Comparative Analysis of Performance of Porous Asphalt Pavement and SMA Pavement Based on Deck Pavement Structure

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Abstract. Viaducts are more and more widely used in China. How to ensure the safety of the bridge deck has become a hot issue of concern? Based on the above problems, the application of porous asphalt pavement in bridge deck pavement is also increasing. Based on the porous asphalt pavement project of Shijiazhuang City Ring Road (West Second Ring of Heping West Road), the performance differences between porous asphalt pavement and stone matrix asphalt pavement were studied. By comparing the gradation characteristics and performance of porous asphalt mixture and stone matrix asphalt mixture, the advantages and disadvantages of the two mixtures in road performance were analyzed. At the same time, we carried out on-site braking test, noise test and long-term temperature monitoring on two types of pavement. By comparing the test results, we thought that porous asphalt pavement could reduce the braking distance by up to 7 m in mid-to heavy rain weather, and porous asphalt pavement could reduce 2-6 dB noise, Porous asphalt pavement has better cooling effect than stone matrix asphalt pavement, and the higher the external temperature was, the better the cooling effect of porous asphalt pavement was, and it could reduce 6-8°C in summer. Through the test comparison, we draw the conclusion that the pavement performance of porous asphalt pavement is better than that of stone asphalt pavement.

Keywords: porous asphalt pavement; stone matrix asphalt pavement; anti-skid performance; noise reduction performance;

1. Introduction
The main function of bridge deck pavement, which is different from other pavement forms, is to protect bridge deck from wheel direct wear. The deck pavement also protects the main girder from rain erosion. Therefore, on the premise of how to ensure traffic safety, it is particularly important to remove rainwater as much as possible to protect bridge deck and main girder.

Porous asphalt pavement and stone mastic asphalt pavement are two pavement structures with excellent road performance. The porous asphalt pavement adopts a large gap structure and a permeable structural layer [1], which can make the rainwater infiltrate into the surface layer structure and flow out along the waterproof and bonding layer to eliminate the surface runoff and reduce the water film thickness [2-3]. Stone mastic asphalt pavement has better high temperature stability and water stability compared with ordinary pavement. Compared with ordinary pavement, stone mastic asphalt pavement has better high temperature stability and water stability [4-5], and also has good anti-sliding performance and sound absorption effect [6-7].
By studying the noise reduction performance and shock absorption performance of the material, Haisheng Zhou obtained that the noise reduction performance of the large void structure is better than that of the dense structure [8]. Later, it was found that adding rubber to the asphalt can improve the noise reduction performance in the large pore asphalt [9]. Liu Yanlin and others studied the relationship between the noise reduction mechanism and the mix design of asphalt pavement, and proposed that the large void pavement structure could effectively reduce the traffic noise [10]. This is because the large void structure can reduce the high-speed pumping and pressure of the air generated when the tire is in contact with the ground, and provides a dissipating channel for such compression and suction [11]. Through the research on the test road, it was found that the porous asphalt pavement can reduce the noise about 2~3dB by compared with the ordinary asphalt pavement when the vehicle speed is between 40km/h and 80km/h [12].

2. Comparative Study On Performance of Asphalt Mixture

2.1. Mix Ratio
The gradation and optimum oil-stone ratio used for porous asphalt pavement and stone matrix asphalt are shown in Table 1 and Table 2.

**Table 1.** The gradation and optimum oil-stone ratio used for porous asphalt pavement and stone matrix asphalt

| Particle size(mm) | 16 | 13.2 | 9.5 | 4.75 | 2.36 | 1.18 | 0.6 | 0.3 | 0.15 | 0.075 | OAC |
|-------------------|----|------|-----|------|------|------|-----|-----|------|-------|-----|
| PAC               | 99.6 | 92.0 | 50.1 | 15.0 | 14.3 | 10.3 | 8.1 | 6.4 | 5.5 | 4.8 | 4.6% |
| SMA               | 100 | 99.9 | 61.9 | 27.2 | 21.2 | 16.7 | 13.6 | 11.3 | 10.0 | 9.1 | 5.86% |

**Table 2.** The proportion of stone with different particle sizes on porous asphalt pavement and stone matrix asphalt

| Particle size(mm) | Pavement type | 10~15 | 5~1 | 3~5 | 0~3 | Mineral powder |
|-------------------|---------------|-------|-----|-----|-----|----------------|
| PAC               | 53.5          | 32    | -   | 10  | 4.5 |
| SMA               | 40            | 33    | 6   | 14  | 7   |

From Table 1 and Table 2, it could be seen that the amount of fine aggregates with particle size of 4.75mm or smaller in porous asphalt mixture was relatively small. That is to say, the gradation characteristics of porous asphalt mixture were less fine aggregate content (0-3mm) and coarser aggregate content. This mix design can ensure the voidage of permeable asphalt mixture.

