Retraction

Retracted: Deformation Analysis of Surrounding Rock of Deep Roadway by the Fluid Structure Coupling Model with MIDAS-GTS

Advances in Materials Science and Engineering

This article has been retracted by Hindawi, as publisher, following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of systematic manipulation of the publication and peer-review process. We cannot, therefore, vouch for the reliability or integrity of this article.

Please note that this notice is intended solely to alert readers that the peer-review process of this article has been compromised.

Wiley and Hindawi regret that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

References

[1] J. Jiang, Z. Hou, K. Hou, Y. Lu, H. Sun, and X. Niu, "Deformation Analysis of Surrounding Rock of Deep Roadway by the Fluid Structure Coupling Model with MIDAS-GTS," *Advances in Materials Science and Engineering*, vol. 2022, Article ID 9945383, 6 pages, 2022.

Research Article

Deformation Analysis of Surrounding Rock of Deep Roadway by the Fluid Structure Coupling Model with MIDAS-GTS

Jun Jiang [1,2] **Zhengmeng Hou** [1,2,3] **Kepeng Hou,**[1,2] **Yongfeng Lu** [1,2] **Huafen Sun,**[1,2] **and Xiangdong Niu**[1,2]

[1]*Faculty of Land and Resources Engineering, Kunming University of Science and Technology, Kunming 650093, China*
[2]*Yunnan Key Laboratory of Sino-German Blue Mining and Utilization of Special Underground Space, Kunming 650093, China*
[3]*Institute of Subsurface Energy Systems, Clausthal University of Technology, Clausthal-Zellerfeld 38678, Germany*

Correspondence should be addressed to Zhengmeng Hou; houzm4199@126.com

In order to verify the universal applicability of the fluid structure coupling model to the analysis requirements of deep tunnels under the MIDAS-GTS geotechnical simulation environment, the study, together with several mining enterprises, carried out verification and analysis on the measured data of 107 deep tunnels in recent years. The reference group selects the mean value of the analysis results generated by the analysis model using the preferred nonfluid structure coupling model in the MIDAS-GTS environment. Finally, it is confirmed that the fluid structure coupling model group data have significant advantages over the reference group data within the buried depth of $550 \sim 1450$ m and the tunnel cross-sectional area of $45 \sim 102$ m^2. Finally, it is considered that the fluid structure coupling model has universal applicability within the analysis range. It is suggested that, in the future work, for example, when the tunnel construction project within the above analysis scope needs to carry out the simulation analysis of roof displacement and anchor bolt tension, the fluid structure coupling model should be directly selected as the analysis model.

1. Introduction

The surrounding rock pressure distribution of deep roadway is relatively complex. In the current ground pressure theory, there is no calculation formula to fully control the deep surrounding rock pressure. Therefore, relevant research records the actual ground pressure data in the process of adjacent roadway excavation and selects the ground pressure model in line with the actual ground pressure performance for subsequent simulation according to the actual data, so as to determine the ground pressure control strategy [1]. The mine pressure control strategy includes active support schemes such as anchor bolt, anchor cable and grouting, and passive support schemes such as steel beam and arch. The combined technical scheme has a more reliable support control effect in the deep roadway with the current buried depth of less than 1600 meters [2].

In this study, MIDAS-GTS (geotechnical and tunnel analysis system) is a finite element analysis control for geotechnical mechanics, which runs on MIDAS CIVIL 2021 software platform. In the study, the fluid structure coupling model is used to analyze the measured data of deep roadway in different mine types and compare the coupling and difference between the simulation analysis results and the measured results, so as to demonstrate whether the fluid structure coupling model has universal adaptability in deep roadway.

2. Data Sources and Research Methods

Thirty five tunnels in Xinjiang, Inner Mongolia, Gansu, and Shaanxi in Northwest China, 15 tunnels in Guizhou and Sichuan in Southwest China, 12 tunnels in Heilongjiang and Liaoning in Northeast China, and 45 tunnels in Shanxi,

Henan, Shandong, and Anhui in Central Plains of China were selected. A total of 107 tunnels were investigated. The main data source related to the tunnel is the channel obtained by contacting the technical department of relevant mining companies for the research, and the secondary data source is the data sharing channel in public reports, papers, and conference documents. The buried depth of the tunnel selected into the research database is $550 \sim 1450$ m, and the tunnel section is $45 \sim 102$ m^2. The specific distribution is shown in Figure 1:

In Figure 1, there are 51 tunnels with a buried depth of $800 \sim 1000$ m, accounting for 47.66%, 96 tunnels with a buried depth of $550 \sim 1200$ m, accounting for 89.72%, 63 tunnels with a cross-sectional area of $55 \sim 75$ m^2, accounting for 58.88%, and 96 tunnels with a cross-sectional area of $45 \sim 95$ m^2, accounting for 89.72%. That is, the core data in the research database are buried depth $550 \sim 1200$ m and cross-sectional area $45 \sim 95$ m^2.

