

Seismic Performance Research of Transmission Tower in Consideration of the Pile-soil-structure System

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Abstract. The seismic performance of transmission tower in consideration of pile-soil-structure dynamic interaction is researched through numerical simulation. Based on a transmission tower of a specific project, pile-soil-transmission tower coupled system is established. By using the method of time history, the pile-soil-transmission tower system dynamic response under seismic load were calculated, and comparing with the results without considering interaction system. Results show that, after considering interaction of the system, the period of the structure have extended and the mode of the structure lagged. On soft sites, compare with no considering the interaction, the results have a big difference, the relative increment of the maximum displacement at the top of the tower is 39.82%, respectively. Therefore it is suggested that the pile-soil-structure dynamic interaction should be fully considered in aseismic design of transmission tower on soft sites and medium soft sites.

1. Introduction

Transmission tower is an important part of power transmission, also is the foundation of safe and reliable operation of the electric power network, in the event of damage will cause big loss to national economy, seriously affected the quality of people's lives. When making the design of the transmission tower, the main control load generally took the wind load, ice load, bolt load, etc., rarely consider the effect of seismic load. And with the rapid development of China's economy, the demand for electricity also presents the fast growth tendency, so in recent years, more and more large span, long distance transmission lines are occurred. The condition of the transmission tower lines which have broken down under seismic load is constantly occurred. Such as, the earthquake of Kobe in Japan in 1995, according to statistics, there are different degrees of damage for 20 transmission towers, most of the damage form is at the basic part of the structure, the earthquake caused widespread users in this region losing power [1]. Chi-chi earthquake in Taiwan in 1999, result a large area of tower have collapsed and deformed of the structures [2], which caused huge losses. On May 12, 2008 Wenchuan earthquake, according to the statistics [3], more than 20 110 KV lines have occurred seriously damage, and also the same condition for 8 500 KV lines, which paralyzed the whole region transmission network, caused great obstacles to the rescue work. Surveys show that most damages of the transmission tower occurs at the foundation of the structure. And also seriously damage to ground soil. So to explore the dynamic characteristics of ground, soil, foundation and the transmission tower is an urgent job.

2. The whole finite element model of pile-soil-transmission tower system

2.1. Model of Transmission Tower



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In this paper, beam elements were used to establish a three-dimensional finite element model of a transmission tower. Literature [4] pointed out that, the result of the transmission tower was calculated by the beam element is more in agreement with the results of the experimental. If all nodes of the transmission tower are regarded as a hinge point. For space model, outside plane of the single truss will be variable geometry system. So when calculate the seismic response of transmission towers that in consideration the dynamic interaction of pile-soil-transmission tower system, all connecting node of the transmission tower is regarded as rigid node.

2.2. Pile-Soil Contact Surface Model

In this paper, ABAQUS was used to simulate the pile-soil contact surface, using master-slave contact algorithm, first of all we need to establish surface separately on the pile and the soil, and we should to establish the corresponding contact pairs. The principle we choose the master surface and the slave surface is that the slave surface must be meshed more precise. If the mesh density of the master surface and the slave surface is very similar, we should choose a stiffer surface as the master surface. Here choose the surface of the pile as the master surface. Since it has a big difference between pile radius and soil radius which we need to calculate, this article take the 40~60 times pile radius as the soil radius [8]. The beam element is used to establish the transmission tower in this article.

2.3. Model of Soil

2.3.1. *The Boundary of the Soil.* Deeks, Jingbo Liu [5] [6] propose the viscous-spring artificial boundary. In seismic response analysis, we should intercept limited soil area, in which we establish a viscous-spring artificial boundary, and its equivalent to continuous spring-damping system that distribute on artificial boundary.

2.3.2. *The Size of Soil Element.* When using time history analysis method to calculate a model, the soil element size have a great influence on the calculation result and the convergence. If the grid size of the soil element is too small, it will increase the number of degrees of freedom, computing time growth, the results may be difficult to convergence; In contrast, soil element size is too big, it will have a significant impact on the high-frequency seismic waves. Finally, it will make a great error of results. Generally, for the S-wave, element height should satisfy the following relation [7]:

$$H_{\max} = \left(\frac{1}{5} - \frac{1}{8}\right)\lambda_{\min} \quad (1)$$

$$\lambda_{\min} = \left(\frac{1}{5} - \frac{1}{8}\right)V_s / f_{\max} \quad (2)$$

Where, λ_{\min} is called minimum wavelength; V_s is called shear wave velocity of the soil; f_{\max} is called the highest frequency.

3. A numerical example

3.1. Project Overview

In this section, the example is a straight tower of drum shape, the height of the tower is 48.4m, the size of the transmission tower at the bottom is 11.6m* 11.6m, one tower legs with one pile, the length of the pile is 10m, radius of the pile is 0.3m, Angle steel of transmission tower used in the model are Q235 and Q345. Plan measure of the transmission tower was shown in Figure 1.

