Research and Prospect of Foundation Pit Monitoring and Early Warning Based on CiteSpace

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Abstract. This paper discusses the research progress in the field of deep foundation pit monitoring and early warning in China. This paper uses CiteSpace software to analyze the literature data of CNKI, and reveals the research context, hot spots and frontier trends in the field of foundation pit monitoring and early warning. Keyword clustering and burst word extraction show that artificial neural network and intelligent construction site have become research hotspots. The research results of this paper show that the future development direction of foundation pit monitoring and early warning is intelligent, which will greatly improve the safety of foundation pit engineering construction and further help the transformation and upgrading of the construction industry.

Keywords: CiteSpace, deep foundation pit, monitoring and early warning, intelligent

1 Introduction

As a key link in engineering construction, the safety of foundation pit engineering is self-evident. Today, with the accelerating development of urbanization, high-rise buildings and large-scale infrastructure projects are increasing, and the scale and depth of foundation pit engineering are also increasing, which undoubtedly puts forward higher requirements for the safety of foundation pit. The foundation pit engineering is not only directly related to the safety of the construction personnel and the safety and stability of the surrounding environment, but also affects the construction period and cost. Therefore, in-depth discussion of foundation pit monitoring and early warning is of great significance for preventing and reducing foundation pit engineering accidents, improving construction efficiency, and ensuring the safety of people 's lives and property.

Bibliometrics and knowledge mapping technology play a vital role in the visual analysis of academic literature and the capture of frontier dynamics in the research field. Some scholars have used visualization tools to analyze the knowledge map of foundation pit safety risk management. The research of Tang Hongxia et al.[1] shows that Chinese scholars ' research on safety risk prevention and management of deep

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foundation pit mines has gradually developed from considering a single factor to considering multiple factors. The research level has deepened from innovative technology to the application of advanced theories and methods such as human factor theory, which has expanded the theoretical system of deep foundation pit mine risk management. On this basis, the application of foundation pit monitoring technology has increasingly become the focus of research. In particular, scholars such as Xia et al.[2] have made significant progress in the use of advanced algorithms such as long-term and short-term memory networks (LSTM) for early warning of deep foundation pit deformation safety risks. By applying these techniques to practical engineering projects, the short-term prediction of the deformation of each monitoring project of the foundation pit can be carried out. In addition, Wu Weigao[3] and other scholars use the risk early warning analysis method of foundation pit engineering based on data correlation to evaluate the safety status of foundation pit more comprehensively through multi-data source correlation analysis, and provide accurate decision-making basis for the adjustment of construction scheme. The integrated application of these technologies not only improves the accuracy and efficiency of monitoring, but also provides new theoretical support and technical means for the prevention and management of deep foundation pit safety risks.

In order to further systematically sort out the research context in the field of foundation pit monitoring and early warning in China, and scientifically analyze its realistic development, research hotspots and frontier trends, this paper uses CiteSpace software to conduct in-depth analysis from four aspects : basic characteristics of literature, authors, research institutions and highly cited literature through the literature data of China National Knowledge Infrastructure (CNKI) covering the whole time period. Through keyword topic path knowledge graph, keyword clustering and burst word extraction, we will visually analyze the current situation and trend of foundation pit monitoring and early warning research in China, aiming to provide reference and theoretical support for subsequent research on foundation pit monitoring and early warning.

2 Data Sources and Research Methods

In order to explore the research hotspots and frontier trends in the field of foundation pit monitoring and early warning, this paper combines the methods of bibliometrics and visual knowledge graph. Before the visual analysis of the knowledge graph, we first quantitatively describe the literature data. Quantitatively describe the time of publication, the author of the article, and the key words of the article, so as to establish a basic understanding of the existing research in the field of foundation pit monitoring and early warning, and provide reference for future research.

CiteSpace is an information visualization software developed by Dr.Chen Chaomei in 2004, which is mainly used for knowledge mapping and scientometric analysis of scientific literature. The software can reveal the development process and structural relationship of scientific knowledge through visualization, and assist researchers to explore the frontier hotspots, research evolution and trends in the research field[4].

