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GRADING OF FACTORS INFLUENCING THE EVOLUTION OF FORMATION AND DEVELOPMENT OF SUBGRADE TRAPS IN LOESS AREAS

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Abstract

To address the frequent occurrence of sinkhole diseases in loess railway subgrades in Northern Shaanxi, China, this study systematically investigates their formation mechanisms and key influencing factors, provides a scientific basis for hazard prevention. Through field investigations of 134 sinkhole cases along the Baotou-Xi'an Railway, we established, incorporating five influencing factors: topography, hydrological conditions, design standards, construction grades, and subgrade types. A Bayesian network-based probabilistic prediction model was developed. The study reveals that complex topography (66.7% hazard incidence) and hydrological conditions (79.2% incidence) are the primary triggers, with continuous rainfall exceeding 50 mm resulting in an 81.5% hazard probability. High-fill subgrades, accounting for 86.57% of cases due to weak erosion resistance, Additionally, insufficient design and construction standards significantly increase risks, while improved engineering specifications can reduce hazard probability. Compared to traditional empirical methods, the model demonstrates enhanced objectivity and dynamic adaptability, fills the gap in systematic prediction of loess railway subgrade sinkholes, and provides a quantifiable decision-making tool for engineering practices.

Keywords:

Loess;
Subgrade pits;
Factors graded;
Prediction model.

1 Introduction

Loess is a kind of porous quaternary sediments, which contains more calcium carbonate and its crystalline material, by the influence of the deposition environment and the composition of the material source, has a significant structural and strong water sensitivity, in the actual engineering, wet subsidence, easy to dissolve the characteristics of the particularly obvious, when the water enters the loess, the structure of the loess in the self-gravitational stress and the additional stress of the impact of the structure, it will be very easy to occur under the influence of the destruction and will produce a certain amount of additional deformation When water enters the loess, the structure of loess is easily damaged under the influence of self-weight stress and additional stress, and additional deformation will be produced, and the stiffness and strength of the soil body will be significantly reduced [1-2]. subgrade traps refers to the wet trapping loess under the influence of surface water erosion or groundwater erosion, the formation of damage to the original subgrade structure of different types and forms of dark ditches, dark holes, with the expansion of the area of the trap, once the external load exceeds the bearing capacity of the subgrade, the road surface will suddenly collapse, jeopardizing the safety of traffic, resulting in the traps of the essence of the cause for the loess of the wet trapping nature [3]. The basic geomorphology of the loess plateau in northern Shaanxi is loess plateau, beams, hill-shaped, due to the loose texture of loess, easy to be eroded by surface water flow, gully system development, topographic fragmentation, while vertical joints development, making the loess structure is fragile, stability is poor, very easy to be affected by water erosion, wind erosion, or gravity erosion and formation of sinkholes, so that the railroad loess subgrade sinkholes frequently, seriously threatening the late operation of the railroad safety.

Academic research on loess subgrade stability has been conducted through multiple dimensions. Regarding the mechanisms and prevention of loess sinkholes, BAO, Y.N. [4] investigated the engineering geological characteristics of collapsible loess in Lanzhou New Area, summarizing its hazards to high-fill subgrade projects and proposing design methods and precautions for similar engineering practices. SONG, G., et al. [5] systematically elaborated on the engineering features and mitigation measures of loess sinkholes, providing practical solutions for field applications. XU, A.H., et al. [6] studied the formation conditions, distribution patterns, and hazards of loess sinkholes to highway engineering based on extensive field surveys and laboratory tests, offering geological references for road construction. In terms of material modification for enhancing loess subgrade stability, NIU, D.Y. [7] addressed landslides and collapses in collapsible loess subgrade slopes by improving waterproofing measures, applying reinforcement materials, and utilizing chemical agents, demonstrating effective solutions for slope-related diseases. JIN, M.L., et al. [8] improved loess collapsibility using industrial steel slag waste, revealing its potential as a cementitious agent to replace cement for subgrade stabilization. For sinkhole prevention techniques, SUN, B.Z. [9], LI, Z.L. [10], SUN, Y.J. [11], WANG, Y.J. [12], and ZHOU, Q.B. [13] employed the compaction pile method to enhance subgrade impermeability and reduce collapsibility by optimizing pile length and diameter, effectively resolving settlement-related issues. Additionally, in the evaluation of subgrade sinkhole hazards, XIAO, Z.Q., et al. [14] developed a comprehensive analytical model integrating the collapsed filling method, collapse equilibrium method, stability coefficient method, and Protodyakonov’s theory to address deficiencies in existing assessment methods for heavy-haul railway subgrade sinkholes.Li Junsheng et al. [15] systematically investigated subgrade failure mechanisms through laboratory/field experiments and numerical simulations, proposing specific assessment methodologies.