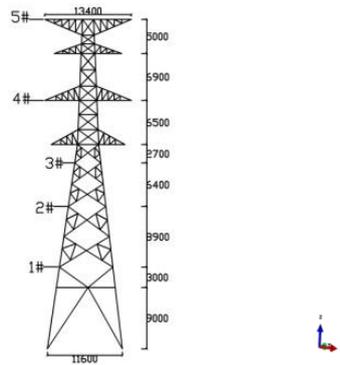


Figure 1. The measure of transmission tower/mm

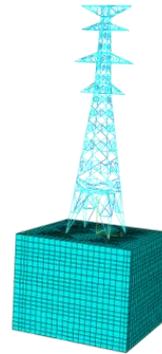


Figure 2. Model of pile-soil-transmission tower coupling

3.2. The Establishment of The Finite Element Model

This article is based on pre-treatment procedures of ABAQUS, use which to create one three-dimensional model of transmission tower (referred to as TW), and two pile-soil-transmission tower dynamic interaction model (referred to as PST1, PST2). It is correspond to the two types of site classification in Table 1.

Table 1 Parameters of four kinds of site soil

Serial number	Thickness (m)	Shear wave velocity (m/s)	Density (kg/m ³)	Elastic modulus (MPa)	Cohesion (Pa)	Internal friction angle
1	5	560	2000	1505.3	25000	15
	5	580	2100	1695.5	35000	20
	10	590	2200	1838	50000	25
2	5	100	2000	48	25000	15
	5	120	2100	72.6	35000	20
	10	130	2200	89.2	50000	25

According to the literature [8] the length, width and height of soil area which we need to calculate is respectively 30m, 30m and 20m. According to formula (1), (2) we can calculate the height of soil element. Take 10HZ as f_{max} , equivalent shear wave velocity of two categories of site soil are 118.6m/s and 579.7m/s. The article is selected 2m as the height of soil element. Finite element model of pile-soil-structure is shown in Figure 2.

3.3. Modal Analysis

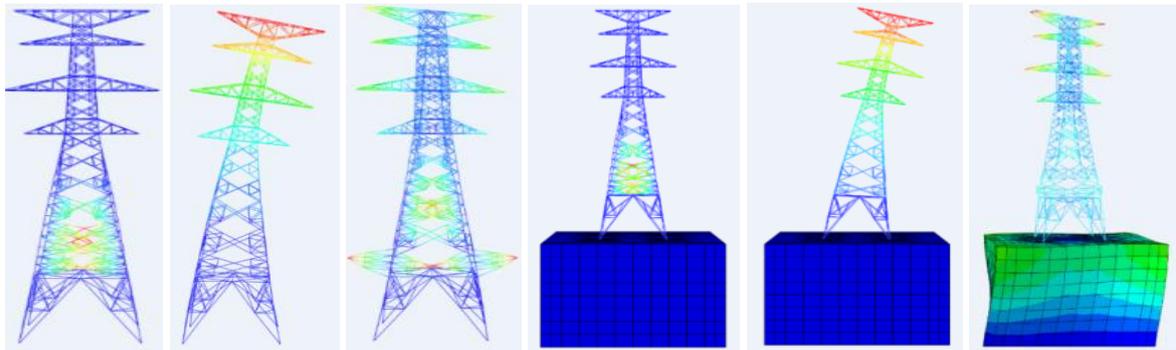
To study the dynamic response of the whole structure of the transmission tower, firstly we should analysis the dynamic characteristic. Table 2 shows five natural cycle of the two kinds site conditions. As can be seen from the table, after considering pile-soil-structure interaction, natural period increased compared with the structure that no considering the interaction. With the softening of the site conditions, the rate of increase of natural period gradually increases. This shows that after taking into account the interaction, the nature period becomes long compared with no considering the interaction. The more soft ground conditions is, the effect of natural period is more significant.

Table 2 The nature period

	T1/s	T2/s	T3/s	T4/s	T5/s
TW	0.383	0.379	0.246	0.184	0.183
PST1	0.499	0.496	0.246	0.191	0.189
PST2	0.687	0.645	0.642	0.635	0.634

Figure 3 (a), (b), (c) is the 1, 3, and 6 mode of TW model. As can be seen from the figure, The first mode is lateral displacement deformation, the first mode is local bending deformation, and the third mode is Local bending deformation and torsional deformation.

Figure 4 (d), (e), (f) is the 1, 5, and 7 mode of PST model. Respectively corresponding to 1, 3, 6 mode of TW model. We can see from the figure that after considering soil-pile-structure dynamic interaction, the mode of the structure lagged when compared with no considering the interaction.



