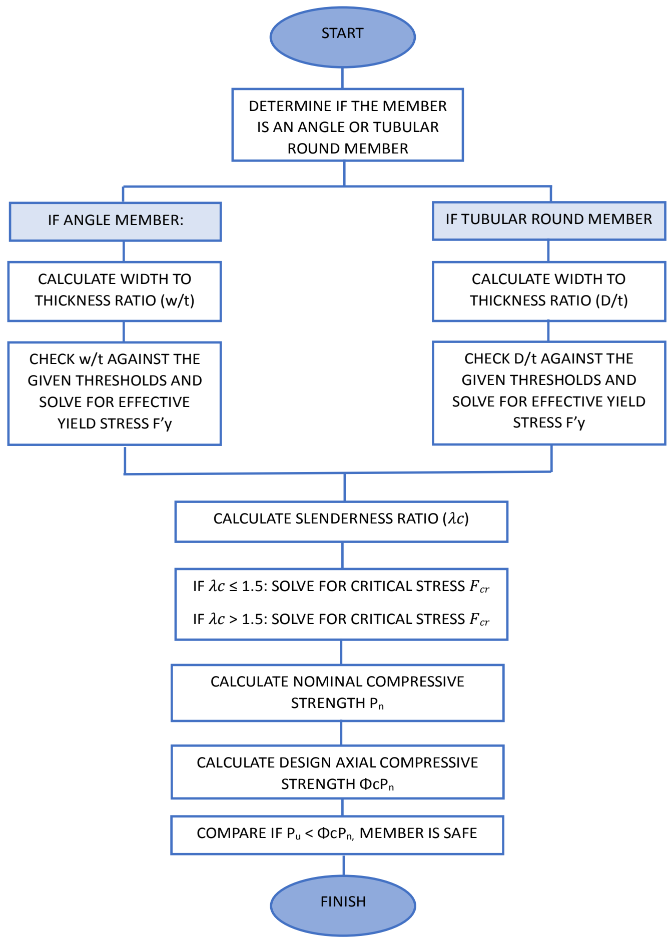

Fig. 5. Design Compressive Strength

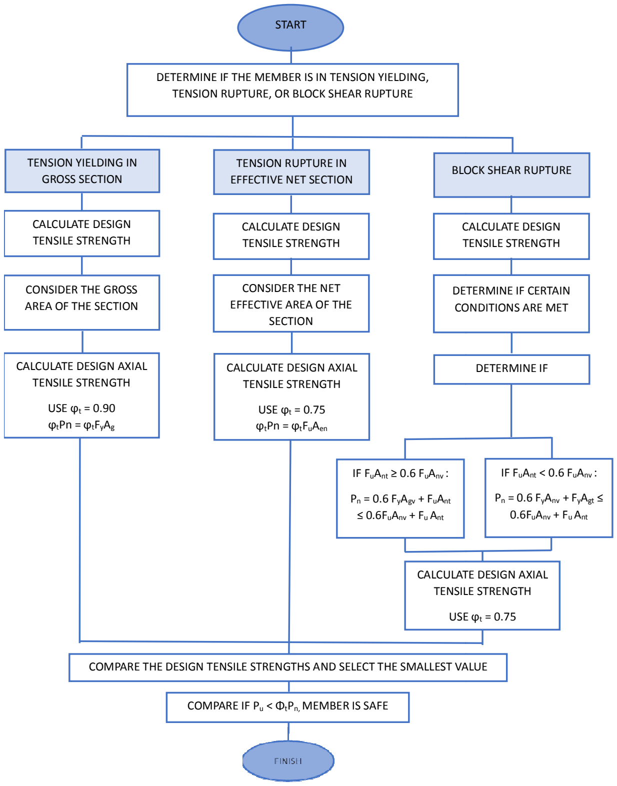

Fig. 6. Design Tensile Strength

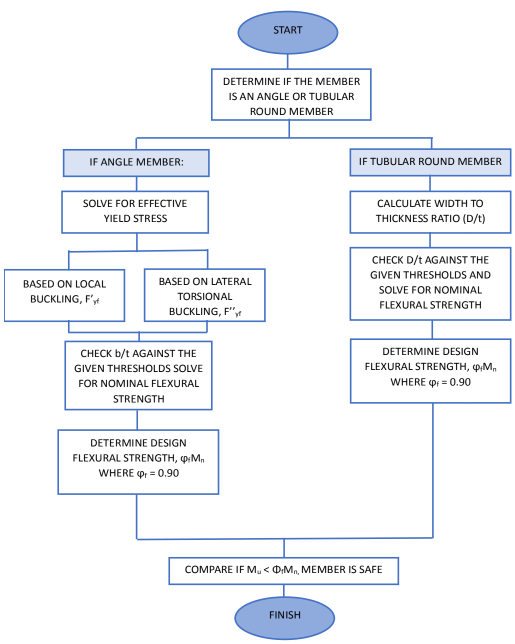

Fig. 7. Design Flexural Strength

J. ***Bolt Connection***

Hot-dip galvanized steel sections in cell towers typically use bolted connections instead of welding due to their superior durability and corrosion resistance in harsh outdoor environments. Bolts are easier to replace or repair, facilitating maintenance, and allow for simpler disassembly and reassembly during installation and future upgrades. Welding, on the other hand, can lead to corrosion and structural integrity issues due to heat-induced stress and potential fatigue, especially in high-wind or seismic areas.

According to TIA-222-G, ASTM A490 and ASTM A325 bolts can be reused only if they have been tensioned up to 40% of their ultimate capacity. Hot-dip or mechanically galvanized A490 bolts and A354 Gr. BD anchor rods are prohibited. For design calculations, the tensile and shear strengths of A325 bolts must use an ultimate tensile strength (Fub) of 120 ksi (818 MPa)[10].

