



Research on Vulnerability Evaluation of Overhead Transmission Line Tower in Coal Mine Goaf Based on InSAR Technology

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Abstract. As China's power state grid continues to expand, transmission line towers are significantly affected by the threat of mining activities. In order to deeply understand the effect of ground deformation induced by coal mine gouging collapse on the vulnerability of transmission towers, the transmission line towers within the coal mine area of Liupanshui City and Bijie City in Guizhou Province in southwestern China were studied as the research objects, and the transmission line towers around Hongxing Coal Mine were taken as an example, and the vertical settlement amount at the tower was obtained using SBAS-InSAR technology. Through on-site investigation, the damage classification level of the transmission tower in the coal mine gouging area was constructed. By introducing a log-normal distribution function, a nonlinear functional relationship between the accumulated vertical settlement amount of the tower and the tower damage probability is established, and the equivalent damage probability of the tower is calculated. The vulnerability of the tower is divided into five levels: extremely high, high, medium, low and extremely low. The vulnerability of the towers at 15 transmission towers within the surrounding area of the Hongxing Coal Mine was finally evaluated, and the evaluation results were consistent with the on-site investigation. This research results can provide a scientific basis for the construction of the power grid disaster prevention system and risk control in coal mine goaf area.

Keywords: mining subsidence, InSAR, transmission line tower, vulnerability evaluation

1 Introduction

As China's state power grid continues to expand, high-voltage transmission lines, as the aorta of energy transmission, must pass through mountains and rivers, and pass through areas with undulating terrain, complex geological conditions and harsh environment. As an important part of connecting this grid, overhead transmission line towers often pass through coal mine mining areas for various reasons, and there is a risk of being affected by human engineering activities^[1,2]. Mining subsidence formed in coal mine goafs are prone to cause structural deformation and failure such as tower foundation settlement and tower body inclination, resulting in chain reactions such as abnormal line spacing and failure of insulation devices. In severe cases, it may cause major accidents such as transmission line breakage and tower collapse^[3]. In recent years, many cases of tower instability have occurred in coal mining areas such as Ningxia, Shanxi, and Guizhou in China^[4-7]. Therefore, the risk assessment of the damage of overhead transmission line tower in coal mine goaf is very urgent^[8,9].

The risk assessment of overhead transmission lines mainly consists of two parts: the probability of tower failure and the vulnerability of towers. According to the definition of risk, $\text{Risk} = \text{Hazard} \times \text{Vulnerability}$ of the affected object. Assessment of the hazard of overhead transmission line towers due to natural disasters at home and abroad, multi-source data is used as evaluation factors, and comprehensive evaluation models are established using machine learning, GIS or numerical simulation technologies. The technology is relatively mature. At present, there are not many literatures on the vulnerability of power transmission towers. Zhu Yichuan et al.^[10] proposed a two-dimensional assessment framework for power grid vulnerability, integrating the structural properties of the towers (internal causes) and geological environmental stress (external causes) to form a grading map of geological disaster vulnerability at the municipal power grid in Yunnan Province in China. Zhang Yanyan^[11] established a dynamic evaluation model for vulnerability of transmission towers based on the analysis of the spatiotemporal characteristics of landslide disaster historical data, and realized risk iterative calculation in engineering scenarios through the quantification of safety risk entropy value. In addition, scholars from some Western and Central Asian countries^[12-15] have conducted research on the evaluation of the vulnerability of transmission line towers in natural disasters such as ground subsidence, wind disasters, ice disasters, and fires. However, there is a lack of in-depth research on the vulnerability evaluation of tower deformation and overturning damage during coal mine goaf mining process.

This paper selects the western coal mine area of Guizhou Province, China as the research scope, and takes the overhead transmission line towers within the impact range of the gouged mining in Hongxing Coal Mine as an example. The vulnerability of a single transmission line towers was evaluated using InSAR technology and probability function. The research results can provide a scientific basis for the construction of the power grid disaster prevention system and risk control in the coal mine gouged mining area.

