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Status of Research on The Dynamic Response of High-speed Railway Roadbeds in Goaf Sites

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Abstract

China is a large coal country, but also has a great dependence on coal, which has left a large number of mining sites in China. And with the construction and development of high-speed railroads, many lines appear to have to cross the phenomenon of mining area sites. The construction of high-speed railroads has extremely demanding requirements for roadbeds and foundations, so the operation of high-speed railroads in open space sites has significant safety risks. But in the past, domestic and foreign research on these two are relatively independent, not well integrated, so this paper will summarize the current status of research on these two, and look forward to the development direction of the field.

Keywords

Goaf site; Roadbed; Foundation; High-speed railway dynamic load.

1. INTRODUCTION

With the development of the national economy, China's urbanization and industrialization rates are rapidly increasing, and these are accompanied by the mining of large amounts of coal and mineral resources, and Shanxi has been China's largest coal production province, Shanxi coal industry is known as "the backbone of the development of the Republic", promoting the industrialization process of China[1]. The coal industry in Shanxi has been the "backbone of the Republic's development" and has contributed to the industrialization of new China. The mining of so much coal has also brought many problems to Shanxi, leaving a large area of coal mine collapse areas for the already fragile ecological environment of Shanxi, resulting in thousands of villages with damaged houses, destroyed arable land and drinking water difficulties.

China's rapid economic development has also driven the pace of high-speed railroad construction, China's high-speed railway "four vertical and four horizontal" trunk line network has been completed ahead of schedule, and to "eight vertical and eight horizontal" network to promote the rapid development of road network scale, covering all provinces except Tibet, built the network is the most modern and developed high-speed railway network in the world. In the process of high-speed railroad development and promotion, people can effectively reduce the cost of economic development factors in the flow of space and time, break the geopolitical barriers, so that the transport industry and modern economic construction to get close contact, shorten the time of China's north-south, east-west passage, so that China's spatial factors in the support of high-speed railroad to get together and integration, and for the rapid development of regional tourism economy has presented new opportunities.

While high-speed railroad is developing rapidly, we should also pay attention to its safety and stability issues. The roadbed project should guarantee the safety and comfort of the train running at high speed. The stiffness of the roadbed structure should meet the requirements that the elastic deformation generated by the train operation is controlled within a certain range; its strength should be able to withstand the long-term effect of the train load; its thickness should make the dynamic stress diffused to its subgrade surface not exceed the long-term bearing capacity of the subsoil of the bed. Therefore, high-speed railroad roadbed has quite stringent requirements, but in the actual construction process many high-speed railroads still inevitably pass through the site of the mining area, when this happens, the problems related to high-speed railroad roadbed need to be taken seriously by us. However, in the past, the research on these two is relatively isolated, so this paper will summarize the current status of the research on these two, and put forward the existing problems and prospects.

