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Evaluation of BTS tower structure to the addition of SST 3 Leg 51 meter antenna tower

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Abstract
Increasing network capacity and quality is done by upgrading or adding devices on telecommunication towers, including the addition of sector antennas or transmission antennas. The addition of devices in telecommunication towers results in an increase in the load that must be carried by the telecommunication tower. This study aims to evaluate the structure of the bts tower against the addition of antenna tower sst 3 leg 51 meters by engineering software for tower antenna. The stability analysis of the telecommunication tower includes the stress ratio variables that occur in the tower elements, tower sway, tower torsion, tower displacement, and support reactions that occur. In addition, the strength of the connections in the structure and foundation were analyzed against the loads received by the tower structure. Analysis and modelling in this research are assisted by engineering software for tower antenna (MS Tower) and refers to the EIA Standard Structural for steel Antenna Tower and Antenna Supporting Structure (TIA-222-F). The results of the analysis of the existing antenna device and the addition of the antenna device with the maximum wind speed according to the EID / TIA-222-F regulations obtained the ratio on the leg of 1.057. Which means it exceeds the permit stress ratio value required by AISC-LRFD which is < 1.0. So that reinforcement is needed on panels that have a ratio above the permit voltage. The results of the analysis of the tower structure, connection, and foundation after reinforcement were found to be safe.

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Keywords
BTS tower, Transmission antennas, SST 3 Legs

Introduction
The necessity of telecommunication day to day increase, it causes cellular operator to improve their service to public like number of towers, capacity of tower, network and signal. Upgrading capacity and quality network is enable to update or add sector antenna or transmission antenna in the cellular tower. The additional of element tower to strengthen tower causes higher load. Cellular tower is three types as light type, medium type and heavy type. The types are classified based on load capacity. For

example light tower is not able to support loads of heavy and medium tower, It will make instability to light tower. The research aims to analyze the capacity and stability of tower due to additional of antenna. The tower is medium tower with three legs and 51 m height, the critical section due to additional antenna is leg section where stress ratio of leg is over than limit stress, it means leg section is unsafe so it should be strengthened.

Previous research discussed about strengthening of tower due to addition of antenna were carried out by Abdalla [1], Kusbiantoro [2]. Analysis of sway, displacement, stress ratio and twist for telecommunication tower was done by Pradipto [3]. Seran [4] analyzed cellular tower with STAAD Pro. All of the analysis after strengthening shows tower is safe to service loads. This research is focused on strengthening the antenna tower structure by adding SST 3 Legs to the 51 Meter Antenna Tower.