In this study, MIDAS-GTS control is loaded in MIDAS CIVIL 2021 software to conduct finite element analysis of tunnel data in the database. Because all data are historical data from 2016 to 2020, the analysis results can be certified in time. Analyze the data before date t to judge the difference and correlation between the ground pressure simulation results and the actual ground pressure records on date t and date $t + n$. The comparison data include roof displacement and bolt tension.

3. Model Design and Experimental Record

The deep roadway involved in this study has different buried depths, cross-sectional area, geological environment, and support scheme. In the support scheme, the length and density of anchor rod and anchor cable are different, the composition of anchoring agent and grouting fluid are also different, and the schemes of passive support are also different (such as steel beam, steel strip, shotcrete, and arch building), so the construction principle of the three-dimensional model of different support schemes should be determined [3], as shown in Figure 2.

In Figure 2, all tunnels are built with three-dimensional models according to the four-layer model, of which the innermost layer is the passive support structure layer, including the support structure other than the metal support structure. The metal passive support structure is built in the passive support structure layer, and the metal passive support structure layer is modeled according to the actual size of metal support structures such as steel beam and steel strip. The surrounding rock part is divided into the anchor layer and the surrounding rock layer. The anchor layer is designed according to 1.2 times of the anchor length or 0.7 times of the anchor cable structure. After determining the thickness of the anchor layer, the surrounding rock layer model with 6 times of the thickness of the anchor layer is designed. The differences of different tunnels due to geological conditions, buried depth, cross-sectional area, and other influencing factors are modeled from the weight of surrounding rock, external stress, and the design parameters of elastic modulus, compressive strength, and shear strength of each layer.
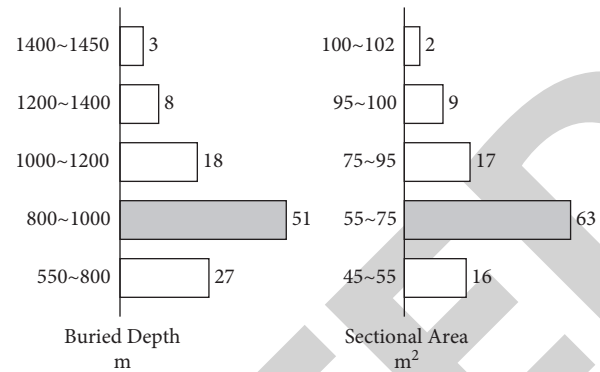

FIGURE 1: Distribution of tunnel characteristics in the research database (data source: collected by the study).
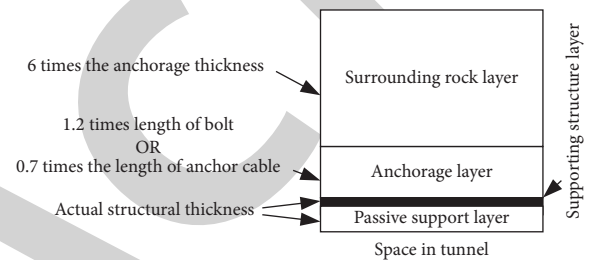

FIGURE 2: Design principle of the finite element three-dimensional model (local of roof section).