2 Overview of the Study Area

Liupanshui City and Bijie City in Guizhou Province are adjacent to each other. They are located in the southwest of China and are one of the most important coal production bases in southern China. Long-term coal mining has formed a large area of coal mine goaf. The movement and deformation of the goaf ground (sinking, tilting, horizontal displacement, etc.) pose a direct threat to the stability of the transmission lines tower foundation. At the same time, as an important hub of China's "West-to-East Power Transmission" project, there are high-density ultra-high voltage transmission lines in Liupanshui City and Bijie City. The safe operation of transmission lines is crucial to regional energy transmission and economic development. The location of the study area is shown in Figure 1.

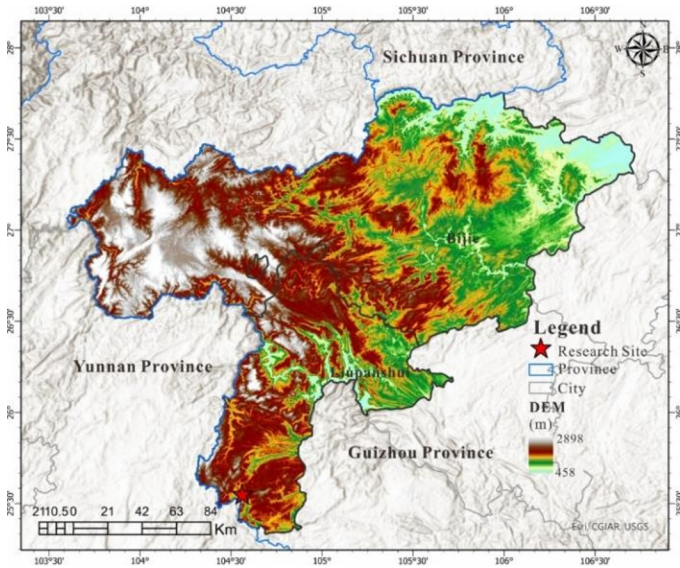


Fig. 1. Geographical location map of the study area.

Hongxing Coal Mine is located in Lemin Town, Pan County, Liupanshui City (see Figure 1. and Figure 2.). The Permian Longtan Formation in Lopingian is a coal-containing formation in the area, with a total of 12 coal seams that can be mined. At present, the coal seams have been mined are the 3rd, 5, 7, 9, 12, and 17 layers of coal. The coal mining method is to move towards a long wall backward type, and the mining technology is to comprehensive mechanized coal mining, and the entire collapse method manages the roof. There are currently 15 high-voltage transmission line towers around the coal mine area, of which 5 towers are located on the ground directly above the goaf area. 5 towers are located within the mine rights scope and directly above the coal mine tunnel, but outside the existing goaf area. 5 towers are located outside the mine rights scope. This study evaluates the vulnerability of these 15 towers under the current conditions of coal mines.

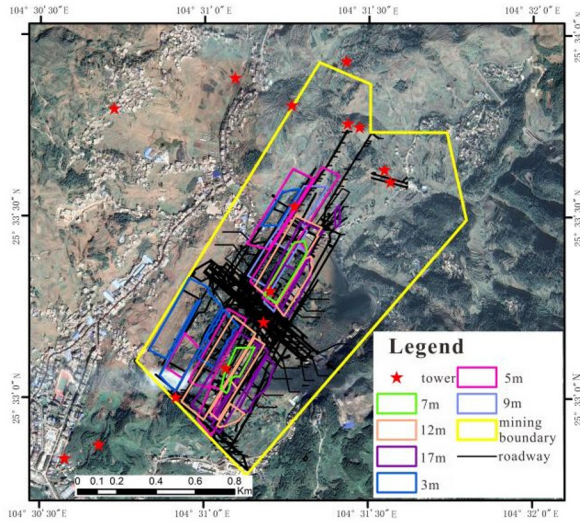


Fig. 2. Overview of the Hongxing Coal Mine Region. (In the legend, “7m” represents the 7th coal seam, and other values also represent the coal seam numbers. In Figure 4 and Figure 6, the same meaning is also shown)

