Comparative Study on Different Structural Forms of Telecommunication Towers

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Abstract

Telecommunication infrastructures plays a key role in providing telecommunication service. The rapid increase in usage of telecommunication devices during the recent past created necessity for construction of new telecommunication structures and upgrading of existing structures to meet the increased demand. Ground based towers, monopoles and guy mast structures are three commonly used structural forms of telecommunication towers. The factors such as land usage for the infrastructure, cost, material usage, structural performance, space available for connection of antennas and constructability to be critically considered during the preliminary design to select most suitable structural form. This study investigates the trend in variation of above-mentioned parameters for different structural forms based on the data collected from 31 telecommunication towers designed by the author in Sri Lanka. The results presented in the form of graphs provide useful information for structural engineers and other decision makers in the telecommunication infrastructure development sector in the selection of a most feasible structural form for the telecommunication structure according to the project constrains. Further, the comparison of lateral stiffness, material usage and the exposed surface area against wind loading for different bracing configurations commonly used for rectangular based telecommunication towers were presented. These results will be useful for structural engineers to select optimum bracing configurations based on the extent of wind loading.

Keywords: *Telecommunication towers, Monopoles, Guy mast, Preliminary design.*

1. Background

Currently, several nations around the world emphasis the digital revolution. The Sri Lankan government has also started working towards “Digital Sri Lanka”. This creates huge demand in the internet usage and data transfer. Construction of new telecommunication structures and upgrading the existing structures have been accelerated in the recent past to create the required space for telecommunication equipment. The selection of the most suitable structural form for a telecommunication structure satisfying the site-specific requirements is a challenging task for structural engineers involved in the design of telecommunication infrastructure (Elhakim et al., 2022). The influence of various critical factors (such as structural performance, cost, land usage and constructability aspects) governing the selection of a structural form for a telecommunication structure are investigated in this study. Available data collected from 31 different forms of telecommunication structures designed by the author was used to develop required comparison in this study. The findings of this study will be useful for structural engineers, project managers and other decision makers involved in the design of telecommunication infrastructures to choose a most viable structural scheme during the conceptual design stage.

Telecommunications structures are often divided into three main structural forms such as Ground based towers (Self-supporting/lattice towers), Guyed masts and Monopoles. Ground based towers (Figure 1) could be either triangular based (with three legs) or rectangular based (with four legs) pin jointed steel structures. In general practice, they are wider at the base level and narrow down to top. In these structures moments induced by the lateral wind loads are resisted as axial tension and compressive forces. Hot rolled angle sections are mostly used in ground base towers. However, in triangular based towers usage of circular hollow sections was also noted.

In guyed masts (Figure 2) steel cables are used to support the steel mast at different levels against the lateral wind loads. In these structures wind induced lateral loads are predominantly resisted by the guy cables in form of tensile forces and steel mast carries compressive forces from the gravity loads and vertical component of the thrust

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transferred from the cables. Compared to the ground-based towers lateral force induced moments are very less in guy masts. Thus, mostly uniform cross sections are used throughout the height. Since larger lever arms are not required for guy masts, closer leg spacing with pinned base is adopted as shown in Figure 2. In the guy mast structures steel is used in most efficient form by transferring majority of the lateral forces in form of tension in the cables. Thus, guy mast is generally found to be the most economical structural form. However, it requires larger land extent for the anchoring of guy cables and require skilled resource for the erection. Further, structural redundancy of the pin-based guy mast is less compared to the ground base towers as failure of a cable may lead to the collapse of the entire structure.

