# Visual Evaluation Model of Asphalt Pavement Performance

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**Abstract.** The pavement performance of asphalt mixture is evaluated by several pavement performance indexes. Because of the lack of data, it is difficult to synthetically evaluate the pavement performance. There are 14 indexes of pavement performance which were taken as the original indexes. Based on the factor analysis, the 14 indexes were integrated into 3 items. Three dimensional space model is established based on this 3 items. With the factor scores of each sample, the discrete points were plotted in the coordinate. Fitting the distribution area of characteristic indexes by ellipsoid. The distribution area is independent of each other. The boundary of the fitting area is clear.

## 1. Instruction

Asphalt mixture is a kind of materials which consist bitumen, coarse-aggregate, fine aggregate, mineral powder and fiber stabilizer. It is one of the main materials for highway pavement. There are several indexes used to reflect the asphalt pavement performance. [1] For a comprehensive analysis of pavement performance, the general indexes should be simplified as comprehensive indexes. In this project, the 14 indicators were summed up in 3 comprehensive indexes, which is temperature stability, shear resistance and durability. Among the 14 indexes, there are not only the traditional index such as marshall stability, dynamic stability, marshall residual stability ratio and freeze-thaw splitting strength ratio [2], but also the physical index such as percentage of voids in aggregate, percent voids in mineral aggregate, asphalt saturation and so on were analyzed as the original data in factor analysis. [3] Based on the factor scores of each samples, a 3D scatter distribution map was formed. By the method of surface fitting and stereo fitting, a 3D comprehensive evaluation model was built up. The pavement performance of asphalt mixture can be more clearly displayed.

## 2. Experiment

### 2.1 Experiment scheme

There are three kinds of asphalt mixtures with different gradation characteristics were taken as the experimental materials, which is AC, ATB and SMA. ATB is a dense graded asphalt stabilized macadam, AC is a dense graded asphalt concrete, SMA is the stone mastic asphalt. Orthogonal experimental method is to choose the right amount of representative program from a large number of experiments, and the method (orthogonal table) of data analysis is used to arrange the experiment and data analysis. The orthogonal table in this experiment is arranged with 3 factors and 3 levels. The 3 factors are coarse aggregate, fine aggregate and asphalt-aggregate ratio. The 3 levels of coarse and fine aggregate are the three position of grading curve. The 3 levels of asphalt-aggregate ratio is the 3 empirical values. The orthogonal experimental scheme is shown in Fig 1 to Fig 3.

*2.2 Specimen*

The specimen was made by the method of   Marshall compaction or rolling wheel. The size of specimen is  φ101.6mm × 63.5mm  Cylindrical and  300mm × 300mm × 50mm  prism. The corresponding experiments were carried out according to the standard experimental procedure.
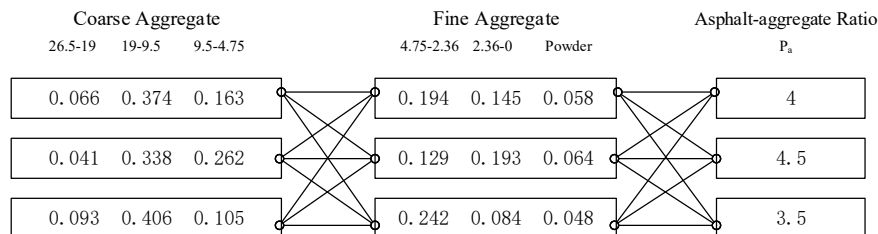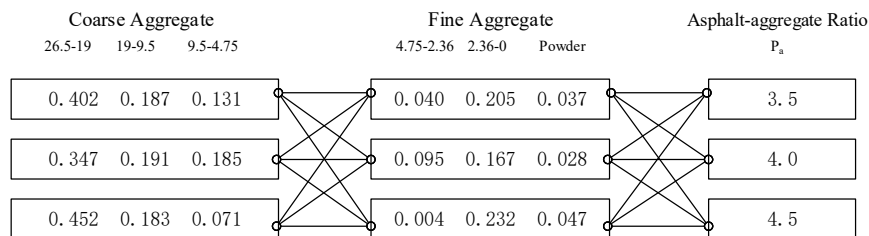
| Coarse Aggregate | | | Fine Aggregate | | | Asphalt-aggregate Ratio |
|---|---|---|---|---|---|---|
| 26.5-19 | 19-9.5 | 9.5-4.75 | 4.75-2.36 | 2.36-0 | Powder | $P_a$ |
| 0.066 | 0.374 | 0.163 | 0.194 | 0.145 | 0.058 | 4 |
| 0.041 | 0.338 | 0.262 | 0.129 | 0.193 | 0.064 | 4.5 |
| 0.093 | 0.406 | 0.105 | 0.242 | 0.084 | 0.048 | 3.5 |

