International Journal of Engineering

Journal Homepage: www.ije.ir

The Effect of Soil Type on Seismic Response of Tall Telecommunication Towers with Random Vibration Analysis

B. Rezayibana*

Department of Civil Engineering, Ardabil Branch, Islamic Azad University, Ardabil, Iran

PAPER INFO

Paper history:
Received 29 October 2019
Received in revised form 23 November 2019
Accepted 17 Januray 2020

Keywords:
Telecommunication Tower
Damping
Random Vibration
Pseudo-excitation Method
Soil

ABSTRACT

Random vibration analysis of tall structures faces multiple problems due to the large number of elements and high degrees of freedom; that is why this type of analysis is mostly used in simple structures and low degrees of freedom. In the past two decades, changes have been occurred in this type of analysis to be used in complex structures and the large number of elements. Pseudo-Excitation Method (PEM) presents a simple formulation for reducing the volume of operations. In this paper, a tall telecommunication tower is fully modeled as an example of such towers; it is analyzed by random vibration analysis with the help of the above method. Different conditions of the soil under the tower and different damping are used in modeling and analysis. The results show that structure response is strongly influenced by the soil conditions. In addition, higher modes have significant effects on the telecommunication tower response.

***doi**: 10.5829/ije.2020.33.03c.06*

1. INTRODUCTION

Since the nature of ground motions can be considered as a kind of random stimulation, random vibration theory and method must be used in the analysis of the seismic response of structures. Generally, random vibration is divided into stationary and non-stationary vibrations. If the cumulative averages for a random stimulation are independent of time, the stimulation is called stationary, and otherwise, it is non-stationary. To a large extent, most of the engineers tend to use stationary random vibration [1]. However, because of the low computational efficiency, it is less used in design codes, and instead of this method, response spectrum method is frequently used. Response spectrum method was firstly used in 1995 in Europe’s Regulations as a tool for seismic analysis of structures [2]. Through random vibration analysis, not only the displacement and internal forces that are of great importance in the design, but also a lot of useful information that is not present in the response spectrum method, are obtained. Given the enormous benefits of this method, it has been mostly used in simple structures and low degrees of freedom, and it is not so efficient in tall and complex structures due to its high volume of calculations.

In recent years, many studies have been done to simplify and make the method more practical; Pseudo-Excitation Method (PEM) was firstly presented by Lin [3]. He showed that PEM is very simple and has high efficiency. By this method, random vibration response of complex structures to stationary and non-stationary random stimulations can be done with sufficient accuracy [4]. In recent years, this method has been developed and used for complex structures such as bridges and tall buildings [5-13]. Huang et al. [14] employed PEM to obtain response of high-rise building under wind-induced multi-excitation using simplified SRSS method. He et al. [15] combined PEM with Mode Acceleration Method (MAM) to improve the computing efficiency of large structures due to stationary random base acceleration excitations.

Due to the installation of sensitive and important equipment above telecommunication towers, they must be controlled against seismic loads and deformations. A simple way to assess such structures is the use of

---

*Corresponding Author Email: *Bahram.deprem@gmail.com* (B. Rezayibana)

Please cite this article as: B. Rezayibana, The Effect of Soil Type on Seismic Response of Tall Telecommunication Towers with Random Vibration Analysis, International Journal of Engineering (IJE), IJE TRANSACTIONS C: Aspects Vol. 33, No. 3, (March 2020) 419-426

random vibration analysis. Most of telecommunication towers have four main parts of foundation, concrete or steel shafts, head structure and antenna. CN Tower (553 meters), Ostankino Tele Tower (540 meters) and Milad Tower (430 meters) are of the towers with concrete shaft. In modeling such structures, a cantilever column is usually used with a centralized mass at the end, which can mostly show the general behavior of the structure; and given that it has only one mode, the effect of higher modes cannot be seen in random vibration analysis. In recent years, with the development of computer systems, the finite element method has been used to model these kinds of structures [16]. Given that numerous modes can be obtained in finite element models, using random vibration analysis is not possible, However analysis can be easier and simpler by using PEM. Since Most of telecommunication towers have one stiff part such as shaft and one ductile part such as antenna, in this study, Tehran's Milad telecommunication tower is selected and modeled as finite element with full details by ABAQUS software [17]. To investigate the effect of different soil conditions under the tower on seismic response of the shaft, the head structure and the antenna, three type of soil (firm, medium, and soft soil) are selected and random vibration analysis is done.