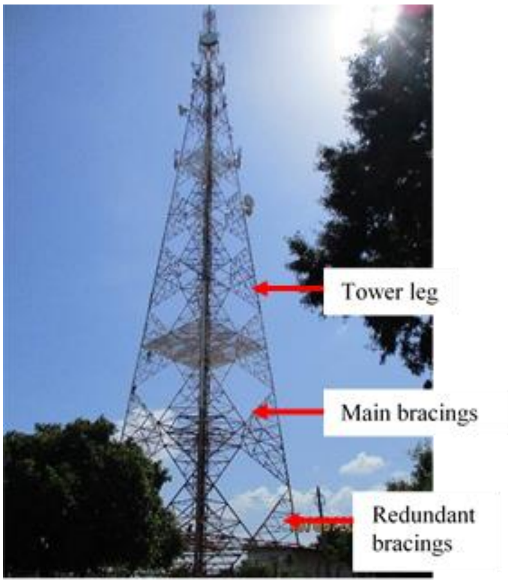

Figure 1: Rectangular based, 100 m high – Ground based tower.

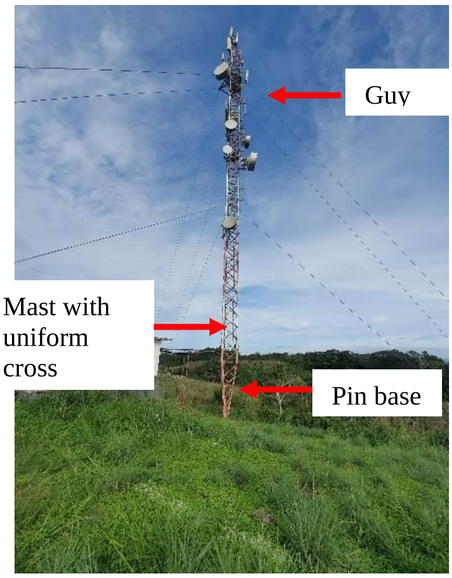

Figure 2: Triangular base, 45 m high – Guyed mast

Monopoles are single cantilevered poles significantly differed from guyed masts and ground-based towers. The moments induced from lateral loads are resisted by the cross section of the pole. Monopoles demand less footprint, easy for construction and have better aesthetic appeal. Camouflage monopoles as shown in Figure 3 can be used in environmentally sensitive areas. Commonly, cantilever poles consume more material to provide required lateral stiffness compared to the ground-based towers.

Based on the general comparison criteria (Aesthetical, Economical, and Structural Considerations) it is obvious that the monopole can be a strong competitor, particularly from a visual perspective while ground based tower earned a significant attention in terms of cost (economical) and structural considerations (Azhar AM & Inam JH, 2018). Monopoles significantly outperform ground-based towers in some aspects. They are more reliable under extreme conditions since they are made with circular hollow sections (CHS). As they have only few components, installations is easy and faster. In addition, they required lesser footprint. Considering all these aspects, it is not possible to conclude mono poles are better options. Because Guyed masts can make a strong impact in cost consideration. Here's something to keep in mind, general statements do not always result in a better solution. A detailed investigation has to be carried out to come up with an optimum solution.

Figure 3: 40 m high - Camouflage monopole

This paper discusses the performance of each tower types with respect to different project constrains such as cost, land usage, material usage, structural performance, and constructability. In addition, the effects of bracing patterns of rectangular based free-standing towers are studied. Trend in variation of different design constrains are predicted based on data collected from existing towers will be useful in the conceptual design.

2. Design Consideration

In this section various key factors to be considered in design of telecommunication structures are discussed. The design of telecommunication towers is governed by lateral wind loads. Thus, estimation of precise wind loading and analysis of the structure against lateral wind load to obtain internal forces and deformations is an important task. Calculation of wind loads through wind pressure gradient are defined in different design codes. The chosen codes must be used with the appropriate wind speed, partial safety factors, and load factors.

2.1 Design codes and standards

There are different design codes and standards available for the design of telecommunication structures. The most often used codes are AS 3995, AS 4100, EIA-222-F, TIA-222-G, ASCE 10-90, ASCE 10-97, BS8100 Part 3, BS449, BS 5950, and IS 802. In Accordance with Telecommunications Regulatory Commission of Sri Lanka (TRCSL), ANSI/TIA-222-G-2005: Structural Standard for Antenna Supporting Structures and Antennas published by Telecommunications Industry Association in August 2005 is used as the primary standard for the analysis and design.