Fig 1. AC Orthogonal Experiment Scheme

| Coarse Aggregate | | | Fine Aggregate | | | Asphalt-aggregate Ratio |
|---|---|---|---|---|---|---|
| 26.5-19 | 19-9.5 | 9.5-4.75 | 4.75-2.36 | 2.36-0 | Powder | $P_a$ |
| 0.402 | 0.187 | 0.131 | 0.040 | 0.205 | 0.037 | 3.5 |
| 0.347 | 0.191 | 0.185 | 0.095 | 0.167 | 0.028 | 4.0 |
| 0.452 | 0.183 | 0.071 | 0.004 | 0.232 | 0.047 | 4.5 |

Fig 2. ATB Orthogonal Experiment Scheme

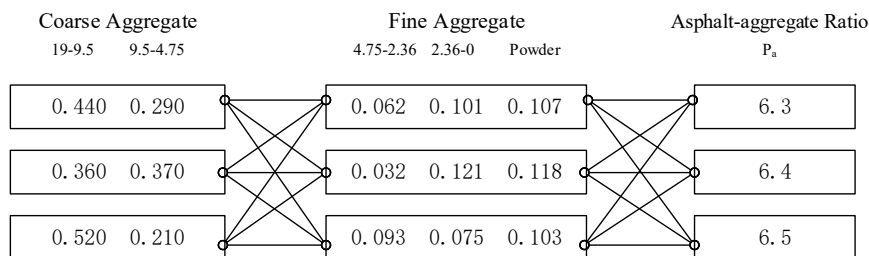| Coarse Aggregate | | Fine Aggregate | | | Asphalt-aggregate Ratio |
|---|---|---|---|---|---|
| 19-9.5 | 9.5-4.75 | 4.75-2.36 | 2.36-0 | Powder | $P_a$ |
| 0.440 | 0.290 | 0.062 | 0.101 | 0.107 | 6.3 |
| 0.360 | 0.370 | 0.032 | 0.121 | 0.118 | 6.4 |
| 0.520 | 0.210 | 0.093 | 0.075 | 0.103 | 6.5 |

Fig 3. SMA Orthogonal Experiment Scheme

*2.3 Results*

Through the standard experiments, several indexes for pavement performance could be obtained. The name of indexes are replaced by abbreviation. VV is the percentage of voids in aggregate, VMA is the percent voids in mineral aggregate, VFA is the asphalt saturation, MS is Marshall stability, DS is dynamic stability, MSR is marshall residual stability, TSR is freeze-thaw splitting strength ratio.

The results of the experiment are shown in Table 1. Because of the units are not same. It is hard to find out which grading scheme shows the best pavement performance. Thus, it is necessary to standardize the data before analyzing. The data in table 1 are the results after standardized.

