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Multiple-Support Seismic Excitation of Tall Guyed Telecommunication Towers

Gholamreza GHODRATI AMIRI[1], Morteza ZAHEDI[2] and Reza SALEH JALALI[3]

SUMMARY

The effect of the spatial variation of earthquake ground motion on dynamic response of multiple-support structures may be important. The objective of this paper is to investigate the seismic response of tall antenna-supporting guyed towers using the traveling wave assumption. Two 607-m and 342-m guyed towers with nine and seven stay levels, respectively, are analyzed. The horizontal component of Tabas earthquake is considered as excitation. Elements of response analyzed are: cable tension, base shear, mast axial force and lateral displacement of the tower tip. Parametric analyses show that the structural response tends to increase as the wave velocity decreases and can become significantly larger than the response obtained from synchronous excitation.

INTRODUCTION

Earthquake ground motions have a high variability in time and space. A typical analysis of a given structure takes into account the variation in time of ground motions, but ignores their spatial variability. Hence, in practice, the earthquake response analysis of structures is usually based on the assumption that the ground just beneath the foundations vibrates in phase along the structure with the same amplitude everywhere. The foundation dimensions of large structures such as offshore platforms, earth and concrete dams, or nuclear power plants are comparable to the wavelength of the earthquake ground motion. Since the speed with which the pulse from an earthquake travels is finite, the assumption that every point at the base of these structures experiences the same excitation at any instant is clearly inaccurate. It is also generally recognized that in multiple-support system, such as bridges, each support might be excited differently than the others due to the distance between supports and the differences in geologic and topographic features at their locations [1]. The traveling wave concept is a simple approach with which to model the effects of spatial ground motion variations on structures and has frequently been used in the earthquake response analysis of structural system having multiple-supports such as bridges [2-6] and pipeline networks [7-9] and large structures [1,10]. These studies show that, depending on the assumed

[1] Associate Professor, Iran University of Science and Technology, Tehran, Iran.
Email: ghodrati@iust.ac.ir
[2] Assistant Professor, Iran University of Science and Technology, Tehran, Iran.
[3] Ph.D. Student, Iran University of Science and Technology, Tehran, Iran. Email: Saleh@iust.ac.ir

travel wave speed, the response to multiple-support excitation can be found to be sometimes larger than that obtained by the traditional fixed support analyses. The object of this paper is to investigate the seismic response of antenna-supporting guyed towers based on the traveling wave assumption. For this purpose, the horizontal displacement of Tabas earthquake is considered as input excitation. Two 607-m and 342-m guyed towers with nine and seven stay levels, respectively, were analyzed [11]. Parametric studies are then used to investigate the wave passage effects on the seismic response of the guyed towers.

DESCRIPTION OF TOWERS

In practice, guyed towers taller than 150m usually provide economical solutions comparing to self-supporting towers. Therefore, the lower height limitation for tall towers could be 150m, which is a common criterion to classify towers with respect to their heights. In this regard two guyed towers taller than 150m were selected for the simulations in the finite element computer program ANSYS [12]. They are 607 and 342 meters tall with nine and seven stay levels, respectively. The material properties and the cross section of elements of the towers have presented in Ref.11. The geometry of 607-m tower is shown in Fig.1 as a typical geometry for the towers. It should be noted that the earthquake direction was selected to coincide with the principle direction of mast cross section to create maximum seismic effects.

