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Telecom Tower Loading Validation Analysis with Reverce Engineering & Provide Strengthening with FRP Solution

Abhishek Arya[1], Dr. Rambha Thakur[2]

[1,2]Department of Civil Engineering, Maharshi Dayanand University, Rohtak, India

ABSTRACT

The mobile phones have become an important part of everyday human life. Hence the number of tow- ers for transmitting and receiving communication signals has grown unprecedentedly over the years and they are to be positioned at building rooftops with the added advantage of better coverage for signals. However, the host structure should be checked for the additional loads brought in by the rooftop telecommunication towers. In the present study, seismic analysis of a low rise commercial building with towers of height 15m, 15m by varying position of towers is performed with SAP2000 software. The main objective of this paper is to give awareness on the structural behavior when the communication tower is installed on the existing structure. For this study, an existing structure G+3building is considered and analyzed with considerations of seismic loads to see the sectional deflections. The most favorable position of tower on the roof is identified by placing the tower at different positions. Stresses and axial forces in the top storey structural members and the influence of tower height on building are studied. The results are compared using Time History Analysis and Response Spectrum Analysis.

Keywords: Tower Loading Validation Analysis Checking Capacity Of Tower With Manual Calculation.

INTRODUCTION

General

The increasing trend of mobile communications has seen exponential growth in the last three years. Increased competitions among mobile operators also have contributed to the in- spallation of many towers to enhance both coverage area and network reliability. The tower locations as specified in terms of latitudes and longitudes with the height of mounted antenna dictated by functional requirements of the network. The availability of land which satisfies ideal installation conditions in urban areas is extremely limited giving no alternative but to adopt roof top towers (with marginal adjustment in position but not in height). The various bracing patterns are available but the most common brace patterns are the chevron and the x-bracing. Most of the researches mainly done on 3 legged self-supporting towers and very limited attention have been paid to the dynamic behavior of 4-legged self-supporting telecom towers.

Radio masts and towers are, typically, tall structures designed to support antennas (also known as aerials) for telecommunications and broadcasting, including television. There are two main types: guyed and self-supporting structures. They are among the tallest man-made structures.

Masts are often named after the broadcasting organizations that originally built them or currently use them. In the case of a mast they are called radiator or radiating tower, the whole mast or tower is itself the transmitting antenna. They are also known as Telecommunication towers.

A large number of lattice towers exist and are being built worldwide for telecommunication purposes. This is due to the fact that such towers are very often installed in mountainous terrain with very limited access to heavy vehicles and cranes. Accordingly, a lattice tower structural system, which can be transported and erected by light machinery and equipment, is almost the only possible solution. Theoretically, lattice towers need more ground space compared to cylindrical, octagonal or similar shell-type systems. However, ground space is plentifully available in remote places outside the densely populated regions. In conclusion, it may be argued that besides general structural engineering purposes, lattice towers are and will remain the main structural system for telecommunication towers. The members of such towers are frequently composed of equal leg angle sections that are often preferred to tubular sections due to their easier connection that results in a simpler on-site erection and easy transport, a requirement set by most telecommunication or power providers. Also, angles are not susceptible to the well-known problems, such as the appearance of cracks after hot dip galvanizing, unlike other types of open or closed cross sections. Equal angle sections are widely used today as legs or bracing members in free standing lattice towers. Angles sizes range from light to heavy sections with leg lengths up to 300 mm that are lately produced in Europe and are employed for towers with increased height. Appropriate long life corrosion protection is ensured with application of angles, since all angle sizes are fully amenable to hot dip galvanizing in contrast to several other types of open or closed sections. The tower members are entirely hot-dip-galvanized and for this purpose welding must be avoided and all connections must be done by hot-dip-galvanized bolts. Welding is allowed only for towers' footings construction, the sections of the climbing stair and the lightning arrester of the towers.

Square Lattice Towers

It works on the principle of simple pendulum. When activated at the time of earthquake, the articulated slider moves along the concave surface making the structure to move in small simple harmonic motions. The Friction pendulum bearings increase the structure's natural time period by causing the building to slide along the concave inner surface of the bearing similar to a simple pendulum. The bearings filter out the experiencing earthquake forces through the frictional interface. Bearings may be designed to hold completely different magnitudes of displacement simply by adjusting the diameter and curvature of the bearing surface.