3 Extraction of Ground Deformation Information Based on InSAR Technology

The vulnerability mainly evaluates the degree of deformation and damage of the transmission line tower. In the hole collapse area, the foundation of the transmission line tower is mainly based on vertical settlement deformation. The tower tilts due to the uneven settlement of the tower foundation. According to the industry standards of China's power grid, the inclination of the tower is an important indicator for judging the degree of damage to the tower. The calculation formula for tower inclination is:

$$I = \frac{d}{l} \quad (1)$$

In the formula, l is the horizontal distance of the tower foundation, and d represents the vertical settlement difference at the center point of the tower.

According to formula (1), the horizontal distance of the tower foundation is generally a constant value, and the inclination value of the tower can be calculated by knowing that d . Therefore, the evaluation of deformation and failure vulnerability of towers in the coal mine goaf transmission line can be determined by establishing a quantitative relationship between the degree of tower damage and the amount of ground settlement. There are many methods to determine the vertical settlement value of a tower, such as through manual measurement and automated monitoring equipment, but these methods can only measure a single tower separately, which has high labor intensity, low work efficiency and high cost. InSAR technology is currently widely used in coal mine goaf

ground deformation monitoring^[16-18], so this study chose InSAR technology with lower cost and better universality to obtain the vertical settlement value of the tower.

3.1 Data source of SAR Images

The SAR data obtained in this study are from the European Space Agency Sentinel-1A satellite, Interferometric Wide Swath mode (IW) Single Look Complex data (SLC). The polarization method adopts VV+VH, which is more suitable for the extraction of vertical deformation signals on the ground than multipolarization data. The data is obtained from the Alaska Satellite Facility (ASF) distributed archive center, using Ascending Track data, and supplemented with Precise Orbit Ephemerides (POD) for orbit error correction, effectively eliminating the impact of satellite platform position deviation on interference phase. This data combination ensures continuous surface observation capabilities through TOPS (Terrain Observation by Progressive Scans) orientation scanning technology, providing a data basis for regional scale deformation monitoring that combines high spatiotemporal consistency and millimeter-level measurement accuracy. The research period was from January 12, 2023 to July 29, 2024, and 128 track data were selected. The Sentinel-1A data-related parameters and SAR image coverage range in the study area are as follows Table 1.

3.2 InSAR Data Processing Method

Considering that SBAS-InSAR can analyze both linear deformation and nonlinear deformation in modeling, it is more suitable for deformation monitoring in mountainous areas than other InSAR technologies. Therefore, in this study, SBAS-InSAR method is used to monitor the ground deformation in the area where transmission lines and towers are located. The basic data processing steps are as follows:

- 1) SAR data preprocessing: geocoding and image registration are carried out by using precise orbit data file and DEM data to eliminate orbit error, unify data coordinates and ensure the accuracy of interference phase. DEM uses Japanese ALOS satellite data with a resolution of 12.5m, and the registration accuracy of DEM is required to be ≤ 0.5 pixels.

- 2) Determine the spatiotemporal baseline threshold and select the interference pair, with the temporal baseline threshold ≤ 60 days and the spatial baseline threshold ≤ 300 m.

- 3) Carry out differential interference processing, mainly including terrain phase removal, filtering, coherence calculation and phase unwrapping. Based on the Minimum-Cost Flow Algorithm, the global phase unwrapping is performed, and the coherence threshold of 0.55 is set to screen the effective unwrapping area.

- 4) Deformation inversion and post-processing: the linear model is used to remove the atmospheric phase, and the deformation rate matrix is solved by singular value decomposition (SVD) to obtain the deformation rate field.