In the field of neural network prediction models, DENG, Z.X., et al. [16] proposed a method for predicting cumulative deformation in high-speed railway subgrades based on an experience-constrained neural network (ECNN). By constructing a cumulative deformation prediction dataset from field or laboratory test data, divided into training and testing sets, they established a neural network model using the training set. Through evaluating prediction accuracy, errors, and uncertainty across six metrics from two levels on the testing set, the optimal neural network model was determined and validated with strong performance. VU, T.V. [17] assessed two soil models and utilized the data to train and test an artificial neural network for predicting slope safety factors. The results demonstrated the reliability of the proposed method in rapidly evaluating slope stability without prolonged searches for critical slip surfaces, provided sufficient training data were available. HATEM, A., et al. [18] developed an artificial neural network model based on destructive and non-destructive test results of geopolymer concrete to assess its compressive strength, achieving favourable outcomes. Existing studies indicate that neural networks can achieve high-reliability predictions when supported by sufficient data, well-defined scenarios, and reasonable model optimization. However, for multi-factor coupled, small-sample, and high-uncertainty challenges such as sinkhole diseases in loess railway subgrades in Northern Shaanxi, further improvements in engineering applicability require hybrid modelling, data augmentation, and enhanced interpretability strategies.

However, existing research still exhibits significant limitations. On one hand, the influencing factors of sinkhole diseases in loess railway subgrades remain fragmented, lacking systematic integration of critical elements such as topography, hydrological conditions, and design-construction standards, with no unified classification system or clear hierarchical methodology. On the other hand, dynamic prediction capabilities for railway subgrade sinkholes are insufficient, as traditional methods struggle to reflect multi-factor risks like continuous rainfall, resulting in constrained prediction accuracy. Considering the Baotou-Xi'an Railway as a representative line traversing typical loess regions in Northern Shaanxi, its complex geomorphology and high hazard frequency provide generalizable insights applicable to railway projects in similar geological conditions. Therefore, this study focuses on the Northern Shaanxi Section of the Baotou-Xi'an Railway (selection rationale: the section crosses a typical loess plateau gully region, with 134 documented sinkhole cases from 2019 to 2023, accounting for 21% of similar hazards across the entire railway network). Through field investigations, cross-validation of meteorological data, and multi-source data fusion, we propose for the first time a "engineering geology-design-construction" dual-dimensional influencing factor classification system and develop a Bayesian network-based prediction model, offering actionable references for the prevention and control of sinkhole diseases in loess railway subgrades in Northern Shaanxi.

2 Statistics on site survey data

2.1 Overview of trap diseases of Loess Subgrade on Baoxi Line

Baoxi Line (Baotou-Xi 'a Railway) is a class I electrified railway in China connecting Baotou city, Inner Mongolia Autonomous Region and Xi' a city, Shaanxi Province. The line position is shown in Fig. 1. Its line on the Loess Plateau of northern Shaanxi runs through northern Shaanxi from north to south. Here are 134 cases of trapdoor disease (Fig.2) on Baoxi line (Fig.1) from 2019 to 2023 are analyzed according to relevant data. (Note: All data in this article is sourced from China Railway Xi'an Bureau Group Co., Ltd., with authorized permission for use.)

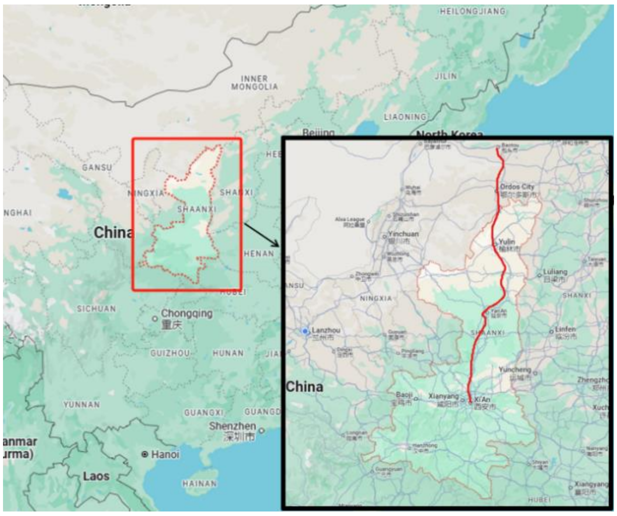


Fig. 1 The position of Baoxi Line

In 2019, the average annual rainfall on the Baoxi Line accumulated 348.5mm, with 12 cases of water damage. 2020, the average annual rainfall on the Baoxi Line accumulated 385.9mm, with 30 cases of water damage. 2021, the average annual rainfall on the Baoxi Line accumulated 305mm, with 30 cases of water damage. 2022, the average annual rainfall on the Baoxi Line accumulated 476mm, with 69 cases of water damage. 2023, the average annual rainfall on the Baoxi Line accumulated 476mm, with 69 cases of water damage. 2023, the average annual rainfall on the Baoxi Line accumulated 297mm, with 7 cases of water damage. In 2022, the average annual rainfall of the Baoxi Line will be 476mm, resulting in 69 cases of water damage.