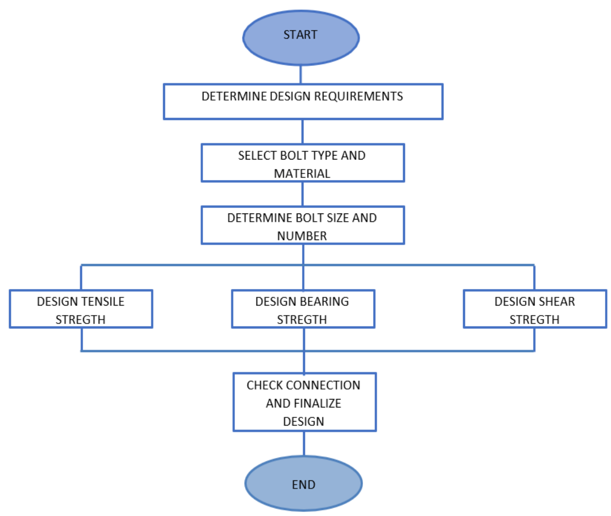

Fig. 8. Design Bolt Connection

K. ***Foundation Design***

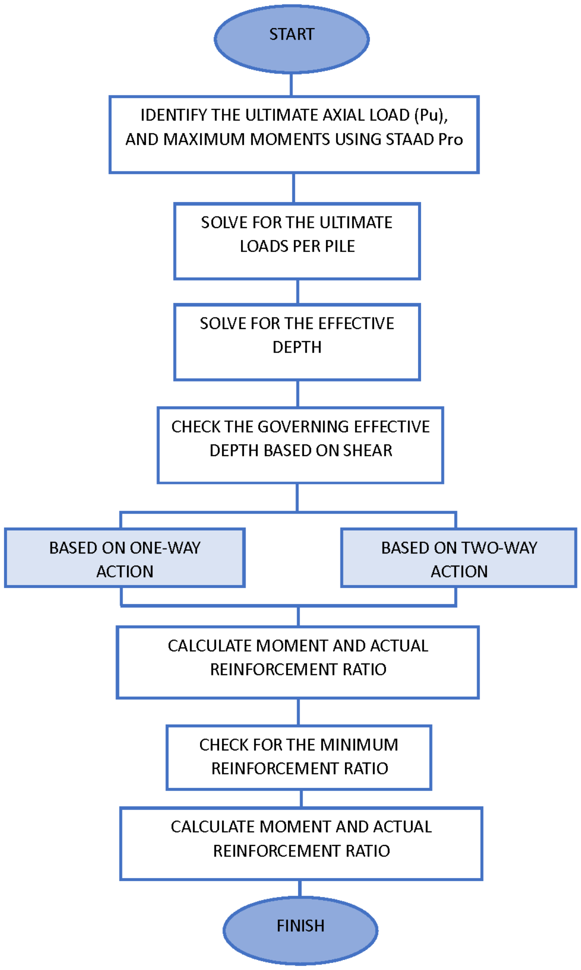

Fig. 9. Design Process of Pile Foundation

According to ANSI/TIA-222-G, the required strength for concrete and steel foundations, as well as anchorages, should comply with ACI 318-05 and AISC-LRFD-99 or the relevant material specification for alternative materials.

Based on the data presented by the Office of the Physical Plant and Facilities on the Geotechnical Evaluation Report for the Construction of the two-storey IRTPC Extension Building in the vicinity of Don Honorio Ventura State University, Bacolor, Pampanga. The Net Allowable Bearing Capacity

within the area is 40 KPa since the net soil bearing capacity Qnet is less than the required bearing capacity Qrequired, and the structure imposes very high loads that exceed the bearing capacity of shallow foundations. This suggests that the soil in close proximity to the surface lacks sufficient strength to uphold the structure. As a result, a pile foundation is required to shift the weight to deeper, more stable soil strata or bedrock.