Deep tunnels are divided into development tunnels and mining area tunnels. The development tunnel is generally excavated in the whole rock in the stable rock stratum, the tunnel section is large, the tunnel is far from the coal seam and soft rock stratum, its service time is long, and the pressure environment is relatively stable. Mining area tunnels are generally excavated near or in coal seams, with short service time and complex pressure environment [4]. The mining area tunnel in this study is subject to the pressure control technology of deep tunnel, and less all coal or all soft rock tunnel is selected. It is generally arranged along the coal seam roof. When the coal seam roof is soft rock, it is generally arranged along the soft rock stratum roof, so as to ensure the stability of the tunnel roof first. Therefore, the cross-section strata of 107 deep tunnels involved in the research database include 85 whole rock structures, accounting for 79.44%. In the actual development scheme, all tunnels are arch sections or circular arch sections, as shown in Figure 3:

In Figure 3, H is the full height of the tunnel, B is the full width of the tunnel, R_L and R_R are the radius of the two shoulder circular arch structure of the arched tunnel, R_M is the radius of the central arch structure of the arched tunnel, O_L and O_R are the center of the two shoulder circular arch structure of the arched tunnel, O_M is the center of the central arch structure of the arched tunnel, R is the radius of the circular arch structure of the arched tunnel, O is the center of the circular arch structure of the arched tunnel, H_A is the height of the side wall of the arched tunnel, and H_C is the height of side wall of the circular arch tunnel. Because the excavation maintenance period of most deep tunnels is
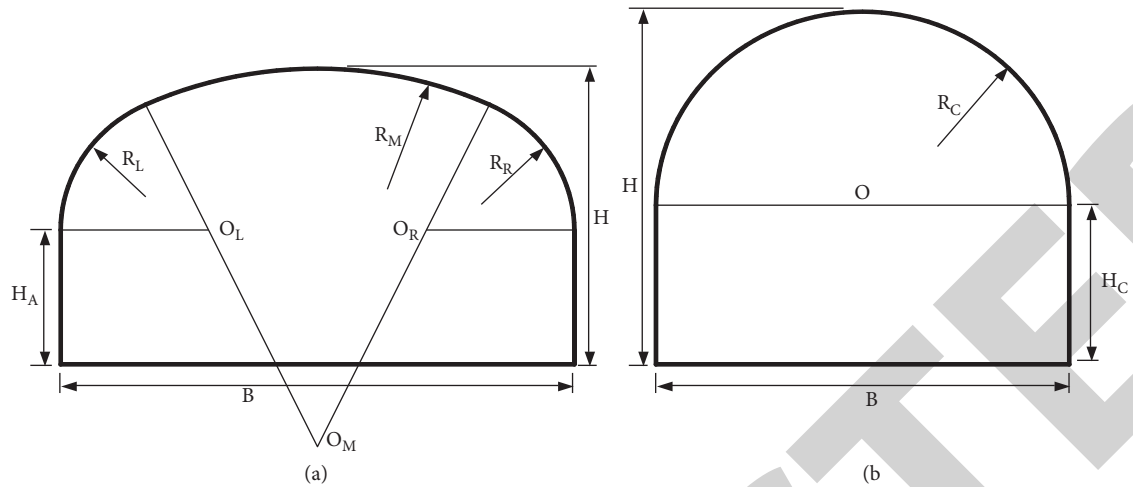
Figure 3: Section composition of two tunnel sections. (a) An arched section and (b) a circular arched section.

about 15 days, the excavation depth per day under the current process conditions is about 4 ∼ 7 m, and a three-dimensional finite element model with a length of 105 m is constructed along the section in the figure.

The excavation process of large section deep tunnel is mostly divided into steps and the multistep excavation method. Generally, one step is set every 3 ∼ 5 m height to form the top, side wall, and bottom plate in turn. The tunnel with height less than 7 m adopts the one-time smooth blasting forming method. Advance support is generally adopted within the 8-hour construction period (2 ∼ 3M), which is generally the construction process of predrilling beam and pregrouting [5]. The preanchor cable method will be used to strengthen the support in the soft rock fracture zone, the active support will be completed within the 24-hour construction period (4 ∼ 7M), and the passive support will be completed within the 48-hour construction period (8 ∼ 14 m), which is generally anchor bolt, anchor cable, permanent grouting, and steel beam. For shotcrete and other support schemes, the arch filling layer will be arranged in the shotcrete layer in the development tunnel. Therefore, the structure of the front end of the tunnel in the model design is more complex, and the structure of the rear section is basically the same [6].

Because the working face structure of the full face tunneling method is relatively simple and limited by space, the modeling method of working face structure of the full face tunneling method is not analyzed in [7]. The 2-step bench excavation method for developing the tunnel with a net height of more than 7 m is shown in Figure 4.

In Figure 4, A_1 is the roof advance support section, A_2 is the roof active support construction section, A_3 is the roof passive support construction section, B_1 is the sidewall advance support section, B_2 is the sidewall active support construction section, B_3 is the sidewall passive support construction section, and C (including the subsequent parts in the model not drawn in the figure) is the action section of complete support [8].