Triangular Lattice Towers

Fig 1.3 – Cow Tower

Triangular lattice towers form an equilateral triangle shape in plan. They are composed of three legs connected at an angle of 1200 by various types of bracing systems (Figure 1.4). The legs are usually inclined from the base to the top, but for short towers they may be vertical or be inclined up to a certain height and then continue vertical. The primary bracing pattern may be either Λ-type, X-type or N-type. Primary bracing is complemented by secondary bracings in various patterns to reduce the buckling length of legs and primary bracing members. Triangular towers are torsional stiffer than square towers. However, there is a restriction in the appropriate cross sections for leg members to tubular sections that is associated to more assembly effort. Alternatively, cross sections for legs may be special angle sections, in which the angle legs are not at a 90-degree angle but at a 60- degree angle. Such cross sections require special fabrication

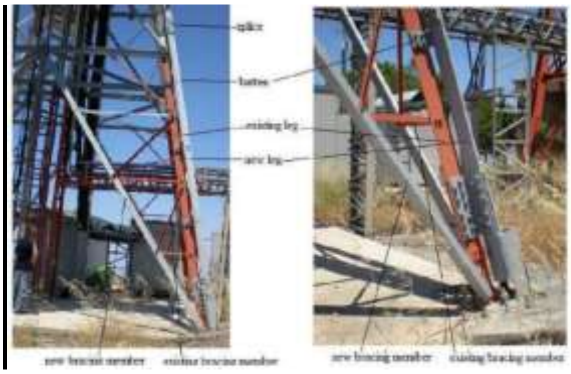
Strengthening Existing Telecommunication Lattice Towers

Severe weather conditions combining low temperatures, snow and wind are often the governing loading condition. Wet snow accumulates in the form of ice on towers and antennas, adding to gravity loads, dramatically increasing wind drag and leading to tower collapse. This is the leading cause for tower collapses in operation, that have occurred on 9 several occasions. Based on that, evaluation of old or corroded towers is necessary to be executed in order to verify their bearing capacity. In addition, code provisions have been evolved significantly and it is proved that latest provisions, especially those regarding calculation of wind and snow loading, are unfavorable and more conservative than the older ones that were used for the design of telecommunication towers during previous decades. This means that the evaluation of existing old towers following the latest provisions would probably lead to the necessity of strengthening these towers.

Failure of Telecommunication Towers: Telecommunication towers constitute a special case due to the fact that wind loading frequently varies during their design life due to modifications, like the provision of more and larger antennas, so that gravity and especially wind loading increase. The communication industries have seen a trem
Fig 1.4 – failure due to snow fall.

Endous development in last years which has resulted in new technologies. Future market needs indicate that more and quite larger triple band and parabolic antennas need to be placed on existing towers in order to fulfil new technology (5G) requirements and enhance the coverage area and network consistency. This may result also in a requirement for strengthening the structure of the tower in order to bear all the extra and future loads.

Conventional strengthening method: In the current practice, replacing the leg member with a larger angle is not feasible, thus, a second angle is usually inserted and connected with the existing section to form a built-up member. For ease of erection, a star battened configuration may be used, where the two angles are connected by pairs of battens in two perpendicular planes. (Figure 1.8). Braces are either strengthened in the same manner or the old section may be replaced by a larger angle section.



Although this is the only feasible solution since it intervenes from outside the existing structure, this is not the best one from the structural point of view due to the fact that it increases the structural weight and the area swept by the wind, and therefore the wind forces. In addition, it results in a fixed degree of strengthening, independent on how much is required due to the application of the same angle profile as the existing one **Damping function:** Provides required amount of damping necessary. LRB mainly are of two shapes. One is conventional round and the other type is square.

Strengthening Using FRP Plates

As an alternative to the previous conventional strengthening method, this thesis introduces a hybrid strengthening solution by which the tower members, whether legs or braces, are strengthened by fiber reinforced polymers (FRP) plates. The hybrid solution is expected to 11 be most advantageous from the structural and constructional point of view due to the combination of the following: a) negligible increase of the reference wind area and therefore of the wind forces, b) no increase of structural self-weight, c) no need for exchange of brace profiles, d) adjustment and fine tuning of the extent of strengthening to the design needs e) great strength to corrosion and fatigue. Although, the application of FRP strips is very common for rehabilitation and strengthening concrete structures, little research effort has been made internationally to strengthening of steel profiles with FRPs up to the present. It is therefore not surprising that, in contrast to reinforced concrete, practical applications for FRP-interventions in steel profiles are rather scarce and there exist no Codes or Recommendations at present at European level apart from a design guide [6]. Until now, FRP strips are usually used instead of FRP plates in steel structures and are applied mainly on strengthening steel pipes, bridges, trusses and transmission towers as shown in Figure 1.9. Using FRPs to enlarge the bending and compression capacity of steel sections was studied in [8]- [13]. Also, strengthening of angle section columns with FRPs was studied by a limited number of experiments at the Institute of Steel Structures, NTUA, [7]. (Figure 1.10).