TABLE IIIII
FOUNDATION DESIGN PARAMETERS

DESIGN PARAMETERS	
Foundation Type	Pile Foundation
Soil Bearing Capacity	40 kPa
Compressive Strength (f’c)	25 MPa
Tensile Yield Strength	414 MPa

III. RESULTS AND DISCUSSION

The tables below are from the results of the Excel Program for Wind Analysis provided by Engr. Marjie Erispe-Gadon, Founder and CEO of MEG Technical Consultancy Services OPC.

TABLE IVV
VELOCITY PRESSURE

Height(m)	K_{zt}	K_z	K_d	q_z (kPa)
3.10	1.00	0.850	0.85	1.465
5.60	1.00	0.886	0.85	1.527
8.10	1.00	0.958	0.85	1.651
10.60	1.00	1.014	0.85	1.747
13.10	1.00	1.060	0.85	1.827
15.60	1.00	1.099	0.85	1.895
20.60	1.00	1.166	0.85	2.009
25.60	1.00	1.220	0.85	2.103
30.60	1.00	1.267	0.85	2.184
35.60	1.00	1.308	0.85	2.254

The data presented in the table illustrates the velocity pressure coefficient, topographic factor, wind probability factor, and velocity pressure for every panel assessed at height z for the lattice tower.

TABLE V
EFFECTIVE PROJECTED AREA

Height(m)	$A_f(m^2)$	$A_r(m^2)$	R_r	EPA_s (m^2)
3.10	0.311	1.819	0.343681	2.604
5.60		1.769	0.343764	1.725
8.10	0.262	1.596	0.343715	2.242
10.60		1.554	0.343687	1.501
13.10	0.213	1.474	0.344066	1.949
15.60		1.437	0.343864	1.351
20.60	0.346	2.616	0.345975	3.236
25.60	0.284	2.519	0.354227	2.782
30.60		2.346	0.357141	1.939
35.60		2.256	0.355323	1.880

TABLE VI
DESIGN WIND FORCE ON STRUCTURE SUMMARY

Height (m)	q_z (kPa)	EPA_s (m^2)	F_{st}(kN)		
			Wind +X Normal	Wind -X Diagonal	Wind ± Z Normal
3.10	1.465	2.604	3.243	3.602	2.809
5.60	1.527	1.725	4.661	2.462	4.037
8.10	1.651	2.242	5.581	3.503	4.833
10.60	1.747	1.501	4.779	2.463	4.138
13.10	1.827	1.949	5.578	3.407	4.831
15.60	1.895	1.351	4.792	2.437	4.150
20.60	2.009	3.236	10.688	6.367	9.256
25.60	2.103	2.782	10.122	5.969	8.766
30.60	2.184	1.939	8.718	4.318	7.550
35.60	2.254	1.880	8.804	4.322	7.625

The height of 20.60 meters appears to be the critical section because it has the highest Effective Projected Area (EPA_s) value, which is 3.236 m², as indicated in the table. This means at this height, the wind force acting on the tower is the greatest when considering the structure's profile in the normal wind direction. The corresponding wind forces (Fx) for both normal and diagonal directions at this height are also among the highest values in the table, with Fx for Wind-X Normal at 10.688 kN and for Wind-X Diagonal at 6.367 kN. Further insights on this topic can be found in reputable sources like the American Society of Civil Engineers (ASCE) publication "Minimum Design Loads for Buildings and Other Structures."

TABLE VII
DESIGN WIND FORCE ON APPURTENANCES SUMMARY

Appurtenances	Fx (kN)	Fz (kN)	Fy (kN)	Mx (kN-m)	Wt. (kN)
Leg-A 4PORTS @ Elev. 33.5M	2.591	0	0	0	0.50
Leg-B 4PORTS @ Elev. 33.5M	1.538	0	0	0	0.50
Leg-C 4PORTS @ Elev. 33.5M	1.538	0	0	0	0.50
Leg-A 1.8M @ Elev. 28M	5.875	0	0	0	2.18
Leg-A 1.2M @ Elev. 26M	-1.449	0.892	0	0.254	1.25

In the context of a cell tower, "appurtenances" are supplementary items attached to the main structure, such as antennas, feedlines, dishes, and lightning rods. Specifically, "Leg-A 4 PORTS @ Elev. 33.5M," "Leg-B 4 PORTS @ Elev. 33.5M," and "Leg-C 4 PORTS @ Elev. 33.5M" refer to equipment positioned at 33.5 meters, each weighing 0.50 kN and evenly distributed across the three legs of the tower.