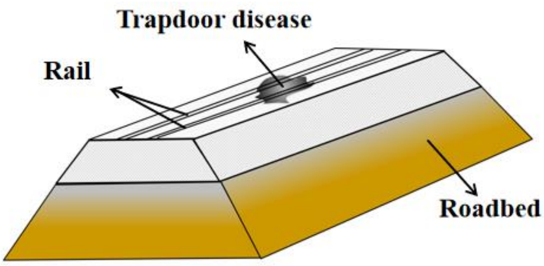


Fig. 2 Trap in the railroad bed of Baoxi Line

From the perspective of subgrade type and continuous rainfall to analyse the occurrence of subgrade disease. There are three types of subgrades: high fill subgrade, part-fief-cut (partially cut and partially filled embankment), and cutting; the amount of disaster-causing continuous rainfall is categorized into: less than 30mm, 30mm～50mm, 51～100mm, 101～150mm, and more than 151mm.

There were 116 cases of high fill subgrade, 17 cases of part-fief-cut, and 1 case of cutting according to the form of subgrade. Among them, there were 37 cases of bridges and culverts. The three subgrade types are shown in Fig. 3.

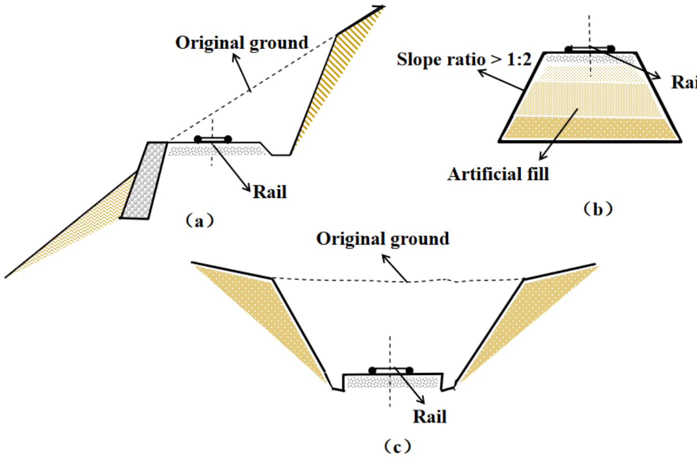
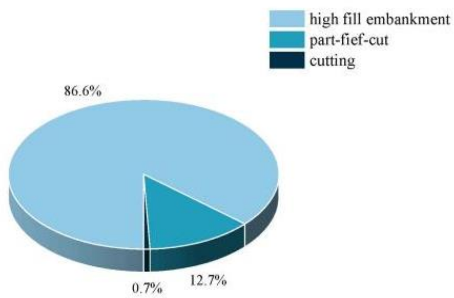
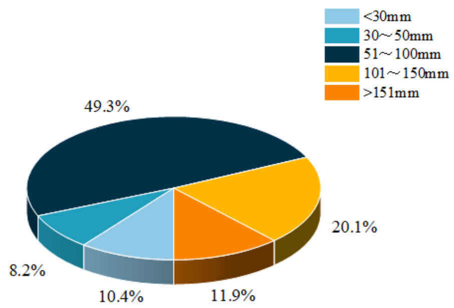


Fig. 3: Three subgrade types: (a) Part-fief-cut;(b) High fill subgrade;(c) Cutting.

Diseases caused by disaster-causing rainfall: 14 cases of water damage caused by continuous rainfall less than 30mm, 11 cases of water damage caused by continuous rainfall from 30mm to less than 50mm, 66 cases of water damage caused by continuous rainfall from 51-100mm, 27 cases of water damage caused by continuous rainfall from 101-150mm, 16 cases of water damage caused by continuous rainfall of more than 151mm, and the maximum continuous rainfall is 237.5mm on July 18, 2022.



(a)



(b)

Fig. 4: Proportion of sinkhole diseases occurring in loess subgrades: (a) Different subgrade types; (b) Different successive rainfalls.

The percentage of loess subgrades experiencing sinkhole disease is shown in Fig.3. From Fig.4 (a), it can be seen that the proportion of subgrade disease occurred in the filler subgrade is 86.57%, the reason is that because the filler subgrade bed filler is sandy loess, the resistance to erosion is weak, and after the water content of the soil body reaches saturation, it is easy to make the side slope instability and collapse, coupled with the defects of the design and construction, which leads to the largest proportion of the disease in the filler subgrade.

From Fig.4(b), continuous rainfall 51~100mm occurred water damage accounted for 49.25%, the reason is that by the local climatic conditions, continuous rainfall of 51~100mm rainfall is the most common, loess road base is affected by rainfall and loess wetness, resulting in trapping triggered by trapping disease.

2.2 Analysis of the causes of trapping disease

Affected by rainfall and loess wet subsidence, resulting in traps triggered by water damage, by checking the completion data, package west line subgrade bed fill for sandy loess, this kind of geological soil is loose, water stability is weak, weak erosion resistance, soil water content reaches saturation, easy to make the slope instability, subsidence.