2. TRAIN DYNAMIC LOAD

In terms of theoretical analysis, Xu Peng and Cai Chengbiao[2] use the vehicle-track coupling dynamics theory, considering the spatial characteristics and interaction of rolling stock, ballast track and roadbed, establishing a train-ballast track-roadbed spatial coupling dynamics model, with a running speed of 200km/h CRH2 rolling stock role to calculate the dynamic characteristics of the roadbed shows that the maximum dynamic stress of the roadbed surface is 49.2kPa which occurs at the wheel position. Lei Xiaoyan[3] considers the influence of the earth, and establishes the model of plate track-embankment-earth coupling system and ballast track-embankment-earth coupling system for the plate track and ballast track respectively, and the vibration response of each part of the system can be solved by the analytical method under the action of dynamic wheel-rail force caused by track unevenness The vibration response of each part of the system can be solved analytically. Based on the vehicle-rail-road vertical coupling model, Cheng Chong[4] introduced the typical differential settlement model, analyzed the wheel-rail contact force and vehicle acceleration response under different train operating speeds, and derived the settlement control standard under different train operating speeds to meet the passenger comfort index and wheel weight reduction rate index as the criterion, and checked the settlement control standard of high-speed railroads in China; gave the typical differential settlement of roadbed after the occurrence of The track spectrum of high-speed railroad after typical differential settlement is given by the periodogram method, which proves the necessity of considering long-wave unevenness. The need to consider long-wave unevenness was demonstrated. Song Huanping[5] and others established an analytical model of vertical vehicle-rail coupling, focusing on the amplification of vehicle-rail dynamics caused by the settlement of slab track roadbed structure. The study focused on the amplification of vehicle-rail dynamics caused by the settlement of slab track foundation structure. Ying Zhou and Jin Chen[6] have researched the ballastless track roadbed structure of high-speed railroad and concluded that: when the single axle load is applied to the location of ballastless track fastener point, the load is mainly distributed by 7 fasteners, and different fastener spacing and stiffness have greater influence on the load distribution ratio at the action point; when one of the two axle loads is applied to the location of ballastless track fastener point, the load is mainly distributed by 11 fasteners; the farther the distance from the roadbed surface, the slower the stress decay. When the stress is transferred to the subgrade of the roadbed, the stress of the roadbed under different axle weights is almost close to. Yu Shui[7] found shows that the train speed and the number of loaded lanes have a large influence on the compressive stress in the foundation mat; the compressive stress in the foundation mat is not uniformly distributed under the train load; the study of the soil as an elastic material has a certain error, but the study of its general distribution law has a good effect in the initial research stage. Lei Huayang[8] research results show that: the greater the train operating speed, the greater the fluctuation of the soil under the tunnel, the more obvious the settlement curve wheel track distribution phenomenon, the greater the horizontal influence of the surface settlement trough, about 4.5 times the tunnel diameter on each side of the tunnel axis, but its post-work settlement with the increase of the subway speed and decrease; in the rapid subway train load under the influence

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of vertical settlement of the soil body is 3 times the diameter of the tunnel; The settlement of the line after one year of operation is about 57 mm, accounting for 30% of the cumulative settlement, and the cumulative settlement after 20 years is about 190 mm. The cumulative settlement after 20 years is about 190 mm.

In terms of numerical simulation, Zhang Ruiguo[9] established a passenger car-plate track and truck-ballast track vertical coupling dynamics model based on the principle of vehicle- track coupling dynamics for the structural characteristics of CRTSIII plate type yesterday track and traditional broken track, and carried out the dynamic response of the roadbed surface under two cases of ballastless track foundation in high-speed railroad ballast spectrum and heavy-load railroad foundation in three mainline spectrum. The results show that the dynamic influence coefficients of the roadbed along the longitudinal direction of the line road obey the Kolmogorov normality test under the two unevenness spectra. Hongguang Jiang[10] established a three-dimensional finite element analysis model of the slab track-roadbed using ABAQUS software, and the stress paths at different depths of the roadbed were derived by simulating the moving train loads, and the area enclosed by the stress paths is larger as the depth of the soil unit increases. Xue Fuchun and Zhang Jianmin[11] established a nonlinear numerical analysis model of track-roadbed-foundation for a two-line high-speed railroad with a design speed of 350km/h, and investigated the distribution characteristics of dynamic stresses in the roadbed along the transverse, longitudinal and depth of the line under the action of moving loads. By establishing the train-slab track-roadbed three-dimensional dynamic finite element model, Chen Renpeng[12] numerically analyzed the dynamic response of the slab track roadbed system under the low disturbance upset spectrum in Germany, and concluded that the dynamic stresses in the roadbed have dispersion along the longitudinal direction of the line, and the dynamic stresses at the same roadbed depth obey normal distribution. Auersch[13] used a semi-infinite space foundation model to parametrically analyze the plate track and floating plate track, and studied the vibration displacement and fluctuation propagation characteristics along the track and foundation, and the vibration characteristics of the foundation. In order to solve the coupled vibration problem of train-track-tunnel soil, Degrande[14] used periodic (Periodic) finite element-boundary element method to study the system response, coupling in the frequency domain-wave number domain, the track was simulated by periodic finite element or analytical solution, and the tunnel-soil was simulated by periodic finite element-boundary element, and it was found that the effect of track plate discontinuity on the rail response is significant. Galvin[15, 16] used 3D finite element-boundary element to simulate ballasted and ballastless track, and the train used multi-rigid body model with rail spacing excitation and track unevenness excitation to compare and analyze the vibration response of ballasted, ballastless and floating plate track, and found that the critical velocity of ballasted track structure is close to the Rayleigh wave velocity of foundation surface, and the static axial weight load determines the foundation response, and the ballastless track structure is derived due to the higher critical velocity. The conclusion that track unevenness controls the foundation response. Alves[17] et al. used 2.5-dimensional finite element combined with infinite element method to analyze the effect of linear elasticity of soil on the vibration response caused by high-speed trains, and found that the vibration response caused by high-speed trains on soft ground foundation is large. The vibration response caused by high-speed trains on soft ground is found to be large. Based on the existing research, Jin Wanfeng[18, 19] et al. added the track unevenness into the 2.5-dimensional model to make the model closer to the real situation, and then studied the vibration problems caused by subway trains based on this model. Then, the vibration problem caused by subway trains was studied based on this model.