The most critical element is "Leg-A 1.8M @ Elev. 28M," with the highest horizontal force (Fx) of -5.875 and a weight of 2.18 kN, indicating a significant horizontal load at a lower elevation, likely due to a large antenna or similar structure with substantial wind load.

The 4 ports at 33.5 meters are likely for broadcasting or receiving signals, benefiting from an elevated position for clear line-of-sight and minimal interference, essential for effective signal transmission and reception.

TABLE VIII
DESIGN STRENGTH OF LEG MEMBERS

LEG MEMBERS				
Section	Length (mm)	Design Axial Compressive Strength, ØcPn (kN)	Design Axial Tensile Strength, ØtPn (kN)	Design Flexural Strength, ØfMn
ST PIP159X6.0	1667	810.31	760.6	33.97
ST PIP168X6.5	1667	631.40	697.83	27.12
ST PIP180X6.5	1675	1010.79	934.38	47.39
ST PIP203X7.0	2513	1178.19	1136.65	65.24
ST PIP219X8.0	2513	1469.31	1398.53	86.23
ST PIP245X8.0	2513	1679.81	1570.74	109.20

TABLE IX
DESIGN STRENGTH OF DIAGONAL MEMBERS

DIAGONAL MEMBERS				
Section	Length (mm)	Design Axial Compressive Strength, ØcPn (kN)	Design Axial Tensile Strength, ØtPn (kN)	Design Flexural Strength, ØfMn
ST PIP50X5.0	1849	72.64	149.5	1.53
ST PIP60X5.0	1849	110.41	182.7	2.32
ST PIP70X5.0	3015	86.95	215.94	3.28
ST PIP76X5.0	3580	81.06	235.82	3.93

TABLE X
DESIGN STRENGTH OF HORIZONTAL MEMBERS

HORIZONTAL MEMBERS				
Section	Length (mm)	Design Axial Compressive Strength, ØcPn (kN)	Design Axial Tensile Strength, ØtPn (kN)	Design Flexural Strength, ØfMn
ST L45X45X5	800	60.19	90.78	0.8
ST L50X50X5	800	73.03	101.58	0.97
ST L56X56X5	1680	36.50	114.53	0.96

The design strength values for different members like leg, horizontal, and diagonal members were provided in the table, including design axial compressive strength, design axial tensile strength, and design flexural strength. The design strengths varied based on the section length of the members, with higher values for longer sections.

The members showed varying capacities to withstand axial compressive, axial tensile, and flexural loads based on their design strengths. The results indicate the structural performance and load-carrying capabilities of the different members used in the study. Overall, the design strengths of the members suggest their suitability for specific structural applications and are considered safe based on the calculated axial compressive, axial tensile, and flexural strengths.

TABLE XI
CRITICAL LOAD CASE

Comb.	Combination L/C Name	Primary	Primary L/C Name	Factor
107	DL+WL (+) X (-) Z	3	DEAD LOAD	0.900
		10	WIND +X-Z DIRECTION	1.600

TABLE XII
BEAM STRESSES OF THE CRITICAL MEMBER

Beam	L/C	Section	Axial (psi)	Bend-Y (psi)	Bend-Z (psi)	Combined (psi)	Shear-Y (psi)	Shear-Z (psi)
2306	107	0.000	2671.979	31380.640	-83.593	34114.738	26.305	-2235.971

The critical section is typically where the stress values are highest and closest to or exceed the material's limits, indicating a potential failure point. In this case, the section with the higheststress value, which is likely the shear stress in the Z direction at 34114.738 psi, would be considered the critical beam section.

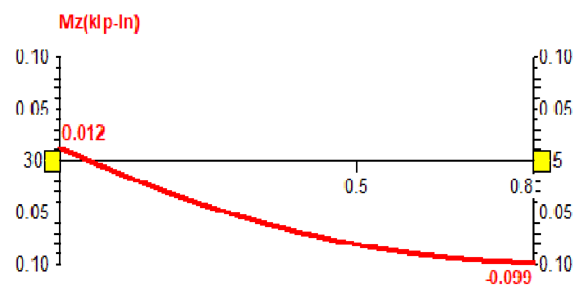

Fig. 10. Bending Moment about Z of Beam 2306

The Bending moment of beam 2306 is defined by a significant negative moment at the ends and a barely positive moment in the middle. This implies that the beam is bending in opposite directions along its length due to a combination of loads. The bending moment at point A is 0.012 kip-in, which indicates that the moment is compressing the top fibers of the beam and tensioning the bottom fibers. With a value of -0.099 kip-in, point B indicates a point of lower moment that may be in close proximity to the point of zero shear. This can be the result of a larger weight, like additional construction equipment or machinery resting on the beam.