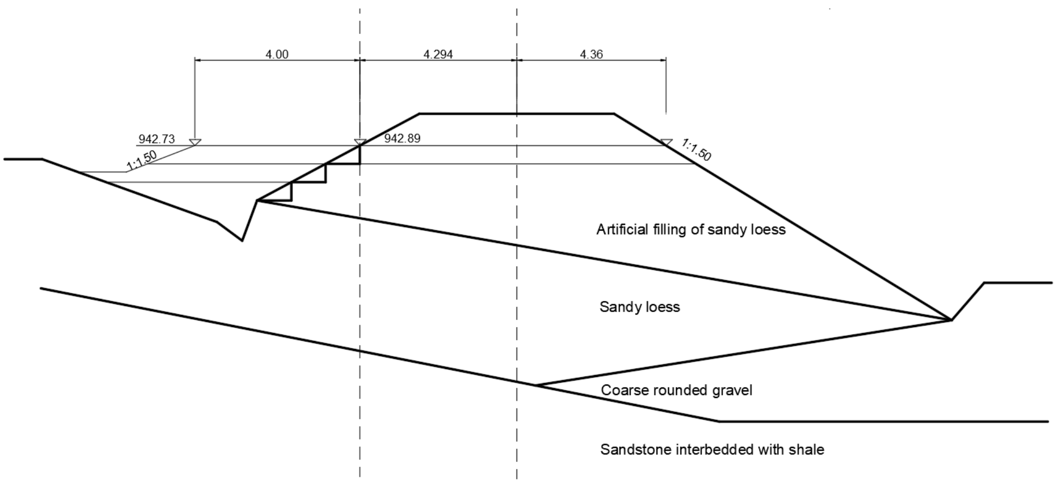


Fig. 5: The base filling material is sandy loam.

In addition, also affected by the design and construction, the existing subgrade construction standards are low, resulting in subgrade traps caused by water damage.

Design: after the transformation of the package west upstream line, the construction is not designed to lay geosynthetics(Fig.6), drainage cross-slope is not smooth, part of the section of the subgrade bed is easy to form puddles of water after rainfall, and then in the train vibration, loess wetness under the action of the formation of ballast capsule, ballast capsule in the role of the train load and the stability of the subgrade to further damage, which triggered the water damage.

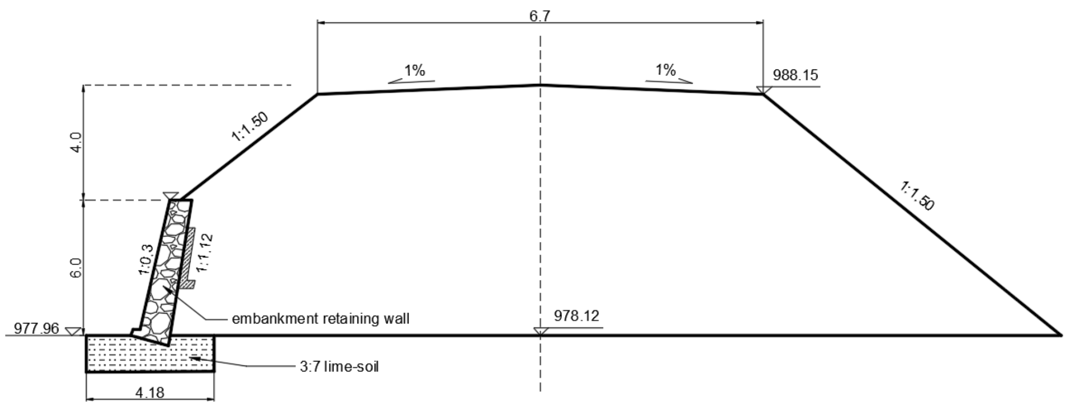


Fig. 6: Geosynthetics not designed to be placed.

Construction: First, the length of the composite geotechnical membrane of the new downstream line of Baoxi is insufficient (Fig.7), and the composite geotechnical membrane has not been extended beyond the bed of the subgrade, resulting in serious scouring of the subgrade slopes. When adding the second line to help widen the subgrade, only in the new line paving composite geotechnical membrane, and the old subgrade without overlap, cover, and parallel sections without intermediate drainage ditch. Thirdly, during the construction of the combined section of the subgrade, the crushing was not in place, the compactness was insufficient, and the combined section of the subgrade settled under the effect of rainfall.

Fig. 7: Geosynthetic clay liner length is insufficient.

It is also affected by the external environment, causing water damage caused by subgrade cave-ins. First, there are dark kilns (Fig.8), caves and ancient tombs in some lots, which are not rammed and filled in the construction process, and the subgrade collapses under the action of rainfall and trains at a later stage. Secondly, due to the erosion effect of water, drilled holes and dark caves are formed in the subgrade slopes, and the upper loess bridge collapses under the effect of gravity.

Fig.8 There is a hidden kiln under the subgrade.

3 Grading of factors influencing the formation of loess subgrade trap disease in northern Shaanxi Province

Combined with the site investigation data and review of relevant information, the author believes that the formation and development of loess subgrade traps hole disease formation and evolution of factors affecting the grading by the complexity of engineering geology and the standard grade of subgrade design and construction of the joint decision. In order to quantitatively determine the probability of occurrence of subgrade cavities, the topography, hydrogeology, design level, construction level, subgrade type for grading, and give each level of the score, and finally according to the total score to determine the probability of occurrence of subgrade cavities level. The formula for calculating the total score of the occurrence of railroad subgrade cavity disease in loess area is as follows.