2. STATIONARY RANDOM VIBRATION ANALYSIS

Equation of the motion of a multi-degree-of-freedom structure, when it is under random ground motion vibration, is as follows [18]:

$$[M]\{\ddot{y}\}+[C]\{\dot{y}\}+[K]\{y\}=-[M]\{E\}\ddot{x}_g(t) \tag{1}$$

In the above equation, $[K]$, $[C]$, and $[M]$ are matrices of mass, damping, and stiffness; and matrix $[E]$ is an index vector of the internal forces. It is assumed that ground motion acceleration ($\ddot{x}_g$) is a Stationary Gaussian random process, so, power spectral density (PSD) matrix of the displacement response can be written as Equation (2).

$$[S_{yy}(\omega)]=\sum_{j=1}^{q}\sum_{k=1}^{q}\gamma_j\gamma_k H_j(\omega)H_k(\omega)\{\Phi\}_j\{\Phi\}_k^T S_{\ddot{x}_g}(\omega) \tag{2}$$

$S_{\ddot{x}_g}$ is the PSD matrix of ground acceleration $\ddot{x}_g$, γ_j is the jth mode participation factor, $\{\Phi\}_j$ is the jth mode and q is the number of modes that are participated in the dynamic analysis, in addition, H_j is the frequency response function of the jth order that is as Equation (3).

$$H_j=\frac{1}{\omega_j^2-\omega^2+2i\xi_j\omega\omega_j} \tag{3}$$

Equation (2) is known as the complete quadratic combination (CQC) method. If the correlation between the parameters is eliminated, Equation (4) appears that is known as Square root of the sum of squares (SRSS).

$$[S_{yy}(\omega)]=\sum_{h=1}^{q}\gamma_j^2\left|H_j\right|^2\{\Phi\}_j\{\Phi\}_j^T S_{\ddot{x}_g}(\omega) \tag{4}$$

As can be seen, the number of operations in Equation. (2) is q^2 times, while in Equation (4) it is q times. But in Equation (4), the correlation between parameters is removed, and it is not correct for random vibration analysis and should be modified. The PEM makes Equation (2) simpler and similar to Equation (4); so that there is a correlation between the parameters and the operation is reduced [3].

$$[S_{yy}(\omega)]=\{Y(\omega)\}\{Y(\omega)\}^T \tag{5}$$

$$\{Y(\omega)\}=\sum\gamma_j H_j\{\Phi\}_j\sqrt{S_{\ddot{x}_g}(\omega)} \tag{6}$$

Equation (5) is known as quick CQC method and is the basis of PEM method [3].

3. PSD FUNCTION OF THE GROUND ACCELERATION

To solve Equation (5) for a multi-degree-of-freedom structure, except $S_{\ddot{x}_g}$ which is related to loading, the rest of the parameters are obtained from the structure modeling. To apply different soil conditions, the modified Kanai–Tajimi spectral density function is used [18].

$$S_{\ddot{x}_g\ddot{x}_g}=\frac{1+4\xi_g^2(\omega/\omega_g)^2}{[1-(\omega/\omega_g)^2]^2+4\xi_g^2(\omega/\omega_g)^2}\times\frac{(\omega/\omega_f)^4}{[1-(\omega/\omega_f)^2]^2+4\xi_f^2(\omega/\omega_f)^2}S_0 \tag{7}$$

Where S_0 is the amplitude of the white-noise bedrock acceleration, ω_g, and ξ_g are the frequency and damping ratio of the first filter related to the soil type ; ω_f, and ξ_f are the frequency and damping ratio of the second filter which are applied to consider the ground displacement. In this study, three types of soil (Firm, Medium, and Soft) are used. Der Kiureghian and Neuenhofer [19] obtained the parameters of Equation (7). The values are obtained by the equality of variance of the Kanai–Tajimi spectral density related to any type of the soil with the variance of the spectral density of the east–west component of the Erzincan earthquake acceleration record [20]. The parameters of the input density function are presented in Table 1 and input power spectral density curve is shown in Figure 1 for all three types of soil.

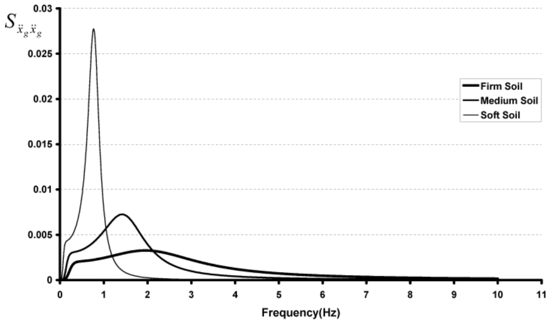

Figure 1. Modified Kanai–Tajimi spectral density function

TABLE 1. Power spectral density parameters for firm, medium and soft soil conditions

Soil Type	ω_g (rad/s)	ξ_g	ω_f (rad/s)	ξ_f	S_0 (m^2/s^3)
Firm	15.0	0.6	1.5	0.6	0.00177
Medium	10.0	0.4	1.0	0.6	0.00263
Soft	5.0	0.2	0.5	0.6	0.00369

4. SAMPLE TOWER

To investigate the behavior of telecommunication towers against random loads, Tehran's Milad Tower is selected. The tower with a height of 435 meters in Tehran (Iran), as well as other towers, is formed of four main parts of foundations, concrete shaft, head structure and the antenna.

