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Analysis of Ground Settlement Induced by Shield Tunnel Construction: A Visualized Review of Hot Topics and Trend Evolution

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Abstract

Shield tunneling is very common in urban tunnel construction, which often leads to surface settlement in the process of crossing complex geological conditions, thus affecting the safety and operation stability of surrounding buildings and other structures.In order to systematically sort out the research progress and development trend of ground subsidence caused by shield excavation, this paper uses bibliometric analysis and visualization technology to comprehensively analyze the research literature on "ground subsidence caused by shield tunnel construction" in recent years.Through the statistics and induction of highly cited literature, core journals, keywords and the evolution path of research topics, it is revealed that the hot topics in this research field are concentrated on the integrated application of settlement prediction model, construction disturbance mechanism, multi-source monitoring technology and intelligent algorithm.The research results show that in recent years, the research scale in this field has continued to expand, the trend of intelligence has become increasingly obvious, and the international cooperation has gradually strengthened. This paper can provide theoretical reference and technical support for the control of ground settlement caused by shield tunnel construction, and provide data basis and research direction guidance for subsequent research.

Keywords: Tunnel Construction, Ground Settlement, Bibliometric, Topic detection

Introduction

Under the background of more shield construction in the current engineering construction, the ground settlement caused by shield tunnel construction has become an important issue in the development of underground space. Shield construction is widely used in subway and other tunnel construction because of its high construction efficiency and small interference to the ground. However, due to the disturbance of undisturbed soil and the change of

underground stress field during shield tunneling, engineering disasters such as surface subsidence, building cracks, pipeline dislocation and so on will be caused. Especially in the areas of weak strata, shallow buried depth and adjacent buildings, the problem of land subsidence is more prominent. In recent years, scholars in relevant fields in the world have carried out a lot of research on land subsidence mechanism, prediction model, monitoring technology and control methods, such as using finite element method, artificial neural network and other analysis methods to study the problem of surface subsidence caused by shield construction. For some complex working conditions and complex address conditions, the existing methods still have limitations. Therefore, it is urgent to systematically review and sort out the research evolution process, hot topics and key methods of settlement caused by shield construction on the basis of existing research, so as to reveal the development pulse and future trend of this field.

This paper intends to use a combination of bibliometrics and visual analysis to comprehensively sort out the relevant literature on "ground settlement caused by shield tunnel construction". The research content mainly includes: analysis of the number and annual trend of literature, highly cited papers and their contributions, keywords, etc. The purpose of this paper is to reveal the research focus and potential research gaps in this field through systematic sorting, and to provide some guidance for future work and research in the field of tunnel construction.

Literature Review

In the process of shield tunnel construction, due to the influence of many factors, it will often cause the disturbance of surrounding soil, and then lead to the surface settlement phenomenon, which will have a serious adverse impact on the overall stability of the tunnel structure.(Li et al., 2020) have carried out a large number of studies on this issue by a large number of scholars around the world. At present, they mainly use engineering experience, theoretical derivation methods, physical model tests and numerical simulation.(Fang et al., 2017) introduced the longitudinal width coefficient J to modify the equation when predicting the surface settlement during construction. The results show that the modified equation can fit the experimental data well.

(Liu et al., 2013) Used peck formula and modified stiffness method to fit the characteristic parameters of the settlement tank, predicted the surface settlement through the formula, and compared with the actual monitoring data. (Martos, 1958) Proposed that the surface settlement trough caused by excavation can be approximately expressed by error function. Based on the analysis of a large number of surface subsidence data, (Peck, 1969) Proposed the assumption that the surface subsidence conforms to the Gaussian distribution. They believe that the deformation caused by formation loss makes the volume of the settlement tank equal to the volume of formation loss.After collecting and analyzing a large amount of data (O'reilly & New, 1982).Summarized several empirical formulas for estimating surface subsidence.Using the algorithm and model test,(Verruijt & Booker, 1998). Analyzed the ground deformation caused by tunnel excavation under different working conditions, and obtained the calculation formula of ground displacement. Based on several engineering examples and model test data,(Lu et al., 2020). Proposed the calculation formula of the maximum settlement above the tunnel varying with depth, and established a Gaussian function model to predict the settlement on the tunnel cross section (Norouzi, 2020) used

neural network to analyze the parameters affecting the surface settlement during the excavation of the advance support tunnel, and used finite element software to model and analyze the static load and dynamic load. (Chakeri et al., 2013) used numerical calculation methods to quantify the factors such as the buried depth of the tunnel, the upper soil pressure, the tunnel diameter, and the face pressure of the tunnel, and compared and analyzed the actual monitoring situation.