$Q_t = Q_p + Q_q + Q_m + Q_n + Q_i$
(1)

where:
Q_p - the score of *topography of loess areas,*
Q_q - the score of *geomorphologies of loess areas.*
Q_m - the score of *subgrade design standards,*
Q_n - the score of *subgrade construction standards,*
Q_i - the score of *subgrade type.*

3.1 Grading of engineering geological complexity

The author deems that subgrade engineering geologic complexity grading by the complexity of terrain and geomorphology and hydrogeological conditions of complexity grading and other factors together. Among them, the topography and geomorphology of loess subgrade in northern Shaanxi Province can be divided into three levels of complexity: simple, medium and complex, and each level is given a certain value, and its division standard should be in accordance with the provisions of Table 1 (Literature [19] cited for geomorphologic data).

According to the complexity of loess area hydrogeological conditions can be divided into three levels: simple, medium and complex, and each level is given a certain score, the division criteria are shown in Table 2.

Therefore, the complexity of loess subgrade engineering geology can be divided into four levels: simple, medium, complex and extremely complex, and its classification criteria are shown in Table 3.

Table 1: Classification of terrain complexity.

Topographic complexity	Topography and environmental characteristics	Score of Q_p
Complex	The ground along the subgrade is located in the edge area of broken zones such as loess, ditch palm, gully and valley, as well as the excessive area between the beam surface and valley and other narrow beams ; There are factories, mines, large-scale villages and towns, high-level highways, railroads, high-level transmission lines, rivers and reservoirs, and other large surface water bodie on the grounds; There are ancient tombs, caves and waterfall holes along the subgrade and the vegetation is poorly developed and soil erosion is serious. There are large surface water bodies such as factories and mines, high-grade highways, railroads, high-grade power transmission lines, rivers and reservoirs, etc.; Areas along the subgrade where there are ancient tombs, caves, and caves of falling water, etc; Areas where the vegetation is poorly developed and soil erosion is serious.	8～10
Medium	The subgrade along the route is located in the small and medium-sized basins in the mountains in the alluvial gully secondary terraces, the line crosses the smaller-scale loess banks, ditch palms, gully cans and other broken areas of the edge of the area and gully and the excessive area between the beam surface and the gully; the ground is only distributed sporadic villages and cantonments, and there are no high-level highways, railroads, high-level transmission lines and rivers, reservoirs, and other large-scale surface water bodies; the ground surface vegetation is well developed.	4～8
Simple	The subgrade line is located in the lower terraces below the second grade terraces of large river valleys, area with good vegetation cover;The subgrade line is located in the center of loess terrace loess, the beam surface of loess beams, and loess mounts with insignificant topographic changes; There are no villages and high-grade electricity towers on the ground.	0～4

Table 2 Classification of the complexity of hydrogeological condition.

Hydrogeological condition	Hydrogeological features	Score of Q_q
Complex	The subgrade along the route is located below the elevation of the depressions along the route, which is prone to waterlogging and natural drainage difficulties; the local rainfall is plentiful, precipitation is concentrated and heavy rainfall is frequent, and the recharge conditions are good; the groundwater recharge conditions are good, and the hydrogeological boundaries are complex.	8～10
Medium	Along the subgrade is located below the elevation of some depressions, the terrain has natural drainage conditions; rainfall is low and less stormy, groundwater recharge conditions are average, and hydrogeological boundaries are more complex.	4～8
Simple	The subgrade is located along the route above the elevation of the depressions along the route, and the terrain is favorable for natural drainage, which is not easy to produce stagnant water; drought, little rain and no heavy rainfall, poor recharge conditions; and simple hydrogeological boundaries.	0～4

Table 3 Grading of engineering geologic complexity of loess subgrades.

Grading of geologic complexity of loess subgrade project	Topographic complexity	Hydrogeological features	Degree of impact	Physical exploration of anomalies
Extremely complex	Complex	Complex	It has a great impact on the subgrade works, and in case of heavy or continuous rainfall, the subgrade is susceptible to sinkhole diseases.	Significant physical exploration anomalies
Complex	Medium～Complex	Medium～Complex	The impact on the subgrade project is large, in case of heavy rainfall or continuous rainfall, the subgrade may be damaged by sinkholes.	Large physical exploration anomalies
Medium	Simple～Medium	Simple～Medium	Low impact on the subgrade works and low potential for the subgrade to develop trap damage	Smaller physical exploration anomalies
Simple	Simple	Simple	There is virtually no impact on the subgrade work and the subgrade is virtually immune to sinkhole disease.	Anomaly-free

3.2 Grading of engineering geological complexity

Loess subgrade design and construction standard grade classification is determined by a combination of loess subgrade design standards, loess subgrade construction standards and other factors.

Among them, the design standards for loess subgrades can be divided into high, medium and low levels according to their grades, and each grade is assigned a certain score, which is divided into criteria as shown in Table 4. The standard grade classification of loess subgrade construction can be divided into three levels: high, medium and low, and each level is assigned a certain value, and its division criteria are shown in Table 5.