Method

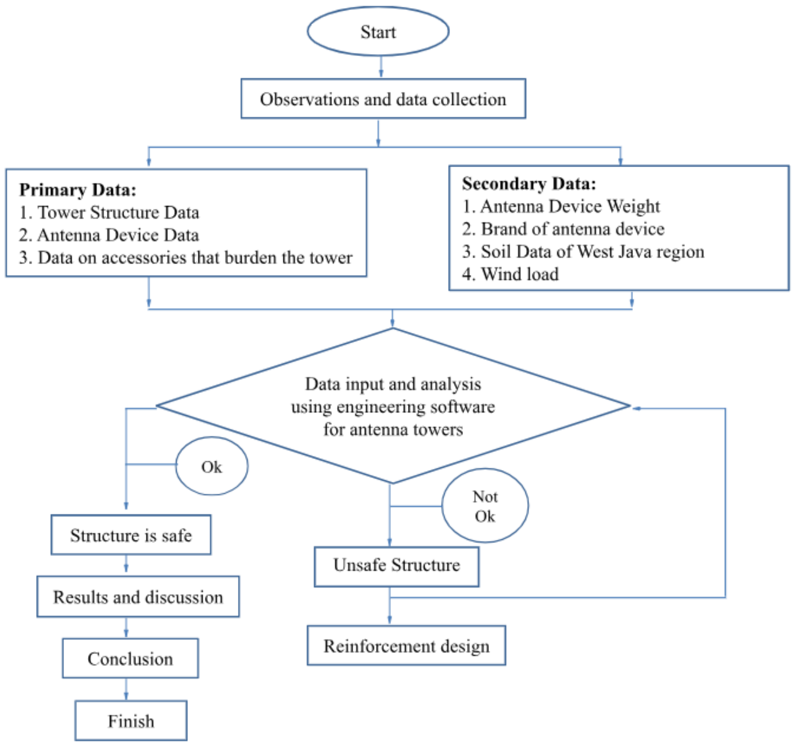

Figure 1. Research flow chart

Primary data collection includes Tower Profile, Dimension, Height, and Number of Antennas, and other tower accessories. Secondary data collection includes Mass or weight of antenna, Sondir and N-SPT results and Analytical Static Method, and Wind load. The analysis carried out includes: Structure modelling, Load Input. Among them are structural loads, antenna loads and wind loads, analysis of twisting, swaying, displacement, and stress ratio on the structure, modelling if the structure requires reinforcement, checking the strength, stiffness, and stability of tensile and compressive bars, connection analysis, and foundation analysis. The research flow chart is presented in Figure 1. Standard to be referred for analysis is Structural

Standards for Steel Antenna Towers and Antenna Supporting Structures (TIA/EIA-222-F), EIA, USA [5], [6].

Result and Discussion

Modelling of Structures

Modeling of the tower structure is done using a computer program, AutoCad. Material input and antenna device loads on the tower were carried out using software MS-Tower [7].

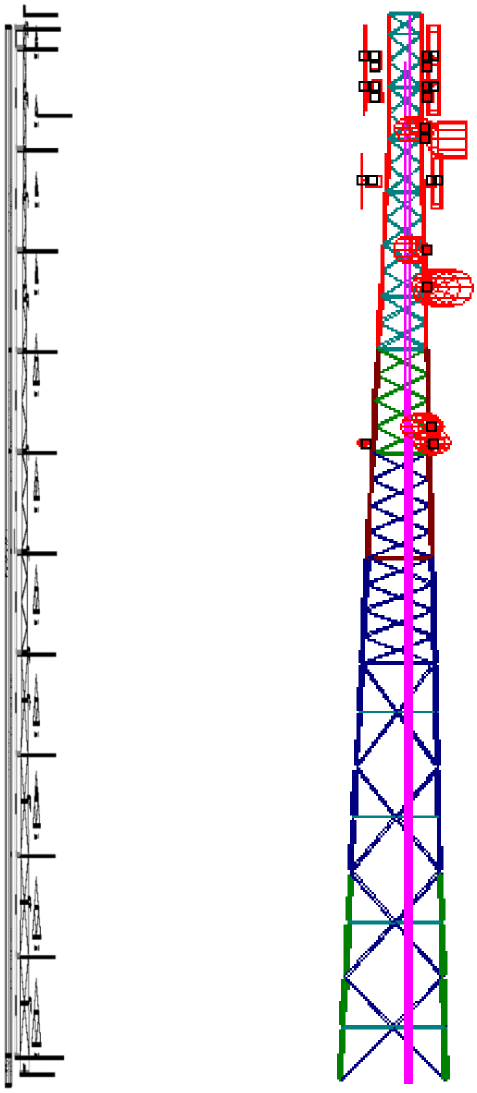

Figure 2. Structure modelling

Figure 2 shows the existing tower of 51 height and three legs, the tower is medium tower and the addition antenna is placed at the top of tower in leg section. The addition of antenna makes load increases.

The loading for tower analysis is dead load which includes the self-weight of the structure, the weight of the antenna, and tower accessories. Antenna loads depend on the type and number of antennas installed. Table 1 presents mass of leg sections. Total mass of leg sections is 5306.15 kg.

Table 1. Mass of Leg Section

Mass Summary			
Sections size	**fy**	**L (m)**	**M (kg)**
3 CHS165.2x7.1	Y 235	30.02	829.46
3 CHS165.2x7.1	Y 235	45.03	975.55
3 CHS165.2x7.1	Y 235	30.02	480.71
11 CHS89.iX5.5	Y 235	48.02	542.80
12 EA60X60X6	Y 245	34.10	184.98
13 EA70X70X7	Y 245	217.03	1601.44
14 EA80X80X8	Y 245	7.20	69.52
24 EA50X50X5	Y 245	164.99	621.70
Mstower V6 Reactions (060619)			5306.15

Wind load is calculated according TIA/ EIA-222-F standard. It is divided into two types, wind load at the structure and wind load at antenna.

