Comprehensive Evaluation of Pavement Waterproofing Layer Materials for Bridge and Tunnel Projects

Zhaoyuan Li*

Hebei University of Technology School of Civil Engineering and Transportation, Tianjin, China.

Abstract: In order to achieve the preferential selection of pavement waterproofing layer materials, so that the waterproofing layer material selection is more scientific and objective, eliminating the impact of subjective factors, this paper uses hierarchical analysis to build a hierarchical evaluation model of pavement waterproofing layer. Based on the literature review method, a two-tier evaluation index of the layered evaluation model of pavement waterproofing layer materials was constructed, mainly three first-tier indexes of performance assessment, service life assessment, and cost assessment, under which the second-tier indexes of waterproofing performance, durability, weather resistance, impermeability, crack resistance, thermal stability, aging resistance, low temperature crack resistance, fatigue resistance, material cost, construction cost, and maintenance cost were established. And through the hierarchical analysis method of calculation, test the consistency by deriving the weight of each indicator, where the most important first layer of indicators for performance, the weight of 0.5390, the second layer of indicators is more important for waterproof performance (0.5303), thermal stability (0.3550), low-temperature crack resistance (0.3550), material cost (0.6333). The study provides a scientific and objective evaluation model for the preferential selection of pavement waterproofing layer materials.

1 Preface

With the continuous promotion of highway construction, the construction of bridge and tunnel projects is also increasing. In bridge and tunnel engineering, pavement waterproofing technology is a very important technical measure, which is of great significance to ensure the safe operation of the project[20]. At present, common pavement waterproofing materials include polyurethane waterproofing coatings, asphalt waterproofing layer, cement concrete waterproofing layer, polymer waterproofing membrane, and many other types. Different materials differ in performance, service life, construction difficulty, maintenance costs, etc. How to choose the right material has become an important issue to be solved in the actual construction of the project.

In addition, with the continuous expansion of the scale of highway construction and technological advances, the type and performance of pavement waterproofing materials are constantly developing and innovating. Therefore, after a comprehensive evaluation study of pavement waterproofing materials, you can keep abreast of the latest development trends and performance of materials to provide better selection and guidance for engineering construction.

In summary, the significance and background of the comprehensive evaluation study of pavement waterproofing materials for highway, bridge, and tunnel projects is essential, and can bring significant value to ensure the safe operation of the project, improve project quality and reduce maintenance costs.

In current research on waterproofing layers in terms of material selection and design, researchers usually conduct extensive experiments and simulation analysis to determine the performance and durability of materials and optimize the design of waterproofing layers according to actual needs. For example, waterproof materials can be prepared by mixing different proportions of polymers, resins, rubber, and other materials. Or use nanotechnology to improve the performance of the material to make it more waterproof, breathable, and durable. It is also possible to improve the shear and permeability resistance by changing the structure and morphology of the material. The current selection of pavement materials is mostly based on experimental experience and lacks an objective evaluation index system for comprehensive guidance. It can only be evaluated unilaterally through experimental measured data.

Highway, bridge, and tunnel project pavement waterproofing is one of the important technologies to ensure the safe operation of Highway, bridge and tunnel projects. The quality and performance of pavement waterproofing materials have a critical impact on the service life, safety, and maintenance costs of the project. Therefore, the comprehensive evaluation study of pavement waterproofing materials for Highway, bridge and tunnel projects is of great

*15081905251@163.com

significance. At present, there have been many studies using hierarchical analysis for construction materials, so the study has a high feasibility[21]. The study adopted hierarchical analysis can help assess the quality and performance of different pavement waterproofing materials, providing scientific technical support and guarantees for engineering construction.

This article provides a more scientific, intuitive, systematic, and objective evaluation method for the preferential selection of pavement waterproofing layer materials by constructing a hierarchical evaluation model for pavement waterproofing layer materials and determining the weights of each index to improve the quality and accuracy of pavement waterproofing layer material selection and reduce the risk of decision making.