Table 4 Design standard grade classification of loess subgrade.

subgrade design standard class	Status of subgrade design	Score of Q_m
High	Designed in strict accordance with the standards.	0～4
Medium	Failure to design in strict accordance with the standards.	4～8
Low	Failure to comply with standard designs, e.g., not designed to lay geosynthetics, poor drainage cross-slopes resulting in ponding of water leading to creation of sinkholes;	8～10

Table 5 Standard grade classification for construction of loess subgrade.

Standard grades for subgrade construction	Construction of the subgrade	Score of Q_n
High	Strictly standardized construction	0～4
Medium	Failure to construct in strict accordance with standards	4～8
Low	Not in accordance with the standard construction, such as: composite geomembrane length is not enough, did not extend beyond the subgrade bed, resulting in serious scouring of the subgrade slopes; new two lines to help widen the subgrade, only in the new line of composite geomembrane paving, and the old subgrade without overlap, cover, and parallel section of the lot without the intermediate drainage ditch; the combination of the subgrade when the construction of the rolling is not in place, the degree of densification is not enough, in the rainfall after the settlement, resulting in the sinkholes.	8～10

The possibility of loess subgrade disease occurrence can be categorized into high, medium and low levels according to the subgrade type, and its division criteria are shown in Table 6. Therefore, the design and construction standards for loess subgrades can be divided into four levels, namely, high, medium, low, and very low, according to the grade, and the division criteria should be in accordance with the provisions of Table 7.

Table 6 Disease potential by subgrade type for loess subgrades.

Disease potential	subgrade type	Score of Q_i
High	High fill subgrade	8～10
Medium	Part-fief-cut	4～8
Low	Cutting	0～4

Table 7 Classification of design and construction standards for loess subgrades.

Classification of design and construction standards for loess subgrades	design standard	Construction Standards	Potential for Disease Occurrence Due to subgrade Type	Degree of stabilization of subgrade works
High	High	High	Low	The subgrade is of good engineering quality and stability and is not prone to trap damage.
Medium	Medium～High	Medium～High	Low～Medium	The quality of the subgrade works is average, the stability is average, in case of heavy rainfall or continuous rainfall may produce the trap hole disease.
Low	Low～Medium	Low～Medium	Medium～High	Poor quality of subgrade work, poor stability and high potential for trap damage.
Extremely low	Low	Low	High	The quality of the subgrade work is very poor, poorly stabilized and prone to sinkhole infestation.

3.3 Classification of Trap Disease Levels in Loess subgrades

According to the above five factors affecting the subgrade trap disease scores are added up to get the total score of the subgrade trap, according to the total score the probability level of the occurrence of the trap disease is divided into five probability levels of unlikely, weak likelihood, moderate likelihood, strong likelihood,very strong likelihood, and the classification criteria are shown in Table 8.

Table 8 Probability of occurrence of trapping disease in loess subgrade class criteria.

Total score Q_t	Probability level description	Probability level
$0 \le Q_t < 10$	Unlikely	Ⅰ
$10 \le Q_t < 20$	Slightly Likely	Ⅱ
$20 \le Q_t < 30$	Moderately Likely	Ⅲ
$30 \le Q_t < 40$	Strong Likely	Ⅳ
$40 \le Q_t < 50$	Extremely Likely	Ⅴ

4 Prediction model of loess railroad foundation trap disease in northern Shaanxi region

4.1 Sample processing

According to Wang Shuaishuai[19], in the article "Research on engineering geology of loess in northern Shaanxi", the geological characteristics and geological conditions of the loess area in northern Shaanxi, and combined with the geomorphological type zoning and engineering geological zoning in northern Shaanxi, according to the grading criteria established in Chapter 3, the investigation data of subgrade trap damage on the Baoxi Line (Table 9) for factor grading.

Table 9 Bayesian network predictive model parameter grading.

Grade	X1	X2	X3	X4	X5	Y1	Y2	T
1	A1 Complex	B1 Complex	C1 High	D1 High	E1 Fill subgrade	A Extremely complex	E Extremely low	M Unlikely
2	A2 Medium	B2 Medium	C2 Medium	D2 Medium	E2 Cutting	B Complex	F Low	L Slightly likely
3	A3 Simple	B3 Simple	C3 Low	D3 Low	E3 Part-fief-cut	C Medium	G Medium	K Moderately likely
4						D Simple	H High	J Strong likely
5								I Extremely likely

4.2 Model Introduction

Based on the hierarchical principle of Bayesian network prediction model, based on the statistical data of the existing disease treading survey, combined with the possible correlation factors of the occurrence of loess subgrade disease can be derived from the Bayesian network topology diagram, as shown in Fig.9.

Naïve Bayes classifiers are a family of simple probabilistic classifiers that rely on Bayes' theorem combined with strong ("naïve") independence assumptions between features [20]. The model is based on Bayesian modelling, which can solve multifactor uncertainty or incomplete problems, and is characterized using graphical representations of structural information among random variables as well as the use of graphical structures and probabilistic rules to reduce the computational difficulty of inference [21].