2.2 Loadings

Dead Load

Self-weight of the structural members and nonstructural components such as ladder, platforms and fixers were considered based on the material unit weights. Another major contributor to the dead load is cellular antenna. Global system for mobile (GSM) antenna/ panel antenna, Microwave (MW disc) antenna, Active antenna unit (AAU) and Remote radio unit (RRU) are some most common types of cellular antennas. Loading from these antennas are taken into the analysis as per the client's requirement.

Wind load

In general, moving air is referred as wind. When this wind hit by a surface, it's dynamic energy is converted to pressure. Then this surface's applied pressure transforms to a force. That is the lateral load acting on the structure due to wind. In general practice, the approximate wind profile is developed to carryout calculations to find out this lateral force. Power law and Logarithmic law are the commonly used methods to describe wind profile (Emeis S & Turk M, 2007).

As per ANSI/TIA-222-G-2005 design code following equation derived from power law is used to define velocity pressure coefficient (K_z),

$$K_z = 2.01\left(\frac{z}{z_g}\right)^{\frac{2}{\alpha}} \text{------------ (1)}$$

where,

Z = height above ground level at the base of the structure

Zg, α and are parameters depend on exposure category.

velocity pressure (q_z) shall be determined as follows:

$$q_z = 0.613 K_z K_{zt} K_d V^2 I \text{----------(2)}$$

where,

K_z = velocity pressure coefficient
K_{zt} = topographic factor
K_d = wind direction probability factor
V = the basic wind speed [m/s]
I = importance factor

Generally, in the design of telecommunication structures, wind loading is calculated in every 30 degree approaching wind angles based on the following parameters (ANSI/TIA-222-G-2005).

- Basic wind speed
- Topographic Category
- Exposure Category
- Structure Class

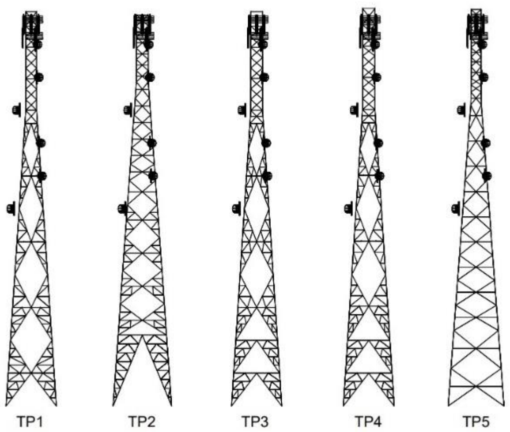

Figure 4: Different bracing system considered for 60 m high – Rectangular ground-based tower

2.3 Load Combinations

Following load combinations are considered for the Ultimate and serviceability limit state design checks (ANSI/TIA-222-G-2005).

- 1.2 Dead Load + 1.6 Wind Load
- 1.0 Dead Load + 1.0 Wind Load

2.4 Limitations

- The deformations under service loads at any location on a structure shall not exceed the following:
- A rotation of 4 degrees about the vertical axis (twist) or any horizontal axis (sway) of the structure.
- A horizontal displacement of 5% of the height of the structure.
- For cantilevered tubular or latticed spines, poles or similar structures mounted on latticed structures, a relative horizontal displacement of 1% of the cantilever height measured between the tip of the cantilever and its base.

3. Procedure

In this study data collected from 31 telecommunication towers with different structural forms were compared to investigate the impact of different design constrains in the selection of a most suitable structural form for a project based on site specific requirements. Twelve number of ground-based towers with rectangular base, seven number of triangular base towers, six number of monopoles and six number of guy masts with heights ranging from 9 m to 120 m were used in this study.

Impact of different structural forms (ground base, monopole & guy mast) in the material usage (steel weight), required base width, land usage (footprint) and cost variation were compared for different heights of the structure. Further, the base shear for different structural forms were compared to assess the windward area of each structural form attracting the wind load. Here, antenna loadings and wind parameters were kept constants for all cases.