CiteSpace has a wide range of application fields, including but not limited to information science, life science, management science, technology science, etc. Its functions mainly include research frontier and research hotspot analysis based on knowledge map, scientometrics and citation analysis, keyword co-word network analysis, author co-citation and author cooperation network analysis[5]. In addition, CiteSpace has been used to identify new trends and trends in scientific development, such as applications in land use[6], military psychology[7], and industrial upgrading[8].

In this paper, CNKI (China National Knowledge Infrastructure) database platform is selected as the retrieval source. The literature retrieval method is as follows : taking foundation pit monitoring as the subject word, according to the correlation degree as the standard, 5995 literature records are preliminarily obtained. In the search results, irrelevant documents such as meeting notices, news and publication headers are eliminated respectively. Finally, 5486 complete literature records are selected, each record covers the necessary information such as title, author, affiliated unit, abstract and keywords.

3 Statistical Analysis of Research Progress

3.1 Basic Feature Description

The annual change of CNKI 's overall publication volume reflects the technical development and practical demand increase and decrease in the field of foundation pit monitoring and early warning in terms of time extension, and also reflects the academic community 's attention to it. The annual changes in the number of publications in the field of foundation pit monitoring from 1995 to 2024 are shown in Figure 1.

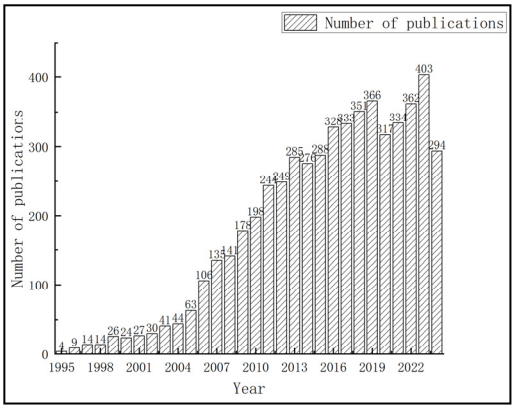

Fig. 1. Annual change in the number of publications

It can be seen from Figure 1 that the research on foundation pit monitoring and early warning began in 1995.From 2000 to 2024, the annual volume of foundation pit monitoring and early warning showed an overall upward trend. The specific course is divided into three stages :

The first stage is the initial development period (1995-2004) ;
the second stage is a period of rapid development (2005-2013) ;
the third stage is the stable development period (2014-present).

3.2 Description of the Author 's Characteristics

When discussing the research status and future research direction of foundation pit monitoring and early warning, we can reveal the core authors and their teamwork in this field by constructing the author cooperation network diagram. According to the literature data of CNKI, the author co-occurrence knowledge map (Figure 2) generated by CiteSpace software can intuitively show the core authors and their cooperation network in the field of foundation pit monitoring. In this map, the size of nodes or labels in the map reflects the number of papers published by the author. The larger the size, the greater the influence of the author in the field of foundation pit monitoring research. The connection between the nodes shows the cooperation network between the authors. The thickness of the connection represents the number of co-authored publications. The thicker the connection, the closer the cooperative relationship. By analyzing the radius of the node and the connection between the nodes, we can comprehensively evaluate the high-yield authors and their cooperative teams, so as to identify the researchers and teams that have important influence in the field of foundation pit monitoring and early warning. This method not only helps us understand the current research trends, but also provides a reference for future research directions and cooperation opportunities.