In order to more comprehensively assess the risk of occurrence of subgrade diseases along the line, after using the identification algorithm to count all the engineering geological conditions and design and construction grades of disease occurrence, the samples were imported, data analysis was carried out, and combined with the above factor grading, the parameter grading of Bayesian network prediction model was obtained, which is shown in Table 9.

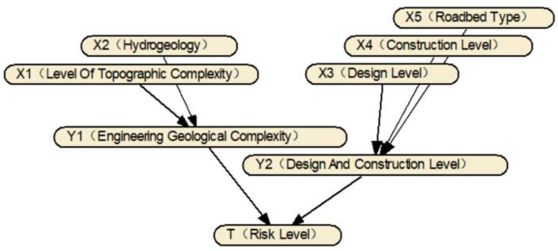


Fig.9 Bayesian Network Topology Diagram

After importing 100 disease samples into the Bayesian network prediction model, the distribution of each input sample and output sample was obtained, as shown in Fig.10.

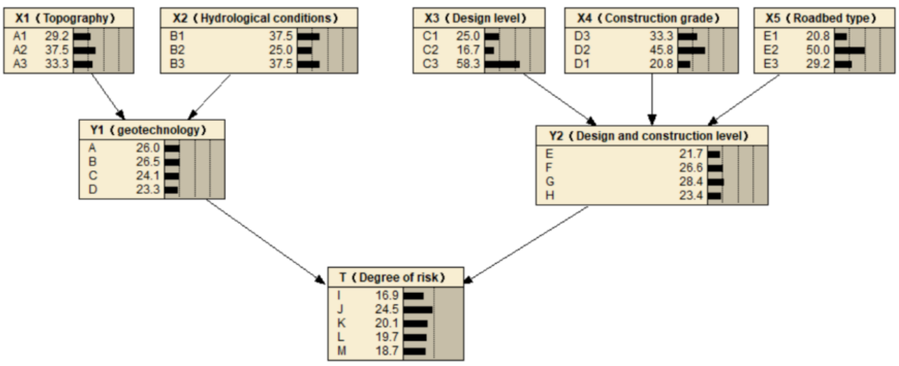


Fig.10 Risk Analysis Model for Sinkhole Disease in Loess subgrades

Table 10: Forward inference prediction results table.

Segment	Sample No.	Topography	Hydrological conditions	Design Level	Construction grade	Road-bed type	Probability level		
							Total score Q_t	Reality	Predictions
Yanan	1	Complex	Medium	High	Medium	A	34	Ⅳ	Ⅳ
	2	Complex	Complex	Medium	Medium	A	32	Ⅳ	Ⅳ
	3	Medium	Medium	Medium	Medium	A	29	Ⅲ	Ⅳ
	4	Complex	Complex	Medium	Low	A	42	Ⅴ	Ⅴ
	5	Complex	Medium	High	Medium	A	36	Ⅳ	Ⅳ
	6	Complex	Complex	Medium	Medium	A	34	Ⅳ	Ⅳ
	7	Medium	Medium	Medium	Low	A	35	Ⅳ	Ⅳ
	8	Complex	Complex	Medium	Low	A	44	Ⅴ	Ⅴ
	9	Complex	Complex	Medium	Low	B	33	Ⅳ	Ⅳ
	10	Medium	Medium	Medium	Medium	A	28	Ⅲ	Ⅳ
Suide	11	Complex	Complex	Medium	Low	A	45	Ⅴ	Ⅴ
	12	Complex	Medium	High	Medium	A	38	Ⅳ	Ⅳ
	13	Complex	Complex	Medium	Medium	A	37	Ⅳ	Ⅳ
	14	Complex	Medium	Medium	Medium	B	35	Ⅳ	Ⅴ
	15	Complex	Complex	High	Medium	A	38	Ⅳ	Ⅳ
	16	Complex	Complex	Medium	Medium	C	32	Ⅳ	Ⅳ
	17	Medium	Complex	Medium	Medium	A	27	Ⅲ	Ⅳ
	18	Complex	Complex	Medium	Low	A	45	Ⅴ	Ⅴ
	19	Complex	Medium	High	Medium	A	32	Ⅳ	Ⅳ
	20	Complex	Complex	Medium	Medium	C	29	Ⅲ	Ⅲ
	21	Complex	Complex	Medium	Low	B	36	Ⅳ	Ⅴ
	22	Complex	Medium	High	Medium	A	37	Ⅳ	Ⅳ
	23	Complex	Complex	Medium	Low	A	46	Ⅴ	Ⅴ
	24	Complex	Complex	Medium	Low	B	38	Ⅳ	Ⅳ
	25	Complex	Complex	Medium	Low	A	44	Ⅴ	Ⅴ
	26	Complex	Complex	Medium	Low	A	46	Ⅴ	Ⅴ
	27	Complex	Medium	High	Medium	A	32	Ⅳ	Ⅳ
	28	Complex	Complex	Medium	Medium	A	35	Ⅳ	Ⅳ
	29	Complex	Complex	Medium	Low	B	29	Ⅲ	Ⅳ
	30	Complex	Complex	Medium	Low	A	37	Ⅳ	Ⅴ
	31	Complex	Complex	Medium	Low	A	37	Ⅳ	Ⅳ
	32	Complex	Medium	High	Medium	A	28	Ⅲ	Ⅲ
	33	Complex	Complex	Medium	Medium	A	39	Ⅳ	Ⅳ
	34	Complex	Complex	Medium	Low	A	44	Ⅴ	Ⅴ

Note：Road-bed type：A-Fill subgrade；B-Part-fief-cut；C-Cutting.

