Research Article

Wind Field Characteristics of Butte and the Influence on the Wind-Induced Responses of Transmission Towers

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The computational fluid dynamics (CFD) simulation on the butte was carried out to obtain the wind field characteristics for a specific mountain in the hilly area of eastern China. Then, the speed-up ratios of butte at each location distributed by height were calculated. The simulation results were compared with the specified value of mountain wind field acceleration ratio in various codes. The finite element model of the transmission tower line system is established by ANSYS, and the wind-induced vibration response of the structural system under the single mountain wind field is calculated, which is compared with the results of flat ground. The results show that the mountain will hinder the fluid passing through it. There is a deceleration zone in front of the mountain and a flow separation phenomenon behind the mountain. The speed-up ratios at the butte top where accelerating effect are the biggest among all positions of the butte. As the height increases, they approach 1. The speed-up ratios calculated by the Chinese code and the Australian code are linearly changing along the ridge of the butte and are symmetric at the windward side and leeward side. The biggest speed-up ratios are calculated by the Chinese code, and the smallest ratios are calculated by CFD. The wind-induced vibration response of the transmission tower line system is influenced by the wind speed-up ratios and reaches the maximum at the top of the butte. The simulation results at the windward side are close to the values calculated by the Australia code and the Euro code, but at the top and leeward side, they are far smaller than others.

1. Introduction

The topography of China is high in the west and low in the east with rolling country and plains in the east, which has obvious characteristics of the mountain wind field. As the carrier of cross-regional power transmission, the transmission tower line system will inevitably be built on the mountain, which is correspondingly related to the influence of complex geological/natural environments [1–3]. Transmission tower belongs to the category of high-rise structure which has flexible stiffness and is very sensitive to wind load effect [4, 5]. For high-rise structures with complex shape and high height, it is necessary to consider not only the downwind wind load but also the vortex caused by the flow effect under the crosswind load or even temperature effect [6–8]. The alternating vortex shedding generates the pulsating loads, and when it is close to the natural frequency of the structure, it will lead to crosswind vortex-induced resonance (VIR), which would do tremendous harm to the transmission tower [9]. At the same time, the mountain wind field is much more complicated considering its unique and changeable geometry and the interaction between rocks and ground. The wind field characteristics of the atmospheric boundary layer will accelerate the incoming wind speed in some areas above the mountain surface after being disturbed by the terrain, resulting in the acceleration effect [4]. Such changes may have an adverse impact on the stability of transmission lines. Therefore, it is of great value to study the wind action and wind-induced response of transmission tower line system in mountainous terrain.

So far, the research on the impact of mountain wind on structures is still in its infancy. Most of the researches are mainly focused on the mountain wind field characteristics [6–8] and established microclimate analysis system over
complex terrain by using numerical simulation methods such as turbulence model and finite volume method in order to predict local weather conditions [10]. Kikuchi et al. modified the terrain factor, which is related to the wind direction variation, and proposed the terrain change coefficient to represent the difference of terrain factors [11]. Bitsuamlak et al. reviewed numerical evaluation of wind flow over different types of topographies with various boundary conditions, grid type and density, and suggested that the numerical results agreed with field data better on the up-stream as opposed to the downstream areas of complex terrain [12]. However, there are fewer studies reported on the impact of wind load on structures under mountain wind field. Li et al. [13] presented the discrete variables-based topology combination optimization (TCO) method and layer combination optimization (LCO) method to optimize the long-span transmission tower structure. Okamura et al. confirmed the factors which have a great impact on the response of transmission tower through actual measurements [14]. Ronaldo C et al. used the 3D finite element (3D-FEM) model to analyze the dynamic coupled behavior of transmission towers under wind load [15]. Huang et al. [16] used a hybrid numerical simulation method to predict the typhoon wind field over complex terrain; they found that, after taking the effect of topography into account, the hybrid numerical simulation method can give a better prediction of the hourly mean wind speed and direction. To make full use of mountain environmental resources, in recent years, the efficient combination of geotechnical engineering design [17–20] and related mountain construction projects has further enhanced the complexity of the mountain environment where the transmission tower is located [21–25]. Based on the actual environmental conditions of undulating terrain, it is necessary to fully study the impact of external actual soil and mountains on the wind site of the transmission tower.