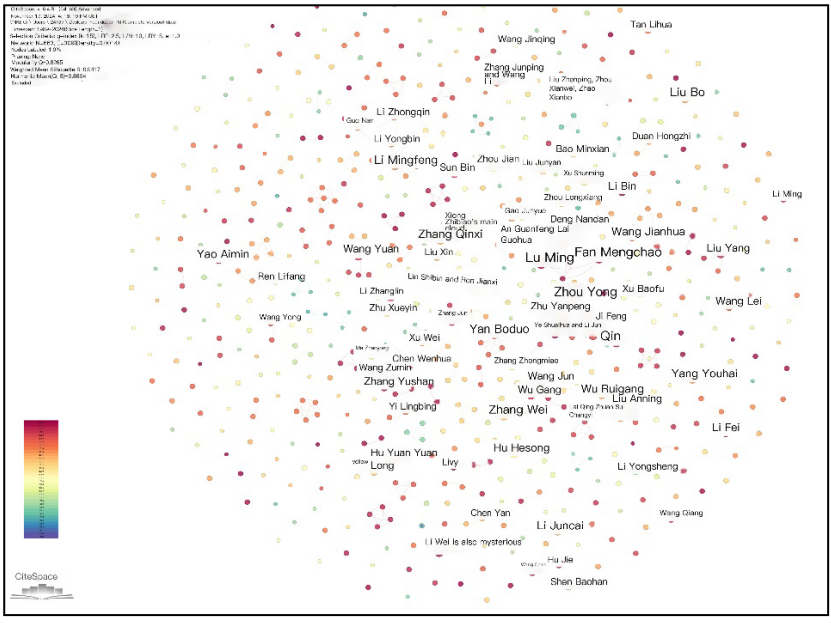

Fig. 2. Co-occurrence knowledge map of high-yield authors

It can be seen from the domestic author 's map (Figure.2) that there are 1002 nodes, 517 connections, and the network density is 0.001. Zhu Yanpeng (11 articles), Ren Jianxi (7 articles), He Qin (7 articles), Zhou Jian (6 articles), Zhou Yong (6 articles), Zhang Wei (6 articles), Yan Boduo (6 articles), Fan Mengchao (6 articles), Lu Ming (6 articles), Deng Nandan (6 articles) were the main authors. Researchers such as Zhu Yanpeng, Zhang Yushan, Fang Dayong and Wang Yuan collaborated frequently with other authors to form a small cooperative network (see Figure 3). This shows that they have built a solid research team as key figures. In general, the interaction within these teams is frequent, and the connection with the outside is weak. At the same time, the authors who publish more articles are often in the core area of the cooperation network, but the number of cooperative articles among the top high-yield authors is not large, which indicates that there is still room for improvement in the degree of cooperation between teams in the field of foundation pit monitoring research in China.

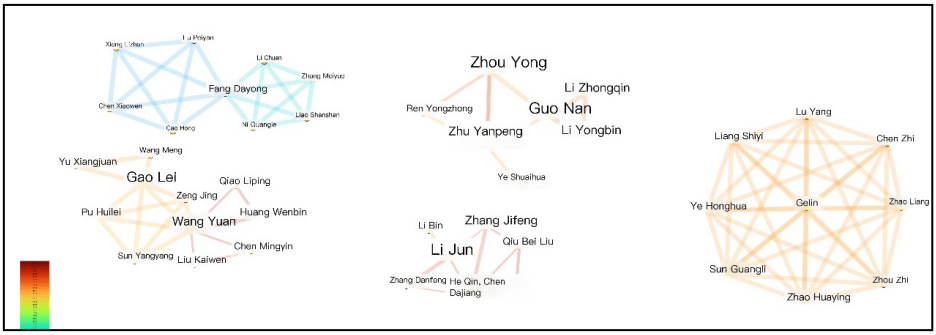

Fig. 3. The largest five author collaboration networks

3.3 Statistical Characteristics of Research Institutions

The CiteSpace software is used to visually analyze the cooperative network of high-yield research institutions in the field of foundation pit monitoring research. From Figure 4, it can be seen that there are 813 nodes, 149 connections, and the network density is 0.0005. CNKI publishing institutions obviously show a research community centered on the Department of Underground Architecture and Engineering of Tongji University, Gansu Provincial Key Laboratory of Civil Engineering Disaster Prevention and Mitigation of Lanzhou University of Technology, China Railway Fourth Survey and Design Institute Group Co., Ltd., School of Civil Engineering and Architecture of Guangxi University, Shanghai Geotechnical Engineering Survey and Design Institute Co., Ltd. In addition, on the whole, from the perspective of the number of research institutions, the Department of Underground Construction and Engineering of Tongji University (34 articles), Anhui University of Science and Technology (27 articles), Beijing Urban Construction Survey and Design Institute Co., Ltd. (23 articles), China Construction Second Engineering Bureau Co., Ltd. (18 articles) are the main publishing institutions in this field.