After importing 100 disease samples into the Bayesian network prediction model, the distribution of each input sample and output sample was obtained, as shown in Fig.10.

As can be seen from Fig. 10, the topography and hydrological conditions in the loess region of northern Shaanxi Province is more complex, the package of the West Line along the subgrade design standards are not high, the construction standards are low, high fill subgrade type is very likely to lead to the occurrence of cave-in disease, so in the loess railroad subgrade design and construction should be maximize engineering standards, subgrade design for half subgrade and half rift valley, the road rift valley to avoid the occurrence of cave-in disease.

After the Bayesian network prediction model is established, to ensure that the structure and parameters of the Bayesian network prediction model are designed reasonably and accurately, it is necessary to check the Bayesian network [21]. Usually, the known parameters that are not involved in the learning of model construction can be substituted into the Bayesian network prediction model, and the model prediction results can be compared with the actual situation, and then the accuracy of the model can be judged.

If the verification results are not good, the Bayesian network prediction model structure can be adjusted or re-screening learning parameters for parameter learning, continuous debugging, and finally get a reasonable and reliable model. The remaining 34 samples in the survey data that are not involved in learning (10 in Yan'an section and 24 in Suide section) are selected as the validation samples to calibrate the model. The comparison table of forward reasoning prediction results is shown in Table 10.

From Table 10, the prediction accuracy of the risk level of loess subgrade trapping disease in northern Shaanxi is about 82%, which is sufficient for the prediction of loess subgrade trapping disease in northern of Shaanxi.

5 Conclusion

In this study, multi-dimensional factors such as topography, hydrological conditions, and design and construction standards are incorporated into the grading system of loess foundation traps for the first time, and a dynamic prediction model based on Bayesian network is established, which breaks through the limitations of the traditional single empirical judgment. Compared with the established research, this model quantifies the risk level through probabilistic reasoning, which significantly improves the prediction accuracy and applicability, and provides a new method for the analysis of trap disease in railroad foundation engineering in loess areas. The main conclusions obtained are as follows:

(1) From the point of view of topography and geomorphology, when the geographic environment along the subgrade is more complex, the likelihood of the subgrade occurring sinkhole disease is stronger, accounting for 66.7%. Therefore, in loess area railroad line selection try to avoid the more complex terrain environment; from the hydrological conditions, loess subgrade along the area of hydrological conditions of loess subgrade has a great impact on the safety of loess subgrade, when the hydrological conditions are complex, the subgrade occurs in the possibility of sinkhole disease is the greatest, accounting for 79.2%, especially when continuous rainfall more than 50mm, occurs in the sinkhole disease as high as 81.5%, so in the inability to control natural Therefore, in the case of uncontrollable natural precipitation, it is necessary to improve the anti-drainage measures of the subgrade project in order to minimize the problem of subgrade cave-in caused by the accumulation of rainwater; from the aspect of design and construction, the possibility of occurrence of disease is greatest when the subgrade type is a fill subgrade, which is as high as 86.57%, so it should be avoided to be designed as a high-fill subgrade as much as possible; at the same time, the design standard and construction standard of loess road base have a great influence on the possibility of loess road base cave-in, and it should be improved.

(2) By analysing the grading of loess railroad subgrade sinkhole disease in northern Shaanxi, it can be seen that: the grading of engineering geological complexity is mainly “complex” (56.1%), the grading of design and construction is mainly “low” (56.6%), and the grading of sinkhole risk is mainly “Ⅳ”, i.e. strong possibility, and the risk of sinkhole is mainly “Ⅲ”. is Ⅳ, i.e., strong possibility (56.1%); the engineering practice should give priority to avoid the complex geomorphology section, strengthen the drainage design (e.g., additional geosynthetics and intermediate drainage ditch), and strictly control the application of high-fill road base, as well as improve the design and construction standards to ensure the composite geomembrane paving length and road base compactness, and to avoid the construction negligence.

(3) proposed a prediction model based on Bayesian network of loess subgrade trap disease, and selected 34 samples into the prediction, the predicted value and the actual value of the comparison, the model accuracy is about 82%, proving the accuracy of the prediction results, the study can provide reference for the prediction and management of railroad subgrade trap disease in loess area of northern Shaanxi. In the future, the Bayesian network parameters can be optimized by combining the real-time monitoring data, exploring the early warning system integrating artificial intelligence and remote sensing technology, and further verifying the universality of the model in other loess regions.

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