2 Literature review

2.1 Bridge and tunnel engineering pavement waterproofing layer materials

Domestic and foreign scholars for pavement waterproofing materials have conducted many studies. Qu Daying[9] proposed that in the cement concrete bridge deck pavement disease is a more serious section, the priority of DLXF new material paving cement concrete bridge deck waterproofing bond layer. Liu Shaowen[2] et al. pointed out that SBS polymer-modified emulsified asphalt has good shear resistance when used as a waterproofing binder layer, as well as anti-aging properties. Wang Xiaofeng[12] et al. experimentally determined the optimal sprinkling amount of different asphalt synchronous gravel seal and its corresponding appropriate concrete slab construction depth. Lv Rui[3] pointed out that the hybrid waterproofing binder layer material "fiber reinforced solvent binder + SBS modified asphalt" in the construction process is a good match, the comprehensive performance is better. Meng Lingguo[6] et al. proposed through experiments that it is more cost-effective to use NKY waterproof bonding material in bridge deck pavement during winter construction. Ma Tao[7] et al. experimentally compared the basic performance of three types of waterproofing bonding materials such as high-dose SBS modified bitumen, epoxy bitumen, and FYT. Malan[8] determined the optimum proportional dosage of SBR modified bitumen, epoxy bitumen, and 4# waterproofing binder type waterproofing binder material through tests to provide reference for the design and construction of waterproofing binder layer on cement concrete bridge decks. Zhou Shaolin[17] et al. proposed that the shear and tensile properties of SBS-modified asphalt synchronous crushed stone are better than those of FYT-1 waterproof coating membrane and SBS-modified emulsified asphalt synchronous crushed stone under conventional material dosage; the temperature, shear rate, and freeze-thaw cycles have significant effects on the shear and tensile strengths of bridge deck pavement waterproofing bonding materials. Sun Lingli [10] et al. proposed through tests that compared with SBS modified emulsified asphalt and SBR modified emulsified asphalt, neoprene-based coatings have better high temperature resistance, relatively high shear strength and tensile strength, and are an excellent waterproofing bonding material. The results presented by He Lihong[1] et al. show that water-based epoxy resin can significantly improve the heat resistance, tensile strength, and shear strength of emulsified asphalt; with the increase of water-based epoxy resin doping, the interlayer bond strength is significantly improved, and the best performance is achieved when the water-based epoxy resin doping is 15%, which provides a good research basis for this paper.

2.2 Hierarchical analysis method

In past studies, many scholars have explored the application of hierarchical analysis for the evaluation of construction materials. Zhang Yijian [15] hierarchical analysis method applied to the comprehensive evaluation of cross-sea and cross-river channel, bridge and tunnel scheme has applicability and feasibility, which can better solve the influence of some difficult to quantify influencing factors on the total objective function, and finally, through the analysis of scheme weights, than select the optimal scheme. Shan Deshan[11] et al. proposed the use of uncertainty hierarchy analysis to establish a comprehensive evaluation model of existing railroad concrete bridges and applied it to the evaluation of the comprehensive performance of existing railroad concrete bridges. Liu Boquan[4] et al. pointed out that the application of hierarchical analysis can quantify the abstract thinking and reflect the real situation of selecting engineering materials, which is conducive to making correct decisions and selecting the optimal solution; its practice is simple and practical, which can be easily grasped by engineers and technicians engaged in civil engineering and construction. Zhang Xewang [18] et al. proposed that program selection based on hierarchical analysis has certain theoretical value in construction management and is worthy of further research, application, and promotion in the field of engineering technology management and decision making. Xiao Xin [14] believes that the assessment system established for the assessment of the technical condition of railroad bridges is based on bridge diseases and combined with the hierarchical analysis method to assess the condition of bridges at all levels, which is conducive to an accurate grasp of the operational status of bridges and has greater significance for guiding bridge maintenance and repair. Wang Xiang[13] elaborated the application of hierarchical analysis fuzzy comprehensive evaluation method in the evaluation of highway maintenance quality, improved the index system of highway maintenance quality evaluation, established index weights by hierarchical analysis, combined inspection data and subjective evaluation, and substituted into the fuzzy comprehensive evaluation model to evaluate the maintenance quality qualitatively and quantitatively, avoiding the errors that exist in subjective judgment.

2.3 Review

From our current research on pavement waterproofing materials, our scholars are more likely to select waterproofing materials that perform better in experiments through the experience gained from experiments. There is no basis for a data-based selection, and the comprehensive evaluation of pavement waterproofing layer materials has not been perfected, based on multi-level, multi-performance weighted comprehensive evaluation of the research still exists gaps. And slow progress in the development of new materials for pavement waterproofing layer.