(Zhan et al., 2021)used the waveform denoising method based on MATLAB to remove the noise in the observation data and get a more accurate signal. Then, through the surface settlement prediction method based on Elman network, they predicted the surface settlement of deep foundation pit in ocean area.(Li et al., 2021) studied the land subsidence caused by the construction of curved shield tunnel, and proposed that the two main factors causing land subsidence were land loss and construction load. They analyzed the subsidence caused by land loss through three-dimensional image theory. (Boubou et al., 2010) elaborated the influence mechanism of multi arch tunnel excavation through peck formula, modified the model combined with the field data of a double tunnel excavation in Wuhan, and derived the prediction formula of surface deformation caused by double tunnel construction. (Boubou et al., 2010) established a nonlinear relationship between TBM parameters and surface subsidence from the perspective of neural network. (Zhang et al., 2021) proposed the extended depth learning method, which uses the extended tunnel data to predict land subsidence in real time, and is used to evaluate the importance of input data to land subsidence variables. (Syahputra, 2020) used field monitoring data and finite element software to analyze the ground settlement law of shield tunnel in different hard rock height ratio strata. The research shows that there are obvious differences in the ground settlement of strata with different hard rock height ratio. (Yang et al., 2020) studied the surface structure change caused by material movement through sandbox simulation, and simulated the surface elevation change caused by mass loss. (Xu & Xi, 2021) studied the settlement characteristics of shield tunnels with small curvature radius, and pointed out that the settlement curve of such tunnels was significantly different from that of straight tunnels. (Suwansawat & Einstein, 2006) took the subway in Bangkok, the capital of Thailand, as the engineering background, and selected the geometric factors (burial depth, driving mileage), geological conditions (geology at the arch crown and invert, groundwater level) that affect the surface subsidence, and the training network was used to predict the surface subsidence ahead.

Research Methodology

We reviewed the research status and related literature in the field of land subsidence caused by large section shield tunnel construction. We conducted a comprehensive search in the web of science database and obtained all relevant articles on the cross topic of land subsidence caused by large section shield tunnel construction from 1998 to 2025. The web of science database covers a wide range of academic publications, altimetric data, patents, research grants, clinical trials and policy documents, and is one of the most comprehensive sets of linked data at present (Bergeron et al., 2018). When retrieving all literature, we used the following keywords: tunnel construction; Ground Settlement. In order to carry out bibliometric analysis of literatures, we exported relevant literatures from the web of Science Database in the format of BibTex and carried out necessary data preprocessing. The bibliometrix software used has high data processing ability and graphical visualization function, which can improve the analysis efficiency on the basis of ensuring scientific rigor.

According to the research of (Yurui & Abdullah, 2024), the software is widely recognized as the most comprehensive and excellent user experience class a open source bibliometric tool.

Results and Discussions

Descriptive Analysis

The primary details of the chosen collection of articles obtained from the "Biblioshiny Tool for R-Package" are presented in Table 1.

Table 1

Demographic Profile of Respondents For Ground Settlement Induced by Shield Tunnel Construction.

Description	Results
Timespan	1991-2025
Sources (Journals, Books, etc)	117
Documents	500
Annual Growth Rate %	5.41
Document Average Age	6.85
Average citations per doc	35.55
References	9432
Keywords Plus (ID)	502
Author's Keywords (DE)	1423
Authors	1261
Authors of single-authored docs	10
Single-authored docs	12
Co-Authors per Doc	4.85
International co-authorships %	23.4
article	471
proceedings paper	22

According to table 1, the research time span of land subsidence caused by shield tunnel construction is from 1991 to 2025. We selected 500 highly cited literatures distributed in 117 different publishing sources, reflecting the universality and diversity of research content in this field. The average annual growth rate of the literature is 5.41%, which shows that the research heat of land subsidence caused by shield tunnel excavation has maintained a relatively stable upward trend in the past 30 years. Especially under the background of the high development of underground engineering, the problem of land subsidence has been paid more and more attention by the academic community.

The average publication age of the literature is 6.85 years, indicating that the field has a certain amount of research accumulation, while maintaining an active state of continuous update. The average number of citations per article reached 35.55, indicating that the achievements in this field have strong citation value and academic influence.