2.2. Comparison and Analysis of Basic Properties of Asphalt Mixture
The test pieces were formed separately from the porous asphalt mixture and the stone matrix asphalt, and the performance comparison study was carried out. The results were shown in Table 3.
Table 3. Test results of asphalt mixture performance

| Test project                  | Unit | PAC-13 | SMA-13 | Test method       |
|------------------------------|------|--------|--------|------------------|
| Voidage                      | %    | 22.2   | 3.5%   | T 0705-2011      |
| Marshall Stability           | kN   | 5.50   | 11.37  | T 0709-2011      |
| Flow Value                   | mm   | 3.3    | 4.0    | T 0709-2011      |
| Retained Marshall Stability  | %    | 91.3   | 97     | T 0709-2011      |
| Tensile Strength Ratio       | %    | 85.1   | 91.1   | T 0729-2011      |
| Leakage Loss                 | %    | 0.6    | 0.08   | T 0732-2011      |
| Kentucky Fort Dispersion Loss| %    | 8.3    | 2.4    | T 0733-2011      |
| Soak Kentucky Fort Dispersion Loss | % | 9.2 | 4.5 | T 0733-2011 |
| Low Temperature Bending Strain | (με) | 2613 | 2528 | T 0715-2011 |
| Dynamic Stability of Rut Test (60°C) | γ/μm | 7838 | 8536 | T 0719-2011 |
| Infiltration Test            | ml/min | 5742 | 10.2  | T 0730-2011      |
| BPN                          | -    | 70     | 64.4   | T 0964-2008      |
| Texture Depth                | mm   | 2.67   | 1.575  | T 0961-1995      |

2.2.1. Analysis of High-Temperature Stability. The high temperature stability test of the porous asphalt mixture and the stone matrix asphalt mixture was evaluated by the vehicle stability value. The dynamic stability of the porous asphalt mixture was 7838 times/mm, and the dynamic stability of the stone matrix asphalt mixture was 8536 times/mm, indicating that the high temperature stability of the stone matrix asphalt mixture is superior to the porous asphalt mixture.

2.2.2. Low temperature performance analysis. Low temperature cracking resistance of porous asphalt mixture and stone matrix asphalt mixture was evaluated by low temperature bending strain. According to the test results in table 4, the low-temperature bending failure strain value of porous asphalt mixture was 2613με, while the low-temperature bending failure strain value of stone matrix asphalt mixture was 2528με, both of which meet the technical requirements and differ very little, indicating that drainage asphalt mixture has the same low temperature performance as stone matrix asphalt mixture.

2.2.3. Analysis of water stability. Different from stone matrix asphalt mixture, drainage asphalt mixture is of macroporous structure, and the retained water can easily cause water damage to the mixture. Through comparison of Marshall residual stability of the two mixtures, it is found that both of them have higher water stability, which is because the porous asphalt mixture adopts high-viscosity and high-elasticity modified asphalt, which has higher dynamic viscosity, so that the mixture maintains higher water stability.

2.2.4. Friction Coefficient. In this experiment, the pendulum friction coefficient meter was used to measure BPN in wet condition on newly repaired porous asphalt pavement and stone matrix asphalt pavement. BPN (British Pendulum Value) can reflect the anti-skid performance of asphalt pavement under wet state. BPN of drainage asphalt pavement is greater than that of stone matrix asphalt pavement, indicating that drainage asphalt pavement has better anti-skid performance than stone matrix asphalt pavement.
3. Comparative Study of Road Performance

3.1. Brake Performance Study
We have chosen the road section which has not been opened after construction for braking test and noise reduction test. The brake and noise test scheme is shown in Fig.1.

![Figure 1. Brake and noise test scheme](image1)

We used sprinklers to simulate the road conditions in sunny, light and moderate to heavy weather, respectively. The braking tests of VW Magten and Buick GL8 were carried out on the porous asphalt pavement and the stone matrix asphalt pavement respectively. Field brake tests are shown in Fig. 2.

