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A METHOD FOR SETTLEMENT DETECTION OF THE TRANSMISSION LINE TOWER UNDER LAND SUBSIDENCE CONDITION

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ABSTRACT

Crustal movement and land subsidence will cause tower foundation settlement, which seriously affects the safety of transmission line operation. This paper proposed a short-term failure warning method for transmission tower under land subsidence condition based on finite element method, strain monitoring and time series prediction. By simulating the stress distribution of the tower in actual foundation settlement, the weak components of the settlement tower were founded. Combined with the finite element simulation results in various conditions, the reliability of simulation results is verified, and the strain variation range of the corresponding measuring point is obtained. By installing the real-time strain monitoring system and establishing the autoregressive integrated moving average (ARIMA) time series forecast model, warning of the failure of the tower can be sounded in short time according to the strain monitoring and forecasting results. The field results show that the tower is in good condition and with no risk in short term. The method proposed by this paper is economical and easy to operate, which can be used to conduct the emergency treatment of the dangerous tower under land subsidence condition.

INTRODUCTION

Chinese state-owned key coal mines statistical data show that about 8.76 billion tons of coal deposits are located under buildings and about 60% of these are located under village areas. With increasing shortages of coal resources, in order to maintain normal operation, various mining enterprises have been exploiting coal deposits under such village areas. Large-scale exploitation of underground coal resources will inevitably lead to uneven subsidence and displacement of the ground surface, resulting in different degrees of damage to surface buildings. However, many other factors unrelated to mining can also cause damage to buildings, which can lead to disputes between mining enterprises and building owners. Such conflicts are especially intense in areas with more complex natural conditions, where mining operations are conducted near buildings. Therefore, within the theme of sustainable and stable development, accurate technical assessment of mining-related building damage has become necessity.

Previous research on mining-related damage produced significant results, but most of the results have been based solely on the prediction of mining subsidence. However, because of the complexities of mining subsidence, a reliable prediction of the mining induced subsidence is still a challenge. The main reason is the existence of numerous interrelated factors, such as the rock masses characteristics, the ground surface topography, the natural precipitation, the method of excavation, which making the subsidence analysis becomes more complex. Furthermore, such building damage assessment work concentrated primarily on the influencing factors, evaluation indicators, and methods of assessing building damage, whereas the effects of mining subsidence-induced secondary disasters have not been considered, for example, the mining-induced reduction of slope stability could lead to slope creep, resulting in building damage. Particularly in mountainous areas, the limitations of conventional subsidence prediction models make it difficult to determine the boundary of mining influence accurately. Previous studies have rarely addressed these aspects.

The breakdown or collapse of transmission towers is common during an earthquake. In the United States, the Landers earthquake in 1992 and the Northridge earthquake in 1994 severely damaged the transmission system, respectively. The Kobe earthquake in Japan in 1955 resulted in the destruction of a large number of transmission towers whose main failure modes were the subsidence of foundation, the tilt of tower, and compressive yield of structural member. The Kocaeli earthquake in Turkey in 1999 also caused landslides, faulting, and ruptures of earth's surface, thereby damaging a considerable number of transmission towers. Moreover, transmission lines also broke down in the Wenchuan earthquake in China in 2008.

The objective of this work is to establish a general finite particle method framework for simulating the collapse process of the transmission steel tower, including the discretization of the structure, motion equation of particles, the internal force calculation, and the explicit time integration and solution. This study conducts the collapse simulation of the transmission steel tower model based on the FPM. The three-dimensional finite particle model of transmission steel tower is developed in MATLAB. The static and elastic seismic response analysis of transmission tower is carried out and calculation results of the FPM agree well with those of the FEM, respectively. The failure criterion based on the ideal elastic-plastic model and the failure mode are proposed. Finally, the collapse simulation of the transmission steel towers subjected to unidirectional and three-dimensional earthquake ground motions can be successfully carried out using the finite particle method.