1.1. Three-Dimensional (3D) Modelling and Boundary Setting of Butte

1.1.1. Numerical Modelling. Since a two-dimensional (2D) mountain wind field cannot accurately describe the wind movement process in the whole space, this paper chooses to simulate a three-dimensional (3D) axisymmetric butte for the wind field calculation. The selected mountain model is a 3D cosine typical butte with a diameter of 400 m at the bottom and a height of 100 m. The mountain contour can match the following equation:

\[
z(x, y) = H \cos \left[ \frac{\pi(x^2 + y^2)^{0.5}}{D} \right],
\]

where \( z \) is the coordinate of mountain height direction; \( x \) and \( y \) refer to the horizontal coordinate; \( H \) is the height of the mountain; \( D \) is the diameter of the bottom of the mountain.

The combination of Gambit and ICEM was utilized to establish the 3D mountain terrain calculation domain model with a size of 4 km × 3 km × 1 km \((x \times y \times z)\). This model is centered on the mountain top; the calculation domain size is 1.6 km upstream and is 2.4 km downstream with a blocking rate of less than 3%. The illustration of the 3D model is shown in Figure 1. The ICEM CFD hexahedral structured grid is used to grid division of the computational area in the whole flow field.

After grid independence verification, the grid division is determined as follows: the grid resolution of the calculation area, which is centered on the top of the mountain within 600 meters along and perpendicular to the flow direction, is 4 m and is increased at a growth rate of 1.05 times in outward direction, the grid at the inlet and side of the flow field is increased to 30 m, and the grid at the outlet of the flow field is increased to 40 m. In the vertical direction, the height of the first layer grid is selected as 2 m, the growth rate is 1.05, and the resolution of the top grid is 30 m. The overall number of grids is about 6.045 million. The grid of the 3D single mountain computing domain is shown in Figure 2 from which we can find that the grid has a good mesh fit.

1.2. Boundary Conditions and Numerical Algorithms. It is assumed that the negative direction of the \( x \)-axis is the incoming wind direction. Due to the large turbulence in the atmospheric boundary layer, a standard \( k-\varepsilon \) calculation turbulence model then is utilized to correctly simulate the mountain wind field, in which the average wind speed profile, the turbulence intensity, and the turbulent kinetic energy could be expressed as

\[
u = \frac{u_*}{k} \sqrt{C_1 \ln \left[ \frac{z + z_0}{z_0} \right]} + C_2,
\]

\[
k = \frac{u_*^2}{\sqrt{C_{\mu}} \sqrt{C_1 \ln \left[ \frac{z + z_0}{z_0} \right]}} + C_2,
\]

\[
\varepsilon = \frac{u_*^3}{\kappa (z + z_0)} \sqrt{C_1 \ln \left[ \frac{z + z_0}{z} \right]} + C_2,
\]

where \( u_* \) is the ground friction speed; \( \kappa \) is the von Karman constant, usually taken as 0.4; \( z_0 \) is the ground rough length; \( z \) refers to the height; \( C_\mu \) is the turbulence model constant, usually taken as 0.09; \( C_1 \) and \( C_2 \) are constants, which can be obtained by the fitting results of the measured turbulence data. The other parameters are the same as those mentioned before.

Setting the computational boundary needs to be considered before the numerical simulation of mountain terrain [26–28]. The side and top surfaces of the calculation area are set as symmetrical boundary conditions according to engineering experience [29, 30]. It is considered that the gas flow to the outlet plane has been fully developed and set as the free outflow boundary condition. The ground is considered to be no-slip, so the no-slip wall boundary condition is adopted for the lower interface, and the wall roughness height \( k_\varepsilon \) is taken as 0.2. The gas is an incompressible fluid, and the velocity inlet is selected as the inlet interface. The self-preservation of the inlet wind velocity profile before reaching the peak is the premise to ensure the accuracy and
reliability of the complex terrain numerical simulation. Therefore, it is necessary to understand the self-preservation of the inlet profile before numerical calculation.

