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RESEARCH ON THE SELECTION METHOD OF TYPICAL RCS BENCHMARK BASED ON AHP

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Abstract

Uncertainty introduced by complex target testing requires repeated measurements several times, resulting in high test costs and long test cycles. Therefore, an uncertainty analysis method for complex targets based on typical RCS benchmark is particularly important. Aiming at how to choose the RCS benchmark, this paper proposes a method of selecting RCS benchmark based on AHP for quantitative analysis. Quantify the thought process of RCS benchmark selection and use the expert system to evaluate the importance, and select a set of typical RCS benchmarks that can be used to evaluate the uncertainty of complex targets. The feasibility and effectiveness of the method are proved by numerical examples.

Keywords: RCS, Uncertainty, Benchmark, Complex goals

1. Introduction

Stealth performance has become one of the important indicators for evaluating the combat effectiveness of modern aircraft. Radar Cross Section (RCS) is a key physical quantity to characterize the stealth performance of a target. In the process of actual RCS testing, the uncertainty causes the difference between the actual measured results and the actual results of the target. Uncertainty analysis has become a key component of RCS testing, representing the reliability and confidence of test results, and has great application and research value.

With the urgent need for high-precision RCS testing technology, relevant units have carried out a series of RCS uncertainty research work in accordance with the IEEE 1502 standard[1-2]. In 2008, Lin Xiaohuan et al. studied the main sources and processing methods that affect their test uncertainty [3]. In 2011, Yongpeng Wu studied the influence of two factors, aircraft jitter and flight attitude, on the RCS test results[4]. In 2015, Zhang Liangcong analyzed the non-uniform plane wave, the interference between the target and the support in the compact field, and estimated its impact on the RCS test [5]. In 2018, Wei Guangyu's research results showed that the RCS measurement method based on the extrapolation method is suitable for the establishment of the RCS measurement system [6]. In 2019, Shen Peng et al. analyzed the influencing factors of uncertainty in the RCS test process [7].

RCS uncertainty analysis usually takes a long time and bears a high cost. Therefore, in practical engineering applications, it is quite feasible to use RCS benchmark resources to evaluate the uncertainty of complex targets. However, there are many benchmarks, choosing which benchmark to evaluate complex targets has become an urgent problem.

This paper proposes a typical RCS benchmark selection method based on AHP. The AHP method is used to change the subjective qualitative selection into the objective selection with clear hierarchy and quantitative evaluation.

2. Typical benchmark characteristic analysis

From the perspective of engineering application, in order to improve the convenience and reliability of practical engineering applications, the benchmark should usually have three types of characteristics: obtaining the exact value of its RCS easily, manufacturing the benchmark easily and minimizing the installation error. Analyze the existing typical RCS benchmark and their characteristics, and evaluate the shape, material and use characteristics of different benchmarks. At present, the characteristic analysis of typical benchmark of 9 different shapes has been completed, mainly include: metal ball, metal plate, dihedral corner reflector, trihedral corner reflector, metal spherical column, amygdala, cuboid and other common standard bodies in modern RCS test fields. Some models are shown in Figure 1.