In addition, the effect of bracing types on structural performance were checked for selected 5 bracing configurations of rectangular based four leg towers. In this study following bracing topologies were considered,

Analytical models of the towers were developed using the special purpose program called “MS Tower”. A basic wind speed of 33 m/s is used for the analysis. Utility ratio, deflections, base shear, and weight of each case were extracted from the analysis model.

4. Results and Discussions

The material usage in a structure indicates the efficiency of a structural form and determines its sustainability. Figure 5 shows the steel usage of different structural forms considered. As expected, the guy masts consume less material for all the heights considered. In ground-based towers triangular based towers are lighter than the rectangular based towers. However, due to the limitation on structural performance mostly rectangular based towers were preferred beyond 70 m height. Interestingly, for the loadings considered steel usage of the monopole structure was lesser than the rectangular based structure up to 20 m height.

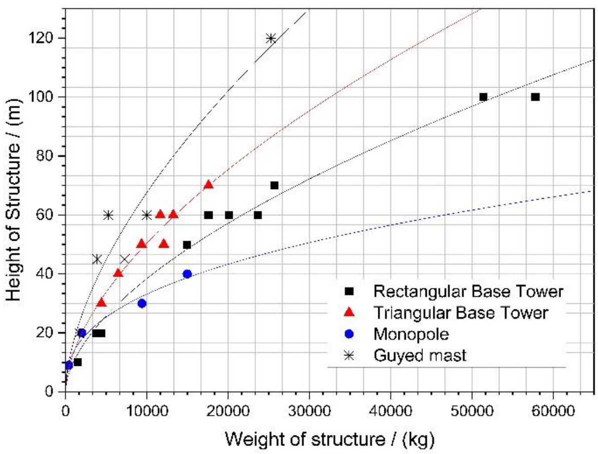

Figure 5: Variation of weight with height of structure

Land usage is an important constraint that determines the type of structural form to be used for the telecommunication structure. The extent of land availability is not only a challenging factor in urban cities but also it is a critical factor in hilly terrains and forest reservations where significant number of newly prosed expansions are located. Figure 6 presents the variation of land usage for different structural forms with the height. The extent of land usage is calculated considering the total land area required for construction of the telecommunication structure including the foundation and guy cable anchorage blocks. The guy masts require a larger area for all the heights considered. This limits the usage of guy masts in many cases although it is the most economical structural form. The monopoles utilize less space compared to all other structural forms for all the cases considered. Thus, monopoles are used to overcome the space restrictions. However, the available data for monopoles is only up to 40 m height. Due to the increased cost and limitations on structural performance monopoles beyond 40 m heights are not often.

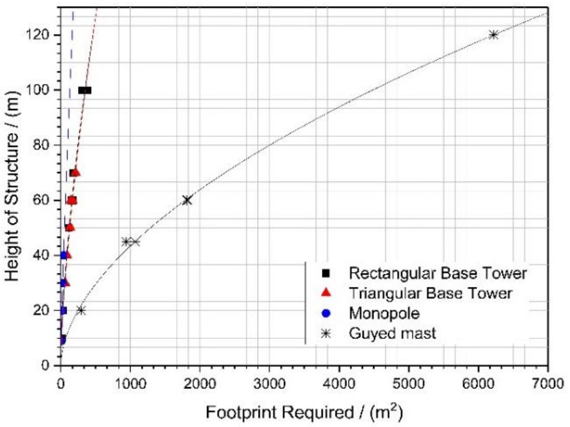

Figure 6: Variation of footprint with height of structure

Cost for the infrastructure is a significant component of capital investment for the telecommunication service provider. Thus, the developer prefers to adopt a structural form with minimum cost. However, in the design of telecommunication structures along with the cost for the infrastructure land usage is also critically checked to overcome the space limitation and minimize the recurrent expense on rental for the land. Total structural cost is presented in Figure 7. Guy masts are the cheapest solution for all heights considered. Rectangular based towers are found to be more expensive up to around 20 m height, and beyond 20 m cost for the monopole structures exceeds the four leg towers. Next to the guy masts, triangular based towers are most found to be most economical form for height ranging from 20 m to 70 m for the loading considered. Monopole structures will be more economical for structures up to around 20 m height under the loading considered. The total infrastructure cost consists of foundation cost plus the superstructure cost. The proportion of foundation to superstructure cost of all the 31 cases considered are presented in Figure 8 – 11.