Much research has been conducted globally on the building damage caused by mining activities. With consideration of the diversity and uncertainty of the factors that cause building damage, Malinowska proposed a fuzzy reasoning method for the assessment of damage to buildings affected by mining. An earlier study by Malinowska and Hejmanowski employed GIS analysis methods to assess the damaging effect of underground mining on buildings in Poland. Saeidi et al. focused on the application and comparison of different methods with a case study; and their research results show that, the Dzegeniuk method is more realistic in comparison of the other empirical methods. The InSAR technique also has been used in assessing the mining-induced damage to structures in mining subsidence regions. Yang et al. analyzed the influence of mining on buildings under various topographic conditions, including areas of plains, hills, and mountains. Other studies have proposed assessment models that utilize and compare various methods for delineating mining damage boundaries. Tan and Deng summarized the typical methods used for the technical assessment of building damage caused by mining exploitation. Similarly, Cui et al. and

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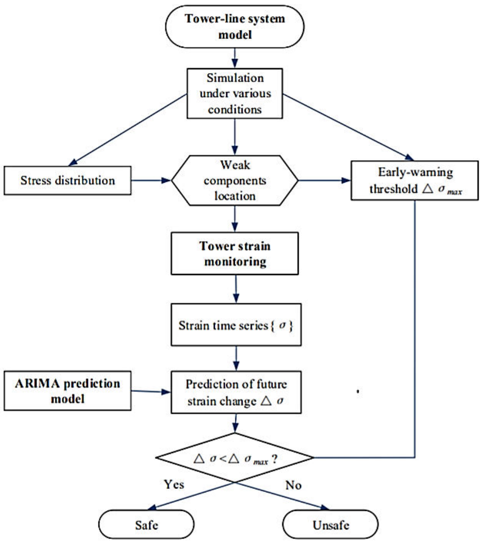
Xu et al. conducted important research on mining damage assessment methods.

Transmission line is the key facility of power grid system all over the world. According to statistics, natural disasters are the primary cause of transmission tower damage. High voltage transmission lines are usually of several hundred kilometers long and may pass through complex topography or seismically active zones. Research shows that in many mountainous areas and hilly areas, crustal movement and land subsidence will lead to tower foundation settlement, which may further cause the yield of steel structure or even collapse of transmission towers. It will seriously affect the safety of transmission line operation. But the existing approaches cannot accurately monitor the safety margin of tower, which brings great inconvenience to grid corporations. This paper aims to address such challenge by accurately monitoring and judging safety of transmission line tower in real time, so that the State Grid Corporation can make correct emergency decisions.

In recent years, the failure mechanism of transmission towers under icing and wind loads had been systematically studied based on the finite element model in mechanical simulation of tower, while few have studied the mechanical characteristics of towers under foundation settlement. The tower-line system finite element modeling has become a general analysis method to study the tower failure problem. Huang et al. analyzed the variation law of the maximum equivalent stress undertaken by the components of tower for different tower foundation settlement conditions. Du et al. used beam element and cable element to establish the integral finite element model of towers, lines and insulators, and analyzed the mechanical properties and weak steel structure for towers in specific ice-coated microclimate zone.

FLOWCHART



Subsidence fissures begin at the margins of subsiding basins, probably as a small crack at the ground surface. Unfortunately, to my knowledge anyway, nobody has ever witnessed this formative event. That's probably because water finds the incipient cracks first and quickly begins to erode them, making them wider and deeper. Although subsidence fissures begin at basin margins, they do not necessarily form concentric contours around the basin as one might expect. Local soil type and structure, surface and subsurface geometry, and subsidence rate probably contribute significantly to eventual fissure shape, length, and distribution throughout the basin.

Young fissures are tensile in nature, hence they usually display little or no vertical or horizontal offset across the fissure. Young fissures look more like a simple crack than a fault along which shearing has removed most irregularities. Subsidence fissures tend to be highly irregular, both in plain view and in cross section. Because streams quickly occupy them, many unaware state or local

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transportation personnel, land use managers, and real-estate developers confuse them with dry washes, subsequently placing infrastructure entities over them with conduits to permit water flow beneath. They don't realize that water seldom flows along the fissure for long as most fissures form nearly parallel to basin contours, or trend uphill. Water quickly drains vertically into the fissure forming a rapid shortcut into the groundwater table for surface water and pollutants.