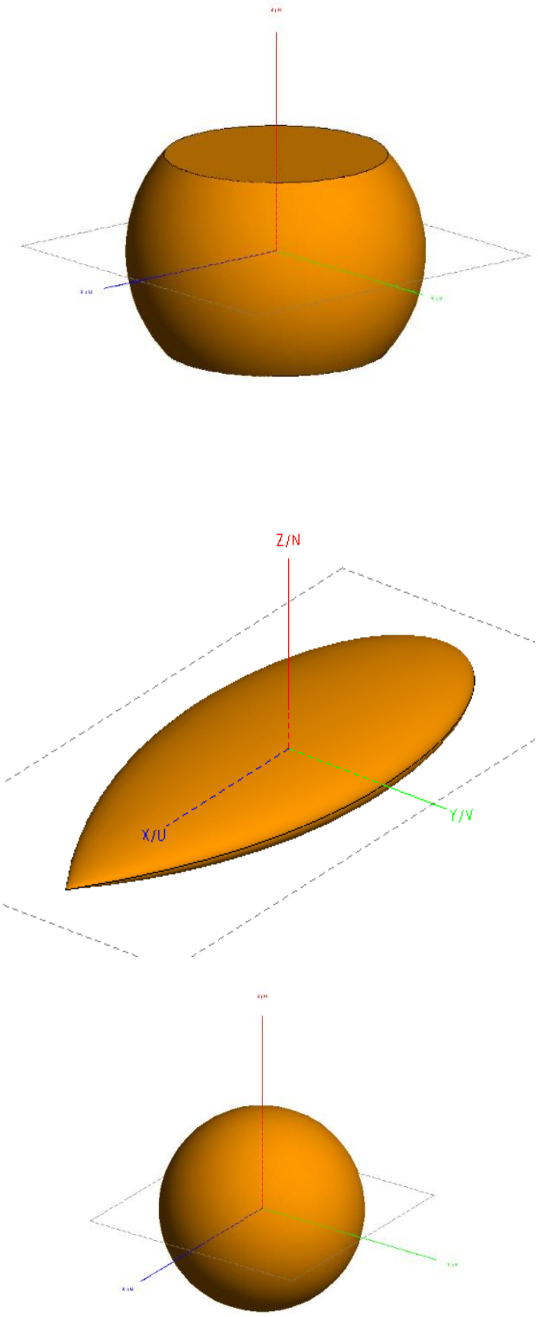

Figure 1 – Schematic diagram of part of the benchmark model

3. Selection method of typical benchmark based on AHP

3.1 The overall technical framework for the selection of typical RCS benchmark

Through the above investigation, the characteristics, advantages and disadvantages of some typical RCS benchmark are relatively clear. In view of how to select typical RCS benchmarks for uncertainty analysis of complex targets, an AHP-based benchmark selection method is proposed. Combined with the characteristics of complex targets and the expert evaluation system, from the five dimensions of the benchmark shape, size, processing technology, test frequency band and cost, through expert evaluation, the qualitative evaluation is transformed into quantitative evaluation, so as to be closer to the needs of the test site and more accurate. Perform complex target uncertainty assessments.

Use the principle of the AHP method to draw a general frame diagram for the selection of typical benchmarks, and briefly summarize the AHP process, as shown in Figure 2. Introduce the current situation of AHP method and the principle of AHP. Combined with complex target characteristics and expert evaluation system, a hierarchical structure model is established.

The benchmark selection is divided into three levels. The target layer is the selected benchmark, the criterion layer is the 5 dimensions of the benchmark shape, size, processing technology, test frequency band and bracket coupling, and the solution layer is the 9 typical benchmarks.

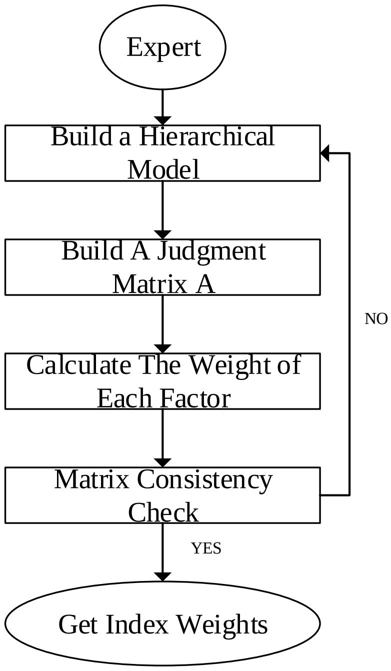

Figure 2 – AHP Workflow

In quantitative evaluation, the AHP method is optimized to increase the weight analysis of the knowledge and experience of the expert system. A pairwise comparison matrix at each level is constructed as the data basis for the final evaluation. Through hierarchical single ranking and consistency check, hierarchical total ranking and decision evaluation, different weights of typical benchmarks for specific complex targets are finally obtained. Transform qualitative evaluation to quantitative evaluation to improve the objectivity of evaluation, so as to be closer to the needs of the test site and to evaluate the uncertainty of complex targets more accurately.

3.2 Build a Hierarchical Hierarchy Model

When using the AHP method to make decisions, the most critical step is to model the problem in layers. These layers can be divided into three categories, as shown in Table 1. The target layer involved is the final benchmark that needs to be selected, and the middle layer is relevant factors to consider, the bottom layer is a typical benchmark of 9 different shapes.