The foundation of the tower consists of two parts: circular mat foundation and the transitional structure. These parts are shown in Figure 2. The diameter of the mat foundation is 66 meters and the thickness is varied between 3 and 4.5 meters. The foundation is placed from height level -14 to height -11 at the center and -9.5 at the corners of the foundation. The transitional structure is an incomplete pyramid placed on the foundation and continued to height level 0.0. The diameter of the transition structure is 49.6 meters at height level -9.5 and is equal to 28 meters at the height level 0.0. This structure consists of central core, inclined walls and walls of triangular shape. To control the stresses under the foundation and also to control the punching shear, a post-tensioned peripheral system is constructed around the foundation which provides compression stresses in the foundation and concrete confinement.

The concrete shaft is the main load carrying part of the tower which transfers the entire lateral and gravity loads to the foundation. This structure begins from the height level 0.0 and continues to the height level 315. The diameter of the concrete shaft decreases by moving from the bottom to the top. The cross section of the concrete shaft at different height levels are shown in Figure 3.

The head structure is at height level 247.5 to the height level 315. It is placed around the concrete shaft and forms a 12-storey structure. The head structure consists of the following parts: Radial and peripheral beams, Columns, Steel basket, concrete cone. The head structure is shown in Figure 4.

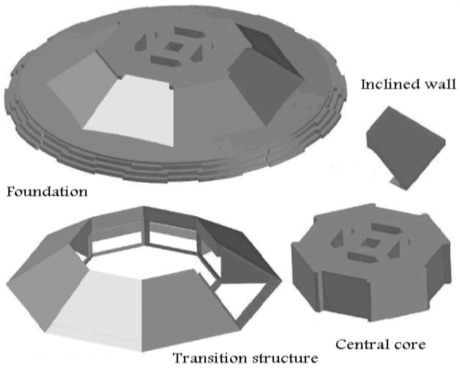

Figure 2. The foundation and its parts

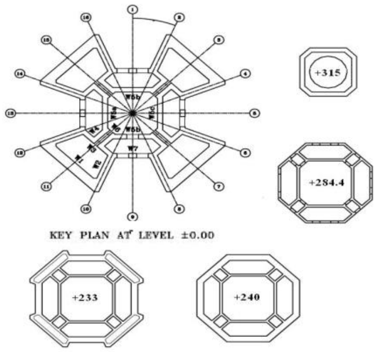

Figure 3. The cross section of the concrete shaft at different elevations

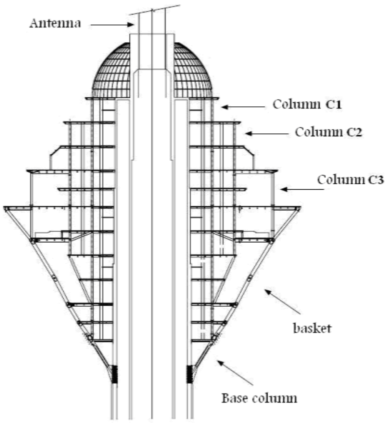

Figure 4. The cross section of the concrete shaft at different elevations

The antenna is installed from the height level 308 to the height level 436. It is composed of four parts. The first part is installed from the height level 308 to the height level 382. The diameter is decreased from 6 meters at the lowest part to 3.5 meters at the highest part. The second part is installed from the height level 382 to the height level 408. The exterior diameter is 1.9 meters. The third part is installed from the height level 408 to the height level 420.8. The exterior diameter is 1.3 meters. The fourth part is installed from the height level 420.8 to the height level 436. The exterior diameter is 0.6 meter. To decrease the unbraced length of the plates and also to control the lateral buckling of the antenna, vertical and horizontal stiffeners are used. These stiffeners are made of steel profiles and plates.