Table 1. Experimental Result (standardized)

| No. | VV(%) | VMA(%) | VFA(%) | MS(kN) | DS(times/mm) | RS(%) | TSR(%) |
|---|---|---|---|---|---|---|---|
| AC 1 | 0.03 | -0.42 | -0.31 | 1.04 | 1.24 | 1.61 | 1.04 |
| AC 2 | -0.35 | -0.53 | 0.07 | 1.14 | -0.39 | 0.04 | 0.43 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| AC 3 | 2.12 | 1.52 | -1.04 | -0.31 | -0.22 | 0.08 | -1.49 |
| AC 4 | -0.20 | -0.05 | 0.23 | -0.10 | 0.91 | 0.12 | 0.24 |
| AC 5 | 0.11 | -0.38 | -0.38 | 1.52 | 0.65 | 0.09 | 1.18 |
| AC 6 | 2.51 | 0.66 | -2.09 | -0.28 | -0.57 | 0.74 | 1.10 |
| AC 7 | -0.82 | -0.76 | 0.50 | 0.94 | 0.91 | 1.77 | 1.14 |
| AC 8 | -0.35 | -0.91 | -0.22 | 1.77 | -0.71 | 0.11 | 0.93 |
| AC 9 | 2.35 | 0.59 | -2.01 | -0.14 | 1.24 | 0.72 | 0.78 |
| ATB 1 | -0.61 | -1.35 | -0.27 | 0.87 | -0.98 | -0.72 | -0.97 |
| ATB 2 | -0.62 | -1.28 | -0.20 | 1.04 | -1.18 | -0.43 | -0.15 |
| ATB 3 | -0.22 | -1.13 | -0.61 | 0.42 | -1.12 | 0.00 | -0.33 |
| ATB 4 | -0.45 | -1.21 | -0.36 | 0.73 | -0.83 | -0.07 | -1.04 |
| ATB 5 | -0.22 | -1.09 | -0.57 | 1.14 | -1.00 | -0.50 | -0.39 |
| ATB 6 | 0.66 | -0.72 | -1.37 | 0.24 | -0.81 | -0.36 | -0.24 |
| ATB 7 | -0.63 | -1.32 | -0.22 | 0.80 | -1.01 | -0.88 | -1.40 |
| ATB 8 | -0.64 | -1.17 | -0.07 | 0.76 | -1.14 | 1.49 | -2.38 |
| ATB 9 | 0.37 | -0.87 | -1.14 | 0.38 | -1.07 | -0.68 | -0.25 |
| SMA 1 | 0.27 | 1.16 | 0.45 | -0.86 | 1.65 | 1.09 | 0.73 |
| SMA 2 | -0.62 | 0.80 | 1.13 | -0.96 | 2.21 | 0.65 | 0.00 |
| SMA 3 | 0.31 | 1.18 | 0.42 | -1.14 | 0.26 | 0.24 | 1.23 |
| SMA 4 | -0.60 | 0.77 | 1.11 | -1.03 | 0.91 | 1.28 | 0.90 |
| SMA 5 | -1.07 | 0.57 | 1.56 | -1.43 | 0.44 | -2.12 | -1.70 |
| SMA 6 | 0.20 | 1.10 | 0.49 | -1.28 | -0.67 | -1.62 | -0.54 |
| SMA 7 | -0.04 | 1.06 | 0.77 | -1.32 | 1.65 | -1.73 | -0.72 |
| SMA 8 | -1.59 | 0.42 | 1.98 | -1.01 | 0.26 | -1.36 | -0.53 |
| SMA 9 | 0.05 | 1.09 | 0.65 | -1.05 | 0.11 | -0.74 | 1.19 |

*2.4. Factor analysis*

Factor analysis originated from psychology and developed in 1960s. By studying the internal dependency structure of the correlation matrix, the multiple variables are converted into few factors, which will reproduce the relationship between original information. It is a kind of multivariate statistical analysis method to further explore the underlying causes of these relationships.