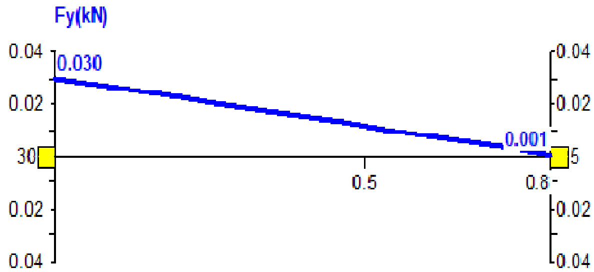

Fig. 11. Shear along Y of Beam 2306

The Shear along the Y-axis of the length of beam number 2306, which is located at an elevation of 28 meters of the tower, is 0.030 kN at point A and 0.001 kN at point B. This indicates that, as a result of the particular loading and support circumstance, the beam undergoes a tiny internal shear force that eventually drops to zero. The Shear along the Z-axis has a continuous sheer force of -2.57kN over the whole beam's length. This constant shear force indicates that a consistent loading condition–likely a uniformly distributed load–is applied to the beam. The beam's cross-section and material should be designed to guarantee that the shear stress stays within the permissible limits.

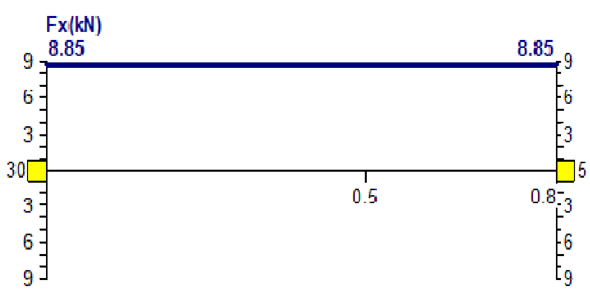

Fig. 12. Axial Force of Beam 2306

The internal force acting along the length of a beam is referred to as the axial force in a beam. The axial force of 8.85 kN is mentioned at both ends of beam 2306, which indicates that a compressive force of 8.85 kN is applied to each end of the beam. This usually happens when the beam is pushed or pulled by external weights or supports, which causes it to either stretch or compress throughout its length. Therefore, in this instance, the compression at either end of the beam is 8.85 kN.

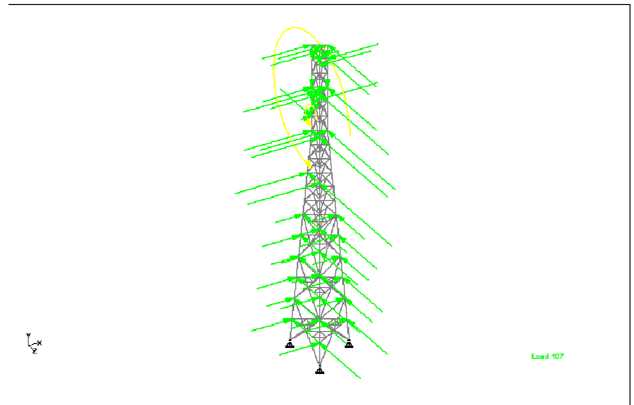

Fig. 13. Wind Load Diagram for Critical Load Case: 107

The green lines extending horizontally from the structure at multiple levels suggest wind loads, which are critical to consider since cell towers are tall, slender structures that can be significantly affected by wind. The arrows on these braces may indicate the tension and compression forces that these members experience as a result of the applied loads. The vertical lines likely indicate the self-weight of the tower and the vertical component of the loads from the tower's equipment.

According to TIA-222-G Section 3.5, Displacement effects denoted as P-Δ, are not required to be taken into account for self-supporting latticed towers that have heights under 450 ft [137 m], given that the height to face-width ratios, hi/fwi, do not exceed 10, as illustrated in Figure 3-1. Since, the tower's height is 35 m and the hi/fwi do not exceed 10, P-Δ are not required.

TABLE XIII
DESIGN TENSILE STRENGTH OF BOLTS

Bolt Size	Nominal Unthreaded Body Area of Bolt, Ab(mm²)	Nominal Unthreaded Body Area of Bolt, Ab(kN)	Ultimate Tensile Strength of Bolt, Fub(MPa)	Nominal Tensile Strength, ØRnt(kN)
M16	157	0.157	818	96.32
M24	353	0.353	818	216.566

For an M16 bolt, the calculated tensile strength (ØRnt) is 96.32 kN, based on a tensile stress area of 157 mm² and an ultimate tensile strength of 818 MPa, ensuring it meets high-strength bolt standards. For an M24 bolt, the tensile strength area is approximately 353 mm², taking into account the threaded portion's minor diameter, resulting in a tensile strength (ØRnt) of 216.566 kN. This calculation confirms that M24 bolts can safely support the specified load before failure.