5. FINITE ELEMENT MODEL

The ABAQUS finite element software is used for the modeling of the tower. This program is able to simulate the behavior of concrete structures under dynamic loadings. Eight-node solid elements (C3D8) are used for modeling the circular foundation and the central part of the transitional structure. Triangular shell element (S3R) and Four-node shell element (S4) are used for modeling the triangular and inclined walls, respectively. 3D truss element (T3D2) is used for modeling the post-tensioned tendons which are embedded in the exterior ring of the circular foundation. Reinforcements are placed exactly in the finite element model according to the executive details. There are 2972 elements, 3408 nodes and 10992 degrees of freedom in the foundation finite element model. S4 elements are used from the height level 0.0 to the height level 307, where the section of the shaft is changed for attaching the antenna to the concrete shaft. C3D8 elements are used above the height level 307 for modeling the concrete shaft. Stiffener beams are modeled using B31 element (3D Timoshenko beam). Since the reinforcements could not be embedded in shell elements, reinforcement layer method is used to simulate the post-tensioned tendons. The concrete shaft model consists of 4412 elements, 4056 nodes and has 22896 degrees of freedom. Columns, radial beams, peripheral beams horizontal braces and basket members are modeled using B33 element (3D Euler-Bernoulli beam in which the shear deformation is ignored). To consider the rigidity of the floors in the model, the nodes in a floor are tied together to have equal movements in x and y directions and equal rotation around the Z axis. S4 elements are used for modeling of the concrete cone. The head structure model consists of 3976 elements, 6496 nodes and has 24352 degrees of freedom. S4 element is used for the modeling of the antenna and the stiffeners are modeled by B33 elements. The antenna model consists of 1924 elements, 1833 nodes and has 6870 degrees of freedom. The total Milad tower model is shown in Figure 5. The total model consists of 13284 elements and 17920 nodes.

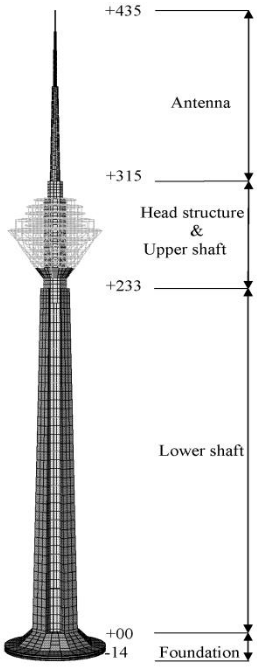

Figure 5. Finite element of the tower

6. MODAL ANALYSIS

Since the random vibration method uses structure modes, modal analysis must be performed on the structure at first. Due to the large number of elements, some additional modes will be resulted which do not affect the dynamic analysis, so, the volume of calculations will be increased. Using the PEM, only main modes, which have high participation rate, will be used. The main modes of the tower are provided in Table 2.

In this table, mass participation factor is presented for lateral modes to determine effective modes. Moreover, vertical and torsional modes are specified in the table. It should be noted that the main modes were derived from more than 2,000 modes. According to the modes obtained, and mode participation factors, it is determined that the first mode is the main structure mode, and four, six and ten are other effective modes. It is worth noting that the total mass of the structure is about 198,000 tons and the head structure mass is 17,000 tons; and 51% of the total mass of the structure is participated in the first mode.

For verification of finite element model, the study of Amiri and Yahyai [21] is used. In this study, using ambient vibration monitoring method, natural

TABLE 2. Natural frequencies of the tower and modal participating factor

Mode Number	Frequency (Hz)	Modal participating factor	Component
1	0.13802	0.513	Lateral
2	0.46204	0.009	Lateral
3	0.4806		Torsion
4	0.71942	0.200	Lateral
5	1.164	0.007	Lateral
6	1.6935	0.093	Lateral
7	1.8954		Torsion
8	2.4257	0.002	Lateral
9	2.5372		Vertical
10	3.009	0.062	Lateral
11	3.6771		Torsion
12	4.4815	0.014	Lateral
13	4.8008	0.031	Lateral
14	4.9395		Torsion
15	5.4729		Torsion
16	5.5701		Torsion
17	5.9333		Torsion
18	6.3566	0.020	Lateral
19	6.6845		Torsion
20	6.7886	0.011	Lateral
21	6.8226		Torsion
22	7.0067		Vertical
23	7.8113		Torsion
24	7.9388	0.018	Lateral
25	8.0082		Torsion
26	8.5637		Torsion
27	8.7376	0.001	Lateral
28	9.3215	0.018	Lateral
29	9.4449		Torsion
30	9.9922		Torsion

frequency and damping ratio of the main modes of the tower were obtained. Natural frequencies of the first, second, fourth, fifth and sixth modes were 0.146, 1.248, 1.155, 0.765, 0.629, and 0.424, respectively. Referring to Table 2, it is observed that the natural frequency of the various modes of the sample tower using the finite element method is in good approximation compared with the experimental values. The damping ratios for the first and second modes were estimated equal to 1.84 and 2.49%. In addition, using Riley method, damping ratio for the first mode was calculated equal to 5.25%. According to the damping ratio values obtained in this study, two values of 2 and 5% are used to check the response.