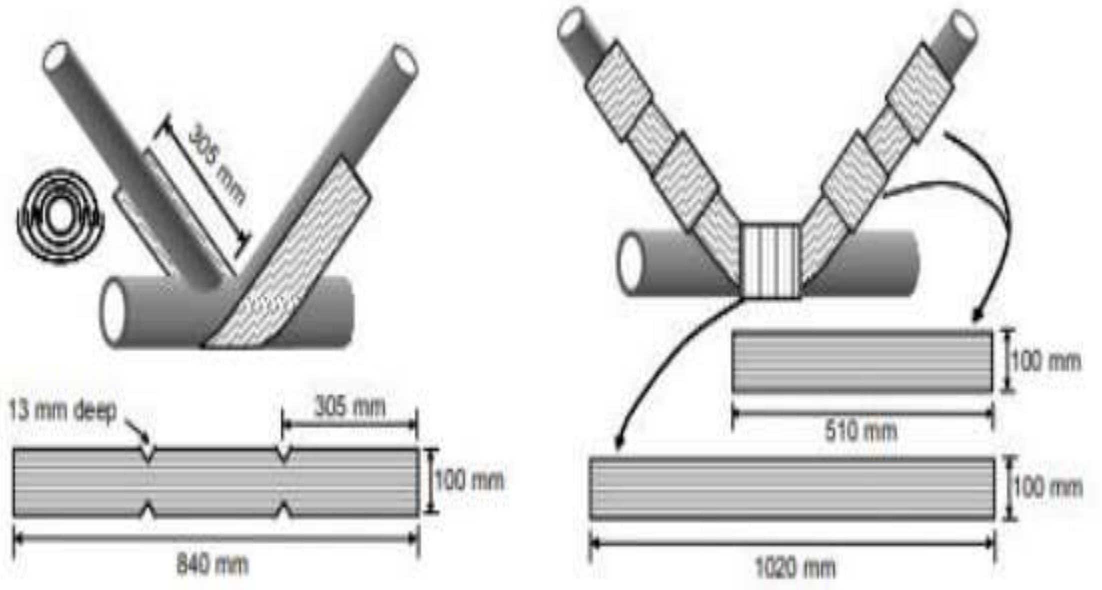


Fig-Fiber Reinforced Polymer Material

Composite Material

A Composite in engineering sense is any materials that have been physically assembled to form one single bulk without physical blending to foam a homogeneous material. The resulting material would still have components identifiable as the constituent of the different materials. One of the advantages of composite is that two or more materials could be combined to take advantage of the good characteristics of each of the materials. Usually, composite materials will consist of two separate components, the matrix and the filler. The matrix is the component that holds the filler together to form the bulk of the material. It usually consists of various epoxy type polymers, but other materials may be used, plastic for example.

The filler is the material that has been impregnated in the matrix to lend its advantage (usually strength) to the composite. The fillers can be of any material such as carbon fiber, glass bead, sand, or ceramic. Fiber Reinforced Polymer Composites, or FRP Composites in short, are lightweight, strong materials used in the manufacturing of numerous products used in our daily life. FRP Composites, is a term used to describe a fiber reinforced composite material that uses fibers as the primary structural component and thermosetting resins such as epoxy, polyester, or vinyl ester as the matrix.

FRP main advantages are: a) High tensile strength combined with its low weight. For example, a decent rule of thumb when comparing steel to CFRP composites is that a carbon fiber structure of equal strength will often weigh 1/5th that of steel b) High stiffness c) High durability and excellent fatigue properties only for wind and gravity loads.

There are two stages in the performance of an FPB, a static and a dynamic phase, distinguished by the friction in the sliding interphase. When the lateral forces acting on the structure is below the frictional d) Good adaptation to loading conditions The main disadvantages are: a) Totally brittle failure. It has no plastic behavior, so it has not the ability to absorb energy b) Anisotropic response and strength. There are many variables that could change its behavior and strength. The grade and quality of materials, the manufacturing process, fiber architecture, and the quality need to be taken into account. There are mainly three kind of fibers, Carbon, Aramid and Glass fibers. Composite materials, reinforced with carbon fiber, are different than other FRP composites using traditional materials such as fiberglass or aramid fiber. The properties of CFRP composites which are advantageous include: • Light Weight. A traditional fiberglass reinforced composite using continuous glass fiber will commonly have a larger density than a Carbon FRP composite, with the same fiber weight • Higher strength and stiffness. Not only carbon fiber composites are lighter weight, but CFRP composites are much stronger and stiffer per unit of weight. This is true when comparing carbon fiber composites to glass fiber and aramid fibers, as shown in Figure 1.11