Table 1 –Hierarchical Model

No.	Level	Content
1	Top layer (target layer)	The RCS benchmark that needs to be selected
2	Middle layer (criteria layer)	Influencing factors involved
3	The bottom layer (schematic layer)	Different RCS benchmark

The typical benchmark is evaluated based on two levels. The first level is the importance evaluation of the five factors of the typical benchmark. The five criteria-level factors that experts are most concerned about are determined through investigation. The importance evaluation of this level is based on expert system evaluation. The importance of the five key factors was established through a pairwise comparison to establish a comparison matrix for quantitatively judging the weight of each factor.

The second level is to conduct a pairwise comparison and evaluation between the existing typical benchmark for the five criterion-level factors, as the basis for the subsequent selection of typical benchmark, and form a typical benchmark expert scoring matrix for each element. .

3.2.1 Construct a pairwise comparison matrix at each level

When determining the weights between different levels and factors, usually qualitative results (for example, trihedral angles account for 70%, dihedral angles account for 30%, etc.) are not easy to be recognized, so the consistent matrix method is used to construct them. The core is not to compare all the factors together, but to compare them in pairs, so that the evaluation results are more objective; at the same time, the evaluation scales of pairwise comparison are used for evaluation to improve the accuracy of evaluation. The AHP method constructs the contrast matrix by utilizing the scaling method (as shown in Table 2).

Table 2 –1-9 scaling method

Scaling	Meaning
1	Both factors are equally important
3	Slightly important
5	Obviously important
7	Strongly important
9	Extremely important
2、4、6、8	The median value of the above two adjacent Value judgments

3.2.2 Consistency Check and Hierarchical Ordering

When determining the weights between different levels and factors, usually qualitative results (for example, trihedral angles account for 70%, dihedral angles account for 30%, etc.) are not easy to be recognized, so the consistent matrix method is used to construct them. The core is not to compare all the factors together, but to compare them in pairs, so that the evaluation results are more objective; at the same time, the evaluation scales of pairwise comparison are used for evaluation to improve the accuracy of evaluation. The AHP method constructs the contrast matrix by utilizing the scaling method (as shown in Table 2).

If the contrast matrix is a uniform matrix, then normalize its largest Eigen root, we can get $\{w_1, w_2, \ldots, w_n\}$, and $\sum_{i=1}^{n} w_i = 1$, indicates the influence weight of the i-th level of this level on a certain factor of the previous level.

If the matrix is not uniform, normalize its largest Eigen root to get the weight vector W, then by formula (2-1), we can get λ:

$$\mathrm{AW} = \lambda \mathrm{W} \quad \mathrm{W} = \{w_1, w_2, \ldots, w_n\} \qquad (2\text{-}1)$$

The comparison matrix can accept inconsistent results to a certain extent, and whether it is acceptable is used to quantitatively evaluate the consistency by the consistency ratio CR. It can be obtained from (2-2), where CI represents the consistency index and RI represents the random consistency index, which is obtained according to the order of the matrix. When $\mathrm{CR} < 0.1$, it is considered that A has passed the consistency test, and its weight vector can be obtained after the eigenvectors are normalized. Otherwise, the comparison matrix A needs to be revised and a_{ij} is re-evaluated.

$$\mathrm{CR} = \frac{CI}{RI} \qquad (2\text{-}2)$$

Among them, CI is the consistency index, which can be obtained by formula (2-3).

$$\mathrm{CI}=\frac{\lambda-n}{n-1} \quad \text{(2-3)}$$

RI is a random consistency index, RI can be calculated by randomly constructing 500 comparison matrices $A_1, A_2, ...A_{500}$, and the consistency index $CI_1, CI_2, ...CI_{500}$ can be obtained, and RI can be obtained by formula (2-4).

$$RI=\frac{CI_1+CI_2+...CI_{500}}{500}=\frac{\frac{\lambda_1+\lambda_2+...+\lambda_{500}}{500}-n}{n-1} \quad \text{(2-4)}$$

By counting the values of random consistency indicators RI, as shown in Table 3.

Table 3 – Stochastic Consistency Indicator Value

n	1	2	3	4	5	6	7	8	9	10	11
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.45	1.51

3.2.3 Total Hierarchy Ranking and Evaluation Decisions

The consistency of the total hierarchical ranking is represented by the consistency ratio CR, and its judgment standard is $\mathrm{CR}<0.1$. It is considered that the total hierarchical ranking has acceptable consistency, and the CR of the total hierarchical ranking can be obtained by formula (2-5).