In view of this, this study establishes a reasonable basis for the selection of pavement waterproofing materials through hierarchical analysis, in order to achieve an efficient selection of materials for the pavement waterproofing layer selection program.

3 Based on literature analysis method to build waterproof layer material evaluation index system

3.1 The construction of waterproof layer building material performance evaluation index system

Yu, Haipeng [16] et al. used hierarchical analysis to construct a structural model for the evaluation of wood construction materials using raw materials, process, property, Environment and Economy indicators. Liu Boquan[4] et al. established a hierarchical structural analysis model for engineering material preference based on economic, technical, ecological, and social benefit indicators using hierarchical analysis. Liu Jun [5] et al. used the hierarchical analysis method to construct a hierarchical structural analysis model for the preferential selection of new rural construction materials based on indicators such as advancedness, adaptability, and economy. Zhu Lianbo[19] et al. established a hierarchical structural analysis model for selected building materials using several indicators of cost, ease of construction, service life, and aesthetics using the hierarchical analysis method. So for pavement waterproofing materials, this article starts with the first layer with three indicator factors to analyze: performance assessment, service life assessment, and cost assessment. The second layer of performance assessment is divided into basic performance indicators such as waterproof performance, durability, weather resistance, impermeability, and crack resistance. For the service life, assessment is to assess the service life of different waterproofing materials, and its long-term use of performance changes in the analysis and research, specific indicators of thermal stability, aging resistance, low-temperature crack resistance, and fatigue resistance. For the cost to assess the various costs of different waterproofing materials, including material costs, construction costs, maintenance costs, and other aspects. For the indicators in the second layer, two-by-two comparison of their importance establishes the evaluation weights, constructs the judgment matrix, and then performs a hierarchical single ranking and its consistency test according to the judgment matrix to obtain the feature vectors. The consistency of the entire hierarchical model is then checked to derive consistency indicators, and finally the relative values are calculated to form an evaluation method for the preferential selection of waterproofing layer materials.

3.2 Descriptive Statistics of Individual Information on Decision Making of Survey Sample

In this paper, through the questionnaire, we obtained 30 samples of data containing the years of experience, the number of published papers, and the risk preference of bridge engineering and roadbed pavement engineering practitioners and experts in the related fields of bridge engineering and roadbed pavement engineering, and the results of the descriptive statistics of the above related indexes are shown as follows. Table 1 below shows the results of the years of employment survey.

Table 1. Years of Employment Survey Results.

years of experience in the field	number of people	Percent age (%)	Cumulative percentage (%)
Less than 2 years	4	13.33	13.33
2-3 years	5	16.67	30.00
3-4 years	10	33.33	63.33
4-5 years	6	20.00	83.33
More than 5 years	5	16.67	100.00

The following results were statistically obtained from a questionnaire survey of 20 research-oriented experts and scholars in the field of bridge engineering and roadbed pavement engineering. Tables 2 and 3 below present the results of the survey on the number of published papers and the results of the risk appetite survey, respectively

Table 2. Results of the survey on the number of published papers

Number of papers published	number of people	Percentage (%)	Cumulative percentage (%)
Less than 3 articles	7	35.00	35.00
3-6 articles	5	25.00	60.00
6-9 articles	4	20.00	80.00
9-12 articles	2	10.00	90.00
More than 12 articles	2	10.00	100.00

https://doi.org/10.1051/e3sconf/202343902010

Table 3. Risk appetite survey results

risk appetite	number of people	Percentage (%)	Cumulative percentage (%)
radicalization	6	20.00	20.00
balanced	14	46.67	66.67
conservative	10	33.33	100.00