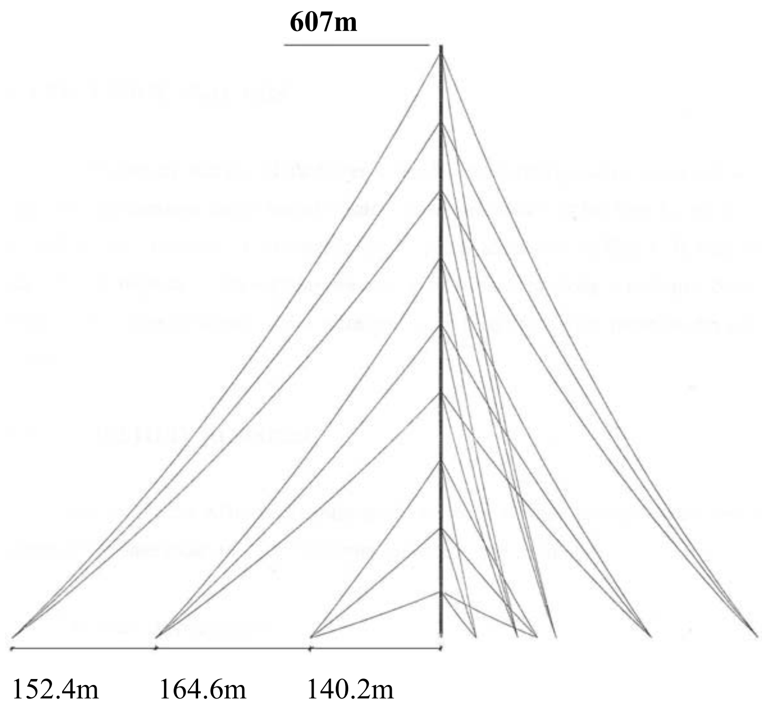


Figure 1. Geometry of 607-m tower

MODELING CONSIDERATIONS

Modeling of Mast

The mast is a spatial structure with response in all three dimensions. The elements making up the masts studied are rolled steel sections. A detailed three-dimensional truss model is employed for the mast where all resist only axial forces [11]. A lumped mass matrix formulation is used at the element level, and material properties are assumed linear elastic. Treating each element of the mast as a beam element with semi-rigid connections would be the most accurate model, however the more traditional solution of using truss elements has proven to provide sufficient accuracy [13]. As the displacements of the mast may be large, the large kinematic formulation is considered for the mast in order to account for geometric nonlinearities.

Modeling of Guy Cables

Guy cables are modeled with two-node truss elements (tension-only) [11]. A large kinematic formulation (but small strains) is used for the cable stiffness to account for geometric nonlinearities. The stress-strain law is defined only in tension to allow for cable slackening effects to be modeled during the earthquake vibrations. The lumped mass formulation is employed in the analysis, and material properties are assumed linear elastic. It should be noted that, because these guy cables are initially pre-tensioned to approximately 10% of their ultimate strength, the initial stiffness matrix is always nonsingular.

Numerical Methods

Stiffness matrix updates using the full Newton-Raphson method are performed in each time step and iteration since nonlinearities in the guy cables can be important. The nonlinear dynamic equation of motions are solved by direct step-by-step integration using the Newmark-β ?method with parameters δ=0.5050 ?and β=0.2525, which does introduce some amplitude decay. The time increment used in all calculations is 0.0008 sec.

Input Ground Motion

In this research, one excitation is used in the numerical simulations. It is the TAB-TR component (horizontal component) of TABAS earthquake (PGA=8.3558 m/s**2 & PGD=0.9458 m). Earthquake ground motion has high variability in time and space. For structures in which the distance between supports is particularly large, the space variability can be very important. Since the absolute velocity of the horizontal ground motion can be determined, we can treat the motion as a traveling wave with specific velocity. Time delays for the arrival of the wave at the base of the structure can then be introduced at support. This is illustrated in Fig.2 for a typical tower, where the ground motion first excites anchorage point 1, then excites the foundation of the mast, and lastly, excites anchorage points 2 and 3 [10].

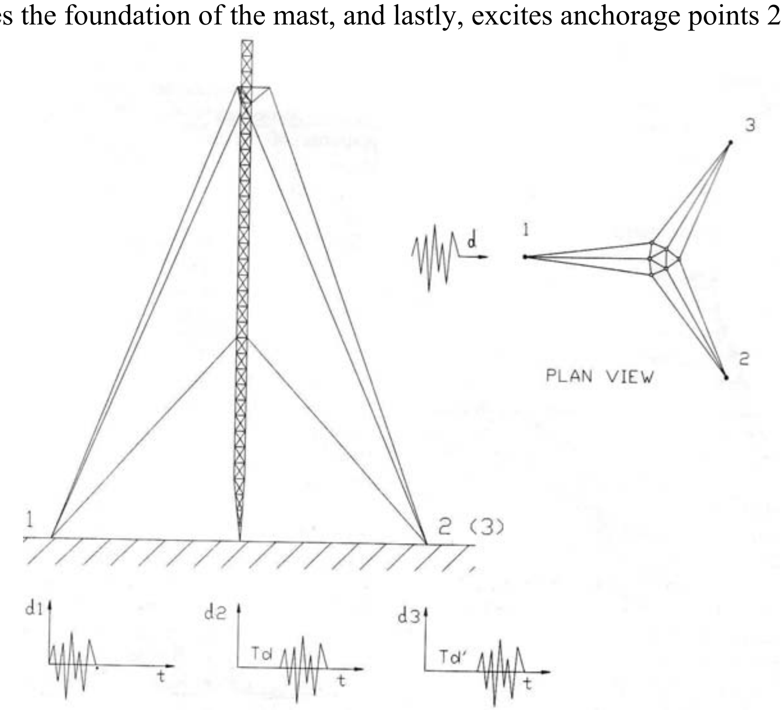


Figure 2. Modeling of support condition for asynchronous ground motion [10]