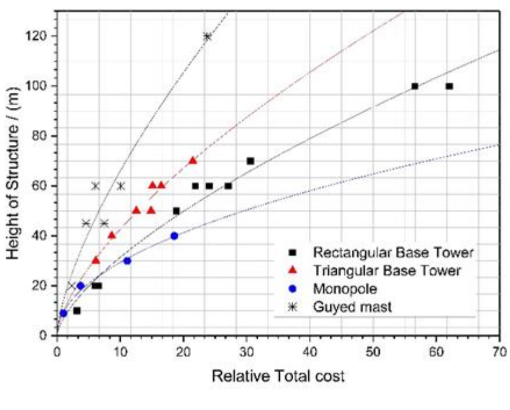

Figure 7: Variation of relative cost with height of structure

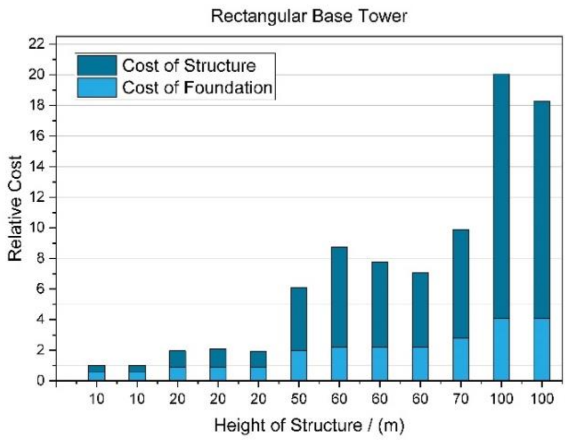

Figure 8: Variation of relative cost with height for rectangular base towers

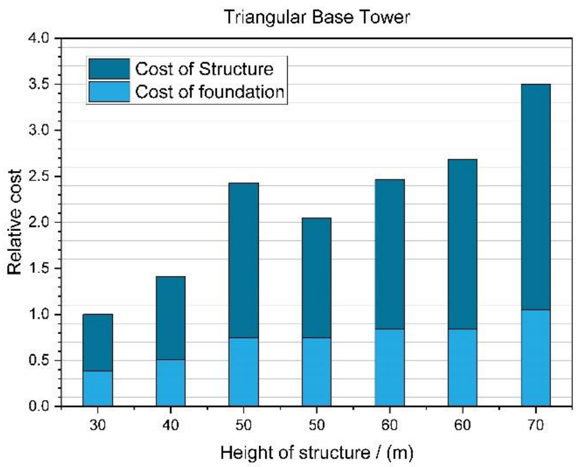

Figure 9: Variation of relative cost with height for Triangular based towers considered.

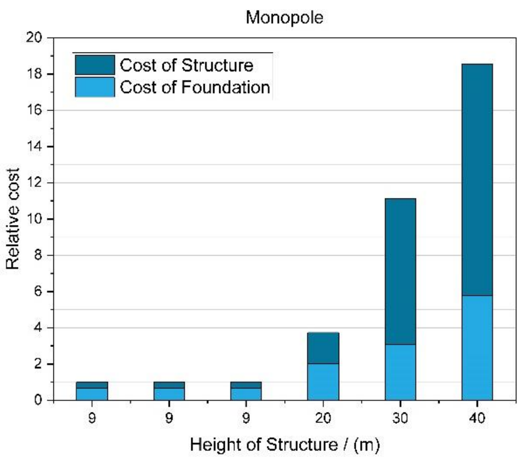

Figure 10: Variation of relative cost with height for monopoles considered.