3.3 Constructing judgment matrix

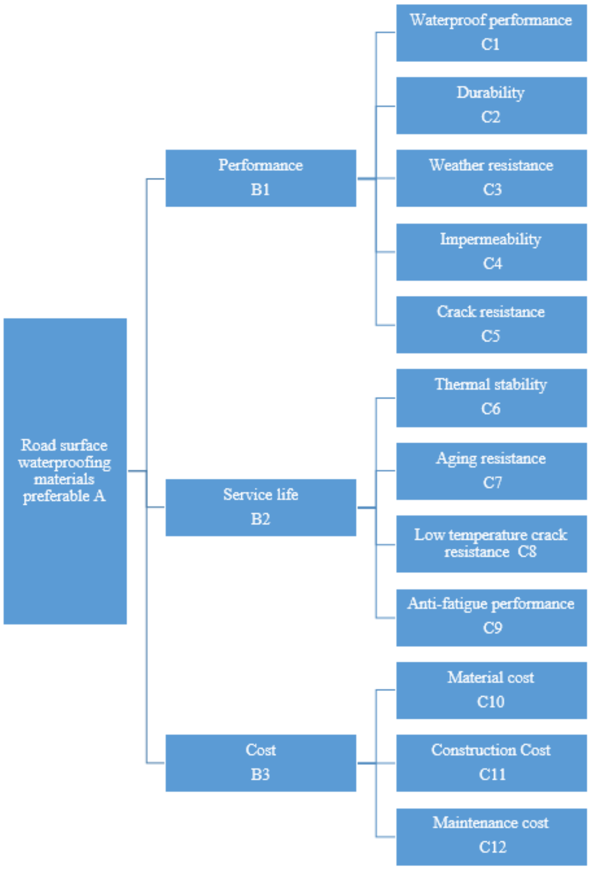

Figure 1. schematic illustration of the stratification of the indicator

Figure 1 above is a schematic of the indicator hierarchy created by the hierarchical analysis approach. After establishing the stratification system, a two-by-two comparison of indicators in the same stratum is conducted to determine the importance of each indicator, with higher importance being given greater weight and having a greater impact on the final assessment results. A more objective way to determine the impact weight is to ask a number of domestic and foreign experts and scholars in related fields to compare the indicators according to the hierarchical analysis method, and then take the expected value after arriving at the expected weight results for each.

A two-by-two comparison of C-level indicators was performed to establish a judgment matrix, as shown in Table 5-7, to assess their importance to higher-level indicators and determine the impact weight distribution. Table 4 below represents the meaning of the absolute values of the Table Hierarchy Analysis scale.

Table 4. Meaning of absolute values of the scale

Absolute value of the scale	Ranking of importance
1	Indicator i is of equal importance compared to indicator j
3	Indicator i is marginally important/advantageous compared to indicator j
5	Indicator i is more important/advantageous compared to indicator j
7	Indicator i is important/advantageous compared to indicator j
9	Absolute importance/advantage of indicator i over indicator j
2、4、6、8	Indicator i is between the above indicator scales in terms of importance compared to indicator j.
The reciprocal of the absolute value of the above scale	Indicator i has an importance scale of n compared to indicator j. Indicator j has an importance scale of 1/n compared to indicator i.

Table 5. Judgment matrix of indicator layer B1

Performance B1	Waterproof performance C1	Durability C2	Weather resistance C3	Impermeability C4	Crack resistance C5
Waterproof performance C1	1	6	5	4	7
Durability C2	1/6	1	3	2	4
Weather resistance C3	1/5	1/3	1	1/2	3
Impermeability C4	1/4	1/2	2	1	3
Crack resistance C5	1/7	1/4	1/3	1/3	1

Table 6. Judgment matrix of indicator layer B2

Service life B2	Thermal stability C6	Aging resistance C7	Low temperature crack resistance C8	Anti-fatigue performance C9
Thermal stability C6	1	3	1	2
Aging resistance C7	1/3	1	1/2	1
Low temperature crack resistance C8	1	2	1	3
Anti-fatigue performance C9	1/2	1	1/3	1

Table 7. Judgment matrix of the indicator layer to the criterion layer B3

Cost B3	Material Costs C10	Construction Costs C11	Maintenance Costs C12
Material Costs C10	1	5	3
Construction Costs C11	1/5	1	1/3
Maintenance Costs C12	1/3	3	1

Table 8 below represents the judgment matrix of the target layer A.

Table 8. Judgment matrix of target layer A

Preferred material for road surface waterproofing layer A	Performance B1	Service life B2	Cost B3
Performance B1	1	2	3
Service life B2	1/2	1	2
Cost B3	1/3	1/2	1

3.4 Consistency test of judgment matrix

Table 9 below shows the results of the consistency test of the hierarchical analysis.