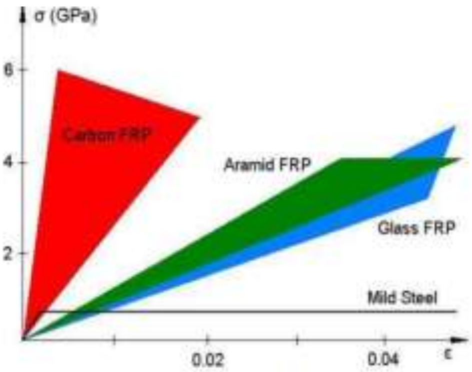


Figure 1.11: Comparison between Carbon, Aramid and Glass FRP

Fig 1.4 – Comparison between carbons. Aramid and glass FRP

Concept of Friction Pendulum Bearing

Cost. At the moment, CFRP composites are cost prohibitive in many instances. Depending on the current market conditions (supply and demand), the type of carbon fiber (aerospace vs commercial grade), and the fiber tow size, the price of carbon fiber can vary dramatically. Carbon fiber's price can be 5 to 25-times more expensive than fiberglass. This disparity is even greater when comparing steel to CFRP composites.

Conductivity. This can be both an advantage, or a disadvantage depending on the application. Carbon fiber is extremely conductive, while glass fiber is insulative. Many applications use glass fiber, and cannot use carbon fiber or metal, strictly because of the conductivity

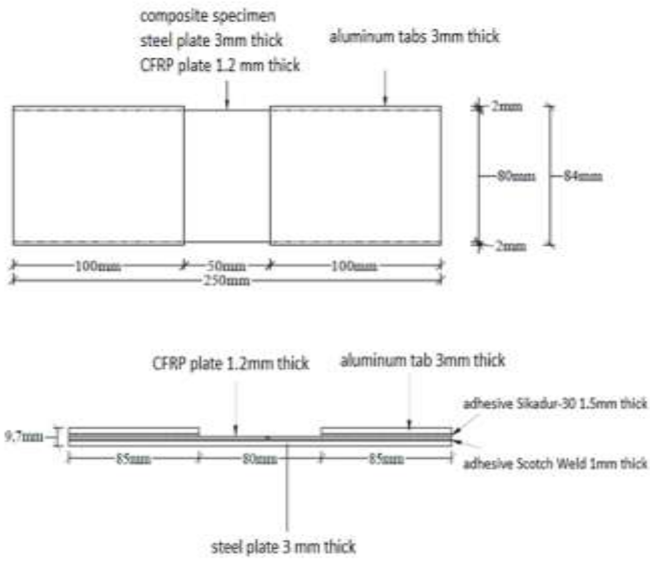


Figure 2.1: Plan and side view of the specimen

EXPERIMENTAL TESTS ON STEEL PLATES WITH CFRP STRENGTHENING

Introduction

For the best possible design of a steel structure strengthened with CFRP plates a crucial factor is the estimation of the steel section's response after application of the CFRP plate. Because both literature and experimental test on steel sections combined with CFRP plates are limited, it is needed to be executed several experimental tests on steel sections strengthened with CFRP plates. In this chapter the results of the experimental tests on steel plates strengthened with Carbon Fiber Reinforced Polymer (CFRP) plates are presented. These tests were executed in the Institute of Steel Structures at NTUA. Three composite (steel-CFRP) specimens were fabricated and were tested on three different ways. The first test was a tensile test while the other two tests were four-point bending tests. The difference between the second and the third test is that in this bending test the CFRP plate is on the tension side of the specimen while on the third test it is on the compression side. Subsequently, the fabrication of the specimens is described analytically as well as the material properties and the testing set-up. Then, the experimental results are presented and are compared with the results occurred through analytical analyses and numerical analyses that were implemented with the ABACUS finite elements software. The main information about these tests is described in “Vlachaki – Karagiannopoulou S. G. (2018). Behavior of reinfo

Modeling is carried out using **ETABS 2019**.