7. RANDOM VIBRATION ANALYSIS

Random Vibration Analysis was carried out for the three types of soil, and damping ratios of 2 and 5%. The structure response (displacement and acceleration) is checked at three levels of the tower: level of 280.8 where the largest head structure floor is, level of 435 at the end of the shaft, and the level of 435 on the tip of the antenna. Figures 6, 7 and 8, show the PSD of the displacement response for the three desired levels and different soil conditions. As seen, the first mode (51% of the mass participates in this mode) has the greatest impact and the maximum response occurs in this mode. For the levels of 280.8 and 315 that are related to the shaft, other modes especially the fourth mode where 20% of the mass participates, have no significant impact. However, for the level of 435 which is the tip of the antenna and has less stiffness compared to the concrete shaft, higher modes have more significant effects. For the tip of the antenna, the effect of the second mode in the firm soil is more than the medium and soft soil; however, it gradually becomes less while the soil becomes softer, in a way that it becomes almost equal with the fourth mode in the soft soil. It should be noted that the second mode has less modal participation factor than the fourth mode, but its effect is more in the response of the structure in firm and medium soil. As anticipated, the structure response is reduced with 5% damping.

In Figure 9, displacement response for the level of 435 is plotted for all three types of soil conditions. As seen, the response of the structure is severely amplified in soft soil so that the ratio of the maximum response in the soft soil to the maximum response in the firm soil is about 20 times while it about 6 times compared to the medium soil. It is also observed that when the damping ratio is reduced from 5 to 2%, maximum response is 4 times, 6 times and about 8 times higher in the firm, medium, and soft soils, respectively.

Since acceleration for the equipment installed in the head and visitors at high altitude are important, it is necessary to examine the effects of acceleration. The PSD of acceleration for the level of 280.8 is shown in Figure 10.

As seen, effective modes are those that have high participation rates (the first, fourth, and sixth modes) while in the displacement response, the second mode was more effective than the fourth mode. Acceleration response at this level, after the sixth mode, for the soft soil is reduced compared to the firm and medium soils. When the soil becomes firmer, acceleration response in the higher modes increases. The maximum acceleration response for damping ratio of 2% is about 6 times higher compared to the damping ratio of 5%.

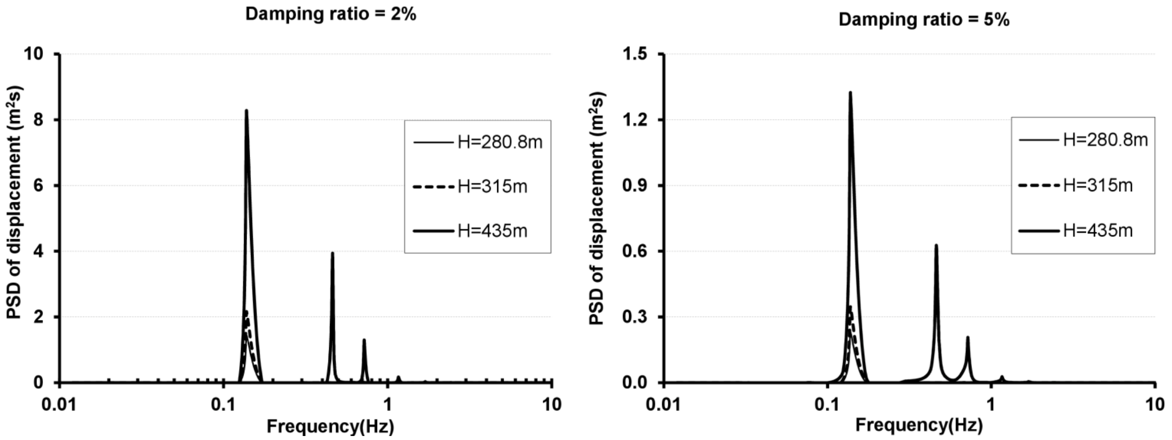

Figure 6. PSD of displacement for firm soil (m^2s)