When the total ranking of the hierarchy has an acceptable consistency (i.e. $\mathrm{CR}<0.1$), the weight of the i-th factor of the plan layer (assumed to be the B layer) to the total objective can be calculated using the formula $\sum_{j=1}^{m} a_{ij} b_{ij}$. Through this method, the quantitative calculation of all the schemes at the bottom can be completed, and the relative important weight for the final selection can be obtained, that is, the total ranking of the hierarchy. Finally, based on the weights of all schemes from large to small, the evaluation and implementation decisions are made. This process is carried out hierarchically from the target layer to the scheme layer.

$$\mathrm{CR}=\frac{a_1 CI_1+a_2 CI_2+\cdots+a_m CI_m}{a_2 RI_2+a_2 RI_2+\cdots+a_m RI_m} \quad \text{(2-5)}$$

4. Method validation

Finally, using the above method, a complex target is selected for case verification. The model is shown in Figure 3, and the model selected for its benchmark is constructed. Sort out the relationship between typical benchmark and complex targets through a hierarchical benchmark selection model, as shown in Figure 4.

First, build a benchmark selection hierarchical model, as shown in Figure 4, according to the principle of level from low to high, from scheme to goal, based on the existing benchmark resources and the factors that the expert system focuses on (i.e. intermediate criteria), to the final Implements how to choose a typical benchmark.