TABLE XIV
DESIGN BEARING STRENGTH OF BOLTS

Bolt Size	Clear Distance Lc(mm)	Thick -ness, t(mm)	Ultimate Tensile Strength of Bolt,Fub (MPa)	Bearing Strength Rn (kN)	Nominal Strength Pn (kN)	Design Bearing Strength ØPn (kN)
M16	65.25	5	818	157.056	628.224	471.168
M24	61	5	818	235.584	942.336	706.752

The design bearing strength for an M16 bolt is calculated to be 471.168 kN, using the lower value of 157.056 kN from standard formulas and applying an LRFD safety factor of 0.75. This meets the required specifications.

For an M24 bolt, the design bearing strength is 706.752 kN, derived from a governing value of 235.584 kN and the same safety factor. This also meets the standard requirements, confirming adequacy for both bolt sizes.

TABLE XV
DESIGN SHEAR STRENGTH (A) WHEN THREADS ARE EXCLUDED FROM THE SHEAR PLANE

Bolt Size	Nominal Unthreaded Body Area of Bolt, Ab(mm²)	Nominal Unthreaded Body Area of Bolt, Ab(kN)	Ultimate Tensile Strength of Bolt, Fub(MPa)	Design Shear Strength, Rnv (kN)
M16	157	0.157	818	64.213
M24	353	0.353	818	144.377

The bolt's shank, which has a bigger cross-sectional area and more strength than the threaded section, is taken into consideration when the threads are removed from the shear plane. By multiplying the nominal area of the bolt shank (Ab) by half the ultimate tensile strength of the bolt material, one can determine the nominal shear strength. This yields a nominal shear strength of 64.213kN for an M16 bolt and 144.377kN for an M24 bolt. These values indicate the highest shear force that a bolt is designed to withstand in concept before failing, guaranteeing a safe and reliable connection.

TABLE XVI
DESIGN SHEAR STRENGTH (A) WHEN THREADS ARE INCLUDED FROM THE SHEAR PLANE

Bolt Size	Nominal Unthreaded Body Area of Bolt, Ab(mm²)	Nominal Unthreaded Body Area of Bolt, Ab(kN)	Ultimate Tensile Strength of Bolt, Fub(MPa)	Design Shear Strength, Rnv (kN)
M16	157	0.157	818	51.370
M24	353	0.353	818	115.502

A nominal shear strength that contains threads in the shear plane is 40% of the product of the ultimate tensile strength and the nominal area of the threaded section. This gives an M16 bolt a nominal shear strength of 51.37kN and 115.502kN for an M24 bolt. This offers a safer design by taking the bolts' weakest point into account when shear force requirements are met.

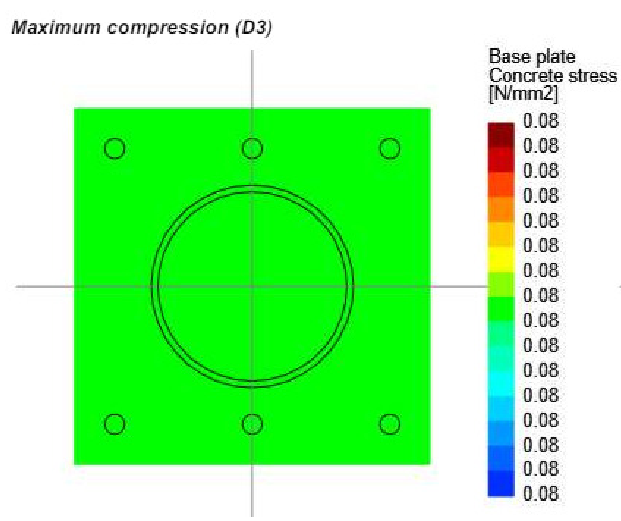

Fig. 14. Base Plate Compression Stress

The image provided is an anchor bolt analysis for a base plate, which is crucial for the design and safety of structures like cell towers. It consists of two main sections: the Maximum Compression (D3) Diagram and the Base Plate Bearing Diagram, along with tabulated reaction forces. The analysis ensures that anchor bolts and base plates can handle expected loads without excess stress concentrations, thereby maintaining structural integrity