1. Wind load at structure

   Wind Calculation (F) at the height 45 – 50 meter. Structure is safety if F is less than wind force limit (F_{limit}) where F = Qz.Gh. (Cf.Ae+Ca.Aa) ……1) and F_{limit} = 2Qz.Gh.Ag……..2) . Based on formula 1) and 2) obtained F = 411,976 kg/m and F_{limit} = 1433,348 kg/ m, so F < F_{limit} and structure is safety

2. Wind load at the antenna

   Calculation wind force of antenna at the height of tower 30,5 meter and diameter antenna 0,3 meter, height of antenna 0,128 m obtained 7,530 Kg

Structural Analysis

Structural Analysis aims to calculate strength of tower and steel element based on TIA-222-F regulation [6]. It was used MS Tower. The results are twist = 0,105 < 0,5 (safe), sway = 0,430 < 0,5 (safe), twist = 0,216 < 0,25 (safe). Stress ratio: Leg = 1,057>1,00 (unsafe), Bracing = 0,903 < 1,00 (safe), Horizontal = 0,391 < 1,00 (safe), Plan bracing = 0,10 < 1,00 (safe). Stress ratio of leg is unsafe so it should be strengthened to be safe.

Tower Strengthening

Due to unsafe at the leg section so it should be strengthened. The method of strengthening is to add several steel members as Figure 3. The new member was connected with bolt and strength of connection calculated by steel structure formula. The result of structural analysis after strengthening are twist = 0,105 < twist limit = 0,5 (safe0, sway = 0,453 < swaylimit = 0,5 (safe), twist = 0,216 < twistlimit = 0,25 (limit), stress ratio at the section: leg = 0,973 < leglimit = 1,00 (safe), bracing = 0,914 < bracinglimit= 1,00 (safe), horizontal = 0,404 < horisontallimit = 1,00 (safe), bracing = 0,10 < 1,00 (safe).

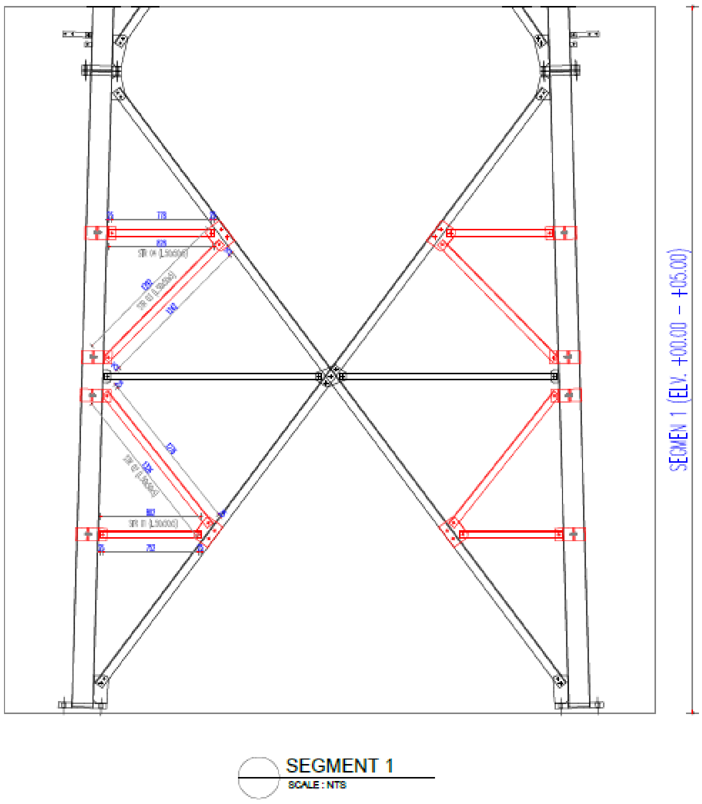

Figure 3. Reinforcement plan

Strength, Stiffness and Stability Analysis of Tensile and Compressive Bars

Strength, stiffness and stability analysis of tensile and compressive bars were done at the lowest member of tower structure.