(a) First mode (b) Third mode (c) Sixth mode (d) First mode (e) Fifth mode (f) Seventh mode
Figure 3. The modes of TW model **Figure 4.** The modes of PST model

3.4. Time history analysis under seismic load

Seismic Response Analysis commonly used response spectrum method and time history analysis. Response spectrum method and time history analysis method are used to analysis the seismic response of structures. The response spectrum method can only solve the maximum response of the structure, and the time history analysis can get the response of the structure in the time of the whole seismic load. So the time history analysis method is adopted in this paper.

According to the current seismic code of our country, the principle of choosing the seismic wave is that the main period of the seismic wave must be similar with the remarkable period of the construction site, so that the characteristic of the input earthquake wave is consistent with the condition of the construction site soil. According to the above principles we select two natural earthquake records as shown in table 3, Corresponding to the two sites in Table 1. The duration that we selected is 20s. Two kinds combination of working condition was calculated in this paper as shown in Table 4.

Table 3 Two natural seismic records

Serial number	Earthquake	Magnitude	Recording point	Peak value	Site class
1	Tangshan aftershock	6.3	Qian'an	118.9	Hard soil site
2	Tangshan aftershock	7.1	Ninghe	200	Soft soil site

Table 4 Case combination

Case combination	Work condition 1	Work condition 2
Computational model	PST1	PST2
Seismic record	1	2

Figure 5 is the time history of displacement curve at the top of tower under the two work conditions, and they are in sharp contrast. It can be seen from the figure that, when considering the pile-soil-structure interaction, the maximum value of the top displacement of the tower under the two conditions is larger, and the peak time of displacement appeared in advance compared with no considering the interaction.

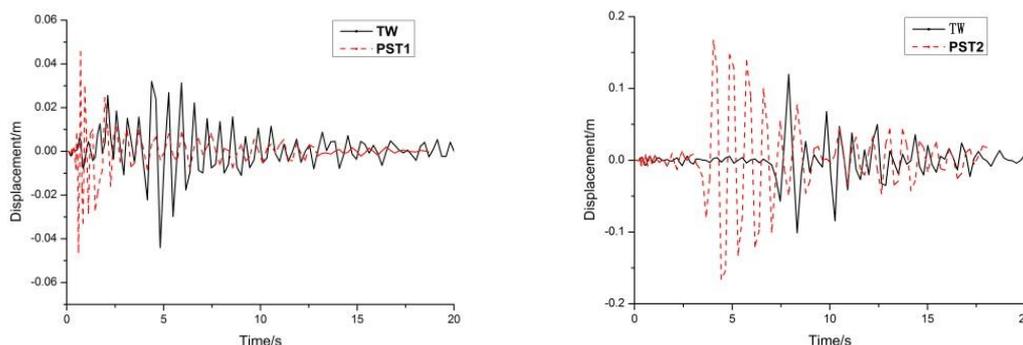


Figure 5. Time history response of displacement at the top of the tower under two kinds of work conditions.

Table 5 lists the maxima of nodes displacement of TW and PST model two conditions, Data observed in Table 5, we can obtain the following conclusions: after considering pile-soil-structure interaction, the maximum value of displacement at the top of the tower has been increased, and with the increase of the height, the relative increment of the nodal displacement becomes smaller, and the absolute increment of the nodal displacement is increasing.

Table 5 the maximum value of nodal displacement under each work condition

		The maximum value of nodal displacement /cm				
Node		1	2	3	4	5
Condition 1	TW	0.275	0.704	1.202	2.31	4.396
	PST1	0.632	1.275	1.846	2.675	4.575
	H%	129.82	81.11	53.58	15.80	4.07
Condition 2	TW	0.806	2.049	3.413	6.412	11.967
	PST4	2.8	5.299	7.385	11.021	16.732
	H%	247.39	158.61	116.38	71.88	39.82

4. Conclusions

In this paper, the seismic response of the transmission tower considering pile-soil-superstructure interaction is studied by using the time history analysis method, and it is compared with the seismic response of transmission tower under the condition of rigid foundation, Draw the following conclusions:

- (1)After considering the pile-soil-structure dynamic interaction, the nature period of the structure becomes longer, and the mode lag.
- (2)In the soft soil site, considering the dynamic interaction of the pile-soil -transmission tower, the absolute increment and the relative increment of the displacement and velocity at the top of the tower are obviously increased; the stress at the root of the transmission tower is increased. Thus, in soft soil site, pile-soil-structure dynamic interaction has great influence on the seismic performance of transmission towers. Full consideration should be given to the seismic design of transmission towers in this area.
- (3)In the hard soil site, the dynamic interaction between pile-soil-structure is very small and can be neglected in the seismic response of transmission towers

5. References

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