3.3 Obtaining the Vertical Deformation of the Ground Ground in Hongxing Coal Mine Area

SBAS-InSAR technology was used to invert the ground deformation around the Hongxing Coal Mine area, and its annual average vertical settlement rate map was obtained (see Figure 3). From Figure 3, it can be seen that the ground settlement in the coal mine goaf is distributed in a funnel-like manner. The settlement rate in the central area is relatively high and the degree of settlement is relatively large. The settlement rate in the edge area extending outward gradually decreases. Two settlement funnels are mainly formed. The center of the largest settlement funnel is the mining area on the south side of the coal mine area. According to the collected coal mine data, the coal seams have been mined in this area are 5 layers, and the maximum settlement rate is -0.06m/a . The two settlement centers are about to connect to form a settlement funnel, and the deformation extends northward and gradually decreases. The settlement rate at the tower in the study area can be obtained through Figure 3. The ground of the towers outside the mining area has basically not shown any obvious deformation, while the ground of the towers inside the mining area has undergone large deformation. The ground of the towers No. 1, No. 2, No. 3 and No. 15 above the coal mine goaf area has the greatest deformation, with the settlement rates being -0.053m/a , -0.041m/a , -0.057m/a , and -0.036m/a , respectively.

Table 1. Basic parameters of Sentinel-1A satellite SAR imagery

parameters	Sentinel-1A
ascending/descending orbit	ascending
orbit	128
incident angle($^{\circ}$)	30.9-46
azimuth ($^{\circ}$)	-12.47
band	C
Resolution (azimuth \times distance)	9.32 \times 13.97
scanning mode	IW
polarization mode	VV+VH
number of images	87

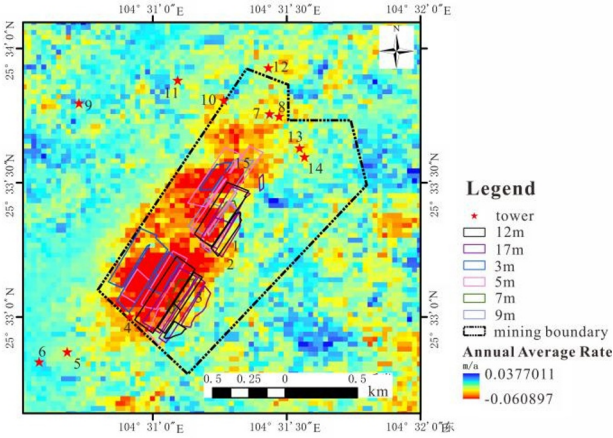


Fig. 3. Annual average vertical settlement rate chart of the ground of the Hongxing Coal Mine Area.

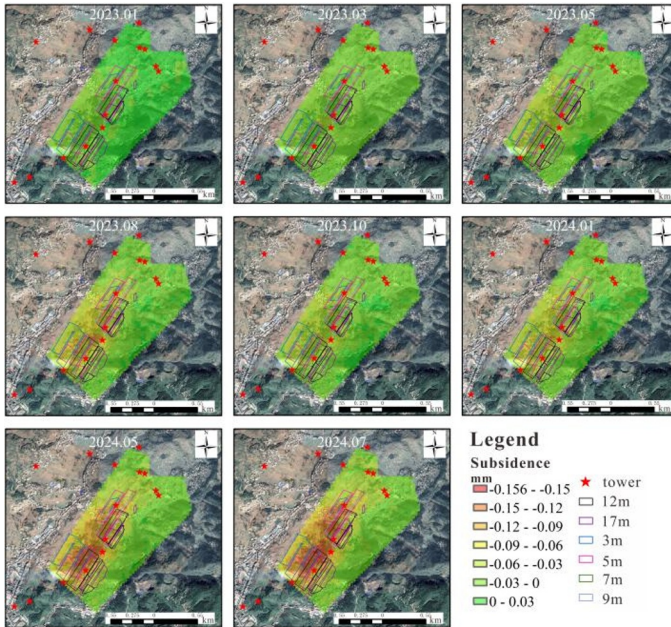


Fig. 4. Cumulative vertical deformation diagram of ground of the Hongxing Coal Mine.