1. Tensile analysis of steel bar
   a. Leg section. Steel profile CHS 165,2 x 7,1. Yield strength of axial load (Pu) = 486,271 kN < capacity of axial load (φ Pn) = 766,16 kN. Ultimate strength of axial load (Pu) = 486,271 kN < capacity of axial load (φ Pn) =1056 kN.
   b. Bracing. Steel profile L 70 x 70 x 7. Yield strength of axial load (Pu) = 18,462 kN < capacity of axial load (φ Pn) = 179,20 kN. Ultimate strength of axial load (Pu) = 18,462 kN < capacity of axial load (φ Pn) =243,81 kN (safe).
   c. Member of horizontal. Profile L 50 x 50 x 5. Yield strength of axial load (Pu) = 0,467 kN < capacity of axial load (φ Pn) = 105,84 kN. Ultimate strength of axial load (Pu) = 0,476 kN < capacity of axial load (φ Pn) =122,40 kN (safe).
2. Strength and stability of compressive steel bar
   a. Leg section. Steel profile CHS 165,2 x 7,1, strength (Nu) = 577,988 kN < capacity of strength (φ Nn) = 733,04 kN (safe). Stability = 0,792 < 1 (safe), stiffness = 0,0821 cm < 0,546 cm (safe)
   b. Bracing. Steel profile L 70 x 70 x 7, strength (Nu) = 19,636 kN < capacity of strength (φ Nn) = 95,685 kN (safe). Stability = 0,302 < 1 (safe), stiffness = 0,0327 mm < 6,66 mm (safe).

c. Horizontal section. Steel profile L 50 x 50 x 5, strength (Nu) = 0,436 kN < capacity of strength (φ Nn) = 95,685 kN (safe). Stability = 0,0545 < 1 (safe), stiffness = 0,0817 mm < 7,50 mm (safe).

d. Plan bracing section. Steel profile L 50 x 50 x 5, strength (Nu) = 1,316 kN < capacity of strength (φ Nn) =117,60 kN (safe). Stability = 0,0207 < 1 (safe), stiffness = 0,0205 mm < 6,25 cm (safe).

Analysis of Connection

The connection used bolts which were set among leg bars. In this condition shear strength of bolts dominated along bars. The results of analysis are shear strength φ. Rn = φ. 0,5. Fub. ab = 76,302 kN/ bolt, bearing strength φ. Rn = φ. 2,4. db. Tp.Fup = 246,24 kN/ bolt, plate shear φ.Tn > Tu = 6604 kN > 450 kN (safe). Number of bolt Tu / φ Rn < Σ Baut = 450 / 76,302 = 5,89, Number installed bolt = 6, It means the connection is safe. Figure 4 is illustration of installed bolts ai the bars.

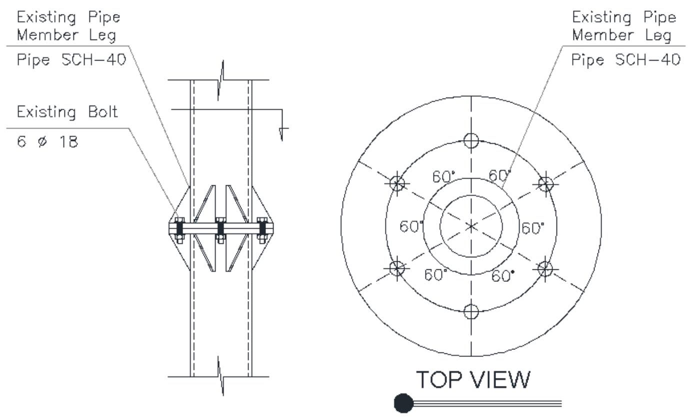

Figure 4. Detail drawing of the connection

Analysis of Foundation

Pile design: $Q_{all} \geq P_{i}$ max + weight of pilecap = 65,08 ton ≥ 56,25 ton (safe), space of pile requires 2,5.d < s < 3d if s = 50 cm, thus space 125 cm ≤ s ≤ 150 cm.pile space obtained 130 cm. Pile reactions:

1. Dead load: $V_1 = P_{column} + W_{pilecap} < Q_{limit}$; 8,473 < 43,390 (safe)

N_{pile}

2. Dead load in case Emergency; $V_e = P_{column} + W_{pilecap} < 1{,}5.\ Q_{limit}$; 13,65 < 65,085 (safe)

Calculation of group pile; $Q_{allgroup} > P_{max} + W_{pilecap}$ where obtained 86,589 > 16,847 (safe), in case emergency $1{,}5Q_{allgroup} > P_{max} + W_{pilecap}$ obtained 129,88 > 56,257 (safe). Uplift calculation; $P_u < Q_{u\ all}$ 34,95 ton < 36,528 (safe), pile cap: $T_u < T_{limit}$.