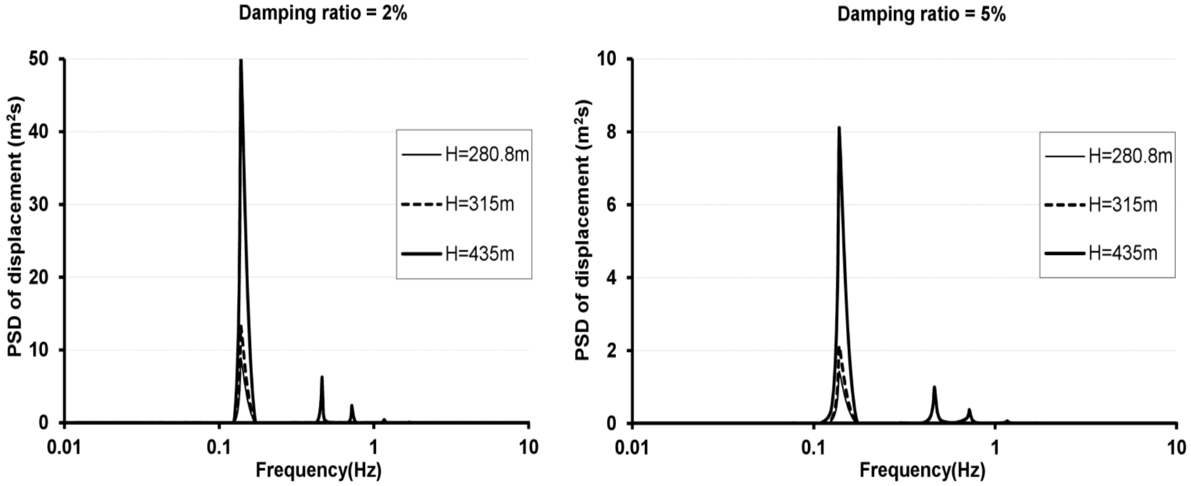

Figure 7. PSD of displacement for medium soil (m^2s)

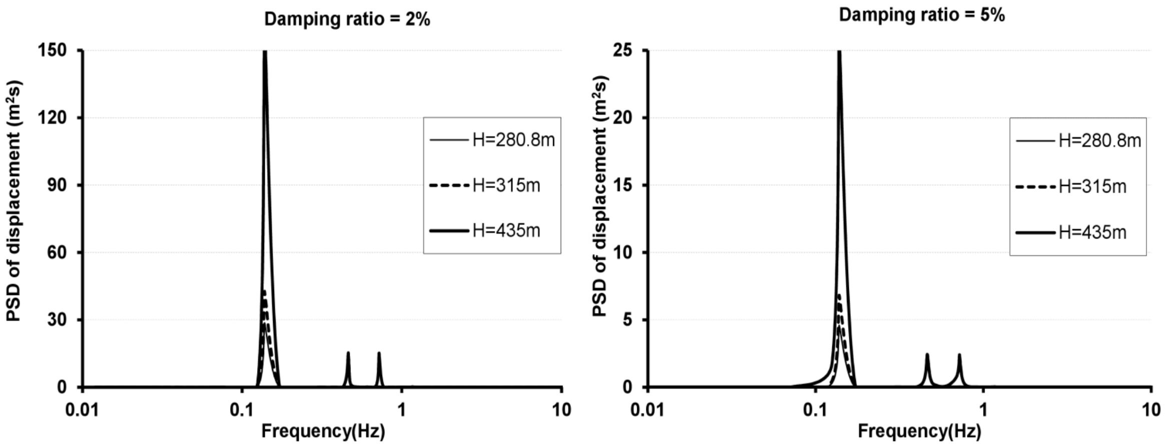

Figure 8. PSD of displacement for soft soil (m^2s)

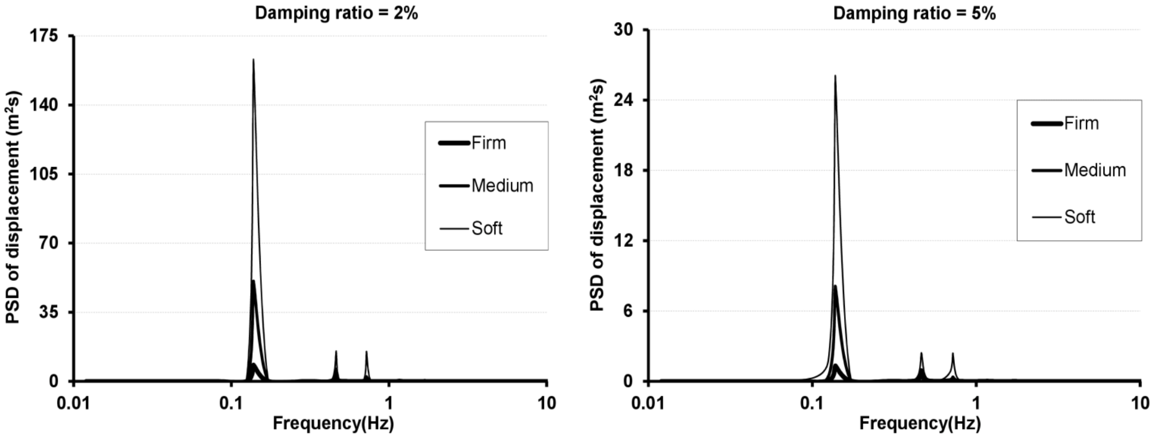

Figure 9. PSD of displacement for level 435m (m^2s)