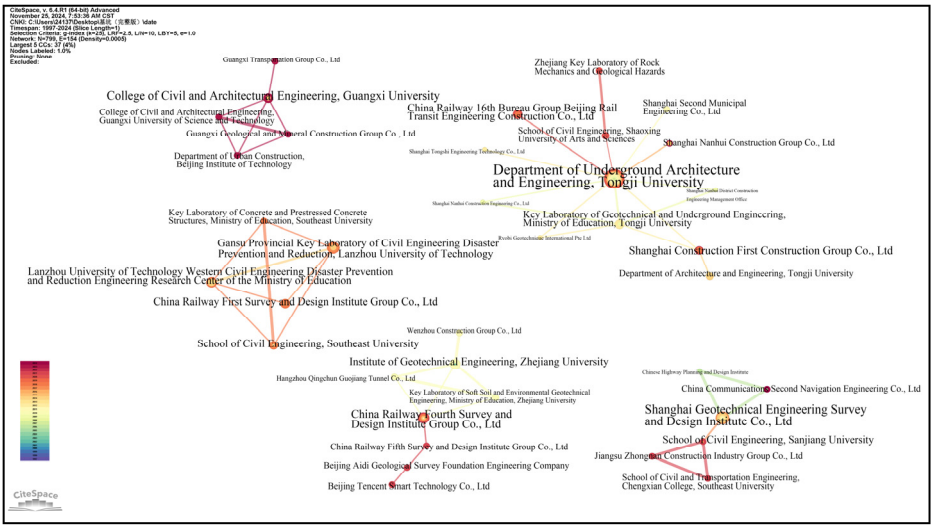

Fig. 4. The five largest institutional collaboration networks

Based on the above analysis, it is obvious that the main research units in the field of foundation pit monitoring are related to the distribution area of special soil, such as the development of soft soil in Shanghai and the development of collapsible loess in Lanzhou.Therefore, Tongji University, Shanghai Geotechnical Engineering Survey and Design Institute and Lanzhou University of Technology have studied more. In addition, the distribution of main research units in the field of foundation pit monitoring is related to engineering business, such as rail transit, high-rise buildings and other engineering foundation pit projects are large in scale and significant in importance. Therefore, China Railway Fourth Survey and Design Institute Group Co., Ltd., Beijing Urban Construction Survey and Design Institute Co., Ltd.and China Construction and other units carry out more work.

3.4 Statistical Characteristics of Highly Cited Papers

The quality, influence and popularity of a paper can usually be measured by the number of times it is cited. By analyzing the frequently cited papers, researchers can quickly identify the key literature, core authors and important academic journals that have a significant impact on specific research areas, so as to help readers grasp the research hotspots and frontier trends. According to the search results of China National Knowledge Infrastructure (CNKI), the relevant information of the literature with the highest number of citations can be obtained according to the order of citation frequency, as follows **Table 1**.

Table 2. Distribution of high-frequency cited papers and authors

Author	Title of cited literature	Periodical	Year of publication	Citation frequency
Liu Jie et al. [9]	Deformation Monitoring and Numerical Simulation of Foundation Pit Retaining Structure of Subway Station	Geotechnics	2010	357
Sun Kai et al.[10]	Construction monitoring and numerical simulation analysis of deep foundation pit	Chinese journal of rock mechanics and engineering	2004	270
Jiang Xinliang et al.[11]	Construction monitoring and numerical simulation analysis of a deep foundation pit project in Tianjin	China civil engineering journal	2007	176
Yang Linde et al.[12]	Dynamic prediction of displacement and safety monitoring of foundation pit support	China civil engineering journal	1999	173
Yang Youhai et al.[13]	Monitoring and analysis of information construction of deep foundation pit of Qiutao Road Station of Hangzhou Metro	Chinese journal of geotechnical engineering	2008	149