Table 9. Consistency test results

Sum-product method for consistency testing	λ	CI=(λ-n)/(n-1)	RI	CR=CI/R
Performance B1	5.2858061	0.0714515	1.12	0.0637960<0.1
Service life B2	4.0412414	0.0137471	0.89	0.0154462<0.1
Cost B3	3.0387146	0.0193573	0.52	0.0372256<0.1
Preferred material for road surface waterproofing layer (A)	3.0092087	0.0046043	0.52	0.0088545<0.1

3.5 Calculation of weights

The weights of the hierarchical evaluation system were obtained by column normalization as in Table 10

Table 10. Stratified evaluation system weights

Evaluation Indicators	Weights	Evaluation Indicators	Weights
Performance B1	0.5390	Waterproof performance C1	0.5303
		Durability C2	0.1921
		Weather resistance C3	0.0947
		Impermeability C4	0.1349
		Crack resistance C5	0.0479
Service life B2	0.2973	Thermal stability C6	0.3550
		Aging resistance C7	0.1450
		Low temperature crack resistance C8	0.3550
		Anti-fatigue performance C9	0.1450
Cost B3	0.1638	Material Costs C10	0.6333
		Construction Costs C11	0.1062
		Maintenance Costs C12	0.2605

The derived weight values show that for the first tier of indicators B1 to B3, performance B1 is more important, accounting for more than half of the weight, then there is service life B2, and the least important is cost B3. For the performance B1 layer under the second layer of indicators C1 to C5, the waterproof performance C1 is the most important the durability and impermeability degree of importance is relatively close, durability is slightly more important than impermeability, followed by weather resistance, and finally, crack resistance. For the second layer of indicators C6 to C9 under the service life B2 layer, thermal stability and low temperature crack resistance are equally important, while thermal stability and low temperature crack resistance are more important than aging resistance and fatigue resistance, but fatigue resistance and aging resistance are equally important. For C10 to C12 under cost layer B3, material costs are the most important, occupying a weight of 0.6333, while maintenance costs are a little more than twice as important as construction costs.

To get the weight of each indicator, the specific assessment needs to be based on the second layer of pavement waterproofing material specific scoring of each indicator, such as material X of the indicators scored: performance under the indicators by C1 to C5 sorted as 60, 20, 50, 40, 30. life under the indicators were 20,10,30,40. cost under the indicators scored as 20, 30, 50, then material X Performance score is (60×0.5303+20×0.1921+50×0.0947+40×0.1349+30×0.0479)×0.5390=25.455892. The service life score is (20 × 0.355 + 10 × 0.145 + 30 × 0.355 + 40 × 0.145) × 0.2973 = 7.4325. The score of this indicator of cost is (20×0.6333+30×0.1062+50×0.2605) *0.1638=4.2878, and finally the three indicators are added to get the final score of 25.455892+7.4325+4.2878=37.176192, and then compared with other materials to select the material with higher score.

4 Conclusion

Finally, the importance of each indicator was derived as 0.5390 for the performance of the pavement waterproofing layer material, 0.2973 for the service life, and 0.1638 for the cost. The water resistance under performance is 0.5303, the importance of durability is 0.1921, weather resistance is 0.0947, impermeability is 0.1349, and the resistance to permeability is 0.0479. The importance of both thermal stability and low temperature crack resistance under service life is 0.355, and the aging resistance and fatigue resistance are both 0.145. Material costs under cost are the most important at 0.6333, construction costs at 0.1062, and maintenance costs at 0.2605. This article through the literature review method to establish the pavement waterproofing layer materials using hierarchical analysis of the two levels of evaluation indicators, and determine the relative importance of each indicator, the construction of a judgment matrix, consistency testing through and finally establish the weight of each indicator to obtain the hierarchical analysis model of pavement waterproofing layer materials. More comprehensive multilevel mathematical embodiment of the importance of waterproofing materials evaluation indexes which has a certain theoretical value for the future selection of pavement waterproofing materials to provide a more scientific, objective reference[22].

