ANALYSIS AND DESIGN OF TELECOMMUNICATION TOWERS FOR EARTHQUAKE LOADING IN SRI LANKA FOR SUSTAINABILITY

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Abstract

Large number of telecommunication towers has been constructed in Sri Lanka during last few decades with the rapid development of telecommunication sector in the country. These towers play a significant role especially in wireless communication and failure of such tower in a disaster like an earthquake is major concern mainly in two ways. One is the failure of communication facilities will become a major setback to carry out rescue operations during disaster while failure of tower will itself cause a considerable economic loss as well as damages to human life in most of the cases. Therefore, design of telecommunication towers considering all possible extreme conditions is of utmost importance and a good design can be considered as a step towards a greater degree of sustainability.

However, almost all telecommunication towers in this country have not been checked for earthquake loading since most of people believe that earthquake threats are not that much of significance to Sri Lanka until recently. With many tremors recorded in recent past, designers have started to rethink about earthquake design of structures and main objective of this research is assessing the performance of exiting towers (which were not initially designed considering earthquake loading) under possible earthquake loading and find cost effective strategies for retrofitting in case such action has to be effected.

Accordingly, behaviour of existing four legged Greenfield towers under seismic loadings appropriate for Sri Lankan conditions were analyzed using equivalent static load method given in ANSI/TIA-222-G. This can be considered as an initiative in this research area under local conditions. Results and conclusions based on this analysis are discussed in this paper.

Key words: Telecommunication towers, earthquake loading

1. Introduction

Telecommunication towers has became an essential item especially in wireless telecommunication sector with the development of wireless telecommunication technologies such as CDMA (Code Division Multiple Access), GSM (Global System for Mobile),WAP (wireless Web Access), etc. In Sri Lankan context, most of telecommunication towers have been constructed with the introduction of mobile telephone networks in early 1990s, even though there are few towers which have histories over 30 years.

More than thousand telecommunication towers with various structural forms are available in this country and almost all of these towers have been design only considering wind loading, since Sri Lanka was considered as a country free from earthquakes until recently. However, with recent recorded tremors in the range of 3 to 4 in Richter scale, the probability of occurrence of earthquakes in the country is highlighted and design of buildings and other structures considering seismic effects is also emphasized.

With these developments, most of the structural engineers in the country started to incorporate seismic effects for their designs especially in building construction sector. But, for the designs of telecommunication towers, seismic effects are not considered by the designers yet. Hence, a comprehensive study in this regard is very important to ensure the safety of these towers during possible earthquakes in future in terms of sustainable development.

A failure of a telecommunication tower especially during a disaster is a major concern in two ways. Failure of telecommunication systems due to collapse of a tower in a disaster situation causes a major setback for rescue and other essential operations. Also, a failure of tower will itself cause a considerable economic loss as well as possible damages to human lives. Hence, analysis of telecommunication towers considering all possible extreme conditions is of utmost importance.

The main objective of this research is assessing the performance of exiting towers (which were not initially designed considering earthquake loading) under possible earthquake loading and finding of cost effective strategies for retrofitting in case such action has to be effected.

However, various types of telecommunication towers with different structural forms are available in the country and this study has been limited to analysis of four legged Greenfield self supporting lattice towers, which are the most common type of telecommunication towers in this country.

In world context, various researches have been carried out regarding the behavior of telecommunication towers under earthquake loadings and most of the Code of Practices such as ANSI/TIA-222-G [1] , AS 3995-94 [2] used for tower designs have also incorporated guidelines for analysis of towers under seismic loading. However, those data would not be directly applicable for Sri Lankan context since local seismic conditions could be different from other countries .

1. Methodology

Seismic effect on four legged Greenfield self supporting lattice towers were considered for this analysis. Three towers having different tower heights of 30m, 50m and 80m were selected for this analysis as most of the Green field telecommunication towers of Sri Lanka are within this height range from 30m to 80m. All of these towers had been designed for wind speed of 50 m/s (180km/h) , which is the recommended design wind speed for Zone 1 Normal structures condition.