According to the Iranian Building Codes and Standards, we assumed the shear wave velocity (Vs) of 750 and 100 m/sec, for soil types II and IV, respectively [14].

RESULTS AND DISCUSSIONS

The response of a structure to multiple-support excitation is divided into a pseudo-static response component, which is the static response induced in the structure by the different support motion, and a dynamic response component, which is the structural dynamic response relative to the fixed multi-support system subjected to ground excitation. The dynamic responses dominate the flexible structure, such as guyed tower, responses. The more-correlated multiple horizontal motions excite the anti-symmetric modes more and the symmetric modes less [15]. So the anti-symmetric modes are excited by the uniform horizontal input, and the symmetric modes are more excited by the non-uniform horizontal ground motion.
For parametric studies we considered five parameters including axial force of mast, base shear of mast, cable tension, base shear of cables and total lateral displacement of tower tip. We analysed two towers 607-m and 342-m with base displacement excitation and assessed the wave passage effects on the dynamic response of towers.

Tower 607-m
The result of analysis of this tower is shown in Figs.3a to 3f. From Fig.3a it is observed that because of excitation of the symmetric modes, the maximum of the total lateral displacement of the tower tip decreases when the time delay of excitation increase or shear wave velocity (Vs) decreases.

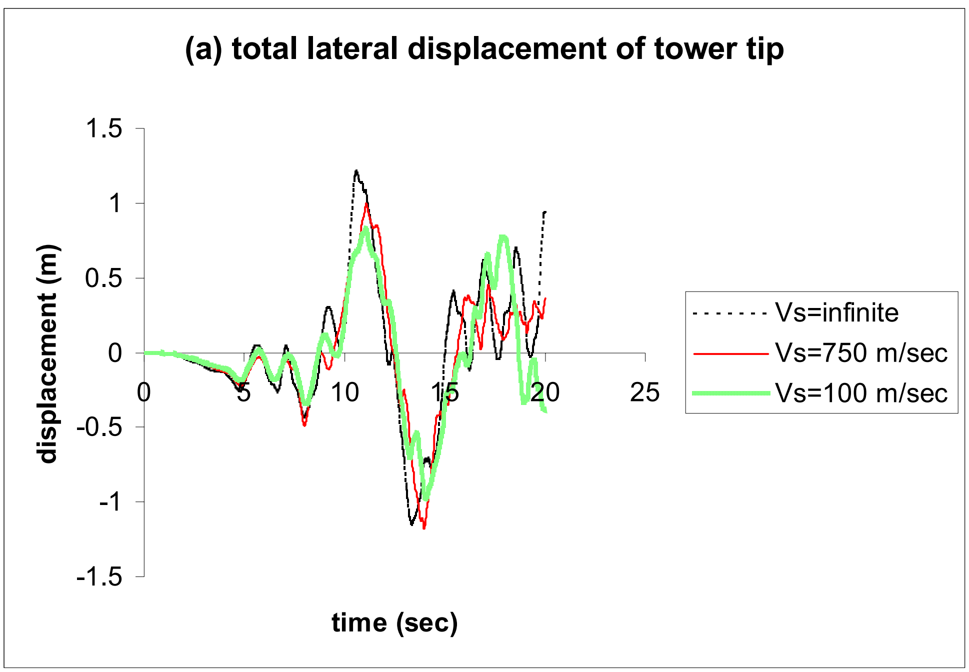
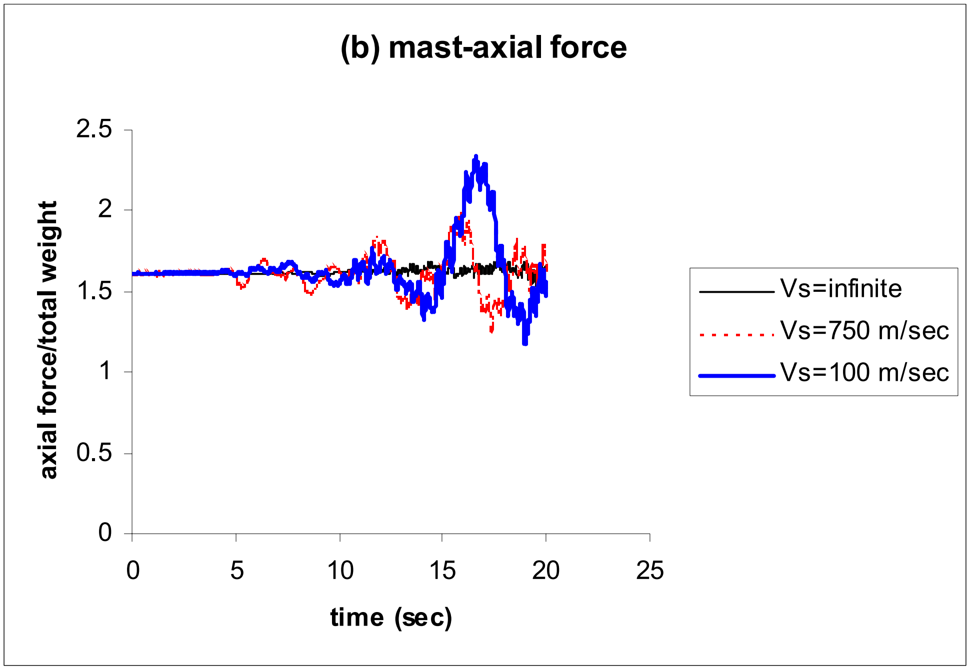