Durability, shear resistance and high-temperature stability were taken as the three dimensions of three-dimensional space. The load of factor scores on the three dimensions is used as the spatial coordinate, and the distribution map of factor scores to each asphalt mixtures can be shown in Fig 4.
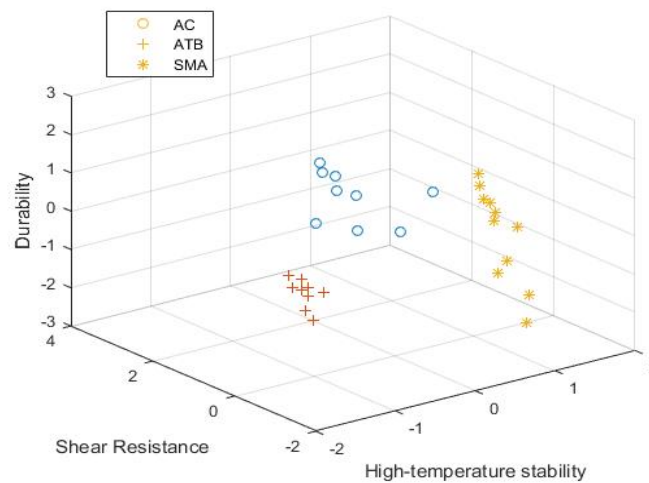
Fig 4. Distribution map of factor scores

## 3. Ellipsoid fitting
The distribution as shown in Fig 5, exist in the form of three groups. They don't interfere and cross. Thus, each group can be fitted with an ellipsoid.

### 3.1 Standard equation
The ellipsoid is a kind of two curved surface, which is a generalization of ellipse in three dimensional space. The standard equation is shown as equation (1),

$$\frac{(x-x_c)^2}{a^2}+\frac{(y-y_c)^2}{b^2}+\frac{(z-z_c)^2}{c^2}=1 \quad (1)$$

Where $(x_c,\ y_c,\ z_c)$ is the ellipsoid center. The variable $a$ and $b$ are the equatorial radius (along the X and Y axes), $c$ is the polar radius (along the Z axis). These three numbers are all fixed positive numbers, which determine the shape of the ellipsoid. [15]

### 3.2 Coordinate transformation
It is obviously that the discrete points are not distributed according to the standard ellipsoid with the origin center. Therefore, it is necessary to transform the coordinates. Two coordinate can be matched through the translation and rotation transformation of coordinate axes as shown in equation (2). [16]

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \lambda R \begin{bmatrix} X' \\ Y' \\ Z' \end{bmatrix} + \begin{bmatrix} \Delta X \\ \Delta Y \\ \Delta Z \end{bmatrix} \quad (2)$$

Where $\lambda$ is the scaling factor for two coordinate systems, $\lambda = 1$ in this paper. $R$ is the rotation factor, which is shown in equation (3).

$$R = R(\theta)R(\varphi)R(\psi)$$
$$= \begin{bmatrix} \cos\theta\cos\psi - \sin\theta\sin\varphi\sin\psi & -\cos\theta\sin\psi - \sin\theta\sin\varphi\cos\psi & -\sin\theta\cos\varphi \\ \cos\varphi\sin\psi & \cos\varphi\cos\psi & -\sin\varphi \\ \sin\theta\cos\psi + \cos\theta\sin\varphi\sin\psi & -\sin\theta\sin\psi + \cos\theta\sin\varphi\sin\psi & \cos\theta\cos\varphi \end{bmatrix} \quad (3)$$

Where $\varphi, \theta, \psi$ are Euler angles representing ellipsoid orientation, in degrees.

### 3.3 Ellipsoid fitting
The key to ellipsoid fitting is to determine the parameters of the ellipsoid. The centroid is the mean value of the score-coordinates. Perform a principal component analysis with 2 variables to extract inertia axes of the scores, then the length of each semi axis was extracted. The length of each semi axis is the distance between the centroid and the point at the border. The axes were sorted from greater to lower, that is a, b and c. Then the axes rotation matrix was extracted. The centroid, semi axis length and axes rotation angles are shown in table 2.

