STRUCTURAL ASSESSMENT OF A LATTICE TOWER IN FEDERAL CAPITAL TERRITORY, ABUJA

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Abstract

Since the licensing of GSM operators in Nigeria from 2001, there was an astronomical increase in construction and maintenance of telecommunications towers. In a bid to reduce maintenance cost, tower sharing was adopted by some telecommunication providers. The Nigerian Communications Commission guideline for installation of masts and towers stipulates that all lattice towers should be checked for their structural health status every five years. This requirement has promoted this research work. The objective of the study includes selection of a lattice tower with weakest parameters, determine the tower's structural stability and its utilization percentage. A 45m tower, with 3-legs, erected over 8 years and shared by three telecommunication operators in the Federal Capital Territory (FCT) was selected. Audit was conducted on the tower and its foundation. There were no warped member and no visible crack on the tower foundation. The average compressive strengths of the stub columns determined using the digital Schmidt hammer were 25.1, 25.9 and 25.9 N/mm² for legs A, B and C. From the structural analysis using the EPA model, the tower utilization percentage was found to be at 59.4% after optimization. The STAAD pro. V8i analyses showed that the utilization ratio of the tower members is ≤ 1. Furthermore, design properties for the tower members are less than the properties of the actual tower members used and there was no failed member identified after the structural analysis. In conclusion, the lattice tower can be said to be stable and fit for continuous use.

Keywords: EPA model, lattice tower, stub column, tower audit, tower sharing

INTRODUCTION

In the recent past, the number of telecommunication towers has risen astronomically due to licensing of more network providers like Globacom, MTN, Airtel and Etisalat (Okonji, 2013). This is due to the growing demand for wireless and broadcast communication which has prompted a dramatic increase in communication tower construction and maintenance. Failure of such structures is however a major concern (Sharma *et al*, 2015). Tower sharing which involves sharing one tower by two or more network operators has increased in a bid to reduce maintenance cost. Such towers may need to be strengthened or made taller to support several sets of antennas (GSMA publication, 2012). It is therefore extremely important that towers are effectively maintained to ensure continued safety and efficient operation throughout their lifetime.

In recent years, a number of tower failures caused by heavy rains and strong windstorms were recorded in Nigeria. These failures resulted in great economic loss and loss of lives. Another problem the telecommunications towers is facing is the upkeep of the aging towers along with staying within a maintenance budget that is decreasing (Sullen, 2015).

The Nigeria Communication Commission (NCC) 2009, specified that major inspections shall be performed at least once in every 5 years for self-supporting towers. The assessment of structural integrity of the selected lattice tower will help determine stability of the selected tower. It will further show the threat posed by poorly maintained towers and their potential danger to life and properties in their host communities.

the effective projected area (EPA) model and STAAD pro. V8i software.

The tower selected has been in service for over eight years and was previously used by one telecoms operator (9mobile). However, it was acquired by an infrastructure provider (IHS), who leased it to two more telecoms operators (Airtel and MTN). This indicates that tower sharing is now taking place on a tower previously erected to be used by a single telecom operator. The tower height is 45m supported on three legs and located in Abuja-FCT as shown in Table 1. Relevant documents (Site approved drawing, Soil test report, Tower drawing) were obtained to aid the tower modelling, design, and analyses.

METHODOLOGY

The materials used for this study includes the following.

- digital Schmidt hammer
- mechanical toolbox
- Microsoft office suite
- STAAD pro V8i software
- measuring tape
- personal protective equipment.

This research work involved tower selection, thorough physical inspection of the selected tower, non-destructive test on tower's stub column using Schmidt hammer and structural analyses of the entire towers using

Table 1: Details of selected tower

Item	Description
Site Identification	B0653 (IHS_ ABJ_0704E)
No. of Operators	3
Site Location	Plot 7, Unity Hill Estate, Behind Sunny-Ville Estate, Dakwo District, FCT, Abuja, FCT
Site Coordinates	Latitude: 8.97312, Longitude: 7.43745
Tower Manufacturer	Mast Projects
Type of Tower	Medium duty Lattice Tower
Tower Design Capacity	12 m^2
Tower Height	45m
Tower Top Rating	1.2m^2/m spread over the upper 10m of tower
Age	8 years
Tower legs	3 legs

FOUNDATION AUDIT USING SCHMIDT HAMMER

A non-destructive test was carried out on the tower stub columns to determine the foundation compressive strength. The test was carried out using a digital Schmidt hammer. The tower legs were labelled alphabetically from A-C in anticlockwise direction for easy referencing.

Member's Audit

The tower audit encompasses a thorough inspection of the tower members and bracings, the bolts and nuts conditions at the connections, the state of other tower accessories like the access ladder, rest platforms, paints, aviation warning lights, earth cables and also records of all the telecom equipment installed on the tower in presented in Table 2.