In terms of testing, Zhao Guotang[20] et al. conducted a field test on a new high-speed railroad CRTS III type plate ballastless track line by , and pre-buried the test elements inside the ballastless track in the construction section to obtain the field measured data of fastener reaction force and track structure load, and combined with the test data to obtain the field ballastless track vehicle load transverse transfer law. Ishikawai[21] studied the settlement development of ballast track bed under cyclic dynamic train load by model test. Ishikawai studied the settlement law of ballasted track foundation under cyclic dynamic train load by model test. Kong Gangqiang[22] studied the effect of excitation frequency on the dynamic response of X-shaped pile-raft composite foundation by applying different frequencies of excitation force to this type of composite foundation. The sine wave load was used to simulate the single wheel load of the train, and the analysis focused on the dynamic soil pressure and pile dynamic stress of this type of composite foundation, and the variation law of velocity response and pile dynamic stress with depth was obtained. The variation of velocity response and pile dynamic stress with depth was obtained. Ying Zhou[23] carried out dynamic tests of the model system under different excitation frequency conditions, tested and analyzed the acceleration response of the roadbed model at different locations, and determined the first-order inherent frequency of the model system. The first-order inherent frequency of the model system was determined. Xuecheng Bian[24] creatively proposed the idea of "fake car and real road", and established a real-scale high-speed railroad roadbed test platform, which can simulate the dynamic load on the roadbed by the maximum speed of 360km/h train, focusing on the amplification effect of dynamic stress inside the roadbed of high-speed railway and the decay law along the depth. The study focused on the dynamic stress amplification effect inside the roadbed and the decay law along the depth. Leng Wuming[25] focused on the maximum dynamic stress at different depths of the roadbed and the variation law of the maximum displacement of the shoulder with the axle weight.

3. GOAF SITE

In terms of theoretical analysis, Sun Hui[26] et al. used a coal mining area in Xuzhou as an example to estimate the residual ground deformation at the site using the probability integral method, so as to provide guidance and reference for the practical construction of this certain coal mine. In this study, we used the probabilistic integral method to estimate the residual ground deformation in a coal mine in Xuzhou. Based on the example of Beibu coal mine in Laiwu City, Qu Bairu[27] used the probability integral method to calculate the surface subsidence in the vicinity of the mining area, which provides a basis for mining land and planning and reasonable management. Wang Jun[28] used the probability integral method to predict the surface subsidence of the mining area in Ganluo County, Chengdu-Kunshan Railway, Sichuan, and analyzed the impact of the resulting deformation on the construction of the railroad roadbed, providing a guidance scheme for the deformation problem and reinforcement of the mining area. Based on the probability integration method, Zhao[29] et al. combined the dual integral permutation method under coordinate rotation transformation, and then used the compound Simpson numerical integration formula for integration to calculate the collapse of arbitrarily shaped working face, and the algorithm was always obtained in the GIS system, and finally applied it to a specific example with good results, which can provide a new method for predicting and calculating the subsidence of the overlying ground surface in the mining area. Han Dan[30] takes the under-volume mining area of Dongfeng coal mine in Fugu County as the research object and calculates and predicts the surface movement deformation of the studied area based on the probability integral method, which provides guidance to the production practice . Zheng Zhigang[31] et al. used the regression analysis method to obtain the functional relationship between the surface movement parameters and the geological mining conditions based on the actual measurement data from the observatory under the comprehensive mining conditions in Lu'an mine. Li Peixian[32] established a genetic algorithm-based probability integration method for parameter selection, which improves the accuracy of calculating surface