The distance from the inlet to the butte edge along the flow direction is 1.4 km. Therefore, the average wind velocity and turbulent kinetic energy profiles at the inlet and 1.4 km away from the inlet are selected to observe the self-preservation of the inlet wind velocity profile and turbulent kinetic energy profile (the average wind velocity at 10 m height is 18 m/s). The obtained results are shown in Figures 3 and 4.

It can be found from the above data that the inlet wind velocity profile error is the largest at 5 m height with a value of 11.67% and an error at about 2.67%. The maximum inlet turbulent kinetic energy profile error is obtained at the ground, which is 29.83%, with an average error at about 5.14%. The error is affected by the bottom boundary conditions of the calculation domain. The closer to the bottom, the greater the influence of the bottom boundary conditions and the greater the error. From the above results, it can be considered that the inlet profile at other heights is in good self-preservation condition except below 10 m, which lays a foundation for subsequent numerical calculation.

1.3. Numerical Simulation of the Butte Wind Field Characteristics. The mountain wind field is obtained by CFD numerical calculation [31–33], including many laboratories’ experimental verification under complex stratum conditions [34, 35]. The wind velocity clouds are intercepted at different heights from the mountain surface and the longitudinal section velocity clouds at the mountain peak in the downstream field direction of the calculation area. Figure 5 shows the wind speed clouds at sections 10 m and 100 m away from the mountain surface, and Figure 6 shows the wind speed clouds at the longitudinal section of the mountain.

It can be seen from Figures 5 and 6 that the flow direction of the whole field is from left to right. The inlet wind velocity profile has been fully developed before reaching the butte. After passing through the mountain, the flow field has been fully developed due to the long distance from the terrain to the outlet. As the wake flow at different heights is basically dissipated, it has no adverse impact on the flow field near the terrain. Besides, since the side and top surfaces are far enough from the terrain, their boundary conditions have no obvious effect on the flow field at the terrain boundary. At the same time, due to the mountain blocking effect, there

Figure 1: Schematic diagram of mountain calculation domain.

Figure 2: Mountain meshing: (a) mountain overall computing domain grid; (b) mountain local grid.
exists a large deceleration zone in front of the butte when the wind flows through. In addition, the wind velocity increased significantly at the mountain peak, forming an acceleration zone, and there is an obvious flow separation phenomenon on the leeward slope, resulting in an eddy current.

Figure 7 shows the wind velocity acceleration ratio along the ridgeline of the windward and leeward mountain foot, the windward and leeward half mountain top, and the mountain top (i.e., the ratio of the wind velocity at z height from the mountain surface to the wind velocity at the same height on the flat ground) obtained from the CFD calculation. The following can be found: (1) The wind acceleration ratio at the top of the mountain is the largest, greater than 1, and decreases with the increase of the height. (2) The wind acceleration ratio at the windward half mountain is greater than that at the leeward half mountain below 100 m and is slightly greater than 1, while the wind acceleration ratio at the leeward half mountain is less than 1 below 50 m height, greater than 1 above 50 m, and tends to approach 1. (3) The wind acceleration ratio at the mountain foot is the smallest, which is generally less than 1, and tends to approach 1 with the increased height.

1.4. Provisions and Comparison of Mountain Wind Field Characteristics in the Code

(1) The variation law of mountain wind field in China’s load specification for building structures is considered by the topographic correction coefficient of wind pressure height variation coefficient. For the butte peak, the correction coefficient can be calculated according to the following formula [36]: 

$$\eta_B = \left[1 + \kappa \tan \alpha \left(1 - \frac{z}{2.5H}\right)^2\right],$$

where \(\tan \alpha\) is the slope of windward hillside or windward butte peak. When \(\tan \alpha > 0.3\), it is taken as 0.3; \(\kappa\) is the coefficient, usually taken as 2.2 for mountain peaks and 1.4 for hillsides; \(H\) is the mountain height; \(z\) is the height from the calculated position of the building to the ground. When \(z > 2.5H\), \(z\) is taken as 2.5 \(H\). The correction coefficient of the starting point before and after the mountain is 1, and the correction coefficient of other positions on the mountain is determined according to linear interpolation.