Table 2: Tower Antenna Audit

Antenna Type	Diameter (mm)	Total Number
GSM 1	2500 x 300 x 200	3
GSM 2	1500 x 170 x 150	8
GSM 3	1300 x 150 x 100	11
RRU	480 x 290 x 180	17
MW 1	300.00	2
MW 2	600.00	7

Structural Analysis using EPA Model

The effective projected area (EPA) model is computed using the Microsoft excel spreadsheet. It is safe to assume that the effect of wind forces on the exposed areas of the antennas gives a quick overview of the present load exerted on the tower since the self-weight of the antennas to the tower is negligible. A typical 0.6m diameter antenna weighs 14 kg compared to tower's maximum uplift force of 890 kN per leg and tower mass of 7582 Kg.

The model is therefore based on calculations of the overall EPA of the antennas against the tower capacity. The dimensions of each antenna and their respective installation heights are recorded.

The result obtained is rated against the tower's design capacity to determine the percentage of tower utilization. The tower loading is optimized using the local basic wind speed as provided by the Nigeria Meteorological Agency.

A tower whose utilization percentage falls below 100% after optimization is termed satisfactory while that whose utilization exceed 100% is termed overloaded. An overloaded towers is recommended for load shedding according Etisalat Tower Specification (2012).

Structural analysis using STAAD Pro. V8i

The STAAD pro. V8i stands for Structural Analysis and Design computer programme. It is a software that is used for analysing and designing structures like buildings, towers, bridges, industrial, transportation and utility structures. It enables 3D modelling of steel structures and aids structural analyses. The load considered includes tower's self-weight as presented in Table 3, equipment load, wind load on the antennas and wind intensity on the tower members. The tower members are designed to BS 5950-1: 2000 (EN 1993-1-8)

The software has a friendly user interface. The tower model starts with the setting-out of the structure in a grid system. The dimensions are defined, subsequently the nodes are connected with beams. The topmost layer is drawn inside the base grid, elevated. Once the simple model is drawn, the tower members are defined with material specifications using the tower assembly drawing. Finally, the tower is loaded with calculated loads.

STAAD Pro can generate quite a large range of outputs. For this research work, the outputs are limited to the utilization ratio on the tower members and safety of the tower.

Table 3: Equipment loading NA means not applicable

S/N	Description	Numbers	Length (mm)	Width (mm)	Thickness (mm)	Weight (Kg)	Total weight (Kg)	Total weight (KN)
1	GSM 1	3	2500	300	200	25	75	0.75
2	GSM 2	8	1500	170	150	20	160	1.6
3	GSM 3	11	1300	150	100	10	110	1.1
4	RRU	17	480	290	180	15	255	2.55
5	MW 1	2	300	NA	NA	10	20	0.2
6	MW 2	7	600	NA	NA	14	98	0.98

Wind pressure on the tower is calculated based on BS 6399-2 (1997) (EN 1991-1-4). It takes into consideration local basic wind speed (V_b) and three multiplying factors (S_1, S_2, S_3) to obtain the design wind speed (V_s). The multiplying factors for topography, height above ground, and structure life represent S_1, S_2, and S_3 respectively. The values for the multiplying factors were obtained from the reinforced concrete designer's handbook by Reynolds and Steedman (1998).

Thereafter, the wind pressure per node is calculated using the equation 1.

$$Wk = 0.613Vs^2 \quad (1)$$

as presented in Table 4.

Where W_k = wind pressure.

Vs = design wind speed

The wind pressures obtained are applied vertically on tower member in STAAD pro. V8i.

Table 4: Wind Pressure Calculation

Height (m)	Abuja Basic Wind Speed (vb) (m/s)	Topography Multiplying Factor (s1)	Height Above Ground and Wind Braking Multiplying Factor (s2)	Life of Structure (s3)	Design Wind Speed (vs) (m/s)	Wind Pressure (wk) (n/m2)	Wind Pressure (wk) (kn/m2)
2	35	1	0.78	1	27.3	456.86277	0.46
4	35	1	0.78	1	27.3	456.86277	0.46
6	35	1	0.79	1	27.65	468.6522925	0.47
8	35	1	0.79	1	27.65	468.6522925	0.47
10	35	1	0.9	1	31.5	608.24925	0.61
12	35	1	0.9	1	31.5	608.24925	0.61
14	35	1	0.9	1	31.5	608.24925	0.61
16	35	1	0.94	1	32.9	663.51733	0.66
18	35	1	0.94	1	32.9	663.51733	0.66
20	35	1	0.96	1	33.6	692.05248	0.69
22	35	1	0.96	1	33.6	692.05248	0.69
24	35	1	0.96	1	33.6	692.05248	0.69
26	35	1	0.96	1	33.6	692.05248	0.69
28	35	1	0.96	1	33.6	692.05248	0.69
30	35	1	1	1	35	750.925	0.75
32	35	1	1	1	35	750.925	0.75
34	35	1	1	1	35	750.925	0.75
36	35	1	1	1	35	750.925	0.75
38	35	1	1	1	35	750.925	0.75
40	35	1	1.03	1	36.05	796.6563325	0.80
42	35	1	1.03	1	36.05	796.6563325	0.80
44	35	1	1.03	1	36.05	796.6563325	0.80
46	35	1	1.03	1	36.05	796.6563325	0.80