By analyzing the contents of the top five highly cited research literatures, it can be seen that these highly cited literatures basically represent the basic monitoring and early warning methods in the field of foundation pit monitoring in China. Liu Jie et al.[9] (2010) used numerical simulation and on-site monitoring methods to solve the deformation problem of the retaining structure of the foundation pit of large urban subway stations. They developed a deformation monitoring scheme for the supporting structure of the foundation pit, analyzed the field monitoring data in detail, and constructed an elastic-plastic finite element model to simulate the construction process. The results show that the combination of steel support and retaining pile can effectively control the lateral soil deformation of foundation pit. By comparing the results of numerical simulation with the data obtained from actual monitoring, it is found that there is a high degree of consistency between the two. This consistency not only confirms the scientificity and accuracy of the simulation method, but also shows the effectiveness of the method in practical engineering applications. Sun Kai et al.[10] (2004) solved the design problem of deep foundation pit supporting structure of Hunan Building by combining sliding body mechanics model, vertical elastic foundation beam model and CSC construction method. They used Tongji Shuguang geotechnical and underground engineering design and analysis software for dynamic construction simulation. The results of field monitoring and numerical analysis are basically the same, indicating that the prestressed anchor cable composite support structure can effectively control the deformation of deep foundation pit and surface settlement, and ensure the safety of foundation pit and surrounding buildings. Jiang Xinliang et al.[11]

(2007) solved the problem of internal force of supporting structure and horizontal displacement of soil in deep foundation pit excavation of Tianjin Causeway Bay Plaza through field monitoring and numerical simulation analysis. They adopted the double ring beam supporting system, combined with field data and numerical simulation, discussed the influence of foundation pit excavation on the surrounding environment, and obtained the change rule of soil horizontal displacement, which provided the basis for the design of deep foundation pit. The analysis results show that the method can effectively control the displacement of soil around the foundation pit, has little impact on the environment and has good effect. Yang Linde et al.[12] (1999) established a dynamic prediction technology for displacement and safety monitoring of foundation pit support by combining field information collection, optimization of inversion parameters and deformation and stability analysis of retaining structure. Based on the field monitoring data, this technology can predict and evaluate the safety of foundation pit excavation in time and provide guidance for construction. Through the monitoring data, the change of the supporting structure of the foundation pit and the development of the surrounding environment can be accurately captured, which is very important for the safety of the foundation pit project. This method is applied to the foundation pit project of a commercial building on Huaihai Middle Road in Shanghai. The results show that the displacement of the foundation pit can be accurately estimated and predicted, which is of great significance to the prediction of the displacement of the foundation pit in the next excavation stage. Yang et al.[13] (2008) analyzed the monitoring data of horizontal displacement of retaining pile, axial force of steel support, surface settlement and groundwater level in the construction of deep foundation pit in Qiutao Road Station of Hangzhou Metro, and solved the problem of information construction monitoring of deep foundation pit. They found that the horizontal displacement of the pile is related to the exposure time of the wall after the excavation of the foundation pit, and the axial force of the steel support will change with the increase of the excavation depth. The distribution of land subsidence shows a specific curve shape, some areas show a parabolic shape, while other areas show a triangular shape. At the same time, the fluctuation of the groundwater level can reflect the effectiveness of the enclosure structure in waterproofing. These conclusions are of great value to ensure the safety and reliability of subway deep foundation pit construction.

4 Research hotspots and Frontier Evolution

As a refined expression of the core content of the article, the keywords can track and identify the research hotspots focused by the academic community in the field of foundation pit monitoring research by clustering and constructing a co-occurrence network map. Using CiteSpace software, the node type is set to ' Keyword ', the network K value is set to 12, and the clustering algorithm uses the IM algorithm to obtain the knowledge map of the keyword topic path of foundation pit monitoring research from 1995 to 2024 as shown in Figure 5. When the S value (Mean Silhouette) is greater than 0.5, the clustering is reasonable. When the S value is greater than 0.7, the clustering is convincing, as shown in Table 2.