(2) In the European specification EN2004-1-4, the mountain wind field is considered by the correction factor \(C_0\), which is based on wind velocity, and its values are as follows [37]:

$$C_0 = \begin{cases} 
1, & \varphi < 0.05, \\
1 + 2s\varphi, & 0.05 \leq \varphi < 0.3, \\
1 + 0.6s, & \varphi \geq 0.3,
\end{cases}$$

where \(\varphi = H/L_u\) is the peak windward slope; \(L_u\) is the horizontal distance of windward slope; \(H\) is the height of the mountain; \(s\) is the topographic coefficient.

(3) In Australian specification as AS/NZS1170.2:2011, the correction factor \(M_h\) based on wind velocity is adopted to consider the mountain wind field, and the value of \(M_h\) is as follows [38]:

When \(H/2L < 0.05\),

$$M_h = 1.0.$$  \(5\)

When \(0.05 \leq H/2L < 0.45\),

$$M_h = 1 + \frac{H}{3.5(z + L_1)} \left(1 - \frac{|x|}{L_2}\right).$$ \(6\)

When \(H/2L > 0.45\) and is in the flow separation area,

$$M_h = 1 + 0.7 \left(1 - \frac{|x|}{L_2}\right).$$ \(7\)
where $H$ is the mountain height; $L$ is the horizontal distance from the mountain top to half mountain windward side. $L_1$ is the larger one between $0.36L$ and $0.4H$; $L_2$ is taken as $4L_1$ for windward side, $10L_1$ for leeward hillside, and $4L_1$ for peak.

Actually, $M_h$ would be calculated according to formulae (5)–(7) when being outside the flow separation area. Based on the mountain characteristics selected in this work, the specified acceleration ratio is obtained through calculation. The wind acceleration ratios at 10 m and 100 m heights along the mountain ridgeline are given in the following, as shown in Figure 8. The following can be found: (1) Among the wind acceleration ratios calculated by the above three codes, the wind acceleration ratio at the mountain top is the largest, and the calculated value in the Chinese code is the largest. (2) The wind acceleration ratio at 10 m from the mountain surface on the ridgeline is greater than that at 100 m height. The wind acceleration ratio of the Australian code and the Euro code is basically the same at the height of 10 m from the top of the mountain, but the wind acceleration ratio of the Australian code is much smaller than that of the Euro code at 100 m height from the mountain top. (3) The data of wind acceleration ratio calculated by the Chinese and Australian codes are symmetrical on the windward and leeward sides, while the data obtained by the Euro code are asymmetric, and the data on the leeward side are slightly larger than those on the windward side. (4) In the whole process, Chinese norms and Australian norms presented an obvious linear change law.

Figure 9 shows the wind acceleration ratios calculated by various codes at the foot of the mountain on the windward and leeward sides, the middle of the mountain on the windward and leeward sides, and the top of the mountain, respectively. The following can be seen: (1) At the foot of the mountain, the calculated value of the Chinese code is 1, and the calculated value of the Australian code is less than 1, while that of the Euro code one is greater than 1, and the calculated values of the Euro code and the Australian code tend to be 1 with the increase of height. (2) On the leeward side, the data from the Euro code are greater than that of the windward side, the acceleration ratio from the Chinese code is the largest in the area below 120 m height in the middle of the mountain, and the data from the Euro code are greater than those from the Australian code. (3) On the windward side, the acceleration ratio from the Chinese code is the largest in the area below 180 m height in the middle of the mountain, and the data from the Euro code are greater than those from the Australian code, but the Australian code is greater than that from the Euro code below 30 m height. Meanwhile, the calculation data of various codes at the top of the mountain and the acceleration ratio obtained by CFD numerical simulation in this work are also given in Figure 9(c). It can be found that the data given by the three codes are greater than the CFD numerical calculation results at a height higher than 30 m, but the simulation value is larger at the lower height.