According to the tunnel design drawing data in the research database and the model design standards shown in Figures 2, 3, and 4, after designing the three-dimensional finite element model for the tunnel, run the simulation calculation process in the finite element simulation system with the help of the fluid structure coupling model and MIDAS-GTS control and compare the simulation results with the real data, so as to evaluate the universal applicability and value of the fluid structure coupling model and MIDAS-GTS control.

4. Simulation Results and Research Conclusions

All simulations are performed in MIDAS-GTS environment. Group A is the simulation analysis directly using fluid structure coupling model, and group B is the simulation analysis closest to the model after comparing multiple available models according to the actual collected data in the traditional mode. In the traditional concept, group B can obtain simulation results closer to the actual analysis requirements. In this study, the actual effects of the two groups of simulation are compared with the simulation results of roof displacement and bolt tension.

First, the results of the two groups are compared from the perspective of overall statistics, and Table 1 is obtained.

In Table 1, the concept of deviation is the difference between the simulation result and the measured value and the ratio of the absolute value to the measured value:

$$D_i = \frac{|S_i - A_i|}{A_i} \times 100\%, \qquad (1)$$

where D_i is the output value of the deviation corresponding to the ith input variable, S_i is the simulation result value in the ith input variable, and A_i is the measured value in the ith input variable.

Maximum deviation is the maximum value in all deviation result sets within the statistical range, and average deviation is the arithmetic average of all deviation result sets within the statistical range. The average calculation method is

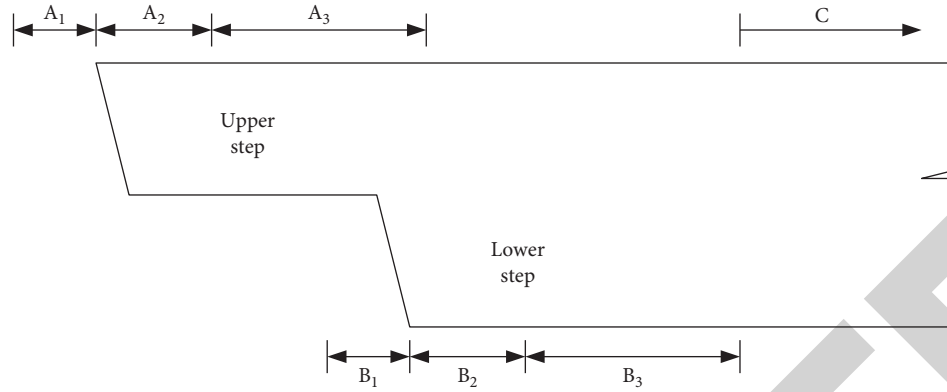$$\mathrm{Arg}(D) = \frac{1}{N} \sum_{i \le N} D_i, \qquad (2)$$

Figure 4: Modeling scheme of two-step bench method heading face (side view).

Table 1: Comparison of overall statistical results (data source: collected by the study).

Grouping	Roof displacement			Bolt tension		
	Maximum deviation %	Average deviation %	STD	Maximum deviation %	Average deviation %	STD
Group A	2.569	1.392	0.854	4.692	2.373	1.037
Group B	2.736	1.438	0.863	5.059	2.527	1.159
Leadership of group A	6.50%	3.30%	—	7.82%	6.49%	—

where $Arg(D)$ is the average output result, D_i is the output value of the deviation corresponding to the ith input variable, and N is the number of data pointers within the statistical range. The meanings of other mathematical symbols are the same as those above.

STD is the standard deviation rate of data, and the statistical method is as

$$STD = \sqrt{\frac{\sum_{i \leq N} (D_i - Arg(D))^2}{N - 1}}, \tag{3}$$

where STD is the output result of the standard deviation rate. The meanings of other mathematical symbols are the same as those above;

In Table 1, group A, using the fluid structure coupling model, has certain data advantages over group B. In terms of roof display, maximum deviation increased by 6.50%, average deviation increased by 3.30%, bolt tension and maximum deviation increased by 7.82%, and average deviation increased by 6.49%. Analyze the reasons for the statistical results, select the model with high predata coupling rate among many analysis models, and do not use fluid structure coupling model, and the analysis accuracy of this model (group B) is lower than that of the analysis model (group A) using the fluid structure coupling model. The representative fluid structure coupling model has general advantages over the common geotechnical analysis models. At least in the geotechnical analysis of deep tunnel, the fluid structure coupling model shows significant advantages.