The cumulative vertical settlement amount of the ground during the research period of coal mines obtained by SBAS-InSAR technology is shown in Figure 4. The maximum cumulative vertical settlement is 0.156m. The settlement amount in the goaf area shows a linear increase over time, and the ground deformation amount and range increase in deformation over time, especially after entering 2024. The time-sequential

deformation curves at 15 towers were extracted (see Figure 5). The results show that the deformation of the tower located directly above the goaf is much greater than that of other towers. Judging from the curve pattern, the tower has experienced two deformation accelerations, two time periods in September 2023 and early 2024 respectively. The towers with the largest deformation are towers No. 1, No. 2, No. 3 and No. 4, with cumulative deformations of 0.10m, 0.125m, 0.124m, and 0.07m respectively, followed by towers No. 11, No. 13 and No. 14, with a small amount of deformation, and the cumulative deformation is about 0.04m. The other towers were relatively stable and did not show significant deformation.

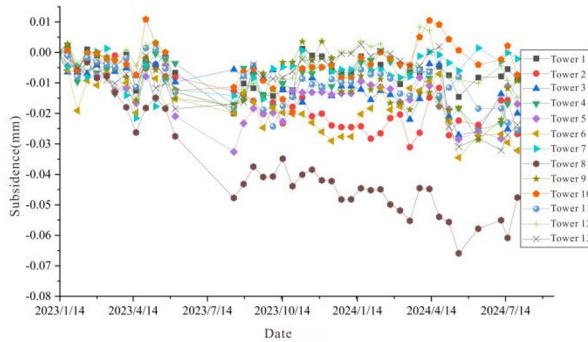


Fig. 5. The timing deformation diagram of the transmission line towers.

4 Evaluation of Vulnerability of Transmission Transmission Line Towers

4.1 Grading Damage Degree of Transmission Line Towers

The vulnerability of overhead transmission line towers in this study refers to the probability or degree of tower damage, failure or even collapse under the action of mine goaf collapse. It reflects the ability of tower structure to resist external disasters, and is one of the core indexes to evaluate the safety and reliability of power system.

In order to obtain the on-site damage data of the towers, field investigations were conducted on 34 towers in the 12 transmission lines passing through the coal mine goaf in the study area in Figure 1. At present, there is no recognized classification method for tower damage classification under the influence of coal mine gouging. This article combines on-site investigation. The damage level is divided into 4 levels: no obvious damage, minor damage, moderate damage, and serious damage, see Table 2.

Table 2. Grading table of damage degree of tower in coal mine goaf transmission line

Degree of damage	Inclination of tower %	Inclination value at the	ground deformation around the tower foundation
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		base of the tower	
C0	$\leq 1\%$	≤ 3	There is no obvious ground deformation or cracking around the base of the tower
C1	1%-1.5%	3-6	A small number of cracks and small collapses appeared on the ground around the tower
C2	1.5%-2.0%	6-10	Large hole collapses around the tower, and many developmental tension cracks (but does not affect the stable operation of the tower)
C3	$> 2.0\%$	> 10	The ground deformation of the tower is obvious, collapse, wide cracks appearing (which poses a threat to the stable operation of the tower and the tower needs to be reinforced)

4.2 Vulnerability Probability Function and Equivalent Damage Probability of Tower

Although Table 2 gives the damage classification table for the towers, there may be cases where the tower base inclination value is the same but the tower inclination degree is different. This is due to the extremely complex ground deformation process caused by the mining subsidence, and the damage to the tower has a certain probability. Therefore, this paper introduces a probability method to evaluate the probability function of the tower damage during different vertical settlements on the ground, that is, the probability of the tower vulnerability.