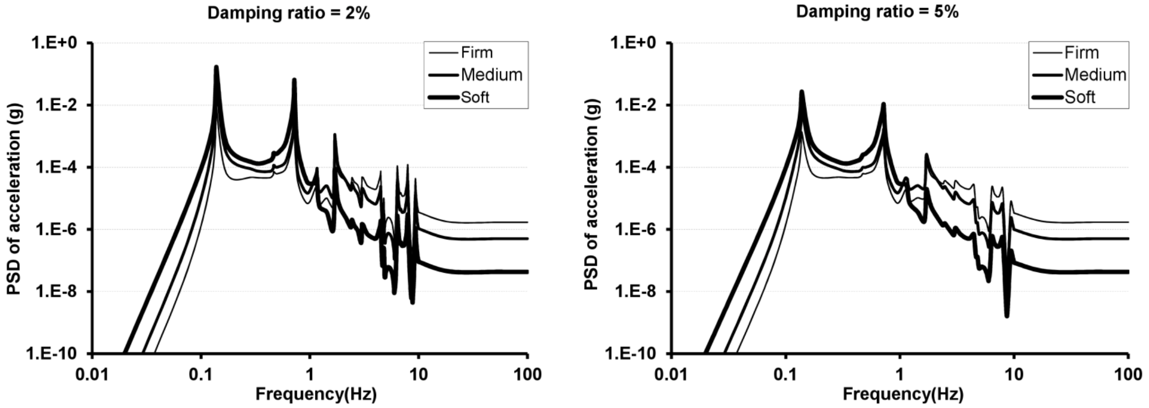

Figure 10. PSD acceleration for level 280.8m (g^2)

8. CONCLUSIONS

Since telecommunication towers have sensitive and important equipment and because of some important reason, telecommunication towers must be controlled against seismic loads and deformations. Random vibration analysis is a simple way to assess such structures. Since most of telecommunication towers have four main parts of foundation, concrete or steel shafts (stiff part), head structure and antenna (ductile part), Milad tower as an example of telecommunication towers built in the world was selected to study the seismic response of telecommunication towers by random vibration. In this article, Milad tower was modeled as an a finite element model, and the random vibration analysis was performed taking into account the different soil conditions to study the effect of the soil conditions on seismic response of the stiff and ductile part of telecommunication towers. Due to the large number of elements of finite element model, PEM method was used for the analysis. The structure response (displacement and acceleration) is checked at three levels of the tower: the largest head structure floor, the end of the shaft, and the tip of the antenna. Thus, the following conclusions can be made:

a) The finite element model can estimate the natural period of the tower as well as experimental test.

b) The first mode with 51% of the mass participates has the greatest impact and the maximum response occurs in this mode. However, for the ductile part such as antenna, higher modes have more significant effects.

c) The structure response is heavily influenced by the type of the soil under the towers; and softer soil leads to increase the response.

d) As the soil becomes firmer, acceleration response in the higher modes increases.

e) Reducing the damping ratio from 5 to 2%, the structural response in soft soils increases further compared to the medium and firm soils indicating that the damping effect in soft soils is more than the firm soils.