ANSI/TIA-222-G-2005 [1] Structural Standard for Antenna Supporting Structures and Antennas, which is highly appreciated and very commonly used code of practice by both local and foreign tower designers for their designs, was used for the structural analysis and design of towers under both wind and seismic loadings.

3D computer models for each tower were prepared using SAP2000 structural analysis software and analysis of towers under both wind an earthquake loads were carried out using such models. Finally, the results of analyses under wind and earthquake loads were compared.

Designs of the towers were verified for design wind speed of 50m/s using computer analysis results as the first step. Towers were also analyzed for the wind speed of 33.5m/s (recommended design wind speed for Zone 3 Normal structures condition for Sri Lanka), which is the lowest allowable design wind speed that can be used for structural design in Sri Lanka, for the purpose of comparison of results.

For analysis of towers under earthquake loading, equivalent static methods given in ANSI/TIA-222-G-2005 [1] were used. Appropriate seismic loads for Sri Lanka was selected as described in section 3.2. Seismic loads were also calculated under very severe and severe seismic conditions as well for the purpose comparison.

2. Loading

2.1 Wind loads

Calculation of wind loads on towers were carried out according to ANSI/TIA-222-G-2005[1] for the design wind speed of 50m/s (180km/h) , which is the recommended design wind speed for Zone 1 Normal structures condition. Wind loads were also calculated for the wind speed of 33.5m/s (recommended design wind speed for Zone 3 Normal structures condition for Sri Lanka), which is the lowest allowable design wind speed that can be used for structural design in Sri Lanka, for the purpose of comparison of results.

2.2 Seismic loads

For the calculation of seismic loads on towers, four methods are given in the ANSI/TIA-222-G[1]. Those methods are;

1. Equivalent lateral force procedure
2. Equivalent Model analysis procedure

3. Model analysis procedure
4. Time history analysis

The first two methods of the above are equivalent static methods and the other two are response spectrum and time history analysis procedures. The equivalent static methods have been used in this study. For the selection of appropriate equivalent static method for an analysis, criteria has been given in the ANSI/TIA-222-G[1] and accordingly for the 30m tower, method 1 was selected, while method 2 was selected for 50m and 80m towers.

Calculation of equivalent static load for 30m tower

The following equation is given in ANSI/TIA-222-G [1] to calculate total seismic shear V_s under method1 and it was used for the calculation of earthquake loading of 30m tower.

$$V_s = \frac{S_{DS}\, W\, I}{R} \qquad \textbf{Equation 1}$$

However, for ground towers V_s need not be greater than

$$V_s = \frac{f_1 S_{D1}\, W\, I}{R} \qquad \textbf{Equation 2}$$

And V_s shall not be less than

$$V_s = \frac{0.5 S_1\, W\, I}{R} \quad \text{when } S_1 \text{eaqual or exceed 0.75} \qquad \textbf{Equation 3}$$

$$V_s = 0.044 S_{DS} WI \quad \text{when } S_1 \text{ less than 0.75} \qquad \textbf{Equation 4}$$

Also,

$$S_{DS} = 2/3\ S_S$$

$$S_{D1} = 2/3\ S_1$$

Where;

S_{DS} - Design spectral response acceleration at short period
S_{D1} - Design spectral response acceleration at period of 1.0 second
S_1 - Maximum considered earthquake spectral response acceleration at 1.0 second
S_s - Maximum considered earthquake spectral response acceleration at short period
f_1 - Fundamental frequency of the structure
W - Total weight of structure including appurtenances
I - Importance factor
R - Response modification coefficient equal to 3.0 for lattice self supporting structures
V_s - Total seismic shear

Hence, for the calculation of seismic shear, S_{DS} and S_1 have to be decided and these values are related to recommended seismic accelerations for the regions.