By referring to the methods put forward by many scholars^[19-21], they established a vulnerability curve for buildings threatened by natural disasters. They all combine the data of the damage degree of buildings with the corresponding specific strength parameters (such as equivalent cumulative displacement or differential settlement of buildings) to derive the probability. Under the condition of given strength parameter (Δ), the probability calculation method of tower reaching or exceeding a certain equivalent damage (C_i) is shown in Formula (2).

$$P(\text{Damage} \geq C_i | \Delta) = \Phi \left(\frac{\ln \Delta - \ln \Delta_i}{\beta} \right) \quad (2)$$

In the formula, P represents the probability that the transmission tower damage degree reaches or exceeds C_i under the vertical settlement amount Δ ; Φ is a standard normal cumulative distribution function. Δ is the cumulative vertical settlement (mm); Δ_i is the median settlement with the tower damage degree C_i , and β is the standard deviation parameter.

Since ground settlement continues to develop, the vertical ground displacement of a tower changes from small to large, and the damage degree of the tower may cover multiple levels. Therefore, in order to reflect the overall damage situation of the transmission line tower, the damage probability at each level is calculated and weighted averaged, and normalized, and the equivalent damage probability (C_μ) is obtained.

$$C_\mu = \frac{\sum_{i=1}^3 P_i \times \Delta_i}{\sum_{i=1}^3 \Delta_i} \quad (3)$$

In the formula, P_i is the probability of level i damage in the tower, and Δ_i is the median settlement amount with the damage level i .

A field survey of 34 towers in the 12 transmission lines passing through the coal mine goaf in the study area of Figure 1 and the SBAS-InSAR timing ground deformation inversion can be obtained by obtaining the vertical cumulative deformation values and corresponding damage levels of 34 towers. From the survey data of these 34 towers, the calculation parameters in formula (2) are obtained: the values of Δ_1 , Δ_2 , and Δ_3 are 25, 44.2, and 72 mm, respectively. According to formula (2), the logarithmic normal distribution probability function can be calculated under each damage level, such as formula (4):

$$\begin{cases} P(\text{Damage} \geq c1|\Delta) = \Phi\left(\frac{1}{0.15} \ln\left(\frac{\Delta}{25}\right)\right) \\ P(\text{Damage} \geq c2|\Delta) = \Phi\left(\frac{1}{0.10} \ln\left(\frac{\Delta}{44.2}\right)\right) \\ P(\text{Damage} \geq c3|\Delta) = \Phi\left(\frac{1}{0.10} \ln\left(\frac{\Delta}{72}\right)\right) \end{cases} \quad (4)$$

Taking the No. 2 tower of the Hongxing Coal Mine as an example, the cumulative vertical settlement $\Delta=34.95\text{mm}$ is substituted into formula (4) to calculate the probability of damage at each level of the tower of No. 2:

$$P(\text{Damage} \geq c1|\Delta) = \Phi\left(\frac{1}{0.15} \ln\left(\frac{\Delta}{25}\right)\right) = 0.987$$

$$P(\text{Damage} \geq c2|\Delta) = \Phi\left(\frac{1}{0.10} \ln\left(\frac{\Delta}{44.2}\right)\right) = 0.009$$

$$P(\text{Damage} \geq c3|\Delta) = \Phi\left(\frac{1}{0.10} \ln\left(\frac{\Delta}{72}\right)\right) = 0$$

The equivalent damage probability of tower No.2 is calculated by formula (3):

$$C_\mu = \frac{\sum_{i=1}^3 P_i \times \Delta_i}{\sum_{i=1}^3 \Delta_i} = 0.1747$$

The same method can be used to calculate the equivalent damage probability values of 34 towers within the survey range. The natural breakpoint method in Arcgis software is used to divide the equivalent damage probability values of 34 towers into 5 levels, namely extremely low, low, medium, high and extremely high, and the vulnerability evaluation of a single coal mine goaf transmission line tower can be completed. The

results of the vulnerability evaluation of the towers of transmission lines within the Hongxing Coal Mine are shown in Figure 6.

