where

$m(z)$, $A(z)$ are the lumped mass and wind area respectively at the height of z;

g is the Peak factor, generally between 2 ~ 2.5,implying a value of 2.2 here;

$\sigma_a(z)$ is the Acceleration mean square error at the height of z,which can be gained by the time history analysis.

The calculation of WVC in ASCE No.74-2009 (2009) may be determined from the following equations:

$$G_t = 0.7 + 1.9E\sqrt{B_t} \tag{9}$$

where

$$E = 4.9\sqrt{\kappa}\left(\frac{33}{z_0}\right)^{1/\alpha}$$

$$B_t = \frac{1}{1 + 0.375h / L_s}$$

where z_0 is the effective height, h is the total tower height; α is power law exponent; κ is surface drag coefficient and L_s is turbulence scale.

The calculation of WVC in EN 50341-1-2001 (2001) can be calculated as follows:

$$G_q = (1 + 2.28 / \ln\frac{h}{z_0})^2 \tag{10}$$

where *h* is the height above ground; z_0 is the ground roughness parameter.

WVC in DL/T5154-2012 (2012) can be obtained from the following process. When the height of the tower is not more than 60 m, the wind load adjustment coefficient can be obtained from Table 6 and the whole tower adopts a uniform WVC, when the height of the tower is more than 60m, the value of WVC increases from bottom to top along the tower according to GB50009-2012 (2012). But its weighted average should be greater than 1.6, otherwise need to be adjusted.

Table 6 Wind load adjustment coefficient

Tower height H/m		20	30	40	50	60
β_z	single guyed tower	1.0	1.4	1.6	1.7	1.8
	other tower	1.0	1.25	1.35	1.5	1.6

Footnote: (1) According to the linear interpolation method to calculate the median; (2) For the self supporting tower, the value is only for that with the ratio between height and root in 4 ~6.

The WVC in GB50135-2006 (2007) is the result of further simplification to the Calculation process in GB50009-2012 (2012) according to the characteristics of the high-rising structure.

Due to the width of the structure in the windward is not so large, the height is the only variable in the expression of the WVC:

$$\beta_z = 1+\xi_1(\zeta_1,\omega_0 T_1^2)\nu(\alpha,H)\frac{\phi_1\left(\frac{z}{H},\frac{l_x(H)}{l_x(0)},e\right)}{\mu_z(\alpha,z)}\cdot\theta_\nu\left(\frac{l_x(H)}{l_x(0)}\right)\theta_B\left(\frac{l_x(z)}{l_x(0)}\right)$$

$$=1+\xi_1(\zeta_1,\omega_0 T_1^2)\frac{\nu(\alpha,H)}{\mu_z(\alpha,H)}\frac{\phi_1\left(\frac{z}{H},\frac{l_x(H)}{l_x(0)},e\right)}{\left(\frac{z}{H}\right)^{2\alpha}}\cdot\theta_\nu\left(\frac{l_x(H)}{l_x(0)}\right)\theta_B\left(\frac{l_x(z)}{l_x(0)}\right)$$

$$=1+\xi_1\left(\zeta_1,\omega_0 T_1^2\right)\varepsilon_1\left(\alpha,H\right)\varepsilon_2\left(\frac{z}{H},\frac{l_x(H)}{l_x(0)},e,\alpha,\frac{l_x(z)}{l_x(0)}\right)$$

$$=1+\xi_1\varepsilon_1\varepsilon_2 \tag{11}$$

Write Eq. (11) as below:

$$\beta_z = 1+\xi\varepsilon_1\varepsilon_2 \tag{12}$$

Where

ξ is the fluctuation amplifying coefficient;

ε_1 is the fluctuating wind pressure and wind pressure height influence coefficient;

ε_2 is the vibration mode and the structure shape influence coefficient.

5.2 Calculation result

WVC adopts a uniform value along the height according to ASCE No.74-2009 (2009). The calculation result is shown in Table 7.

Table 7 WVC in ASCE No.74-2009

h/ft	κ	α	z_0	L_s /ft	E	B_t	G_t
175.52	0.005	7	117.02	220	0.29	0.76	1.18

The result of WVC in EN 50341-1-2001 (2001) is shown in Tabe 8. The terrain category is Ⅱ and ground roughness parameter z_0 is 0.05 in this code.