Recapitulation of Analysis BTS Tower Structure

Table 2 shows that Leg section after strengthening is safe than before, It means addition of leg member reduce fracture risk due to axial load of steel member decreased. Other members like bracing, horizontal and plan bracing doesn't show significantly change after strengthening where axial force of these members is lower than limit design then structure is still safe. Analysis of the existing antenna device and the addition of the antenna device with the maximum wind speed according to EID/TIA-222-F regulations [6] resulted in a leg ratio of 1.057. Which means it exceeds the permit stress ratio value required by AISC-LRFD [5] which is < 1.0. So that reinforcement is needed on panels that have a ratio above the permit stress. The reinforcement carried out on panels 27 and 29 is by adding redundant or rods as stiffeners to channel the load received by the leg to the bracing. Analysis of the structure after strengthening or reinforcement obtained a ratio on the leg of 0.973. Which means that it is less than the permit stress ratio value required by AISC-LRFD which is < 1.0. So, the structure is declared safe after reinforcement. This is similar to the previous study [8].

Table 2. Recapitulation of analysis BTS Tower Structure

Description	Strength before strengthening	Strength after strengthening		Limit Design	Remarks
Leg (Kn)	1.057	0.973	<	1.00	Safe
Bracing (Kn)	0.903	0.914	<	1.00	Safe
Horizontal (Kn)	0.391	0.404	<	1.00	Safe
Plan Bracing (Kn)	0.100	0.100	<	1.00	safe
	Wind speed (22,50 m/sec)				
Twist (Degree)	0.105	0.105	<	0.50	Safe
Sway (Degree)	0.430	0.453	<	0.50	Safe
Horizontal Displacement (Degree)	0.216	0.216	<	0.25	Safe

Table 3. Recapitulation of analysis lower structure of BTS Tower

Description	Results		Design tolerance	Remarks
Connection (bolt)	5.890	<	6 Bolts	Safe
Pile capacity (Ton)	65.08	<	56.25 Ton	Safe
Foundation reaction (ton)	13.65	<	65.085	Safe
Pile bearing capacity (ton)	56.25	<	129.88	Safe
Uplift (ton)	34.950	<	36.258	Safe
Punching Shear (ton)	0.223	<	0.674	Safe

Table 3 shows design of lower structure is safe, strengthening of upper structure didn't impact to the lower structure. The foundation used is a bored pile foundation with a diameter of 0.5 meters and a depth of 15 meters. The pile cap used is a group pile cap of 2 piles with a distance between piles of 130 cm and the dimensions of the pile cap are 2300 mm x 1200 mm x 600 mm. Still able or safe to withstand the Uplift force experienced by the tower. The tower is still able to withstand the force with a maximum capacity of 509.95 kN.

Conclusion

Analysis of the existing antenna device and the addition of the antenna device with the maximum wind speed according to EID/TIA-222-F regulations resulted in a leg ratio of 1.057. Which means it exceeds the permit stress ratio value required by AISC-LRFD which is < 1.0. So that reinforcement is needed on panels that have a ratio above the permit stress. The reinforcement carried out on panels 27 and 29 is by adding redundant or rods as stiffeners to channel the load received by the leg to the bracing. Analysis of the structure after strengthening or reinforcement obtained a ratio on the leg of 0.973. Which means that it is less than the permit stress ratio value required by AISC-LRFD which is < 1.0. So the structure is declared safe after reinforcement.

Analysis of existing bolt connections in the structure using ASTM A325 bolts with a diameter of 18 mm with a total of 6 bolts is still safe. The foundation used is a bored pile foundation with a diameter of 0.5 meters and a depth of 15 meters. The pile cap used is a group pile cap of 2 piles with a distance between piles of 130 cm and the dimensions of the pile cap are 2300 mm x 1200 mm x 600 mm. Still able or safe to withstand the Uplift force experienced by the tower. The tower is still able to withstand the force with a maximum capacity of 509.95 kN.

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