The wind load on the equipment is generated from the force the wind exerts on the projected surface area of the equipment and it is obtained using the equation 2

$$F = cF \ x \ Wk \ x \ A \quad (2)$$

Where cf = force coefficient,

W_k = wind pressure and

A = Area

The force values obtained per equipment are applied perpendicularly to the tower member where the equipment is installed. The Table 5 shows the forces acting on each type of antenna.

Table 5: Wind Load on Equipment

Description	Length (h) (mm)	Width (b) (mm)	Thickness (a) (mm)	h/b	a/b	Force coefficient (cf)	Area (A) (m^2)	Force (F) (KN)
GSM 1	2500	300	200	8.33	0.67	1.7	0.75	1.02
GSM 2	1500	170	150	8.82	0.88	1.7	0.26	0.35
GSM 3	1300	150	100	8.67	0.67	1.7	0.20	0.26
RRU	480	290	180	1.66	0.62	1.2	0.14	0.13
MW 1	300	NA	150	NA	NA	1.2	0.07	0.07
MW 2	600	NA	300	NA	NA	1.2	0.28	0.27

NA means not applicable

RESULTS AND DISCUSSION

It was observed from the physical inspection that the tower and its accessories are in good condition with the only exception being the tower paint. The Nigeria Civil Aviation Authority (NCCA) requires red and white paint of the telecommunications tower to be bright for pilots' visibility. Table 6 provides description on the conditions of the tower and its accessories.

Table 6: Tower Audit Result

Item	Description
Structural Members	No warped member detected
Access Ladder	Accessible and railings are in good condition
Rest Platforms	Gratings on platforms are not blocked and do not accumulate water or not corroded
Bolts and Nuts	Bolts and nuts are not loose and no missing bolts
Aviation Warning Light	Aviation warning lights (AWL) are in place and functional
Earthen cables	Copper cables for tower earthen
Antennas	Antennas properly clamped
Tower paint	Faded
Thunder Arrestor	Properly bolted

Tower Foundation Audit

The average compressive strengths of the tower legs are presented in Table 7. The compressive strength of the stub columns met the foundation design specification as seen on the site drawing approval with mean compressive strengths of 25.1, 25.9 and 25.9 N/mm^2 for legs A, B and C respectively. The physical conditions of the stubs are in good condition as there was no visible cracks or blisters on them.

Table 7 Compressive Strength of Stub Columns

S/N	Rebound Values (R)		
	Leg A	Leg B	Leg C
1	26	28	42
2	27	30	28
3	35	27	35
4	30	25	27
5	32	33	30
6	33	30	31
7	25	28	28
8	25	30	26
Mean Compressive strength X (R)	28.5	29	29
Mean Compressive strength F (N/mm^2)	25.1	25.9	25.9

Structural analysis using EPA Model

The tower utilization percentage after optimization with local wind speed stands at 59.4% as presented in Table 8 The tower loading can therefore be declared satisfactory.

Table 8 Tower Utilization Percentage

Parameters	Result
Tower Height	45m
Tower Capacity	$12m^2$
Tower is rated for top	10m
Summation Antennas EPA	$8.09m^2$
Lever arm	40m
Percentage utilization based on EPA	67.40%
Design Wind Speed	40m/s
Abuja Basic Wind Speed	35m/s
Optimized Tower Utilization	59.4%

Structural analysis using STAAD Pro. V8i

From the report generated using STAAD Pro. V8i, the utilization ratio (actual ratio to allowable ratio) of all the tower members are ≤ 1 (less or equal to one). The average percentage of tower utilization is 83.52%. Also, the sizes of the tower members generated due to the present load exerted on the tower are less than the actual size of tower members. Finally, there is no failed member identified after the analysis as presented in Fig. 1.

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45m Tower Modelling/Analysis

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Utilization Ratio Cont...