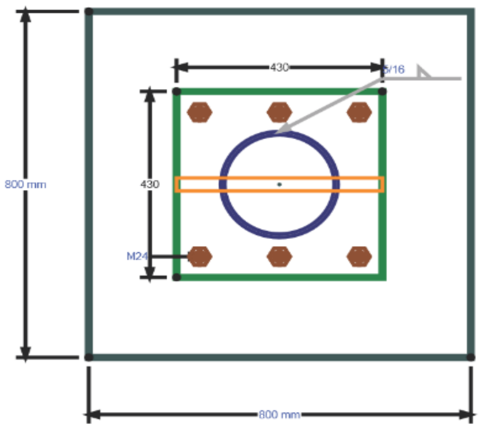

Fig. 15. Anchor Bolt Top View

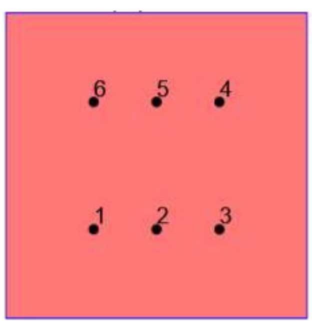

Fig. 16. Results for Tensile Breakout

The image provides a detailed analysis of anchor bolt reactions and results for anchor breakout on a base plate. The Anchor Reactions forces acting on each anchor in various directions, including transverse from 0 to -166.80 kN, longitudinal consists of +166.80 & - 166.80, shear 64.26 kN, and tension forces 4.37 kN. The Major Axis – Results for Anchor Breakout section provides a visual and numeric analysis of the group of anchors, including the group area of 640000.00, tension 26.22 kN, and anchors involved 1,2,3,4,5,6.

TABLE XVII
DESIGN PILE CAP

Pile Cap	Pile Cap Length (PC_L) m	Pile Cap Width (PCw) m	Pile Cap Thickness (t_l) m	Number of Piles	Pile c/c spacing (P_s) m	Pile Diameter (P_d) m
Leg-A	4.00	4.00	1.20	9	1.50	0.50
Leg-B	4.00	4.00	1.20	9	1.50	0.50
Leg-C	4.00	4.00	1.20	9	1.50	0.50

The Geotechnical Evaluation Report for the Construction of the two-storey IRTPC Extension Building in the vicinity of Don Honorio Ventura State University, Bacolor, Pampanga, presented by the Office of the Physical Plant and Facilities involved sample data from two drilled boreholes, necessary to analyze the distinctive characteristics of the subsoil and determine its condition. The field (Standard Penetration Test - SPT) and laboratory procedures used in the study were outlined in the report, along with the analysis of the test results for foundation evaluation.Since the net soil-bearing capacity is insufficient to support the structure using a shallow foundation. A deep foundation, specifically a pile foundation, was utilized to provide stable support in challenging soil conditions, accommodate high structural loads, control settlement, resist uplift forces, and ensure stability in the whole structure.

TABLE XVIII
PEDESTAL DESIGN SUMMARY

Pedestal	Pedestal Dimension (mm)	Pedestal Height (m)	Main Steel Reinforcement	Transverse Steel Reinforcement
Leg-A	800 x 800	0.60	20 – 20mm	16mm
Leg-B	800 x 800	0.60	20 – 20mm	16mm
Leg-C	800 x 800	0.60	20 – 20mm	16mm

To support the 800mm x 800mm pedestal, all of the pile caps of pile footing were designed with an area of 4.0m x 4.0m and a thickness of 1m, with each of the pile caps having a total number of 9 piles. The geotechnical report recommended the usage of piles with a 500 mm diameter and a length of 18 meters to support the tower, the center-to-center distance of the piles is 1.5m. All of the pile caps for Legs A, B, and C of the tower it is reinforced with 16- 25 mm diameter reinforced steel bars both ways.

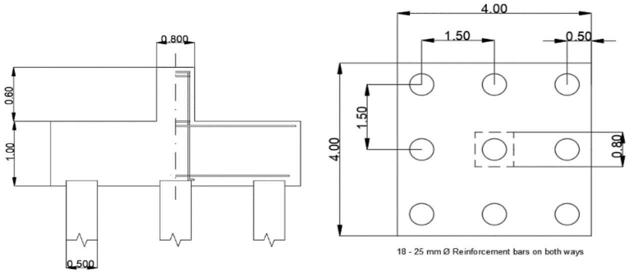

Fig. 17. Pile Cap Details

Comparison of Hot-Dip Galvanized Steel from Traditional Steel:

TABLE XIX
COST ESTIMATE OF MATERIALS SUMMARY

COST ESTIMATION		
Type	Hot-Dip Galvanized Steel	Traditional Steel
Material Cost	2,024,923.50	1,261,569.92
Labor Cost	809,966.40	504,627.96
Total	2,834,892.90	1,766,197.88