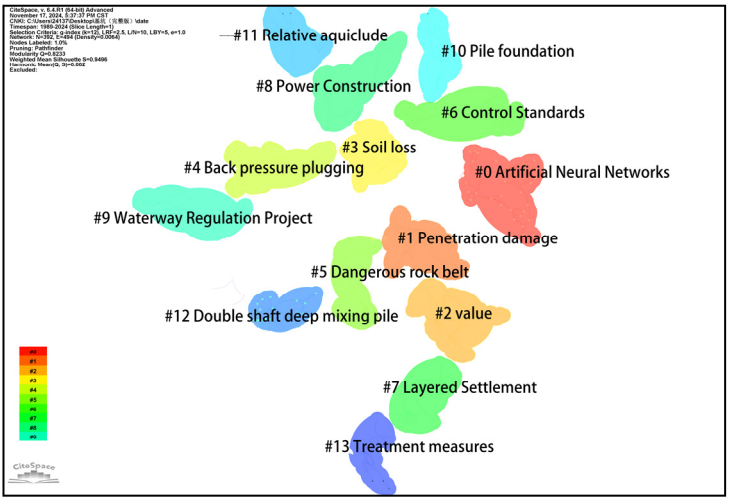

Fig. 5. Keyword clustering

In CiteSpace, the high clustering number usually means that these clusters are considered more important or more prominent in the visual graph, and they are often the main clusters. They may contain more nodes (such as keywords, literature, etc.), indicating that these clusters occupy a central position or have a greater influence in the research field. It can be seen from the above figure that artificial neural network has increasingly become a more important or active part in the field of foundation pit monitoring and early warning, and it has shown significant advantages in data processing and predictive analysis. Specifically, artificial neural network technology has been integrated into the foundation pit monitoring data processing system, which not only improves the standardization of data management, but also enhances the accuracy of the early warning system.

Table 3. Keyword clustering

Clustering	Number of keywords	S value	Average year	The main keywords contained in clustering
0	40	0.939	2012	Artificial neural network ; wavelet noise reduction ; gm ; layout of observation points ; relative error
1	38	0.917	2009	Penetration damage ; river heartland ; the deep lateral displacement of the wall ; shanghai ; horizontal shear force
2	34	0.952	2005	Value ; layout of measuring points ; pile foundation underpinning ; displacement detection ; urban highway tunnel
3	28	0.957	2005	Soil loss ; servo compensation system ; enclosure support pile ; gPS ; deformation standard

4	25	0.972	2010	anti-pressure plugging ; complex road sections ; monitoring indicators ; combined supporting structure ; supporting structure
5	21	1	2004	Dangerous rock belt ; foundation construction ; hazard source ; disturbance soil pressure ; trestle bridge
6	21	0.957	2011	Control standards ; specific application ; comparative measurement ; adjacent to the subway project ; foundation pit support beam
7	20	0.858	2009	layered settlement ; half cover excavation method ; asymmetric structure ; plaxis ; foundation pit group
8	20	0.979	2008	Electricity construction ; foundation pit construction safety technology ; solutions ; protected area ; data forecast