2. Influence of Butte Wind Field on Wind-Induced Response of Transmission Tower Line System

2.1. Transmission Tower Line System Model. The selected research object in this work is a 110 kV “T” shaped mixed voltage narrow base tower on a transmission line of the East China Power Grid. The transmission line model is based on the tower, with a length upstream and downstream of 200 m, respectively. The conductor is LGJ-300/40 steel cord aluminum strand, and the ground wire is JLBv20A-80.
aluminum clad steel strand. The tower height is 68.4 m, the
tower nominal height is 48 m, and the tower foundation size
is 3.5 m × 3.5 m. Q345 angle steel is used as the main material
and cross arm of the transmission tower. Q235 angle steel is
used as the inclined material and other auxiliary materials.
The section sizes of angle steel vary at different heights. The
tower columns are the main components under stress,
the components are bolted at both ends, and the trans-
mision tower and the base are connected by fixed ends. The
transmission line is the general name of transmission
cable and ground wire, which has the characteristics of
high flexibility and large deformation. Under the action of
gravity, the conductor (ground) fixed at two different points
will be in a catenary shape, and the model shall be treated
according to the provisions on sag in the design code. In
ANSYS, the beam element is used to simulate the main
stressed components of the transmission tower, and the rod
element is used to simulate other rods and transmission lines
to establish the finite element model of the transmission
tower line system, as shown in Figure 10. It is placed at
different positions of the mountain to analyze the response under wind load excitation.

2.2. Response Analysis of Transmission Tower Line System. The natural wind with an average wind velocity of 18 m/s at 10 m height is taken as the reference load; the Davenport wind velocity spectrum and the harmonic synthesis method are applied to simulate the fluctuating wind velocity, which is the time history of the fluctuating wind speed at the tower top simulated at the flat ground, as shown in Figure 11. The wind acceleration ratio under the mountain wind field calculated by the above code and CFD can be corrected to the simulated wind velocity and then generate the corrected wind load [39–44].

Input the load into the transmission tower line system finite element model to accomplish the dynamic time history analysis using ANSYS and generate the response of the transmission tower line system under a mountain wind field. The obtained data are shown in Table 1 and Figure 12.

The following can be seen from the above results: (1) The response variation law of transmission tower line system under mountain wind environment is basically the same, which is the largest at the top of the mountain and the smallest at the foot of the mountain. (2) The displacement magnification factor obtained from the Chinese code and the Australian code is symmetrical between the windward side and the leeward side. The displacement magnification factor from the Euro code on the windward side is smaller than that on the leeward side. The CFD calculation is opposite to that from the Euro code, and the windward side is larger. (3) The Chinese code is generally conservative and has the highest safety redundancy among various codes. CFD calculation data are close to the Australian and Euro codes on the windward side and smaller than other specifications on the leeward side.
3. Conclusions

The mountain blocks the movement of the fluid flowing through the mountain. There will be a large deceleration area in front of the mountain, and an acceleration area will be formed at the top of the mountain, which will increase the wind velocity. Besides, there appears an obvious flow separation phenomenon on the leeward slope, resulting in an eddy current. The wind acceleration ratio at the top of the mountain is the largest, greater than 1, and decreases with the increased height. The wind acceleration ratio at the windward half mountain below 100 m is greater than that at the leeward half mountain, and both are slightly greater than 1. The wind acceleration ratio at the leeward half mountain is smaller than 1 at 50 m high, greater than 1 at 50 m, and tends to approach 1. The wind acceleration ratio at the foot of the mountain is the smallest, which is smaller than 1, and tends to approach 1 with the increased height.

Table 1: Displacement response of transmission tower top.

|                     | Chinese code | Australia code | Euro code | CFD  |
|---------------------|--------------|----------------|-----------|------|
| Foot of windward mountain | 0.309        | 0.308          | 0.357     | 0.307|
| Windward half mountain    | 0.530        | 0.440          | 0.421     | 0.391|
| Mountain top             | 0.752        | 0.578          | 0.721     | 0.509|
| Leeward half mountain    | 0.530        | 0.440          | 0.472     | 0.364|
| Foot of leeward mountain | 0.309        | 0.308          | 0.359     | 0.267|

Figure 11: Fluctuating wind speed time history.