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deformation. Majdi[33] proposed five mathematical models for calculating the height of the pressure relief zone by studying the evolution of the fractures in the roof of the mining area. Palchi[34] investigated the height of the fall zone in medium-weathered, strongly weathered and deeply buried hard overburden rocks, and derived the relationship between the height of the fall zone and the rock strength. The relationship between the height of the zone and the strength of the rock was found. Guo Wenbing[35] et al. summarized the current status of research on overburden damage caused by high-intensity mining, based on which they focused on the overburden damage transmission process, proposed a method to calculate the full mining degree of overburden damage and its height based on the overburden damage transmission process, and revealed the formation mechanism of the "two zones" damage pattern of overburden of high-intensity mining. The mechanism of the formation of "two-belt" damage pattern of high-intensity mining overburden is revealed. Chen Pan[36] et al. analyzed the surface movement data of N1200 working face in Shenmu Lizhota coal mine, Shaanxi Province, and compared the differences of surface movement parameters in the overburden with and without the mining void area, and applied the corresponding rock movement theory to explain the differences of surface movement patterns under repeated mining.

In terms of numerical simulation, Wang Shuren[37] et al. based on the MIDAS/GTS finite element program, then construct the FLAC3D three-dimensional computational model, and with the help of MATLAB software, establish the surface settlement assessment model and the method of analysis of the under-volume mining area of the highway tunnel. Liu Zhanxin[38] found that water has a facilitating effect on the deformation of the fractured rock body. By gradient loading of building loads of 0.015 MPa per layer and 0.1 MPa per layer for 4# coal and 9# coal, the simulation results obtained that the allowable applied load on the overlying rock foundation of 4# coal mining area is 0.045 MPa, and the influence depth is 19m, which does not meet the building foundation construction requirements and needs to take reinforcement treatment for 4# coal mining area; the allowable applied load on the overlying rock foundation of 9# coal mining area is 2.0 MPa, the depth of foundation disturbance is 70m, which meets the design requirements. The design requirements were met. Based on the study of structural characteristics of mining overburden, the classical mechanical theory of solid support beam, cantilever beam, stress arch and articulated structure of old top rock block is used to analyze the spatial variation law of overburden stress in the mining area and derive the mathematical model of stress and coal wall distance of collapsed rock in shallow buried mining area. The mathematical model of stress and distance of coal wall in shallow buried mining area is derived[39]. Chen Shuping[40] used the coal (rock) column stability analysis method and the mining area condition characteristics discriminant method to analyze and evaluate the stability of the room and pillar type, strip mining mining void area and long wall mining void area sites under the site respectively, and divided the site into stable, basic stable and unstable zones according to the stability of the mining area site Mohammadali[41] predicted the surface movement caused by underground gun-hole retrieval by establishing a three-dimensional elasto-plastic finite element model of the Diavik mine, and verified that the average relative error between the measured data and the finite element model prediction was 7.95%. The average relative error between the measured data and the finite element model prediction is 7.95%. Wang Qichun and Kuai Yang[42] established a numerical simulation model by using FLAC3D software, and constructed a surface deformation reference tree model by combining with the repeated mining surface deformation law. Taraprasad[43] et al. analyzed the reasonable sequence and surface deformation caused by multi-layer coal mining by numerical simulation. The surface deformation caused by multi-layer coal mining was analyzed by numerical simulation. Li Xinxin[44] studied the effects of coal seam mining advancement speed, thickness and inclination of the mining area on the surface movement deformation by numerical simulation. Based on the measured surface deformation data, Hu Qi[45] studied the

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influence of different undulation patterns on the surface deformation in the mining area by numerical simulation. The effect of different heave patterns on surface deformation in the mining area was studied by numerical simulation. Han Sen[46] et al. used Midas/GTS NX finite element software to numerically simulate the settlement pattern and safety of the mine road in the near-collapse area during underground mining, which provided theoretical data for the effective management of the collapse area.