In order to further verify the above point of view, the analysis error distribution is analyzed from different statistical control variables, and the data statistical grouping method is the same as the above. For example, the error rate

distribution of simulation results obtained under different tunnel depths is shown in Figure 5:

In Figure 5, although the mean deviation rate of the simulation analysis of the fluid structure coupling model is always less than that of other models, the slope of the linear regression function within the buried depth of 550 ~ 1450 m analyzed by the fluid structure coupling model in this study is also significantly greater than that of other models, that is, with the increase of the buried depth of the tunnel. The deviation rate of simulation results of the fluid structure coupling model increases faster than the average value of other models. When the future deep tunnel construction demand reaches the buried depth of more than 1450 m, the applicability of the fluid structure coupling model is likely to be lower than that of other models. That is, the research results show that the fluid structure coupling model is generally applicable to tunnels with a buried depth of 550 ~ 1450 m, but it does not mean that it is applicable to the geotechnical simulation of tunnels with a buried depth of more than 1450 m in inland rivers.

Under the same grouping mode and statistical mode, compare the deviation rate of simulation data driven by tunnel section data, as shown in Figure 6.

In Figure 6, the data analysis results further verify the analysis results of the data in Figure 5. The data analysis scope of the study is the deep tunnel with a tunnel cross-sectional area of $45 \sim 102 \, m^2$ and a tunnel buried depth of $550 \sim 1450$ m. The analysis results of the fluid structure coupling model in this range are better than the average values of other models in terms of the deviation rate of simulation data, indicating that the fluid structure coupling model has universal applicability in this analysis range. This study does not mean that the fluid structure coupling model still has universal applicability in a wider range of tunnel
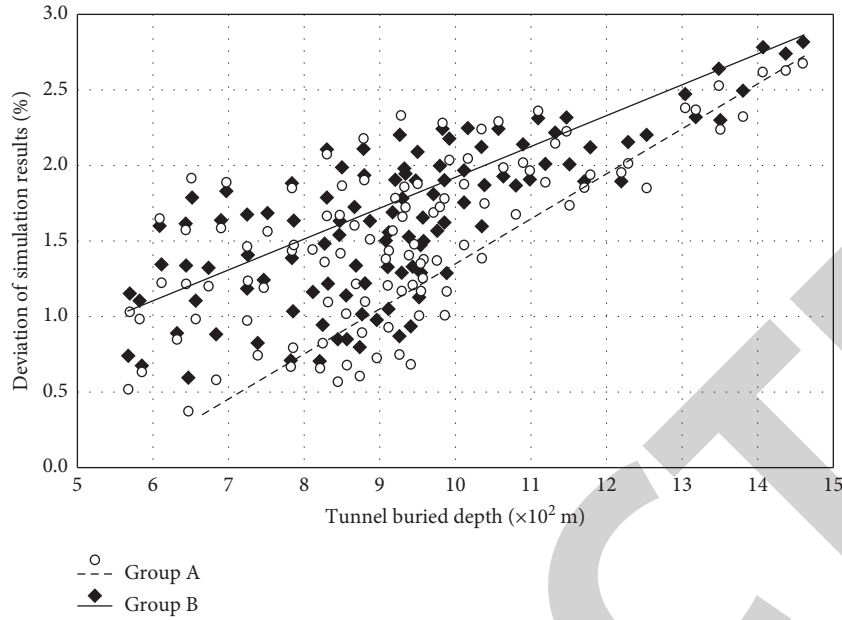
Figure 5: Linear regression relationship between simulation results and measured results (based on tunnel buried depth) (data source: collected by the study).
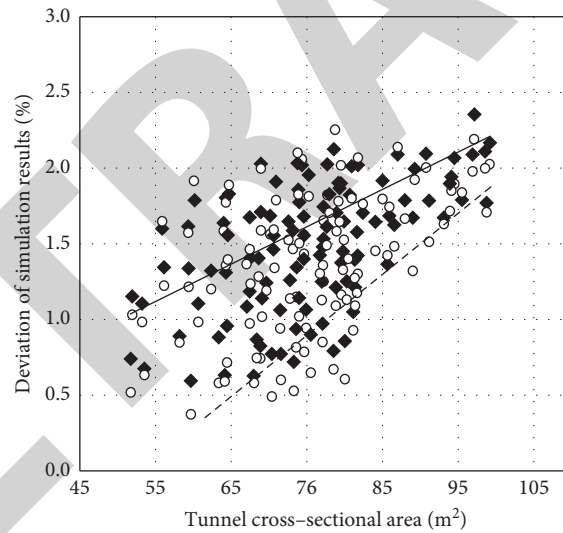