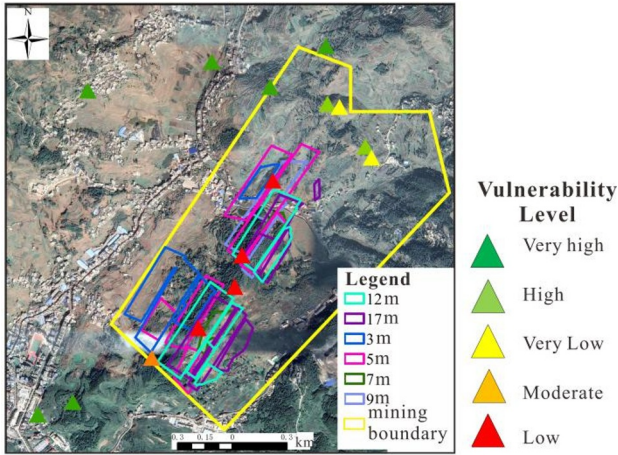


Fig. 6. Distribution of vulnerability of power transmission line towers within the Hongxing Coal Mine range.

From the Figure 6, it can be seen that the closer the tower in the Hongxing Coal Mine area is to the goaf, the higher the vulnerability, and the evaluation results are consistent with the on-site investigation.

5 Conclusions

(1) This paper takes the transmission line towers above the coal mine goaf in Liupanshui City and Bijie City in southwestern China as the research object, and combines SBAS-InSAR high-precision deformation monitoring and on-site investigation data to establish a four-level damage division method for the transmission towers in the mine.

(2) By introducing a log-normal distribution function, the damage probability value of the tower under different vertical settlement levels of tower foundations is realized, and the equivalent damage probability is proposed. The vulnerability of the tower is divided into five levels: extremely high, high, medium, low, and extremely low, realizing the vulnerability evaluation of the tower of the transmission line when the coal mine is mining causes ground settlement. The evaluation results are consistent with the on-site investigation.

(3) This research result can lay the research foundation for the risk assessment of overhead transmission line towers in coal mine goaf.

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References

1. W.B. Guo, K.Z. Deng, "Status and Prospects of Mining Damage and Protection Technology of High Voltage Transmission Line Iron Tower," *Coal Science and Technology*, 39(01):97-102, 2011, doi: 10.13199/j.cst.2011.01.103.guowb.004.
2. X.K. Cao, "Foundation Stability Evaluation of High Voltage Transmission Line Towers over Goaf," *Coal Engineering*, 50(5):50-52, 2018, doi: 10.11799/ce201805014.
3. B. Zheng, W.B. Guo, P.M. Sang, "Research Status and Prospect of Dynamic Process of Mining Subsidence in China," *Morden Mining*, No.479:11-14, 2009, doi: 10.3969/j.issn.1674-6082.2009.03.004.
4. Q. ZHANG, C. Q. WANG, "Research on Control Technology of 750 kV Line Tower Inclination in Coal Goaf," *Ningxia Electric Power*, 1:52-58, 2023, doi: 10.3969/j.issn.1672-3643.2023.01.009
5. J.X. Li, W.W. Li, W.G. Shi, et.al., "Ore Pressing Stability Evaluation of a 1000 kV Electric Power Engineering in Shanxi Based on Comprehensive Geophysical Exploration Method," *Engineering and Technological Research*, 8(15):28-30, 2023, doi: 10.19537/j.cnki.2096-2789.2023.15.009.
6. C.A. Liu, W.L. Gao, J.S. Que, et.al., "Numerical Analysis of Transmission Tower Foundation Stability at Various Zones Affected by Coal Seam Mining," *Journal of Engineering Geology*, 19(6):922-927, 2011, doi: 10.3969/j.issn.1004-9665.2011.06.019.
7. J.H. Yang, X.B. Tang, J. Zhao, et.al., "Safety Evaluation on Tower Foundation of Transmission Lines within Coal Mine Goaf and Its Emergency Treatment," *Journal of Liaoning Technical University(Natural Science)*31(4):456-460, 2012, doi: 10.3969/j.issn.1008-0562.2012.04.006
8. Z.M. Lu, S.Q. Xu, S. Wang, et al., "Research on Risk Assessment Technology for Transmission Lines in Mining Affected Areas," *AIP Advances*, 14(10): 105309, 2024, doi:10.1063/5.0231965.
9. S.Q. Xu, X.K. Meng, S. Wang, et al., "Research and Response Strategies on the Impact of Goaf Collapse on Overhead Transmission Lines," *AIP Advances*, 15(1): 015221, 2025, doi: 10.1063/5.0249887.
10. Y.C. Zhu, K. Xu, X. F. Wang, et. al., "Vulnerability Analysis and Regionalization of Yunnan Power Grid Caused by Geological Disaster," *Journal of Safety Science and Technology*, 9(9):148-154, 2013, doi: 10.11731/j.issn.1673-193x.2013.09.028
11. Y.Y. Zhang, "Study on Vulnerability Evaluation Model of Transmission Towers to Landslides," *Dissertation*, Chongqing University, 2014
12. A. Fekete, U. Nehren, "Climate Change Increased Risk of Forest Fire, Winter Storm and Technical Failure Risks Related to Power Transmission Lines – a Spatial GIS Risk Assessment at Cologne District, Germany," *Progress in Disaster Science*, 24:100387, 2024, doi: 10.1016/j.pdisas.2024.100387.