Recommended seismic acceleration parameters are not locally available, since code of practice for seismic design is not available in Sri Lanka yet. Hence, these values had to be obtained from other foreign sources and previous local studies done in this regards. However, these values for other countries have not been given in ANSI/TIA-222-G [1] and hence, US Geological Survey (USGS) website (www.usgs.gov) [12] was referred as the initial step to find relevant values. The recommended S_S and S_1 values for Sri Lanka in it are 0.03 and 0.01 respectively. Also , as per the research done by Peiris,2008 [11], Peak Ground Acceleration at rock sites for a10% probability of exceedance in 50 year or 475year return period is around 0.026g and this is quite match with recommended value given in www.usgs.gov [12].But, researchers who previously carried out seismic designs for buildings in Sri Lanka had gone for higher values considering lack of earthquake data regarding pattern of loading, etc for Sri Lanka (In the study on Performance of Tall Buildings with and without Transfer Plate under Earthquake loading done by Jayasinghe M. T. R. , Hettiarachchi D.S. , Gunawardena D. S. R. T. N. (2012) [9] had used seismic acceleration in the range of 0.10g to 0.15g in their study). Accordingly, S_s and S_1 were selected as 0.35 and 0.08 assuming moderate damage condition (Initially, S_s and S_1 were selected as 0.3 and 0.05 respectively and those were modified considering site specific geotechnical condition as Site Class " C" , since towers are constructed in hard soil conditions in most of the instances). These values are conservative and appropriate figures to use for seismic design in Sri Lanka, since Sri Lanka is a country where it is possible to expect intraplate type of earthquakes.

Also, base shears were calculated for condition of $S_s = 2.14$ and $S_1 = 0.86$ (which are the values recommended for Nepal by USGS, which has very high seismicity ,) and for condition of $S_s = 1.22$ and $S_1 = 0.49$ (which are the values recommended for Pakistan, by USGS which has high seismicity) to consider very severe and severe seismicity conditions respectively for comparison purpose.

For the calculation of fundamental natural frequency of a tower, a formula has been given in ANSI/TIA-222-G [1]. However, to obtain better accuracy, natural frequencies were obtained from the modal analysis performed using SAP 2000 model and calculated fundamental natural frequency is 3.21Hz for 30m tower. The vertical distribution of seismic force was done according to following formula given in ANSI/TIA-222-G[1].

$$F_{sz} = \frac{W_z h_z^{ke}}{\sum W_i h_i^{ke}} \qquad \textbf{Equation 5}$$

Where;

F_{sz} = Lateral seismic force at level Z
W_z = Portion of total gravity load assigned to level under consideration
W_i = Portion of total gravity load assigned to level i
h_z = Height from the base of the structure to level under consideration
h_i = Height from the base of the structure to level i
ke = seismic force distribution exponent (taken as 2.0)

Calculation of equivalent static load for 50m and 80m towers

The formula given under equivalent model analysis procedure (method 2) is as follows;