Figure 12: The displacement magnification factor of transmission tower top.
Compared with the specification data, the acceleration ratio specified in the Chinese and the Australian codes varies linearly with height and is symmetrical on the windward and leeward sides. The acceleration ratio on the windward side of the Euro code is lower than that on the leeward side. The acceleration ratio specified in the Chinese code is the largest.

Considering the response of the transmission tower line system, the results of CFD numerical calculation are smaller than those of various codes. On the windward side, they are close to the Australian and the Euro codes and far less than the code in other positions. The code has a large safety margin but increases the project cost to a certain extent which needs further optimization.

Data Availability
The data are available from the corresponding author upon reasonable request.

Conflicts of Interest
The authors declare that there are no conflicts of interest regarding the publication of this paper.

Authors’ Contributions
Yan Zhang contributed to the conceptualization and methodology; Wenfeng Huang and Lisha Wang contributed to the investigation.

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References
[1] Q. Zhou, B. Ma, Q. Zhu, and H. Zhang, "Investigation on wind loads on angle-steel cross-arms of lattice transmission towers via direct force measurement," *Journal of Wind Engineering and Industrial Aerodynamics*, vol. 191, pp. 117–126, 2019.
[2] B. Bai, Q. Nie, H. Wu, and J. Hou, "The attachment-detachment mechanism of ionic/nanoscale/microscale substances on quartz sand in water," *Powder Technology*, vol. 394, pp. 1158–1168, 2021.
[3] B. Bai, F. Long, D. Rao, and T. Xu, "The effect of temperature on the seepage transport of suspended particles in a porous medium," *Hydrological Processes*, vol. 31, no. 2, pp. 382–393, 2017.
[4] N. S. Fouad, G. H. Mahmoud, and N. E. Nasr, "Comparative study of international codes wind loads and CFD results for low rise buildings," *Alexandria Engineering Journal*, vol. 57, no. 4, pp. 3623–3639, 2018.
[5] A. Baghaei Daemei, E. M. Khotbehsara, E. M. Nobaran, and P. Bahrami, "Study on wind aerodynamic and flow characteristics of triangular-shaped tall buildings and CFD simulation in order to assess drag coefficient," *Ain Shams Engineering Journal*, vol. 10, no. 3, pp. 541–548, 2019.
[6] S. Roy and C. K. Kundu, “State of the art review of wind induced vibration and its control on transmission towers,” *Structures*, vol. 29, pp. 254–264, 2021.
[7] B. Bai, D. Rao, T. Xu, and P. Chen, "SPH-FDM boundary for the analysis of thermal process in homogeneous media with a discontinuous interface," *International Journal of Heat and Mass Transfer*, vol. 117, pp. 517–526, 2018.
[8] B. Bai and X. Shi, "Experimental study on the consolidation of saturated silty clay subjected to cyclic thermal loading," *Geomechanics and Engineering*, vol. 12, no. 4, pp. 707–721, 2017.
[9] L. Wang, S. Liang, G. Huang, J. Song, and L. Zou, "Investigation on the unsteadiness of vortex induced resonance of high-rise buildings," *Journal of Wind Engineering and Industrial Aerodynamics*, vol. 175, pp. 17–31, 2018.
[10] T. Ishihara, "A Nonlinear Wind Prediction Model MASCOT: Development and Application," *Journal of Japan Society of Fluid Mechanics*, pp. 387–396, 2003.
[11] Y. Kikuchi and T. Ishihara, "A study of topographic multiplier considering the effect of complex terrains and tropical cyclones," *Journal of Wind Engineering and Industrial Aerodynamics*, vol. 104-106, pp. 558–564, 2012.
[12] G. T. Bitsuamlak, T. Stathopoulos, and C. Bédard, "Numerical evaluation of wind flow over complex terrain: review," *Journal of Aerospace Engineering*, vol. 17, no. 4, pp. 135–145, 2004.
[13] H. Y. Guo and Z. L. Li, "Structural topology optimization of high-voltage transmission tower with discrete variables," *Structural and Multidisciplinary Optimization*, vol. 43, no. 6, pp. 851–861, 2011.
[14] T. Okamura, T. Okhuma, E. Hongo, and H. Okada, "Wind response analysis of a transmission tower in a mountainous area," *Journal of Wind Engineering and Industrial Aerodynamics*, vol. 91, no. 1-2, pp. 53–63, 2003.
[15] R. C. Battista, R. S. Rodrigues, and M. S. Pfeil, "Dynamic behavior and stability of transmission line towers under wind forces," *Journal of Wind Engineering and Industrial Aerodynamics*, vol. 91, no. 8, pp. 1051–1067, 2003.
[16] W. Huang and H. Zhou, "A hybrid numerical simulation method for typhoon wind field over complex terrain," *Wind and Structures*, vol. 18, no. 5, pp. 549–566, 2014.
[17] J. E. Ongodia, "Geotechnical Engineering Design of a Tunnel Support System - a Case Study of Karuma (600MW) Hydro-power Project, University of Cape Town, Western Cape, South Africa, 2017.
[18] P. G. Fookes, M. Sweeney, C. N. D. Manby, and R. P. Martin, "Geological and geotechnical engineering aspects of low-cost roads in mountainous terrain," *Engineering Geology*, vol. 21, no. 1-2, pp. 1–152, 1985.
[19] G. O. S. Medeiros, A. R. de Queiroz, R. M. Lima et al., ""Transmission towers spotting in power systems considering engineering and environmental aspects: a dynamic programming approach," *International Transactions on Electrical Energy Systems*, vol. 31, Article ID e13000, 2021.
[20] Q. Xu and X. He, "Geotechnical analysis of building foundation in beihai sand dam," *Journal of Coastal Research*, vol. 112, pp. 349–351, 2020.
[21] H. Junqueira, M. Robaina, S. Garrido, R. Godina, and J. C. O. Matias, "Viability of creating an offshore wind energy cluster: a case study," *Apply Science*, vol. 11, p. 308, 2021.
[22] K. Ha, "Dynamic response analysis of composite tether structure to airborne wind energy system under impulse load," *Apply Science*, vol. 11, p. 166, 2021.
[23] J. Jeong and K. Ha, "Numerical investigation of three-dimensional and vortical flow phenomena to enhance the power
performance of a wind turbine blade," *Apply. Science*, vol. 11, p. 72, 2021.