Beam	Analysis Property	Design Property	Actual Ratio	Allowable Ratio	Ratio (Act./Allow.)	Clause	L/C	Ax (cm²)	Iz (cm⁴)	Iy (cm⁴)	Ix (cm⁴)
356	ISA70X70X6	ISA50x50x3	0.929	1.000	0.929	BS-4.8.3.3.1	5	2.950	2.891	11.409	0.089
357	ISA70X70X6	ISA65x65x5	0.996	1.000	0.996	BS-4.8.3.3.1	4	6.250	10.081	41.010	0.521
358	ISA70X70X6	ISA50x50x3	0.823	1.000	0.823	BS-4.8.3.3.1	5	2.950	2.891	11.409	0.089
359	ISA70X70X6	ISA45x45x3	0.936	1.000	0.936	BS-4.8.3.3.1	5	2.640	2.072	8.252	0.079
360	ISA70X70X6	ISA65x65x5	0.928	1.000	0.928	BS-4.8.3.3.1	6	6.250	10.081	41.010	0.521
361	ISA70X70X6	ISA65x65x5	0.857	1.000	0.857	BS-4.8.3.3.1	4	6.250	10.081	41.010	0.521
362	ISA70X70X6	ISA45x45x3	0.800	1.000	0.800	BS-4.8.3.3.1	4	2.640	2.072	8.252	0.079
363	ISA70X70X6	ISA60x60x5	0.960	1.000	0.960	BS-4.8.3.3.1	5	5.750	7.871	31.944	0.479
364	ISA70X70X6	ISA45x45x3	0.786	1.000	0.786	BS-4.8.3.3.1	4	2.640	2.072	8.252	0.079
365	ISA70X70X6	ISA60x60x5	0.833	1.000	0.833	BS-4.8.3.3.1	5	5.750	7.871	31.944	0.479
366	ISA70X70X6	ISA40x40x3	0.917	1.000	0.917	BS-4.8.3.3.1	4	2.340	1.435	5.730	0.070
367	ISA70X70X6	ISA60x60x4	0.895	1.000	0.895	BS-4.8.3.3.1	5	4.710	6.558	26.074	0.251
368	ISA70X70X6	ISA35x35x3	0.891	1.000	0.891	BS-4.8.3.3.1	4	2.030	0.939	3.787	0.061
369	ISA70X70X6	ISA60x60x4	0.782	1.000	0.782	BS-4.8.3.3.1	5	4.710	6.558	26.074	0.251
370	ISA70X70X6	ISA35x35x3	0.886	1.000	0.886	BS-4.8.3.3.1	4	2.030	0.939	3.787	0.061
371	ISA60X60X5	ISA35x35x3	0.921	1.000	0.921	BS-4.8.3.3.1	5	2.030	0.939	3.787	0.061
372	ISA60X60X5	ISA60x60x4	0.825	1.000	0.825	BS-4.8.3.3.1	5	4.710	6.558	26.074	0.251
373	ISA60X60X5	ISA50x50x4	0.857	1.000	0.857	BS-4.8.3.3.1	4	3.880	3.742	14.782	0.207
374	ISA60X60X5	ISA35x35x3	0.803	1.000	0.803	BS-4.8.3.3.1	4	2.030	0.939	3.787	0.061
375	ISA60X60X5	ISA35x35x3	0.722	1.000	0.722	BS-4.8.3.3.1	5	2.030	0.939	3.787	0.061
376	ISA60X60X5	ISA50x50x3	0.820	1.000	0.820	BS-4.8.3.3.1	5	2.950	2.891	11.409	0.089
377	ISA60X60X5	ISA20x20x3	0.327	1.000	0.327	BS-4.8.3.3.1	4	1.120	0.159	0.647	0.034
378	ISA60X60X5	ISA40x40x3	0.934	1.000	0.934	BS-4.8.3.3.1	5	2.340	1.435	5.730	0.070
379	ISA60X60X5	ISA20x20x3	0.294	1.000	0.294	BS-4.9	3	1.120	0.159	0.647	0.034
380	ISA60X60X5	ISA20x20x3	0.558	1.000	0.558	BS-4.8.3.3.1	4	1.120	0.159	0.647	0.034
381	ISA50X50X6	ISA20x20x3	0.889	1.000	0.889	BS-4.8.3.3.1	4	1.120	0.159	0.647	0.034
382	ISA50X50X6	ISA20x20x3	0.153	1.000	0.153	BS-4.8.3.3.1	3	1.120	0.159	0.647	0.034
383	ISA50X50X6	ISA20x20x3	0.392	1.000	0.392	BS-4.8.3.3.1	4	1.120	0.159	0.647	0.034

Failed Members

There is no data of this type.

Fig 1: Extract of STAAD Pro computation sheet

CONCLUSION

The structural assessment of a lattice tower was presented. From the study, the following can be deduced:

i. The tower's physical condition is satisfactory. No cracks on the foundation and no deformed member seen on the tower. However, the tower coating (paint) was found to have worn out hence would need repainting.

ii. The structural analysis of the tower shows that members are in stable condition and within permissible specifications.

iii. In view of paragraphs (i) and (ii) above, the tower can therefore be considered fit for continuous use.

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