Figure 3. The results of tower-607m

According to Fig.3b, when shear wave velocity is infinite (uniform input motion), the maximum axial force of mast is equal to 1.7 times of the total weight of tower. But by increasing of time delay, the corresponding value increases and when Vs=100 m/sec, this value is equal to 2.34 times of the total weight of tower. In other word, in this case the maximum axial force of the mast increases up to 38% with respect to uniform input motion (without time delay). From Figs.3c and 3d it is clear that by increasing the time delay, the maximum base shear of the cables decrease, while for the mast, this value increases.

When Vs=100 m/sec, the maximum base shear of the cables decreases up to 29%, while the corresponding value of the mast increases up to 39% with respect to uniform input motion.



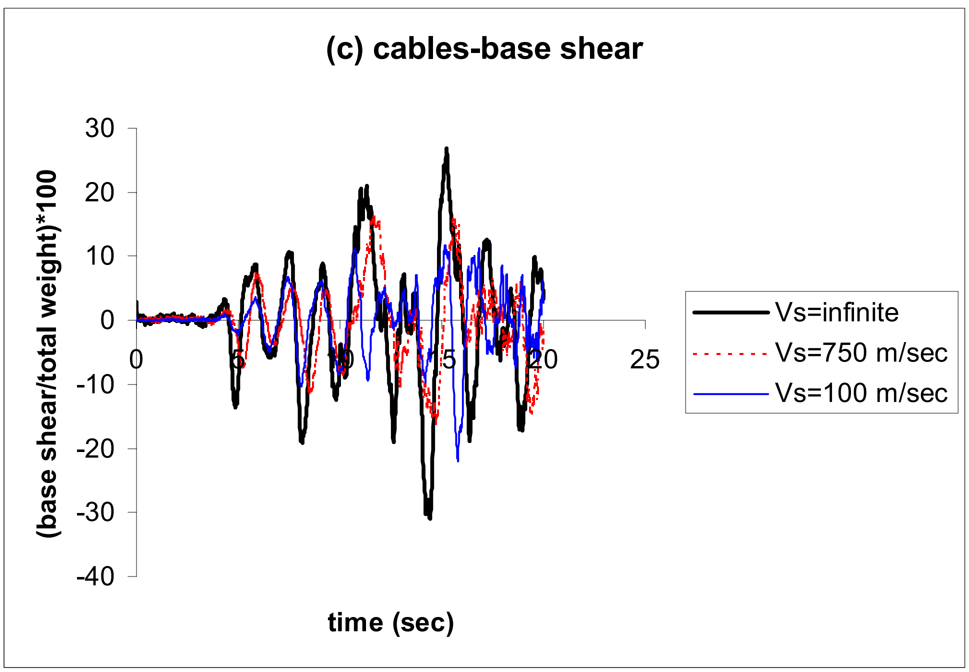
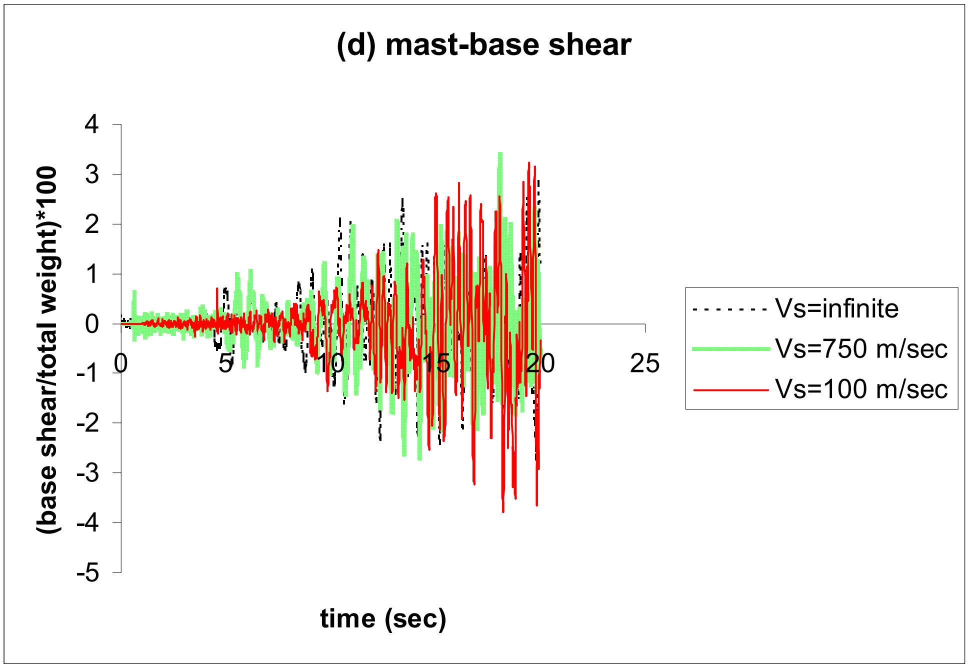
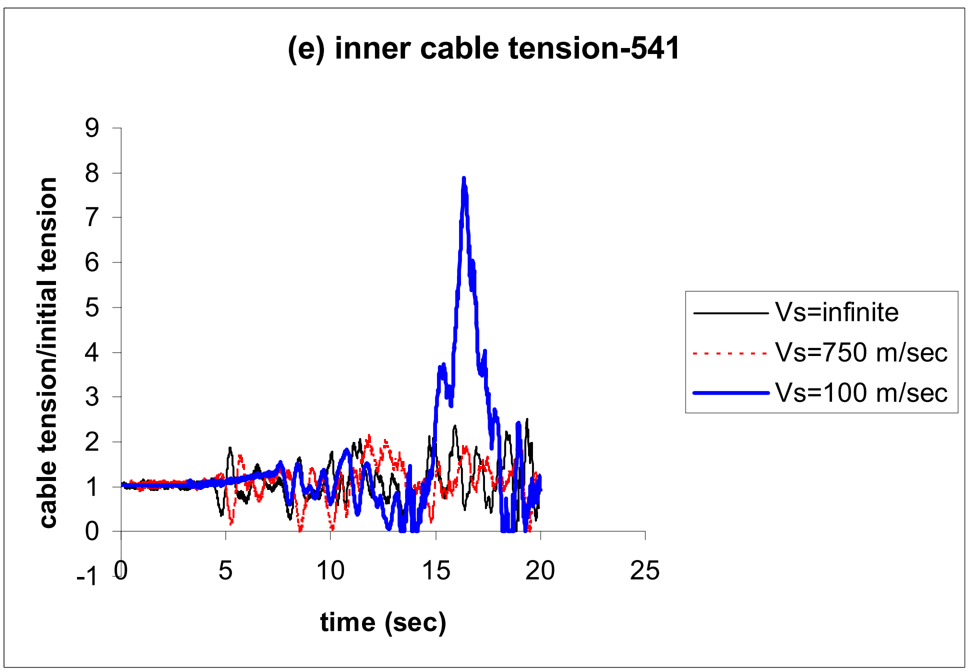