Table 8 WVC in EN 50341-1-2001

h /m	z_0	G_q
53.5	0.05	1.76
50.5		1.77
48		1.77
42.88		1.79
37.75		1.81
27.25		1.85
18.25		1.92
10.75		2.03
4.15		2.30
2.075		2.60

The calculation result of WVC in GB50135-2006 (2007) is shown in Table 9. For guyed tower, the ratio between top and bottom width is greater than 1, the value of ε_2 is calculated with the ratio of 1.

Table 9 WVC in GB 50135-2006

height	ξ	ε_1	ε_2	β
53.50	2.66	0.52	1.00	2.37
50.50			0.94	2.30
48.00			0.89	2.23
42.88			0.80	2.10
37.75			0.70	1.97
27.25			0.50	1.70
18.25			0.34	1.47
10.75			0.20	1.28
4.15			0.07	1.11
2.075			0.04	1.05

Based on the linear interpolation method, a uniform WVC is adopted along the whole height according to DL/T5154-2012 (2012). The value of β is 1.735 here.

The calculation result of WVC of single guyed tower and transmission tower line system by time history analysis is showen in Table 10 and Table 11.

Table 10 WVC of single tower

height/m	weight/kg	$\sigma(z)$/m·s^2	μ_s	μ_z	ω_0/N·m^2	$A_Z(z)$/m^2	β	note
53.5	72.86	0.7	1.30	1.71	456	0.58	1.19	--
50.5	637.43	0.54	1.30	1.68	456	3.35	1.23	position of cross arm
48	1047.15	0.46	1.30	1.65	456	4.51	1.24	position of cross arm
42.875	706.99	0.33	1.30	1.59	456	2.77	1.20	position of guy
37.75	494.36	0.33	1.30	1.53	456	2.55	1.16	position of guy
27.25	519.33	0.63	1.30	1.38	456	2.92	1.30	--
18.25	449.21	0.76	1.30	1.21	456	2.52	1.41	--
10.75	366.62	0.65	1.30	1.02	456	2.08	1.42	--
4.15	222.98	0.34	1.30	1.00	456	1.28	1.22	--
2.075	94.99	0.21	1.30	1.00	456	0.54	1.14	--

Table 11 WVC of transmission tower line system

height/m	weight/kg	$\sigma(z)$/m·s^2	μ_s	μ_z	ω_0/N·m^2	$A_Z(z)$/m^2	β	note
53.5	72.86	0.35	1.30	1.71	456	0.58	1.10	--
50.5	637.43	0.28	1.30	1.68	456	3.35	1.12	position of cross arm
48	1047.15	0.24	1.30	1.65	456	4.51	1.13	position of cross arm
42.875	706.99	0.18	1.30	1.59	456	2.77	1.11	position of guy
37.75	494.36	0.18	1.30	1.53	456	2.55	1.09	position of guy
27.25	519.33	0.52	1.30	1.38	456	2.92	1.25	--
18.25	449.20	0.58	1.30	1.21	456	2.52	1.32	--
10.75	366.61	0.43	1.30	1.02	456	2.08	1.28	--
4.15	222.98	0.17	1.30	1.00	456	1.28	1.11	--
2.075	94.99	0.10	1.30	1.00	456	0.54	1.07	--

The calculation result above studies is shown in Fig. 8. The result indicates that the value in EN 50341-2001 and DL/T5154-2012 is mare than that of time history analysis and is relatively conservative; the value on one third of the hejight of the tower in GB 50135-2006 tends to insecure and the rest is also conservative compared with the result of time history analysis; The value in ASCE No.74-2009 is close to that of time history analysis but is uniform and relatively unsafe.

Meanwhile, the comparison of WVC between single tower and transmission tower line system is shown in Fig. 9. The result shows that the value of single tower is more than that of transmission tower line system.