From the perspective of the author and cooperation, 1261 scholars have participated in the research in this direction, with an average of 4.85 collaborators per article, indicating that cooperative research is relatively common, and teamwork has become the norm. Among them, the proportion of international cooperation is 23.4%. Although it does not occupy a

dominant position, it has formed a certain transnational cooperation network, which shows that this field has the potential of global collaborative research.

In terms of content composition, the literature contains 502 enhanced keywords plus and 1423 author-defined keywords, which reflects the diversity of research perspectives in this field. The total number of references cited reached 9432, which further confirmed the important position of this research direction in the field of geotechnical engineering and urban infrastructure construction.

The research on land subsidence caused by shield construction has gradually formed a knowledge system with stable structure and continuous expansion. Its academic output has the characteristics of strong collaboration, citation and content diversity, which has laid a good foundation for revealing its research hotspots and trend evolution. With the continuous exploration of underground space, the research direction is expected to continue to expand and evolve to a deeper level.

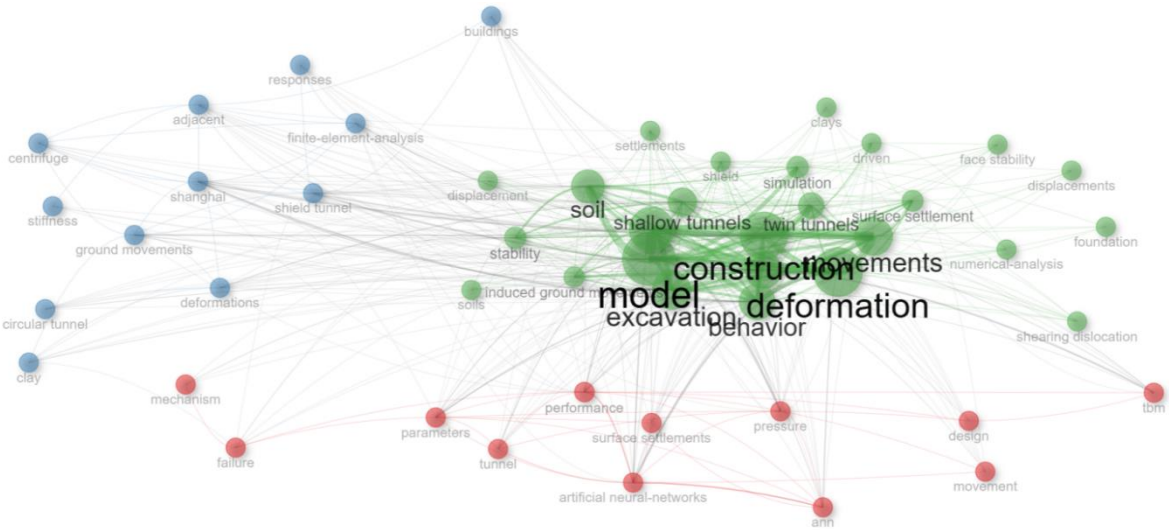

Figure 1. CoWordNet for Ground Settlement Induced by Shield Tunnel Construction

From the figure 1 analysis results, it can be seen that "model", "construction" and "deformation" have the highest centrality in the whole network, and constitute the core terminology system for the study of land subsidence caused by shield tunnel construction. These terms serve as a bridge between different research topics and also play an important role in semantic communication. Further division shows that the research in this field mainly focuses on three directions: numerical modeling and prediction technology, numerical simulation analysis and settlement mechanism and risk control practice. It reflects that the technology evolution and theme focus in this field are becoming more and more mature and diversified.