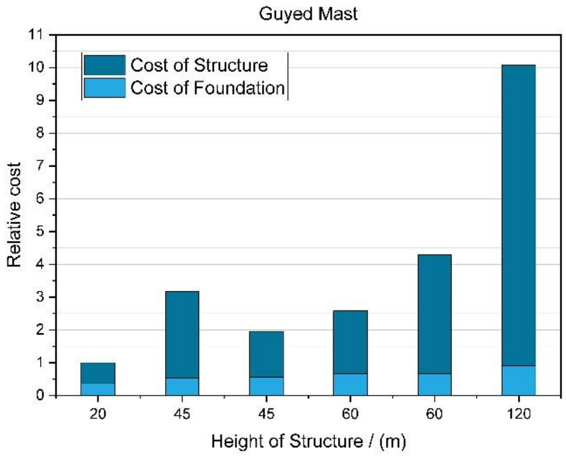

Figure 11: Variation of relative cost with height for guyed masts considered.

In ground-based towers selection of an optimum base width considering the structural performance and the economy is a crucial task. Figure 12 presents the variation of base widths used in rectangular towers considered in this study. This information will be useful for the selection of base width during the conceptual design stages.

Variation of base shear of different structural forms for the similar approaching wind characteristics is presented in Figure 13. This variation indicates that monopoles experience less wind loads up to 30 m height due to the less effective surface area. However, in the 30 m – 40 m range because of increasing the section size of monopoles attracts more wind loads compared to guy masts and triangular base towers. Four leg towers experience higher structural wind loads due to the larger exposed areas of structural elements.

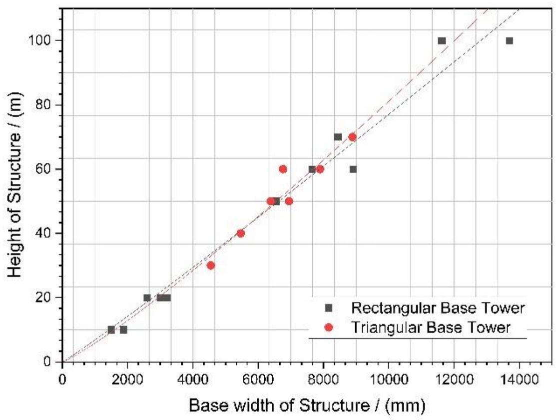

Figure 12: Variation of base width with height of structure

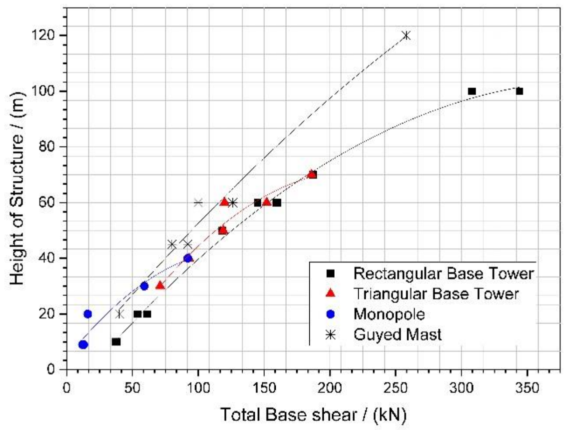

Figure 13: Variation of base shear with height of structure

The results from the comparison of five different bracing configurations (TP 1- TP 5) for a 60 m four leg tower are presented in Figure 14 to 17. The comparison of material usage presented in Figure 14 illustrates that, X bracing arrangement with internal redundant members (TP 1) consume less material than the X bracing without redundant members (TP 5). Further maximum utilization ratio of the critical member with this bracing configuration (TP 1) is lesser than that of TP 5 as per Figure 16. However, the configuration TP 1 is more flexible with less lateral stiffness resulting in larger deformation. Although the K braces combined at the lower portion of a tower with X braces are relatively heavier, reduce lateral deformation and minimize the stress ratio in the members. Using these comparisons presented relatively stiffer configuration can be chosen for heavily loaded towers in higher wind zones whereas the towers with minimum weights can be used for lightly loaded towers.