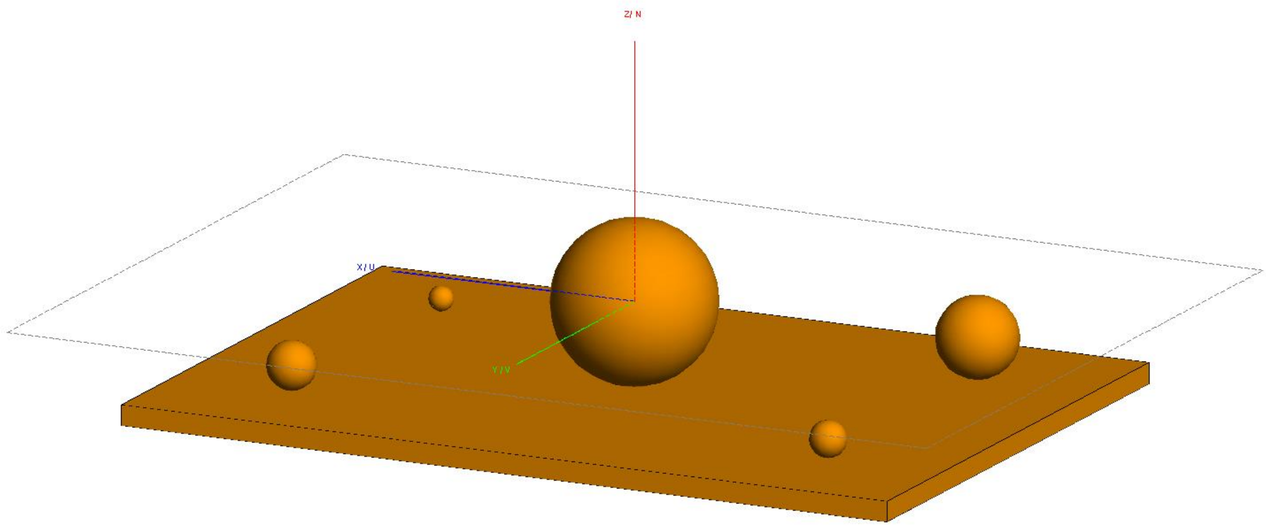

Figure 3. Complex Target Model

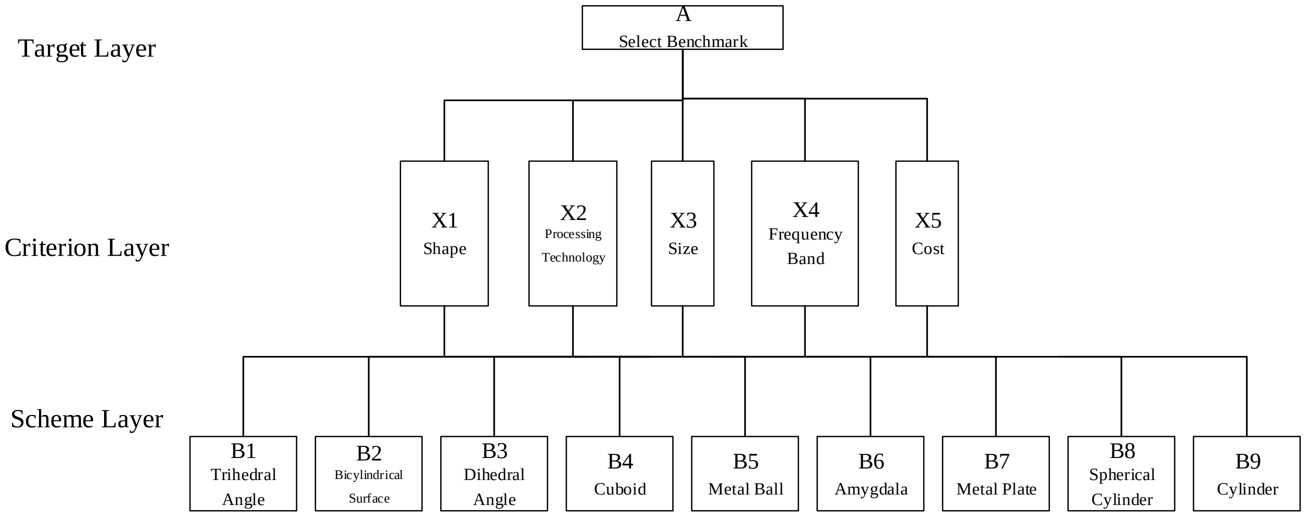

Figure 4. Benchmark Selection Model

The five criteria layer elements are: one is the shape, because the shape is one of the most critical factors affecting the RCS value, and the shape design directly determines the RCS magnitude; the second is the processing technology, the deviation caused by the processing technology in actual manufacturing. , such as length, verticality and roughness, etc., so that there may be a big difference between the RCS value of the actual test and the RCS value calculated by the simulation; the third is the size. The size also needs to be characterized by selecting a benchmark of suitable size; the fourth is the frequency band, according to the frequency band requirements of the test site, select the shape and size of the typical benchmark to support the test needs of different frequency bands; the fifth is the cost, due to engineering feasibility and Application requirements, material costs and processing costs have also become the focus of attention.

4.1 Pairwise comparison matrix construction

Through the evaluation of the expert system, the judgment matrix of the scheme layer to the criterion layer and the criterion layer to the target layer is obtained, and the scheme sorting and consistency test are carried out according to the judgment matrix, so as to obtain the final evaluation result of the benchmark. Through the verification of typical cases, the effectiveness and feasibility of the method can be proved, and the objective and quantitative standard selection decision can be realized.

The expert system is used to evaluate the scheme layer (that is, 9 different standard bodies) with respect to 5 influencing factors, and each influencing factor is used as the evaluation dimension to construct a pairwise comparison matrix of the scheme layer, which represents 9 different standard bodies with the shape as The comparison matrix when the evaluation is based, represents the comparison matrix when 9 different standard bodies are based on processing technology, represents the comparison matrix when 9 different standard bodies are based on size, and represents 9 different standard bodies when the evaluation is based on frequency bands The comparison matrix at the time of evaluation represents the comparison matrix of 9 different standard bodies when the evaluation is based on cost.

$$A=\begin{bmatrix} 1 & 3 & 2 & 4 & 6 \\ 1/3 & 1 & 1 & 4 & 5 \\ 1/2 & 1 & 1 & 7 & 6 \\ 1/4 & 1/4 & 1/7 & 1 & 4 \\ 1/6 & 1/5 & 1/6 & 1/4 & 1 \end{bmatrix}$$