Figure 3. Continued





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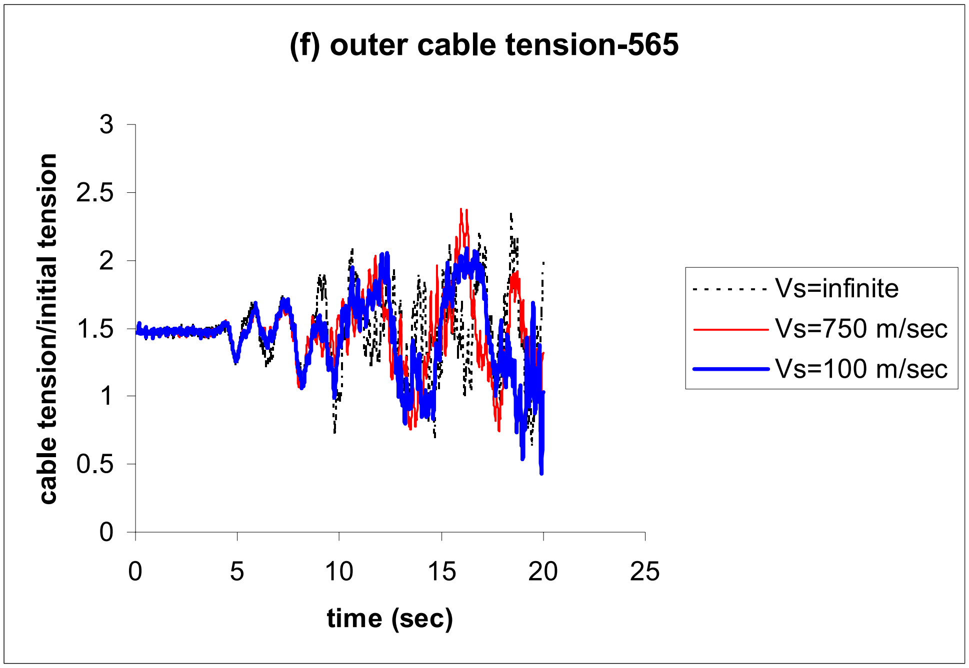

Figure 3. Continued

The wave passage effects on cable tension are shown in Figs.3e and 3f. It has to be noted that the elements of 541 and 565 are inner and outer cable elements in X direction at guy level 1 and 9, respectively. According to Fig.3e, the maximum cable tension of element 541 increases, by increasing the time delay, and when Vs=100 m/sec, this value increases up to 2.15 times with respect to uniform input motion. For cable element 565, the wave passage effect on cable tension is negligible (Fig.3f).

Tower 342-m

The result of analysis of this tower is shown in Table 1. It is observed that, when Vs=100 m/sec, the maximum axial force of the mast increases up to 25% in relative to that without time delay. And the maximum base shear of the cables decreases more than 37% but the corresponding value of the mast increases up to 16% in respect to uniform ground motion. When Vs=100 m/sec, the inner cable tension increases up to 2.38 times in respect to uniform ground motion, while the effect of wave passage on outer cable tension is negligible.

Table. 1. The maximum internal forces of tower 342-m

	Mast axial force/total weight	(cables-base shear/total weight)*100	(mast-base shear/total weight)*100	Inner cable tension/initial tension
Vs=infinite	1.98	30.93	12.25	1.70
Vs=750 m/sec	2.33	24	11.69	2.24
Vs=100 m/sec	2.48	19.5	14.18	5.75

CONCLUSIONS

The followings summarize the main results of this study:

By decreasing the shear wave velocity, or increasing the time delay

1) The maximum of the total lateral displacement of the tower tip decreases, because of excitation of the symmetric modes.

2) The maximum base shear of the cables decreases. For the case studied, this value decreases more than 29% and 38% for 607-m and 342-m towers, respectively, in respect to uniform ground motion.
3) The maximum base shear of the mast increases. For the case studied, this value increases more than 39% and 15% for 607-m and 342-m towers, respectively, in respect to uniform ground motion.
4) The maximum axial force of the mast increases. For the case studied, this value increases up to 38% and 25% for 607-m and 342-m towers, respectively, in respect to uniform ground motion.
5) The maximum tension of inner cables increases high considerably, while this effect is less important or negligible in outer cables. For the case studied, this value increases more than two times for inner cables, in respect to uniform ground motion.

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