Figure 6: Linear regression relationship between simulation results and measured results (based on tunnel cross-sectional area) (data source: collected by the study).

geotechnical simulation. In particular, according to the linear regression results of the deviation rate of the simulation data, when the tunnel depth is larger or the tunnel cross-sectional area is larger, the deviation rate of the simulation results of the fluid structure coupling model may exceed the average value of other models. However, in the actual construction, under the design specifications for deep underground mining of coal mines and iron mines, the vast majority of deep tunnels are within the scope of this analysis, so the fluid structure coupling model has universal applicability in the actual construction.

Comprehensively, compare the analysis results of the deviation rate of the above simulation results. Under the grouping conditions set in the study, compared with group A using the fluid structure coupling model and group B using the preferred model, the comprehensive advantages of the model are shown in Table 2.

In Table 2, linear regression R^2 value represents the reliability of linear regression. The statistical method is shown as

$$R^2 = \frac{\text{SSR}}{\text{SST}} = 1 - \frac{\text{SSE}}{\text{SST}}, \tag{4}$$

where SSR is the sum of regression squares and the sum of longitudinal axis squares of projection points on the regression line, SSE is the sum of squares of residuals, that is,

TABLE 2: Statistics of deep tunnel simulation advantages of the fluid structure coupling model (data source: collected by the study).

| Grouping | Average deviation | | | Comprehensive deviation | Linear regression R^2 value |
	550~800 m %	800 m~1200 m %	1200~1450 m %	%	
Group A	0.46	0.92	2.56	1.57	0.7297
Group B	1.37	1.64	2.69	1.83	0.7836
Leadership of group A	66.42%	43.90%	4.83%	14.21%	—

the sum of squares of the vertical axis of the actual projection point of the original data to be regressed, SST is the sum of squares, and SST = SSR + SSE.

According to the data in Table 2, as the buried depth of the tunnel increases, the deviation rate of the simulation results of the fluid structure coupling model decreases from 66.42% to 4.83% compared with the average deviation rate of other preferred models. It can be considered that the advantages of the fluid structure coupling model gradually lose with the increase of the buried depth of the tunnel. However, in the data collection scope of the research database, that is, under the construction requirements of the underground system and deep tunnel system of most domestic coal mines and iron mines, the fluid structure coupling model has universal applicability.

5. Summary

The research cooperates with many domestic mining companies to analyze the original data of 107 deep buried tunnels provided by them and compares the difference of simulation analysis results between the simple use of the fluid structure coupling model and the use of the optimal model in MIDAS-GTS simulation analysis environment. It is found that, within the range of deep buried tunnel types involved in the research database, the fluid structure coupling model has universal applicability. That is, under the conditions of a certain tunnel buried depth range and a certain tunnel cross-sectional area, the fluid structure coupling model is significantly better than the average value of the analysis results of other models in terms of the deviation rate of the simulation analysis data of tunnel roof displacement and tunnel anchor bolt tension. Because the database volume involved in this study is large and limited by space, in addition to the analysis objectives of roof displacement and tunnel anchor bolt tension, this study does not involve other geotechnical analysis scope, and only tunnel buried depth and tunnel section are counted separately in data statistics, so this study still has certain limitations. However, this study is sufficient to confirm that the fluid structure coupling model is generally applicable at least in the current deep tunnel analysis tasks in China (limited to roof displacement simulation analysis and anchor bolt tension simulation analysis). In the future deep tunnel simulation analysis in this category, it is recommended to directly use the fluid structure coupling model as the analysis model.

Data Availability

The data underlying the results presented in the study are available within the article.

Disclosure

The authors confirm that the content of the manuscript has not been published or submitted for publication elsewhere.

Conflicts of Interest

The authors declare that they have no potential conflicts of interest in our paper.

Authors' Contributions

All authors have seen the manuscript and approved to submit to the journal.

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