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Table 2. Ellipsoid Parameters

|         | AC    | ATB   | SMA   |
|---------|-------|-------|-------|
| $x_c$   | -0.25 | -1.02 | 1.04  |
| $y_c$   | 0.50  | 0.18  | -0.56 |
| $z_c$   | 1.04  | -0.90 | -0.11 |
| $a$     | 3.56  | 1.22  | 2.67  |
| $b$     | 1.45  | 0.68  | 1.93  |
| $c$     | 0.65  | 0.12  | 0.11  |
| φ       | 1.02  | 1.29  | -0.18 |
| θ       | 0.43  | 0.27  | 1.46  |
| ψ       | 0.96  | -1.60 | 0.12  |

According to the ellipsoid parameters, it is easy to get the fitting ellipsoid as shown in Fig 5 to Fig 7.


Fig 5. Ellipsoid fitting of AC

In Fig 5, it is easy to find that the semi axis to Shear Resistance of AC is short and the performance is not stable. On the contrary, there are not much changes in Durability and High-temperature Stability, the performance is stable.
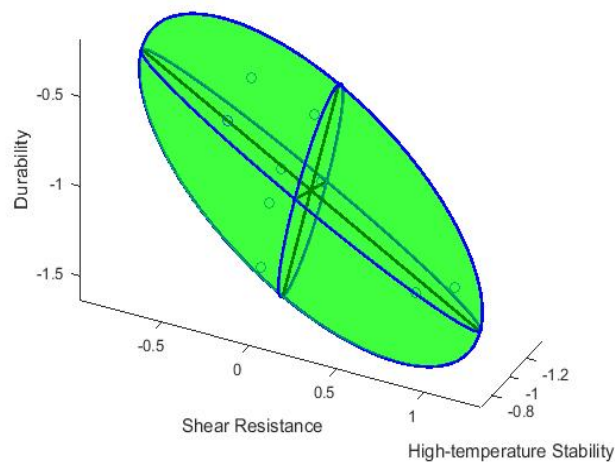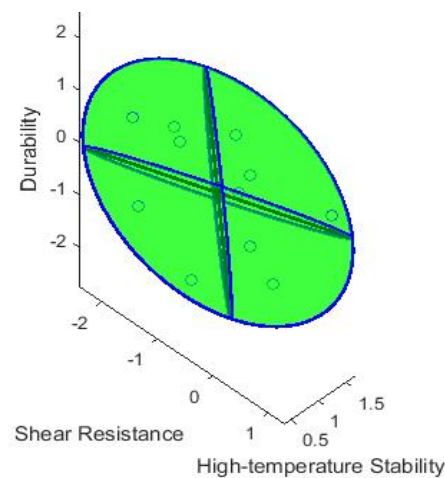

Fig 6. Ellipsoid fitting of ATB

Fig 7. Ellipsoid fitting of SMA

In Fig 6 and Fig 7, the shape of ellipsoid is flat. The semi axis to High-temperature Stability is shorter than others. That means the factor score distribution is more concentrated and the pavement performance of ATB and SMA is more balanced in High-temperature Stability. The length of semi axis of Durability and Shear Resistance is far longer than that of High-temperature Stability. That means Durability and Shear Resistance of ATB and SMA are not stable.

## 4. Conclusion

Based on factor analysis, the road performance evaluation indexes can be simplified to three. The visual model of pavement performance can be constructed in 3D apace. The purpose the visual evaluation model is to analyze the factors influence of pavement performance and the relationships among the character indexes.

The characteristic of the road performance is significant in ellipsoid model. It's easier to find out the difference and relationship in performance factors. It is easy to find that asphalt SMA has a higher temperature stability. Asphalt ATB has the best shear resistance. Asphalt AC has a better durability. Because of the limitation number of samples, the fitting accuracy needs to be improved in the future research.

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