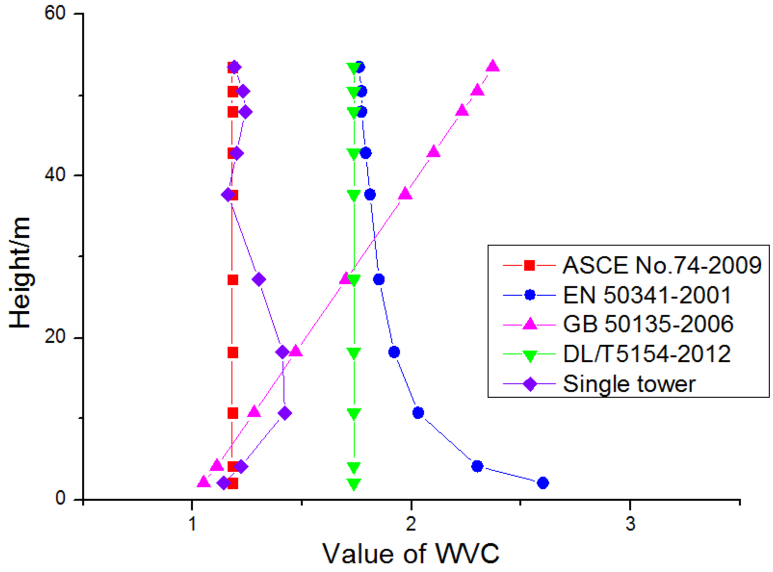

Fig. 8 Comparison of WVC

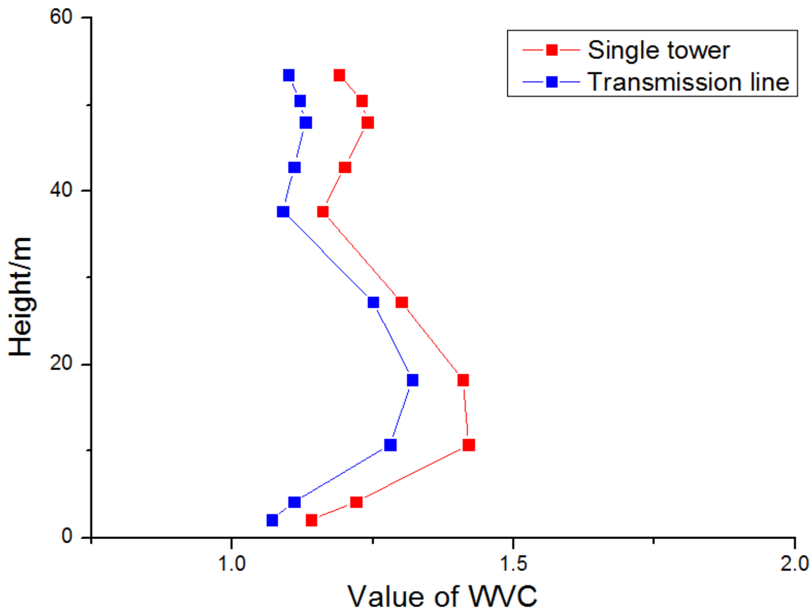

Fig. 9 Comparison of WVC

From the analysis results of single guyed tower, the change of WVC of guyed tower is relatively uniform along the height, but has mutations in the position of the guys, because the shape of the guyed tower is very different from that of traditional self-supporting tower. Under the restraint of the guy, the WVC is reduced and changes slowly near the position of the guy. In the cross arm where the quality and wind area are constrated, the value of WVC is influenced by guys and becomes tiny, but is more than that at the top of the tower. The max of WVC appears in the position of 10～20 m, where the wind vibration force is significantly greater than that in other parts of the tower. Thus for guyed tower with reverse size, the WVC has a difference in the current code, which cannot accurately reflect the change of WVC along the height of such structure.

The result of time history analysis of transmission tower line system shows WVC of the transmission tower line system is smaller than that of the single tower at the same height. However the same as single tower, max of wind vibration force appears is at one third of tower height below the guy and max of WVC is 1.32. Therefore, the conductor and ground wire have a weakening effect for the wind-induced vibration response of guyed tower and thus WVC that is obtained according to the result of single tower can meet the designing demand.

6. CONCLUSIONS

This paper established the guyed tower model by SAP2000 and AR method is used to simulate the random wind dynamic loads based on object-oriented programming language. Then the simulation of wind load applied on guyed tower as the input for nonlinear time history analysis and the main conclusions are as follows:

- The bottom of the guyed tower is inverted cone, which is easy to lead to torsional deformation of the structure along the height direction, so it should be paid attention to increase the torsional stiffness of the bottom of the tower. Besides, more likely transversal first order bending vibration appears for the guyed tower. In addition, due to the coupling effect between the conductor and the tower, frequency of the same mode is reduced and period is increased.
- The time history analysis result of transmission line shows that the conductor and ground wire have a weakening effect for the wind-induced vibration response of guyed tower and the value of WVC is reduced. So it is realistic to adopt the transmission line model for analysis.
- The WVC has been calculated and the value of design has been recommended in this paper. Using time history analysis method to evaluate the wind resistance of guyed tower can yet be regarded as a relatively accurate method.

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