9. REFERENCES

1. Wijker, J. J., “Random Vibrations in Spacecraft Structures Design: Theory and Applications”, Springer, (2009).

2. Euro Code 8, “European committee for standardization, structures in seismic regions-design part 2: bridge”, Brussels, (1995).
3. Lin, J. H., “A fast CQC algorithm of PSD matrices for seismic responses”, ***Computers and Structures***, Vol. 44, No. 3, (1992), 683–6877.
4. Lin, J. H., Zhao, Y., Zhang, Y. H., “Accurate and highly efficient algorithms for structural stationary/non-stationary random responses”, ***Computer Methods in Applied Mechanics and Engineering***, Vol. 191, No. 1–2, (2001),103–111.
5. Lin, J. H., Zhang, W. S., Li, J. J., “Structural responses to arbitrarily coherent stationary random excitations”, ***Computers and Structure***, Vol. 50, No. 5, (1994), 629–633.
6. Lin, J. H., Li, J. J., Zhang, W. S., Williams, F. W., “Non-stationary random seismic response of multi-support structures in evolutionary inhomogeneous random fields”, ***Earthquake Engineering and Structural Dynamics***, Vol. 26, (1997), 135-145.
7. Li, Q. S., Zhang, Y. H., Wu, J. R., Lin, J. H., “Seismic random vibration analysis of tall buildings”, ***Engineering Structures***, Vol. 26, (2004), 1767-1778.
8. Zhang, Y. H., Li, Q. S., Lin, J. H., Williams, F. W, “Random vibration analysis of long-span structures subjected to spatially varying ground motions”, ***Soil Dynamics and Earthquake Engineering***, Vol. 29, (2009), 620-629.
9. Zhang, D. Y., Li, X., Yan, W. M., Xie, W. C., Pandey, M. D., “Stochastic seismic analysis of a concretefilled steel tubular (CFST) arch bridge under tridirectional multiple excitations”, ***Engineering Structures***, Vol. 52, (2013) 355–371.
10. Zeng, Z. P., Yu, Z. W., Zhao, Y. G., Xu, W. T., Chen, L. K, Lou, P., “Numerical simulation of vertical random vibration of Train-slab Track-bridge intersection system by PEM”, ***Shock and Vibration***, Article ID 304219,(2014), 21 pages.
11. Zhao, B., Wang, Y., Chen, Z., Shi, Y., Jiang, Y., Wang, Y., “Research on the random seismic response analysis for multi- and large-span structures to multi-support excitations”, ***Earthquake Engineering and Engineering Vibration***, Vol. 14, (2015), 527-538.
12. Lin, Z., Pei, S., Li, X., Qiang, S., “Probabilistic evaluation approach for nonlinear vehicle-bridge dynamic performances”, ***Journal of Sound Vibration***, Vol. 339, (2015), 143-156.
13. Zhang, W., Liu, H., Gao, T., “Topology optimization of large-scale structures subjected to stationary random excitation: An efficient optimization procedure integrating pseudo excitation method and mode acceleration method”, **Computers *and* Structures**, Vol. 158, (2015), 61-70.
14. Huang, D. M., Zhu, L. D., Chen, W., “Covariance proper transformation-based pseudo excitation algorithm and simplified SRSS method for the response of high-rise building subject to wind-induced multi-excitation”, ***Engineering Structures***, Vol. 100, (2015), 425-441.
15. Fei, H. E., Hongqiang, L., Jihong, Z., Zhongze, G., “Structural topology optimization under stationary random base acceleration excitations”, ***Chinese Journal of Aeronautics***, Vol. 32, No. 6, (2019), 1416-1427.
16. Yahyai, M., Rezayibana, B., Saedi Daryan, A., “Nonlinear seismic response of Milad tower using finite element model”, ***Structural Design of Tall and Special Buildings***, Vol. 18, No. 8, (2009), 877 – 890.
17. ABAQUS, ABAQUS Theory Manual and Users’ Manual Version 6.14, (2016).
18. Clough, R. W., Penzien, J., “Dynamics of Structures”, McGraw Hill, New York, (1993).
19. Der Kiureghian , A., Neuenhofer, A., “Response spectrum method for multi- support seismic excitations”, ***Earthquake Engineering and Structural Dynamics***, Vol. 21, No. 8, (1992) 713–740.
20. Dumanoglu, A. A., Soyluk, K., “A stochastic analysis of long span structures subjected to spatially varying ground motions including the site-response effect”, ***Engineering Structures***, Vol. 25, No. 10, (2003), 1301–1310.
21. Amiri, M. M., Yahyai, M., “Estimation of damping ratio of TV towers based on ambient vibration monitoring”, ***Structural Design of Tall and Special Buildings***, Vol. 22, No. 11, (2013), 862-875.

The Effect of Soil Type on Seismic Response of Tall Telecommunication Towers with Random Vibration Analysis

B. Rezayibana

Department of Civil Engineering, Ardabil Branch, Islamic Azad University, Ardabil, Iran

PAPER INFO

Paper history:
Received 29 October 2019
Received in revised form 23 November 2019
Accepted 17 Januray 2020

Keywords:
Telecommunication Tower
Damping
Random Vibration
Pseudo-excitation Method
Soil

چکیده

آنالیز ارتعاشات تصادفی برای سازه های بلند به دلیل داشتن تعداد المانهای زیاد و تعداد درجات آزادی بالا با مشکلات فراوانی روبرو است و به همین دلیل است که از این نوع انالیز بیشتر درسازه های ساده و تعداد درجات آزادی پایین استفاده میشود. در دو دهه اخیر تغییراتی در این نوع آنالیز انجام گرفت تا برای سازه های پیچیده و با تعداد المانهای بالا استفاده شود.روش PEM فرمول بندی ساده ای برای کاهش حجم عملیات ارائه میدهد. دراین مقاله یک برج مخابراتی بلند به عنوان نمونه ای از چنین برجها، به طور کامل مدل شده و به کمک روش فوق مورد آنالیز ارتعاش تصادفی قرار میگیرد. در مدلسازی و آنالیز از شرایط متفاوت خاک زیر برج و میرایی مختلف استفاده میشود. نتایج نشان میدهد که شرایط خاک، پاسخ سازه را به شدت تحت تاثیر خود قرار میدهد. همچنین مودهای بالاتر اثر قابل توجهی در پاسخ برجهای مخابراتی دارد

doi: *10.5829/ije.2020.33.03c.06*