The distribution of keyword salience is shown in Figure 6.According to the extraction of emergent words, the smart site has appeared since 2020 and has continued to this day. Smart construction site, which integrates cutting-edge technologies such as Internet of Things, big data, cloud computing and artificial intelligence, is becoming the key to the transformation and upgrading of the construction industry. With the continuous progress of technology and the active promotion of policies, the market scale of smart site continues to grow and is expected to expand further in the future. Through real-time monitoring and precise management, the intelligent construction site effectively improves the construction efficiency and safety, and indicates that its important role in the construction industry will become increasingly prominent, providing strong technical support for the sustainable development of the industry. The application of intelligent construction site in the field of foundation pit monitoring has significantly improved the real-time monitoring and the accuracy of early warning. By deploying high-precision sensors, the intelligent construction site system can monitor the safety status of the foundation pit in real time, including the internal force of the supporting structure, the settlement of the surrounding buildings, the change of the horizontal displacement of the top and deep layers of the foundation pit, and the change of the height of the groundwater level. These data are automatically recorded and stored to provide a scientific basis for engineering decision-making and facilitate subsequent review and traceability. The system visually displays the changing trend of monitoring data through the data visualization interface, and assists managers to quickly grasp the on-site status. Combined with big data analysis and artificial intelligence technology, the intelligent site platform can deeply excavate the monitoring data and predict the future deformation trend of the foundation pit. In addition, the smart site uses wireless transmission technology to achieve high-speed and stable transmission of data, and supports multi-channel early warning systems such as mobile phone APPs to ensure that alarm information is not missing and responds quickly to security risks. These applications of smart construction sites not only improve the

monitoring accuracy and efficiency, but also significantly improve the construction safety and project management efficiency through real-time data monitoring, early warning and intelligent management.

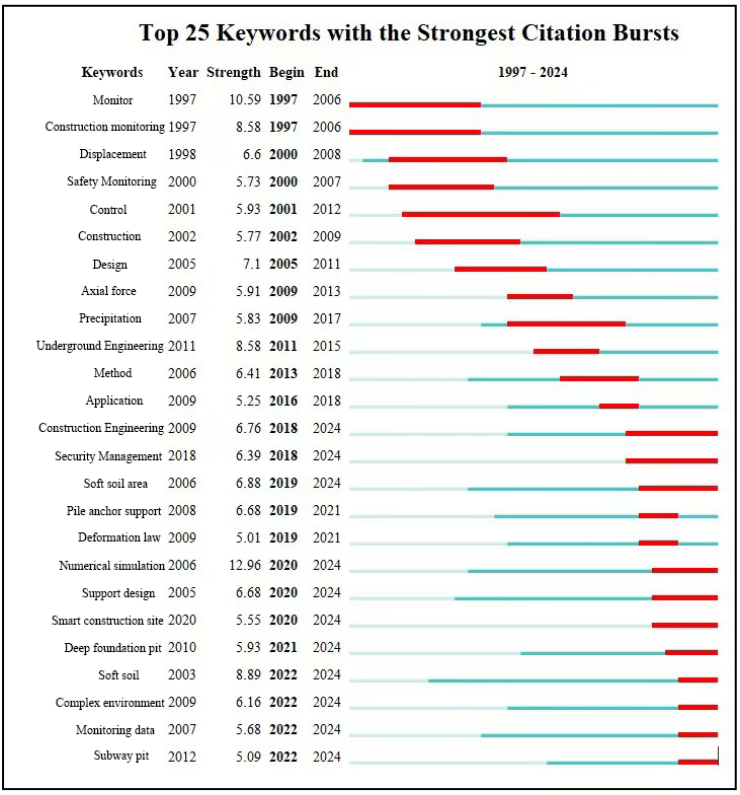

Fig. 6. Keyword salience map

5 Conclusion

The future development direction of foundation pit monitoring and early warning is intelligent, which will mark a great progress in construction safety management in the construction industry. With the rapid development of technology, especially the deep integration of cutting-edge technologies such as the Internet of Things, big data and artificial intelligence, the foundation pit monitoring and early warning system will become more intelligent. In the future, foundation pit monitoring will no longer rely on frequent manual inspection and experience judgment, but collect data in real time through intelligent sensors, use cloud computing and big data analysis technology for in-depth processing, and realize comprehensive perception and accurate evaluation of foundation pit status. The artificial intelligence algorithm will further optimize the early warning model, improve the timeliness and accuracy of early warning, and re-

duce the risk of foundation pit instability accidents. In addition, the digital platform will make the storage, sharing and analysis of monitoring data more efficient, and provide strong data support for project management. The digital and intelligent foundation pit monitoring and early warning system will greatly improve the safety of engineering construction, optimize the allocation of resources, improve the efficiency of engineering, and further help the transformation and upgrading of the construction industry.

Acknowledgments

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