13. Reda Snaiki, Siddharth S. Parida, "A data-driven physics-informed stochastic framework for hurricane-induced risk estimation of transmission tower-line systems under a changing climate," *Engineering Structures*, 280:115673, 2023, doi: 10.1016/j.engstruct.2023.115673.
14. Kazemian Alireza, Angelopoulos Konstantinos, Sett Kallol, et al., "Multihazard Vulnerability and Risk Assessment of a System of Lattice Steel Transmission Towers Prone to Wind and Ice," *Journal of Infrastructure Systems*, 31(3) ,2025, doi: 10.1061/JITSE4.ISENG-256.
15. Amir Akbari Garakani, Sara Tahajomi Banafshehvaragh, Sohail Saheb, et al., "Assessing the Vulnerability of Power Transmission Towers to Land Subsidence and Forecasting Future Trends Using Multi-source Datasets: Insights from Moein Abad, Iran," *Innovative Infrastructure Solutions*, 10:148, 2025, doi: 10.1007/s41062-025-01958-3.
16. Y. Li, K. Yang, J. Zhang, et al., "Research on Time Series InSAR Monitoring Method for Multiple Types of Surface Deformation in Mining Area," *Natural Hazards*, 114(3): 2479-2508 , 2022, doi: 10.1007/s11069-022-05476-8.
17. Przyłucka M., Kowalski Z., Perski Z., "Twenty Years of Coal Mining-induced Subsidence in the Upper Silesia in Poland Identified Using InSAR," *International journal of coal science & technology*, 9(1): 86 , 2022, doi: 10.1007/s40789-022-00541-w.
18. Declercq P. Y., Dumar M., Pirard E., et al., "Post Mining Ground Deformations Transition Related to Coal Mines Closure in the Campine Coal Basin, Belgium, Evidenced by Three Decades of MT-InSAR Data," *Remote Sensing*, 15(3): 725, 2023, doi: 10.3390/rs15030725.
19. Fotopoulou S.D., Pitilakis K.D., "Vulnerability assessment of reinforced concrete buildings subjected to seismically triggered slow-moving earth slides," *Landslides*, 10 (5): 563–582.,2013, doi:10.1007/s10346-012-0345-5
20. Peduto D, Ferlisi S, Nicodemo G, et al. "Empirical fragility and vulnerability curves for buildings exposed to slow-moving landslides at medium and large scales," *Landslides*, 14:1993–2007, 2017, doi:10.1007/s10346-017-0826-7
21. Bijing Jin,Taorui Zen,Tengfei Wang, et al."Advanced risk assessment framework for land subsidence impacts on transmission towers in salt lake region,"*Environmental Modelling and Software*,177: 106058,2024,doi:10.1016/j.envsoft.2024.10605

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