TABLE XX
COMPARISON IN TERMS OF PERFORMANCE, LIFESPAN, AND MAINTENANCE

	Hot-Dip Galvanized Steel	Traditional Steel
Performance	-Excellent corrosion resistance due to zinc coating - High durability in various environments (urban, rural, coastal) - Better performance in harsh weather conditions	- Susceptible to rust and corrosion without additional protection - Requires protective coatings or paints in harsh environments - Can deteriorate faster in harsh weather conditions
Lifespan	- Typically, 50-70+ years depending on the environment - Longer lifespan in most environmental conditions - Consistent performance over time	- Typically, 10-20 years without protective coatings - Lifespan significantly reduced in corrosive environments - Requires frequent inspections and repairs to maintain integrity
Maintenance	- Low maintenance due to durable zinc coating - Rarely needs repainting or additional treatments - Periodic inspections recommended but less frequent	- High maintenance due to susceptibility to corrosion - Requires regular painting, coating, or treatments - Frequent inspections and repairs needed to prevent structural damage

In conclusion, hot-dip galvanized steel lattice towers offer better long-term value due to their enhanced strength and lifespan, despite the higher initial material cost, even though typical steel lattice towers may be initially less expensive.

IV. CONCLUSIONS

The importance of cell towers lies in theirpivotal role in modern communication networks, facilitating seamless connectivity and enabling various opportunities for individuals and communities. However, the Philippines needs help with slow internet speeds and poor network connectivity, specifically in Bacolor, Pampanga, which has significant implications for the country's economic and social development. In addition, the increasing population of students in Don Honorio Ventura State University because of newly added programs and buildings is a challenge in sustaining reliable, consistent network connectivity. Hence, the study's main purpose was to provide a comprehensive analysis that would guide cellular infrastructure development in the future, guaranteeing the development of durable, resilient, and dependable networks close to Don Honorio Ventura State University.

The three-legged lattice cell tower's design adheres closely to the tower specifications set by The Department of Public Works and Highways (DPWH). The DPWH oversees and implements the regulations outlined in Presidential Decree (P.D) No. 1096, commonly referred to as the National Building Code of the Philippines. This includes the enforcement of penalties for any administrative violations, which states that "No building or structure shall be used or occupied and no change in the existing use or occupancy classification of a building or structure or portion thereof shall be made until the Building Official has issued a Certificate of Occupancy thereof as provided in this Code." and the height clearance permit from the Civil Aviation Authority of the Philippines (CAAP). If the telecommunications tower exceeds fifty (50) meters in height and is within a three (3)-kilometer radius of an airport, or if it is to be built within a ten (10)-kilometer radius of communication-navigation surveillance facilities off-airport, a CAAP height clearance permit is mandatory. The DICT, however, is tasked with enhancing the efficiency of the procedures involved in applying for, renewing, and obtaining permits, licenses, and clearances necessary for infrastructure construction or equipment installation in collaboration with relevant national and local government entities. In addition, several telecommunication providers, such as Globe Telecom, have a minimum requirement for a property area of 144 sq. m.

Furthermore, to optimize the design of the section of the lattice tower, a Circular Hollow Section (CHS) was utilized for the leg and bracing/diagonal member of the tower, and Angular bars were used for the Horizontal members, both of which provide durable and economical sections for the lattice cell tower. The combination of angular sections and CHS for horizontal and vertical elements ensures a balanced and economical design that optimizes cost and performance when constructing a three-legged lattice tower.

In this study, the researchers concluded that integrating the codes and standards outlined in TIA 222-G can significantly impact the design and analysis of a three-legged lattice cell tower. It guarantees enhanced overall structural stability and ensures that the lattice cell tower design meets industry regulations and safety requirements, promoting consistency and reliability in structural performance.

The construction of a cell tower is a complex endeavor that requires a delicate balance between various factors to ensure efficiency and cost-effectiveness. The project's scope, which includes the tower's type, height, and the number of antennas and transceivers, directly influences the materials and ultimately impacts the overall cost. The choice of materials, such as galvanized steel or concrete for the tower's structure, can significantly affect the project's budget, as some materials may be more expensive.

Additionally, the availability of materials in the local market can impact the project's efficiency and cost, as skilled workers may be in high demand, leading to increased labor costs. The equipment needed for the project, such as cranes, lifts, and specialized tools, can also contribute to the overall cost, especially if specialized equipment is required for the site's terrain or location. External factors, such as weather conditions, site accessibility, and zoning regulations, can also significantly impact the project's efficiency and cost.

Furthermore, obtaining necessary permits and approvals from local authorities can add to the project's timeline and expenses. In conclusion, a thorough understanding of the relationships between these variables is crucial for project managers to make informed decisions and ensure the completion of a cell tower construction project within budget and timeline constraints.

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