$$F_{sz} = \frac{S_{az} W_z I}{R} \qquad \textbf{Equation 6}$$

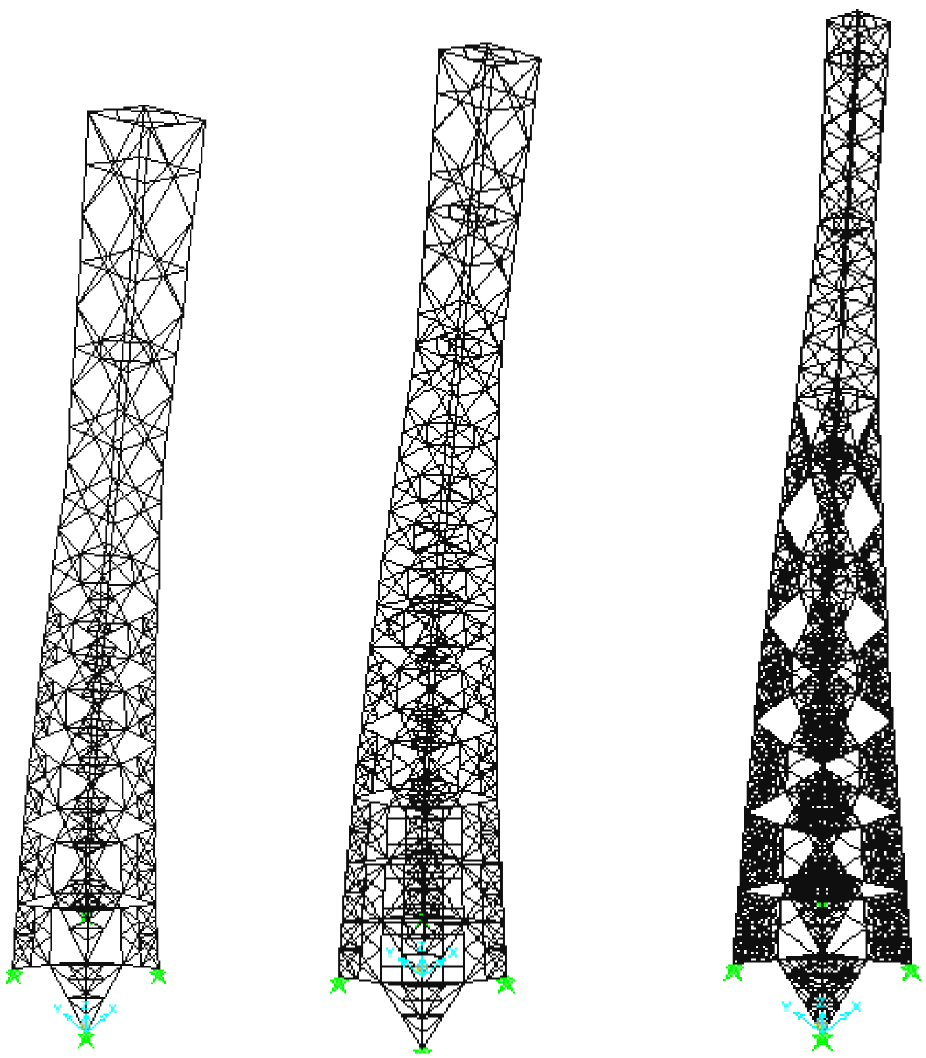
Where;

F_{sz} = Lateral seismic force at level under consideration
S_{az} = Acceleration coefficient at height z

$$= \frac{a\,(S_A)^2 + b\,(S_{DS})^2}{\{(S_A)^2 + c\,(S_{DS})^2\}^{1/2}}$$ **Equation 7**

a,b,c = Acceleration coefficients
S_A = $S_{D1}f_1$ when $f_1 <= S_{DS}/S_{D1}$, otherwise $S_A = S_{DS}$
f_1 = fundamental frequency of structure
S_{DS} = Design spectral response acceleration at short period
S_{D1} = Design spectral response acceleration at period of 1.0 second
W_z = Portion of gravity load assigned to level under consideration
I = Importance factor

The fundamental frequencies (2.7Hz for 50m tower and 1.37Hz for 80m tower) of respective towers were obtained from modal analysis of SAP2000 models and equivalent static loads were calculated for same three different conditions described under 30m tower case for comparison purpose.



30m tower
Frequency of
1st mode =3.21Hz

50m tower
Frequency of
1st mode =3.21Hz

80m tower
Frequency of
1st mode =1.37Hz

Figure 1 – Tower models

3. Three Dimensional Modeling

As mentioned earlier, 3D finite element truss models were prepared for all three (30m, 50m and 80m) towers. All structural members of these towers were defined as standard "L" angel members and Grade of steel of leg members were considered as S355 and all other members as S275 as in actual towers.

Each of the towers was subdivided to panels according to geometries of towers and wind and earthquake loads were separately calculated for each panel. The calculated wind and earthquake loads were for each panel were assigned as nodal loads for respective tower models.

Since maximum support reactions and stresses in leg members are developed when lateral loads are applied along a diagonal of the plan of a tower, both wind and seismic loads are applied along a diagonal direction. As per ANSI/TIA-222-G[1] specifications, following load cases given in Table 1 were considered in this study.

Results of the modal analysis of respective towers were used to calculate equivalent static loads under earthquake loading.