$$B_1=\begin{bmatrix} 1 & 1/2 & 1/7 & 1/3 & 1/6 & 1/4 & 1/8 & 1/2 & 1/2 \\ 2 & 1 & 1/5 & 1 & 1/5 & 2 & 1/7 & 1 & 1 \\ 7 & 5 & 1 & 5 & 1/2 & 3 & 1/2 & 4 & 5 \\ 3 & 1 & 1/5 & 1 & 1/4 & 5 & 1/3 & 3 & 2 \\ 6 & 5 & 2 & 4 & 1 & 2 & 1/4 & 2 & 3 \\ 4 & 1/2 & 1/3 & 1/5 & 1/2 & 1 & 1/5 & 4 & 2 \\ 8 & 7 & 2 & 3 & 4 & 5 & 1 & 7 & 7 \\ 2 & 1 & 1/4 & 1/3 & 1/2 & 1/4 & 1/7 & 1 & 2 \\ 2 & 1 & 1/5 & 1/2 & 1/3 & 1/2 & 1/7 & 1/2 & 1 \end{bmatrix}$$

$$B_2=\begin{bmatrix} 1 & 2 & 1/8 & 1/4 & 1/7 & 1/4 & 1/7 & 1/3 & 1/2 \\ 1/2 & 1 & 1/5 & 1 & 1/5 & 2 & 1/7 & 1 & 1 \\ 8 & 5 & 1 & 4 & 1/2 & 3 & 1/2 & 4 & 4 \\ 4 & 1 & 1/4 & 1 & 1/4 & 1 & 1/3 & 3 & 2 \\ 7 & 5 & 2 & 4 & 1 & 2 & 1/2 & 2 & 3 \\ 4 & 1/2 & 1/3 & 1 & 1/2 & 1 & 1/5 & 4 & 2 \\ 7 & 7 & 2 & 3 & 2 & 5 & 1 & 6 & 7 \\ 3 & 1 & 1/4 & 1/3 & 1/2 & 1/4 & 1/6 & 1 & 1/2 \\ 2 & 1 & 1/4 & 1/2 & 1/3 & 1/2 & 1/7 & 2 & 1 \end{bmatrix}$$

$$B_3=\begin{bmatrix} 1 & 1/2 & 1/6 & 1/3 & 1/6 & 1/4 & 1/8 & 2 & 1/2 \\ 2 & 1 & 1/5 & 1 & 1/3 & 2 & 1/7 & 3 & 1 \\ 6 & 5 & 1 & 5 & 1/2 & 3 & 1/2 & 4 & 5 \\ 3 & 1 & 1/5 & 1 & 1/4 & 5 & 1/3 & 3 & 2 \\ 6 & 3 & 2 & 4 & 1 & 2 & 1/4 & 2 & 3 \\ 4 & 1/2 & 1/3 & 1/5 & 1/2 & 1 & 1/3 & 4 & 2 \\ 8 & 7 & 2 & 3 & 4 & 3 & 1 & 8 & 5 \\ 1/2 & 1/3 & 1/4 & 1/3 & 1/2 & 1/4 & 1/8 & 1 & 1/4 \\ 2 & 1 & 1/5 & 1/2 & 1/3 & 1/2 & 1/5 & 4 & 1 \end{bmatrix}$$

$$B_4 = \begin{bmatrix} 1 & 2 & 1/8 & 1/2 & 1/7 & 1/4 & 1/8 & 1/3 & 1/3 \\ 1/2 & 1 & 1/9 & 1/4 & 1/8 & 1/7 & 1/8 & 1/3 & 1/6 \\ 8 & 9 & 1 & 4 & 1/2 & 3 & 1/2 & 4 & 3 \\ 2 & 4 & 1/4 & 1 & 1/4 & 1 & 1/4 & 3 & 2 \\ 7 & 8 & 2 & 4 & 1 & 2 & 1/2 & 2 & 3 \\ 4 & 7 & 1/3 & 1 & 1/2 & 1 & 1/3 & 4 & 2 \\ 8 & 8 & 2 & 4 & 2 & 3 & 1 & 6 & 3 \\ 2 & 3 & 1/4 & 1/3 & 1/2 & 1/4 & 1/6 & 1 & 1/2 \\ 3 & 6 & 1/3 & 1/2 & 1/3 & 1/2 & 1/3 & 2 & 1 \end{bmatrix}$$