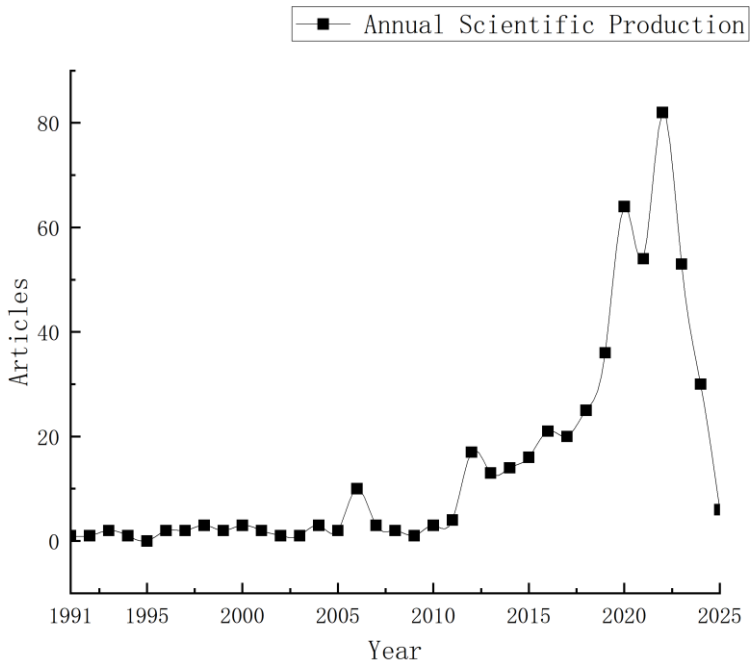

Figure 2. Annual Scientific Production for Ground Settlement Induced by Shield Tunnel Construction.

It can be seen from Figure 2 that the annual scientific research output of the research on land subsidence caused by shield tunnel construction shows obvious characteristics of Phased Evolution. From 1991 to 2010, the research in this field was at the initial stage, and the overall annual number of papers was low. The period from 2011 to 2016 is the initial stage of development, with the annual average number of papers steadily rising and gradually breaking through 10, indicating that with the intensification of urban underground space development, the academic community has begun to strengthen the research investment on such engineering problems.

After 2017, especially during the period from 2020 to 2023, the annual number of papers published has increased significantly, with a peak of 82 in 2022, which has become the highest output year in this field, showing that the settlement control of shield construction has become a research hotspot in the engineering and academic circles. In 2024 and 2025, although there is a decline, it still remains at a high level, indicating that the research heat in this field continues.

On the whole, the research direction is closely in line with the process of urbanization. With the rapid development of intelligent construction technology, it is expected that it will remain active in the future and develop further in the direction of more precision and systematization.

Table 2
Most Relevant Sources for Ground Settlement Induced by Shield Tunnel Construction

Sources	Articles
TUNNELLING AND UNDERGROUND SPACE TECHNOLOGY	117
COMPUTERS AND GEOTECHNICS	28
ADVANCES IN CIVIL ENGINEERING	19
CANADIAN GEOTECHNICAL JOURNAL	18
KSCE JOURNAL OF CIVIL ENGINEERING	17
UNDERGROUND SPACE	17
APPLIED SCIENCES-BASEL	16
GEOMECHANICS AND ENGINEERING	12
INTERNATIONAL JOURNAL OF GEOMECHANICS	11
ENVIRONMENTAL EARTH SCIENCES	10

It can be seen from the source analysis of major journals that, 《Tunnelling and Underground Space Technology》, The journal has a high degree of academic authority and leading role in the field of tunnel engineering and underground space development, and is also the most important academic communication platform for the subject research. Computers and geotechnology (28 articles) and advances in Civil Engineering (19 articles) rank second and third respectively, which shows that the research in this field not only depends on the support of engineering theory, but also highly depends on the integrated application of numerical simulation and information technology. The Canadian geotechnical Journal (18), ksce Journal of Civil Engineering (17) and underground space (17) reflect the academic contributions and regional engineering practice background of different countries on this research topic. 《Applied Sciences-Basel》 《Geomechanics and Engineering》 《International Journal of Geomechanics》 The emergence of Environmental Earth Sciences and other journals shows that the research on land subsidence has gradually taken on the characteristics of interdisciplinary intersection. The research content is not only limited to structural response and construction control, but also covers the multi-dimensional perspectives of geological environment effect, ecological impact and material mechanics behavior.