Load case	Case Name	Partial safety factors			Remarks
		Dead	Wind	Earth.	
1	1.2XDead + 1.6XWind	1.2	1.6	-	Under 50m/s wind speed
2	0.9XDead + 1.6XWind	0.9	1.6	-	Under 50m/s wind speed
3	1.2XDead + 1.6XWind	1.2	1.6	-	Under 33.5m/s wind speed
4	0.9XDead + 1.6XWind	0.9	1.6	-	Under 33.5m/s wind speed
5	1.2XDead + 1.0XEarth.	1.2	-	1.0	Earthquake load under Appropriate condition for Sri Lanka
6	0.9XDead + 1.0XEarth.	0.9	-	1.0	Earthquake load under Appropriate condition for Sri Lanka
7	1.2XDead + 1.0XEarth.	1.2	-	1.0	Earthquake load under very severe seismicity condition
8	0.9XDead + 1.0XEarth.	0.9	-	1.0	Earthquake load under very severe seismicity condition Under very severe
9	1.2XDead + 1.0XEarth.	1.2	-	1.0	Earthquake load under severe seismicity condition
10	0.9XDead + 1.0XEarth.	0.9	-	1.0	Earthquake load under severe seismicity condition

Table 1- Load Cases considered for analysis

4. Analysis Results

Supports reactions, maximum axial forces in leg members and maximum horizontal deflections of each tower with respect to the load combination describe above were obtained from SAP 2000 analysis results of respective tower models.

Figure 2, 3 and 4 show the maximum uplift, downward and horizontal reactions in towers respectively. As expected, maximum uplift reactions in each and every case are observed when dead load has a factor of safety of 0.9, while maximum downward and horizontal reactions are observed when dead load has a factor of safety of 1.2.

According to results of the graphs, support reactions under assumed earthquake loading condition for Sri Lanka are very much less than the support reaction under design wind loading, even if for design wind speed of 33.5m/s. However, the gap between reaction values under wind loading and earthquake loading increases with the increase of the tower height. Accordingly, there is no uplift reaction under assumed earthquake loading condition for Sri Lanka in 50m and 80m tower cases. But, when it considers 30m tower under earthquake loading of very severe seismicity condition, tower almost reach to the design support reaction condition if it has been designed considering design wind speed 33.5m/s.

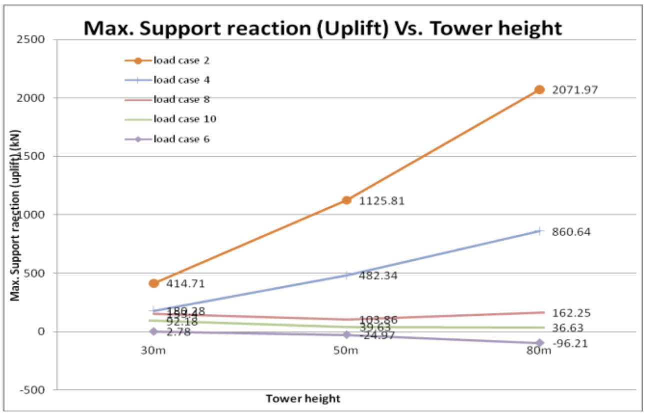


Figure 2 – Variation of Support reactions (uplift)

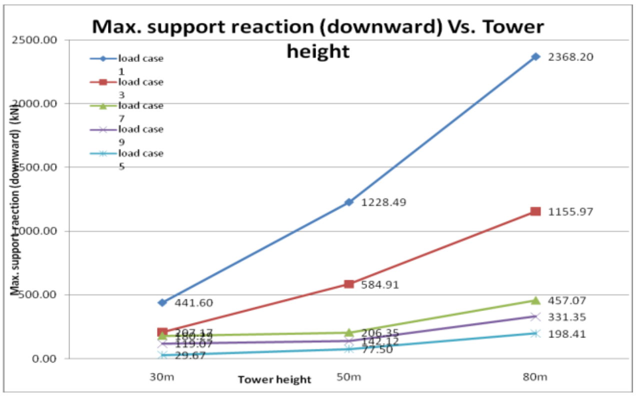


Figure 3 – Variation of Support reactions (Downward)