$$B_5 = \begin{bmatrix} 1 & 1/2 & 1/7 & 1/3 & 1/6 & 1/4 & 1/8 & 1/2 & 1/2 \\ 2 & 1 & 1/5 & 1 & 1/5 & 2 & 1/7 & 1 & 1 \\ 7 & 5 & 1 & 5 & 1/2 & 3 & 1/2 & 4 & 5 \\ 3 & 1 & 1/5 & 1 & 1/3 & 1/2 & 1/3 & 3 & 2 \\ 8 & 5 & 2 & 3 & 1 & 2 & 1/4 & 2 & 3 \\ 5 & 1/2 & 1/3 & 2 & 1/2 & 1 & 1/2 & 3 & 2 \\ 8 & 7 & 2 & 3 & 4 & 2 & 1 & 4 & 5 \\ 2 & 1 & 1/4 & 1/3 & 1/2 & 1/3 & 1/4 & 1 & 2 \\ 2 & 1 & 1/5 & 1/2 & 1/3 & 1/2 & 1/5 & 1/2 & 1 \end{bmatrix}$$

4.2 Hierarchical order

At present, the construction of the judgment matrix of the scheme layer and the judgment matrix of the criterion layer has been completed. It is expected to complete the consistency test of all judgment matrices and the sorting of schemes. The decision sorting of different schemes can be obtained through the final score, and the final results are used to verify the implement ability of the method.

By calculating the maximum eigenvalue and its corresponding eigenvector of the above comparison matrix, the consistency test is performed using the consistency index, random consistency index and consistency ratio, as shown in Table 4.

Table 4 – Hierarchical single sorting and consistency check calculation results

Comparison matrix / Result	B1	B2	B3	B4	B5	A
W_k	0.0234 0.0528 0.1901 0.0948 0.1749 0.0673 0.3140 0.0447 0.0381	0.0308 0.0520 0.1871 0.0762 0.1902 0.0806 0.2891 0.0453 0.0487	0.0288 0.0623 0.1946 0.0951 0.1703 0.0695 0.2981 0.0293 0.0519	0.0267 0.0182 0.1924 0.0792 0.1978 0.1046 0.2658 0.0456 0.0697	0.0245 0.0583 0.1968 0.0692 0.1785 0.0936 0.2857 0.0516 0.0419	0.3959 0.2104 0.2744 0.0796 0.0396
λ_{max}	10.0353	9.9191	10.1429	9.4761	9.8289	5.3857
CI_k	0.1294	0.1149	0.1429	0.0595	0.1036	0.0964
CR_k	0.0893	0.0792	0.0985	0.0410	0.0715	0.0861

By analyzing the results of single-level ranking and its consistency test, because the consistency ratio CR_k <0.1, it is considered that the inconsistency degree of the constructed pairwise comparison matrix is within the allowable range, and there is satisfactory consistency, so it passes the consistency test.

4.3 Hierarchical order

Combined with the calculation results, calculate the total ranking weight vector and its consistency check. Calculated $CR = 0.069$, since $CR < 0.1$, the total hierarchical ranking has passed the consistency test, and the total hierarchical ranking has satisfactory consistency. Therefore, the total hierarchical ranking is directly calculated as shown in Table 5, and the final decision is made.

Table 5 – Hierarchical total sort result

Scheme layer	B1	B2	B3	B4	B5	B6	B7	B8	B9
Result	0.0392	0.0696	0.1295	0.1047	0.1837	0.0714	0.3124	0.0464	0.0426

Through the quantitative analysis of the results of the AHP method based on the knowledge and experience of the expert system, the final weights of the comprehensive criterion layer and the scheme layer are ranked as: Metal plates, spherical cylinders, and cylinders. Therefore, since all symmetric matrices have passed the consistency check, the final selection of standard bodies are metal plates, metal spheres, and dihedral angles. In the uncertainty analysis, these three can be used. A typical benchmark represents the complex object shown in Figure 3.

5. Conclusion

This paper firstly analyzes the current typical standard bodies and their characteristics. Combined with the characteristics of complex standard bodies that need to be evaluated, the evaluation criterion layer is divided into five elements: shape, processing technology, size, frequency band, and cost. The standard bodies were compared in pairs to construct a quantitative evaluation matrix. In order to improve the objectivity of the evaluation, experts are classified and evaluated according to their knowledge and experience, and the final evaluation matrix is given based on their weights. The new criterion layer and scheme layer evaluation matrix are obtained, and finally verified by an example to prove the effectiveness of the method.

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