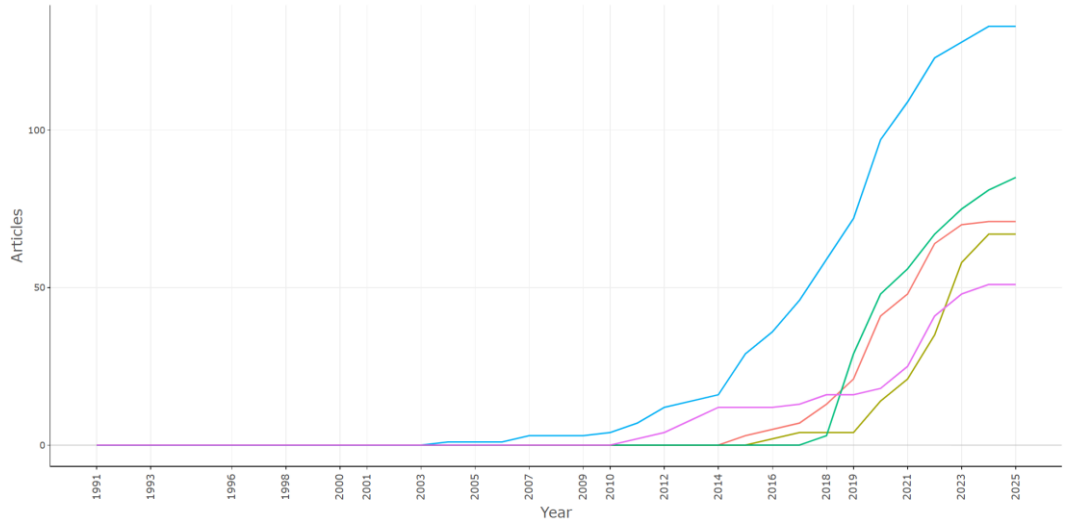

Figure 3. Affiliations' Production over Time for Ground Settlement Induced by Shield Tunnel Construction.

It can be seen from the figure that the output of research institutions around the theme of "ground settlement caused by shield tunnel construction" shows obvious clustering characteristics, especially in recent years, showing an explosive growth trend. Taking Tongji University as a representative, its scientific research output has gradually increased since 2006, and has achieved a leap forward improvement since 2020. The annual average number of papers published from 2023 to 2025 has stabilized at more than 120, establishing its absolute academic leading position in this field. The direction of deep ploughing tunnel and underground engineering during the headmaster's term has a complete scientific research system and engineering project support, which is the key to its sustainable high yield.

Colleges and universities such as Zhejiang University, Beijing Jiaotong University, Central South University and Hunan University have also risen rapidly in recent years, especially after 2022. Among them, Hunan University reached 75 papers in 2023, showing rapid progress in intelligent monitoring, deep foundation pit control and shield construction response.

It is worth noting that before 2015, the number of papers issued by most colleges and universities in this field was single digits or even zero. With the rapid development of this field in the past decade, the research on shield tunnel settlement has evolved from a few traditional geotechnical universities to a multi-point layout with Tongji University as the core and many high-level colleges and universities promoting together.

Table 3
Country Scientific Production for Ground Settlement Induced by Shield Tunnel Construction

region	Freq
CHINA	1507
USA	43
IRAN	41
SINGAPORE	38
FRANCE	36
SOUTH KOREA	26
GERMANY	23
UK	23
AUSTRALIA	19
CANADA	17
JAPAN	16
ITALY	12
THAILAND	12
NETHERLANDS	11
SPAIN	11

From the perspective of the distribution of national scientific research output, focusing on the research theme of "land subsidence caused by shield tunnel construction", China has the absolute advantage in the leading position, and has published 1507 relevant literatures, accounting for far more than other countries, constituting the main force of global research in this field. On the one hand, it is due to the rapid development of large-scale urban rail transit and infrastructure construction in China in recent years. On the other hand, it is also due to the continuous investment and research accumulation of universities and scientific

research institutions (such as Tongji University and Zhejiang University) in tunnel engineering, settlement control and intelligent monitoring.

In addition to China, the United States (43), Iran (41), Singapore (38), France (36) and other countries ranked in the forefront of literature output. Their research has a high influence in theoretical models, numerical methods or material innovation, representing the diversity and depth of research in this field. In addition, although the output of Britain, Australia, Canada, Italy, the Netherlands and other countries is not much (all less than 20), they often reflect their academic influence in the form of transnational joint projects or participation in the formulation of international standards.