Structural Properties-

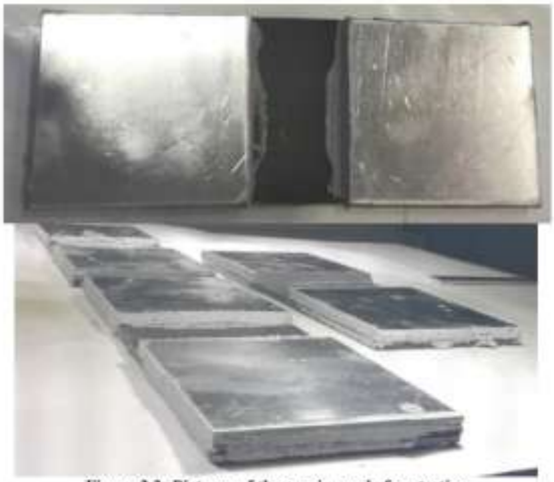
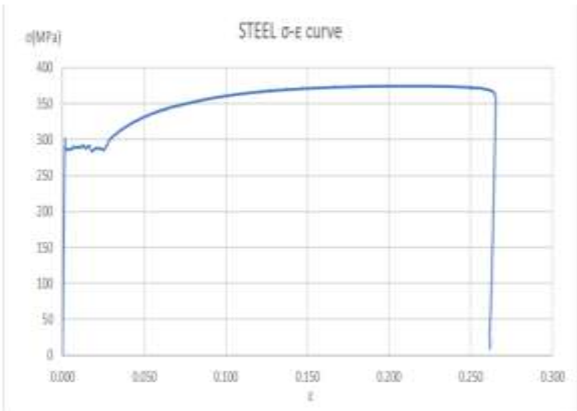


Figure 2.2: Pictures of the specimens before testing

Material

Steel Steel’s exact material properties are unknown, so they must be exacted through experimental tests on steel specimens. For this purpose, two tensile tests were executed on steel specimens made from the same material. The test procedure is analytically described in [1]. According to test’s results, Figure 2.3 shows steel’s stress-strain curve. The characteristic values of steel’s properties are shown in Table 2.1



E (MPa)	Yield stress σ_y(MPa)	Yield strain ε_y(%)	Hardening stress σ_R(MPa)	Hardening strain ε_R(%)	Ultimate stress σ_{max} (MPa)	Ultimate strain ε_{max} (%)
210000	287.5	0.1364	291	2.886	375	39.818

Ultimate Limit State (ULS)

Then, 3rd order analysis was performed to verify the stability of the structure, the plasticity level and the utilization factor of each member. In 3rd order analysis, both nonlinear material and geometrical nonlinearity is taken into account. This type of analysis was used instead of linear analysis, because it is quite complicated to calculate the buckling resistance and make the relevant verifications of the strengthened members, with the new composite section (CFRP plate and angle section), in accordance with Eurocodes. The results of the analysis are summarized below. The maximum total utilization factor of each group of members is shown in Table 4.4. Table 4.4: Maximum utilisation factor for members Group of members Maximum utilisation factor Legs 0.991 Vertical Braces 0.967 Horizontal members 0.431 Secondary and horizontal braces 0.606 horizontal members 0.158 Horizontal braces at platform's level 0.445 Members at the top of the tower 0.063 The utilisation factor of the legs and braces along the height of the tower is shown in

Table 4.4: Maximum utilisation factor for members

Legs	0.991
Vertical Braces	0.967
Horizontal members	0.43
Secondaryand horizontal braces	0.60
horizontal member	0.158
Horizontal braces at platform's level	0.445
Members at the top of the towe	0.06

The utilization factor of the legs and braces along the height of the tower is shown in Figure

CFRP code	**Width (mm)**	**Total Length (m)**
S151	**150**	**132**
S121	**120**	**54**
S1012	**100**	**132**
S812	**80**	**54**
S61	**60**	**36**
S51	**50**	**102**

CONCLUSIONS

This chapter addressed the design of a typical telecommunication tower strengthened with CFRP plates. Strengthening towers by using CFRP plates proved to be a possible solution, which has certain advantages comparing with the conventional strengthening method. The main advantage is that using CFRP plates there is no increase in the wind loads, since CFRP plates apply on existing members. On the other conventional strengthening method uses star battened configuration for legs and larger profiles for braces, which results in the increase of the wind loading and the self-weight of the structures. In addition, this method of strengthening needs less time to be accomplished, less equipment and construction machinery. Therefore, it can be applied easily on mountainy and inaccessible areas in short time. The total length of the CFRP plates that are needed is calculated and is shown in Table 4.10. The thickness of all plates is 1.2mm. Based on this, several parameters of the strengthening procedure can be estimated, such as the total cost and the total time of construction