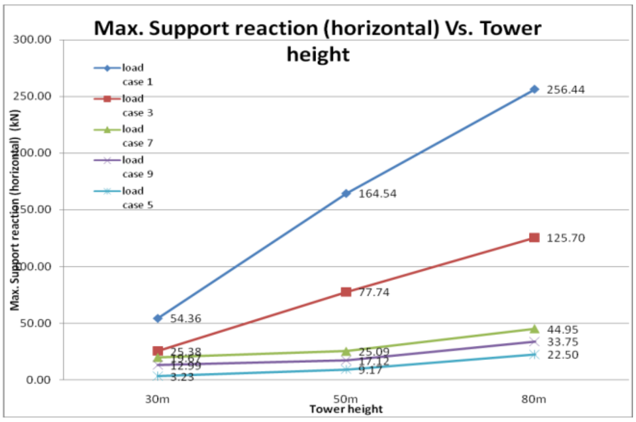


Figure 4 – Variation of Support reactions (Horizontal)

Figure 5 shows the variation of maximum ultimate deflection of towers with respect to the considred load combinations. It is also very clear that tower deflection under assumed earthquake loading condition for Sri Lanka is far below the deflection under wind loading conditions. However, earthquakes could induce higher deflections due to dynamic nature of forces.

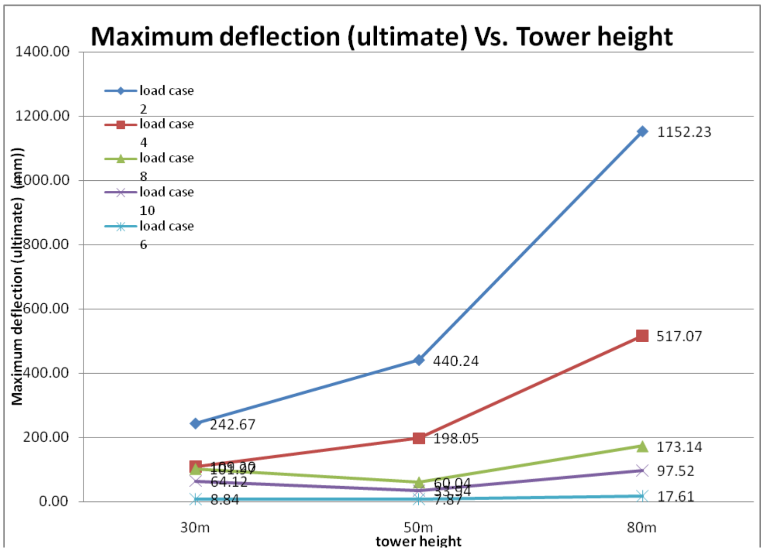


Figure 5 – variation of Maximum deflection (Ultimate)

Figure 6 and Figure 7 shows the maximum axial forces of the towers with respect to the load combination that are considered.