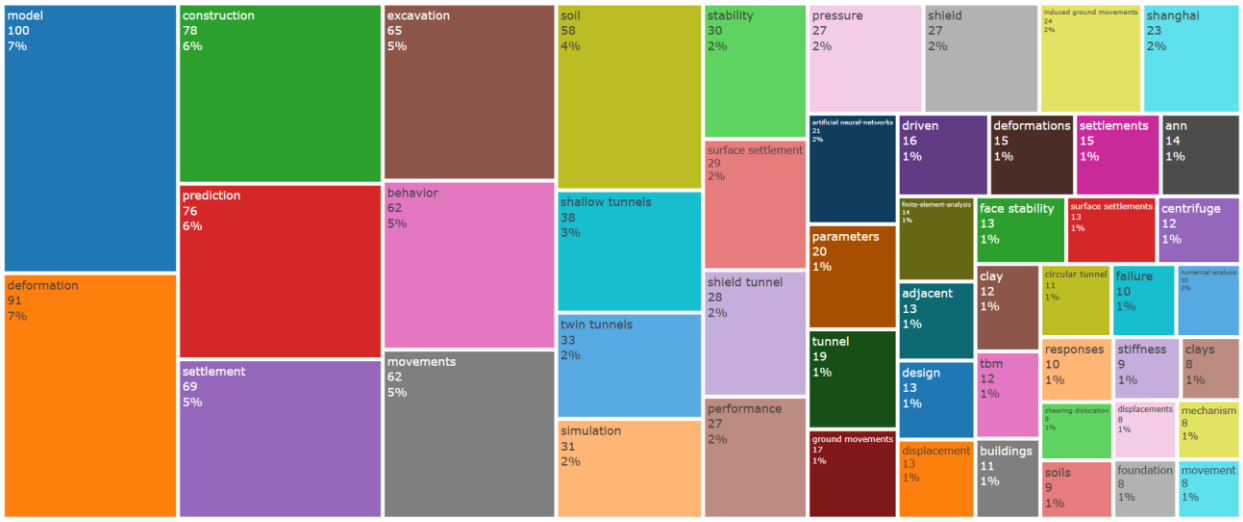

Figure 4. Most Frequent Keywords for Ground Settlement Induced by Shield Tunnel Construction

According to the statistical results of high-frequency keywords, the distribution of keywords around the research theme of "ground settlement caused by shield tunnel construction" has typical characteristics in three aspects:

First, the "model" ranks first with 100 occurrences, indicating that the field highly relies on modeling tools for deformation evolution simulation and settlement prediction. The following words are "deformation", "construction", "prediction" and other words, reflecting that the problem of land subsidence is essentially a mechanical response problem caused by construction disturbance, and prediction and control has become one of the research themes. "Settlement" and "exclusion" directly reveal the core characteristics of such problems.

Secondly, some keywords such as "behavior", "movements", "soil", "simulation" and "stability" reflect the importance of researchers in mechanism understanding, parameter inversion and risk assessment. Structural terms such as "shallow tunnels" and "twin tunnels" appear more frequently.

The keywords of "artificial neural networks", "finite element analysis", "numerical analysis" and other methods have also appeared many times, indicating that modern research methods are advancing with the development of society.

Discussion

With the continuous growth of the demand for underground space development, the problem of land subsidence caused by shield tunnel construction has attracted increasing attention, and has become a key research direction in geotechnical engineering and urban infrastructure construction. The bibliometric and visual analysis results of this paper show that in recent years, the research in this field has shown a trend of rapid growth and focused topics, especially in the settlement prediction model, construction disturbance mechanism, intelligent monitoring system and so on. However, with the continuous change of social environment, this research field will also face many challenges and transformation opportunities in the future.

For example, the underground facilities are dense and staggered, and the construction of ultra shallow tunnels is complex.

In terms of future development trends, the following directions can be paid attention to:

The first is the smart tunnel and digital monitoring system: the monitoring platform is built through big data analysis and artificial intelligence algorithm.

Secondly, complex working condition modeling: improve the reliability of settlement prediction in the face of different stratum structures and surface loads.

Finally, multidisciplinary collaborative integration: future research will rely more on the integration and collaboration of civil engineering, geological science, data science, urban planning and other disciplines.

Conclusions

In recent years, the research on land subsidence caused by shield tunnel construction has shown a continuous growth trend, reflecting the key position of this field in urban underground space development and infrastructure construction. Literature analysis shows that since 2000, the number of relevant studies has increased rapidly, especially in the high-yield stage after 2020. The research results are mainly published in international core journals such as tunneling and underground space technology and computers and geotechnology, indicating that the subject has attracted great attention from the academic community. At the same time, the key words frequently focus on the terms such as "model", "prediction", "settlement", "behavior", "shield", which reflects the diversity of research methods. At the same time, the research in this field has obvious international and interdisciplinary characteristics, especially among the scientific research institutions in China, Singapore, the United Kingdom and other countries, which has formed a certain degree of academic collaboration and data sharing, and promoted the continuous evolution of prediction models, monitoring technologies and numerical analysis methods.

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