[24] B. Bai, G.-c. Yang, T. Li, and G.-s. Yang, "A thermodynamic constitutive model with temperature effect based on particle rearrangement for geomaterials," *Mechanics of Materials*, vol. 139, Article ID 103180, 2019.

[25] B. Bai, R. Zhou, G. Cai, W. Hu, and G. Yang, "Coupled thermo-hydro-mechanical mechanism in view of the soil particle rearrangement of granular thermodynamics," *Computers and Geotechnics*, vol. 137, Article ID 104272, 2021.

[26] Y. Wang and X. Chen, "Simulation of approaching boundary layer flow and wind loads on high-rise buildings by wall-modeled LES," *Journal of Wind Engineering and Industrial Aerodynamics*, vol. 207, Article ID 104410, 2020.

[27] X. Zhang, A. U. Weerasuriya, and K. T. Tse, "CFD simulation of natural ventilation of a generic building in various incident wind directions: comparison of turbulence modelling, evaluation methods, and ventilation mechanisms," *Energy and Buildings*, vol. 229, Article ID 110516, 2020.

[28] E. Buffa, J. Jacob, and P. Sagaut, "Lattice-Boltzmann-based large-eddy simulation of high-rise building aerodynamics with inlet turbulence reconstruction," *Journal of Wind Engineering and Industrial Aerodynamics*, vol. 212, Article ID 104560, 2021.