In terms of testing, Justyna Orwathe and Ryszard Mielima[47] fitted the average settlement process after mining using the J. Bialek settlement equation and a smooth spline curve using the Budrik hard coal mine as an example. Australian scholars Ng[48, 49] et al. Spanish scholars Yerro et al. used synthetic aperture radar interferometry to conduct a sophisticated monitoring study of ground subsidence in different mining areas and to predict the development of subsidence in mining areas. Fu Ruizhi[51-53] studied the relationship between surface deformation and time through similar material simulation experiments and found that repeated mining would intensify surface deformation but also shorten the time of subsidence stabilization[50] Goodman et al. studied the change of permeability of overburden rock and groundwater flow pattern after coal mining, and concluded that the change of permeability of the top rock layer after mining. Song Xugen[54] et al. used the west area of Chengchao iron ore mine as the research object, and analyzed the characteristics of the roof slab collapse and the mechanism of surface subsidence at the beginning of mining in 2006 by means of monitoring the roof slab collapse borehole and high-density electrical exploration in the collapse area, and explored the surface deformation law in the mining area. The surface deformation pattern of the mining area was discussed. Zhao[55] et al. established an indoor pseudo-3D geomechanical model to study the deformation of the overlying rock layer of the slowly inclined coal mining site, and analyzed the deformation and damage mechanism of the mining landslide, using a natural slope in Madaling, Guizhou as the prototype. The deformation mechanism of mining landslide was analyzed. Li Dongyang[56] et al. established an indoor three-dimensional mining area model, used the masonry method for laying the mold, and monitored the displacement of the rock surface and the strain of the roof and pillar by loading the rock layer step by step, and also filmed the damage process of the pillar and roof using an endoscope, and derived the corresponding change law. It was found that after mining in the shallow buried thin bedrock area, the overburden rock in the mining area is very prone to full-thickness cut-down phenomenon, and the ground surface is seriously deformed in a discontinuous manner. Desertification is serious The mine area is severely desertified[57]. Miao Xiexing, Guo Guangli[58] et al. studied the structural characteristics of the overburden rock of solid dense filling mining, and the results showed that only fracture zones and bending zones are developed in the mining void area of solid dense filling mining, and the cavities and voids inside the mining void area are little or almost not distributed. Cuenca and M. Hanssen[59] et al. analyzed the surface deformation of the Limburg mining area in the Netherlands over the past 20 years using radar images, and pointed out that the mine water would flow back to the mining area after the pumping stopped, resulting in the rebound of the subsurface dive level, which induced the continuous surface uplift, and obtained a model of the function between the change of the subsurface dive level and the surface uplift. The model was obtained as a function of the change in subsurface dive level and surface uplift.

4. SUMMARY

Scholars at home and abroad have done a lot of research on the dynamic response of roadbeds under cyclic dynamic loading of high-speed railroads. From the viewpoint of research objects, most of these studies focus on the roadbeds themselves, and a small part of them are for the dynamic response of special types of foundations such as composite foundations, seasonal frozen soil and ground cracks. From the research means, numerical simulation

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basically used various types of finite element software to study the dynamic response of roadbed; model test, there are tests to establish a smaller scale model, there are also tests to establish a 1:1 model, the simulation of train load is also gradually close to the actual situation.

Although a lot of research has been done at home and abroad on the dynamic response of high-speed railroads and mining subsidence in the mining area, the impact of vibratory loads on the mining area, especially the cyclic dynamic loads of high-speed railroads, is still relatively insufficient and scattered at home and abroad. Initially, the research on the upper load of the mining area was mostly focused on the static load and road load, and in recent years, a small amount of research on the effect of train load on the mining area has appeared one after another, but basically through theoretical analysis or numerical simulation methods, which is largely due to the lack of relevant research equipment.

Based on the existing problems, the following prospects are proposed: (1) How to increase the on-site monitoring of high-speed railroad roadbeds in the extraction area sites, and thus complete the corroboration of the existing theoretical and test results. (2) It is necessary to develop a targeted test system to make up for the shortage of existing test equipment, and thus provide new solutions to the related problems.

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