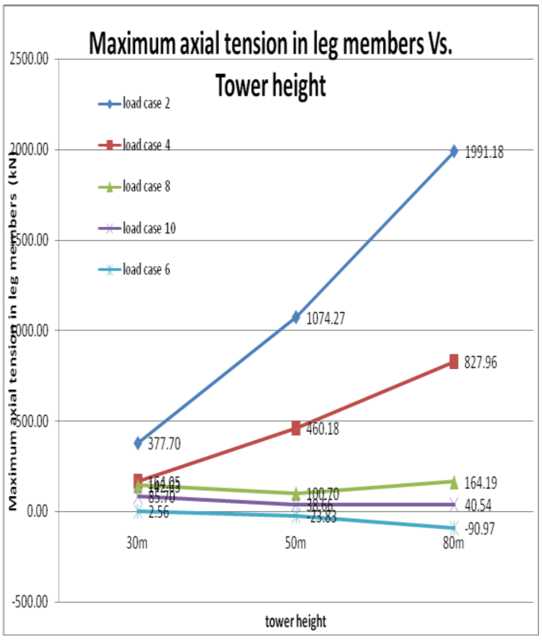


Figure 6- variation of max. Axial tension in leg members

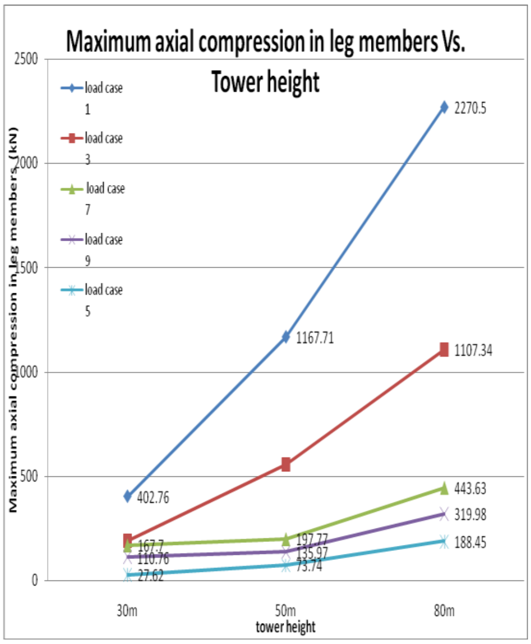


Figure 7- variation of max. Axial compression in leg members

Maximum axial forces (both compression and tension) in leg members vary in same way as in support reactions. Axial tensile stress in leg members have not been developed under assumed Sri Lankan earthquake condition in both 50m and 80m tower cases. This means the uplift force that develops due to overturning moment due to earthquake loading is less than the self weight of the tower. In other words this means, member stresses developed under assumed earthquake loading for Sri Lanka is insignificant compared with member stresses under design wind load condition of towers. However, under earthquake loading calculated based on very severe seismicity condition, axial forces of leg members has almost reached the design values under 33.5m/s wind load.

The results obtained from this study match with the results of previous studies carried out in other countries in this regard. A research carried out by Amiri and Boostan in 2002[6] regarding telecommunication towers in Iran has observed a similar behavior where design forces/reactions under wind loads is always dominant with respect to earthquake loading and difference between magnitude of forces/reaction under wind load and seismic loading are increasing when height of the tower is increased. Also, ANSI/TIA-222-G-2005[1] in itself has specified that analysis under earthquake loading for normal towers are not required if S_s is less than or equal to 1.00. This has also been proved by this analysis.

The better performance of the telecommunication towers under seismic loads that is observed in this analysis has also been practically observed under actual earthquakes. According to the field report prepared on structural and geotechnical damages sustained during the 26 January 2001 M 7.9 Bhuj Earthquake in Gujarat by Department of Civil Engineering, Indian Institute of Technology, Kanpur [10] , the telecommunication tower have performed very well and no significant damages have been observed. Also, in the research by Moghtaderi-Zadeh on performance of life line systems in Bam Earthquake of 26 December 2003 in Iran[8], the good structural performance of telecommunication towers have been highlighted.

5. Conclusion

As per the objective of the this research, performance of the existing towers (which are originally not designed for earthquake loading) were analyzed considering different earthquake loading as per equivalent static method given in ANSI/TIA-222-G[1] for selected four legged green field towers.

According to findings of this study, it quite evident that four legged Green field towers in the height range from 30m to 80m will survive without any problem under minor to moderate earthquake (which is the most probable magnitude for earthquake that can occur in a country like Sri Lanka), if such towers have been properly designed for recommended design wind speed of the respective wind zones. Even under sever or very severe earthquake loading conditions, all of the above towers will behave satisfactorily, if such towers have been designed considering a designed wind speed of 50m/s.

However, under a very severe earthquake loading condition, 30m towers may have almost reached to the designed stress state if such towers have been designed considering design wind speed 33.5m/s. However, 50m and 80m tower will not subject to such situation even if such towers are designed under wind speed of 33.5m/s.

Hence, as the concluding remarks based on the results of this analysis, it can specify that the four legged Green field towers will behave without a trouble under minor to moderate earthquake if such towers are properly designed and constructed considering design wind speed of the respective zones. The shorter towers in the range of 30m only may have a possibility to be affected under severe earthquake, if such towers have been designed considering a wind speed of 33.5m/s, which is the lowest allowable design wind speed that can be used for structural design in Sri Lanka.

Also, further studies in this field are recommended with dynamic analysis procedures such as Response Spectrum and Time History Functions developed based on local conditions.

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