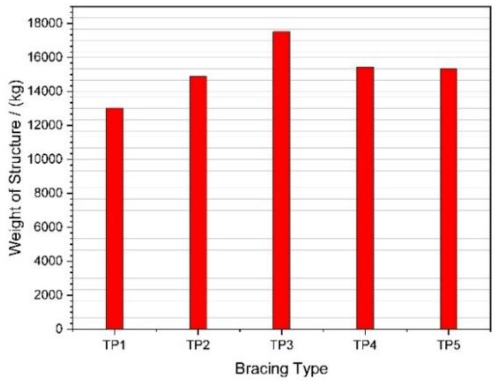

Figure 14: Variation of steel usage with topology

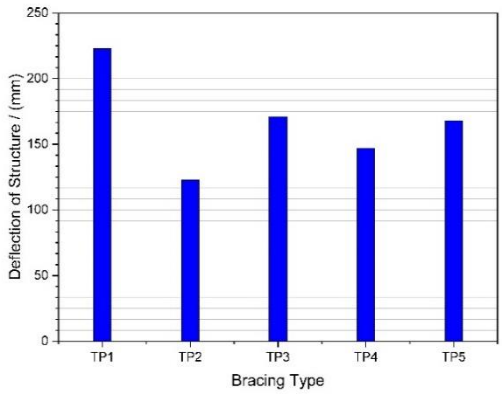

Figure 15: Variation of deflection with topology

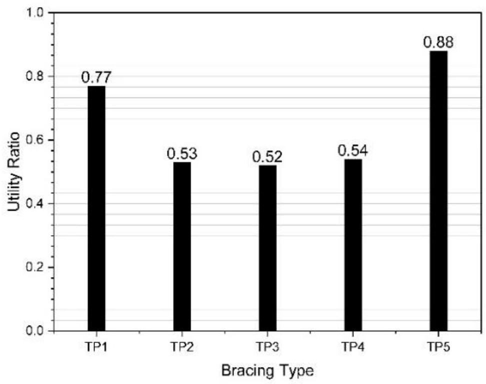

Figure 16: Variation of utility ratio with topology

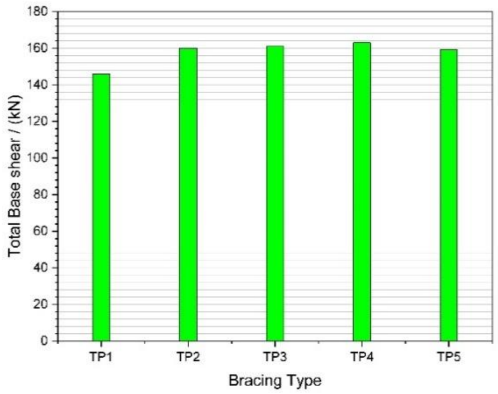

Figure 17: Variation of base shear with topology

5. Conclusions

This study presented the comparison of different structural forms of telecommunication structures such as ground based towers, guy masts and monopoles based on the data obtained from 31 projects implemented in Sri Lanka. The material consumption, land usage, cost, base width, exposed area for wind loading and structural performance were compared for heights ranging from 9 m to 120 m. Further, the comparison of five different commonly used bracing configurations for four leg ground-based tower is presented. Based on this comparison, the following generalized observations can be made under the loading scenario considered.

- Guy masts are the most economical structural form as expected if land usage is not restricted. The approximate extent of land usage with height can be predicted using the given plots.
- Monopoles may be a more feasible structural form for shorter telecommunication structures (less than 20 m) considering all constraints such as space required, cost, wind exposed area and material consumption.
- Triangular based towers are most economical for heights ranging from 20 m to 70 m. However, beyond 70 m mostly rectangular based towers are used.
- Monopoles up to 40 m utilize minimum land space compared to all other structural forms.
- An optimum base width for ground-based towers is proposed based on the available data.
- Along with the redundant X – bracings combined with K-bracing at the lower portion of the rectangular based towers are heavier and capable to resist higher level of loading.
- Introducing redundant members for rectangular based structures with X – bracing will assist in reducing the material usage and improve structural performance.

The results presented in this paper in the form of graphs will be useful for designers in the selection of suitable structural form based on the project specific priorities and constraints.

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