[29] B. Yuan, Z. Li, Z. Su, Q. Luo, M. Chen, and Z. Zhao, "Sensitivity of multistage fill slope based on finite element model," *Advances in Civil Engineering*, vol. 13, Article ID 6622936, 2021.

[30] B. Bai, D. Rao, T. Chang, and Z. Guo, "A nonlinear attachment-detachment model with adsorption hysteresis for suspension-colloidal transport in porous media," *Journal of Hydrology*, vol. 578, Article ID 124080, 2019.

[31] B. Bai, D. Rao, T. Chang, and Z. Guo, "A nonlinear attachment-detachment model with adsorption hysteresis for suspension-colloidal transport in porous media," *Journal of Hydrology*, vol. 578, Article ID 124080, 2019.

[32] Q. Zhou, Y. Zhu, Y. Wang, and J. Han, "CFD-based wind field correction method for terrain wind tunnel tests," *Journal of Physics: Conference Series*, vol. 2083, Article ID 32083, 2021.

[33] Y. Hua, W. Nie, Q. Liu, S. Yin, and H. Peng, "Effect of wind curtain on dust extraction in rock tunnel working face: CFD and field measurement analysis," *Energy*, vol. 197, Article ID 117214, 2020.

[34] B. Bai, Q. Nie, Y. Zhang, X. Wang, and W. Hu, "Cotransport of heavy metals and SiO2 particles at different temperatures by seepage," *Journal of Hydrology*, vol. 597, Article ID 125771, 2021.

[35] B. Yuan, Z. Li, Z. Zhao, H. Ni, Z. Su, and Z. Li, "Experimental study of displacement field of layered soils surrounding laterally loaded pile based on transparent soil," *Journal of Soils and Sediments*, vol. 21, no. 9, pp. 3072–3083, 2021.

[36] China Architecture & Building Press, *Load Code for the Design of Building Structures, GB 50009-2012*, China Architecture & Building Press, Beijing, China, 2012.

[37] European Committee for Standardization, *Actions on Structures: European Standard: EN 1991-1-4 [s]*, European Committee for Standardization, Brussels, UK, 2004.

[38] Department of Justice and Community SafetyConsumer Affairs Victoria, *Australian/New Zealand standard AS/NZS 1170. 2: AS/NZS[1], Department of Justice and Community SafetyConsumer Affairs Victoria, Sydney, NZ, 2011.

[39] L. Yang, J. I. Rojas, and A. Montlaur, "Advanced methodology for wind resource assessment near hydroelectric dams in complex mountainous areas," *Energy*, vol. 190, Article ID 116487, 2020.

[40] T. Ha, I.-b. Lee, S.-W. Hong, and K.-S. Kwon, "CFD assisted method for locating and processing data from wind monitoring systems in forested mountainous regions," *Biosystems Engineering*, vol. 187, pp. 21–38, 2019.

[41] D.-X. Zhao and B.-J. He, "Effects of architectural shapes on surface wind pressure distribution: case studies of oval-shaped tall buildings," *Journal of Building Engineering*, vol. 12, pp. 219–228, 2017.

[42] B. X. Yuan, Z. H. Li, Y. Chen et al., "Mechanical and microstructural properties of recycling granite residual soil reinforced with glass fiber and liquid-modified polyvinyl alcohol polymer," *Chemosphere*, vol. 268, Article ID 131652, 2021.

[43] M. Shirzadi, P. A. Mirzaei, and M. Naghashzadehgan, "Improvement of k-epsilon turbulence model for CFD simulation of atmospheric boundary layer around a high-rise building using stochastic optimization and Monte Carlo Sampling technique," *Journal of Wind Engineering and Industrial Aerodynamics*, vol. 171, pp. 366–379, 2017.

[44] M. Mifsud, A. Vendl, L.-U. Hansen, and S. Görzt, "Fusing wind-tunnel measurements and CFD data using constrained gappy proper orthogonal decomposition," *Aerospace Science and Technology*, vol. 86, pp. 312–326, 2019.