Reference

1. He LH, Zhang B, Ma YF et al. Research on the performance of waterborne epoxy emulsified asphalt bridge deck waterproofing binder layer materials[J]. New Chemical Materials,2022,50(11):240244.DOI:10.19817/j.cnki.issn10063536.2022.11.048.
2. Liu SW, Zhang M. Research on road performance of SBS polymer modified emulsified asphalt as bridge deck waterproofing binder material[J]. Engineering Mechanics,2009,26(S1):98-103.
3. Lv R, Research on the application of hybrid bridge deck waterproofing binder material in bridge deck paving[J]. Low Temperature Construction Technology,2018,40(07):79.DOI:10.13905/j.cnki.dwjz.2018.07.003.
4. Liu BQ, Wu DC, Wang JJ. Comprehensive evaluation of engineering material preference based on hierarchical analysis[J]. Journal of Chang'an University(Natural Science Edition),2006(02):5760.DOI:10.19721/j.cnki.1671-8879.2006.02.014.
5. Liu J, Yu XS, Liu N. Evaluation method of new rural economic building materials based on AHP-FPR model[J]. Journal of Shenyang University of Architecture(Natural Science Edition),2009,25(06):1115-1119.
6. Meng LG, Jiang RL, Zhu QY. Comparative study on the performance of bridge deck waterproofing binder materials[J]. Forest Engineering,2016,32(03):7375+80.DOI:10.16270/j.cnki.slgc.2016.03.016.
7. Ma T, Huang XM, Jv H. Research on the performance of bridge deck waterproofing bonding materials[J]. Highway Transportation Science and Technology,2007(01):43-46.
8. Ma L. Research on the performance of high permeability bridge deck waterproofing binder layer materials[J]. New Building Materials,2020,47(10):164-168.
9. Qu DY, Comparative study on the performance of DLXF new bridge deck waterproofing binder material[J]. Petroleum Asphalt,2018,32(02):10-14.
10. Sun LL, Liu JJ, Chang Y. Experimental study on road performance of cement concrete bridge deck waterproofing binder[J]. New Building Materials,2011,38(11):64-67.
11. Shan DS, LI Q, Xu W. Application of uncertainty hierarchy analysis in performance evaluation of concrete bridges[J]. Journal of Chongqing Transportation Institute,2007, No.112(01):19-22+64.
12. Wang XF, Song GR, Yang B, et al. Research on shear stability and fatigue resistance of typical waterproofing bonding materials[J]. New Building Materials,2021,48(09):125-128+137.

13. Wang X. Application of highway maintenance quality evaluation model based on hierarchical analysis fuzzy comprehensive evaluation[J]. Transportation World,2022(33): 5255.DOI: 10.16248/j.cnki.113723/u.2022.33.006.
14. Xiao X, Assessment of technical condition of railroad bridge based on hierarchical analysis method[J]. Railway Construction,2020,60(10):46-50.
15. Zhang YJ. Application of hierarchical analysis method in the optimization of bridge and tunnel scheme comparison[J]. Traffic and Transportation,2020,36(05):41-44.
16. Yu HP, Chen WS. Hierarchical analysis model and preferred comprehensive evaluation of wood building materials[J]. Journal of Building Materials,2009,12(02):190-196.
17. Zhou SL, Chu F, Wu B et al. Experimental study on mechanical properties of waterproof bonding materials for bridge deck pavement[J]. Chinese and foreign highway,2014,34(03): 272-275.DOI:10.14048/j.issn.1671-2579.2014.03.080.
18. Zhang XK, Luo YS. Research and application of ready-mixed concrete supplier preference model based on hierarchical analysis[J]. Chongqing Construction,2021,20(S1):93-96.
19. Zeng J. Hierarchical analysis model of building materials and its application in the optimization of ceramic countertop basins[J]. Sichuan Building Materials,2019,45(05):1-4.
20. P.O. Akadiri, P.O. Olomolaiye, Development of sustainable assessment criteria for building materials selection, Eng., Constr. Arch. Manage. 19 (6) (2012) 666–687.
21. Q. Shi, Y. Xu, The selection of green building materials using GA-BP hybrid algorithm, in: International Conference on Artificial Intelligence and Computational Intelligence, IEEE Computer Society, 2009, pp. 40–45.
22. G. Soronis, An approach to the selection of roofing materials for durability,Construction & Building Material. 6 (1) (1992).