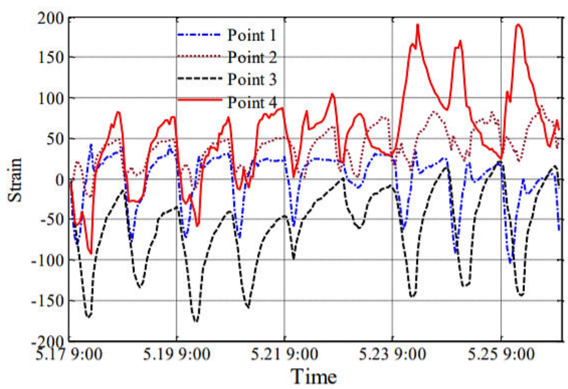
METHODOLOGY

The field survey was divided into two parts:

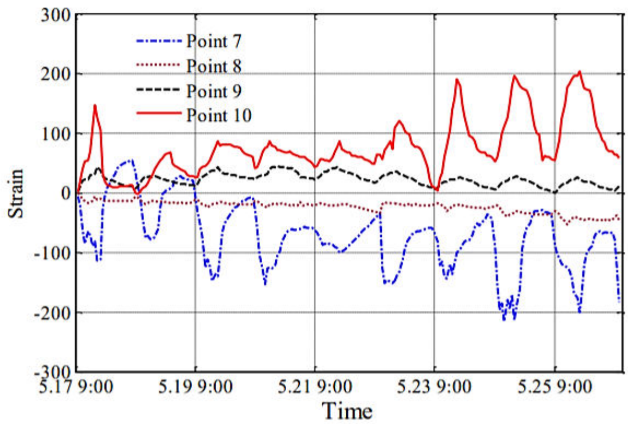
1. Investigation of the extent of building damage and
2. Measurement of the surface cracks.

The method of investigation of the extent of building damage involved on-site recording of the name(s) of the resident(s) of each building and the details of the damage condition, including the location, shape, number, and width of any cracks and the amount and direction of tilt of any walls. The plan metric locations of surface cracks were established and numbered using GPS, and their widths were measured using a steel tape.

SIMULATION RESULTS AND DISCUSSION

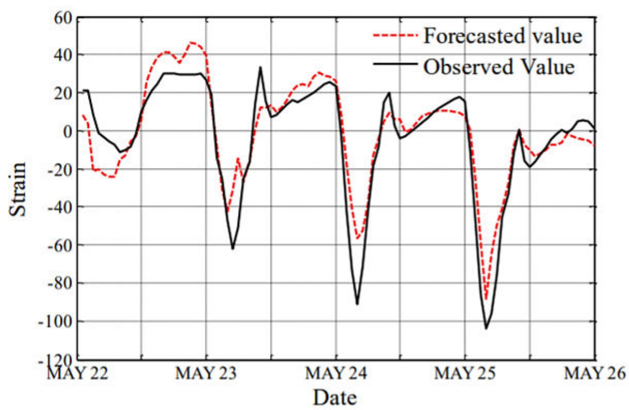


Curve of strain change at the elements of the tower legs



Curve of strain change at the first transverse partiti

After obtaining the tower strain time series, it is necessary to ensure that the series is stationary or not. If the series is nonstationary, then the series has to be differentiated so as to make it stationary, otherwise the time series cannot be predicted. If a time series is stationary, which means that it is only related with the variable time interval and has nothing to do with the starting and ending point. It shows that the mean value and covariance of the series in a fixed period of time do not change with time.



Strain rolling prediction results of monitoring point

CONCLUSION

This paper puts forward a short-term failure warning method for transmission tower under land subsidence condition based on the finite element simulation, strain monitoring and ARIMA time series forecast model. This method has been successfully applied to an actual 500kV transmission line emergency treatment under land subsidence condition. A precise tower-line system model based on finite element method has been established. By simulating the stress distribution of the tower under actual foundation settlement condition, the weak components of the settlement tower have been located. Combined with the finite element simulation results in various conditions, the reliability of simulation results is verified, and the strain variation range of the corresponding measuring point is obtained, which provides a basis for judging the safety status of the tower. Strain time series have been obtained by installing resistance-based strain monitoring device on the tower. By building ARIMA model of its trend component and seasonal component respectively, the rolling strain series forecasting results have been obtained. Strain time series prediction results are almost consistent with the actual observed values, and most of the time the forecast error is within 50με. In the future, a better strain monitoring method for transmission towers is needed to be researched since the resistance strain sensor is not suitable for long-term on-line monitoring. Some other prediction models, such as LSTM, can be studied for the strain time series forecasting to obtain a longer and more accurate prediction result, which can provide more accurate suggestions for the early warning of tower failure.

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