![Figure 2. Field brake test](image2)

The braking speed of the brake test was fixed at 80 km/h and 100 km/h respectively. The test results are shown in Table 4.
### Table 4. The braking distance between the two roads under different rainfall weather conditions

| Vehicle type | Driving speed | Pavement type | Brake distance under different rainfall weather conditions (m) |
|--------------|--------------|---------------|-------------------------------------------------------------|
|              |              | Sunny | Light rain | Moderate to heavy rain |
| Magten       | 80km/h       | PAC   | 20.18     | 23.5             | 25.15         |
|              |              | SMA   | 24.3      | 26.85            | 29.75         |
|              | 100km/h      | PAC   | 26.1      | 30.7             | 34.62         |
|              |              | SMA   | 30.23     | 34.55            | 41.2          |
| GL8          | 80km/h       | PAC   | 21.59     | 24.71            | 27.15         |
|              |              | SMA   | 25.42     | 29.5             | 34.03         |
|              | 100km/h      | PAC   | 27.33     | 32.81            | 36.92         |
|              |              | SMA   | 33.43     | 37.53            | 44.11         |

3.1.1. Analysis of brake data in sunny days. As could be seen from the data in Table 4, when braking tests were carried out on sunny days, that is, when the road was dry, the braking distance of the same car on the two roads at the same speed was relatively small. However, the braking distance on porous asphalt pavement was reduced by 4 m than that on stone matrix asphalt pavement. This is due to the fact that porous asphalt pavement is a macro porous structure, which accounts for a large proportion of coarse aggregate in mix design, and points contact between coarse aggregate, which greatly increases the structural depth of porous asphalt pavement. Although coarse aggregate accounts for a large proportion of stone matrix asphalt pavement, stone matrix asphalt pavement is watertight pavement with dense gradation, which leads to its structural depth smaller than that of porous asphalt pavement.

At the same time, in order to further verify the anti-skid performance of two kinds of pavement, we used the method of artificial sand shop for the brake test section depth of pavement structure was studied. The measured results showed that the average construction depth of porous asphalt pavement road surface was 2.67mm, and that of stone matrix asphalt road surface was 1.575mm, while that of general asphalt road surface measured was only 0.72mm. In theory, the anti-skid performance of porous asphalt pavement is much better than that of other asphalt pavement, which is consistent with the braking test results in sunny days. That is, the deeper the pavement structure is, the shorter the braking distance of the car on sunny days.

3.1.2. Analysis of brake data in light rain environment. In the light rain, as the stone matrix asphalt pavement has a large structural depth, it can store a certain amount of water and the precipitation can flow laterally through the structural depth of the road surface, which can effectively reduce road surface runoff. Under the premise that road surface runoff was not formed, we could regard the contact surface between the road surface and the tire in the light rain weather as a wet state. By comparing the friction coefficient values of the two road surfaces, we could predict the braking condition of the two road surfaces: the average pendulum of the porous asphalt pavement is 70, and the average pendulum of the stone matrix asphalt pavement is 64.4. Therefore, the porous asphalt pavement has better driving safety than the stone matrix asphalt pavement when the pavement is slippery. According to the braking test data, the braking distance of the same vehicle on the porous asphalt pavement road was shorter than that on the stone matrix asphalt road in the light rain weather, indicating that the pendulum value was positively correlated with the anti-skid performance of the road when the road was wet.
3.1.3. Analysis of brake data under heavy rain. With the increased of precipitation, the gap between braking distance on porous asphalt pavement and braking distance on stone matrix asphalt pavement was increasing. This is due to the large pore structure of porous asphalt pavement, which can effectively drain the rainwater out of pavement structure. Thus, the water film thickness of the road surface was reduced, and the probability of water drift was greatly reduced. Although stone matrix asphalt pavement has a certain depth of pavement structure, precipitation can only be discharged through the gradient of road instead of infiltration. With the increase of rainfall, when the water storage capacity of the road structure depth is lower than the rainfall, the road surface runoff will be formed and the surface water film will be produced. As a result, the braking distance on PAC road is shorter than that on stone matrix asphalt road.

In the heavy rainfall environment, when the vehicle speed reached 100 km/h, the brake distance between the porous asphalt pavement road surface and the stone matrix asphalt road surface increased more than that of the vehicle speed at 80 km/h. That is to say, when Volkswagen magotan reaches 80km/h, the relative reduction of the braking distance between porous asphalt pavement road and stone matrix asphalt road is 8.6m; when the speed reaches 100 km/h, the relative augment of the braking distance between porous asphalt pavement road and stone matrix asphalt road is 10.09m. When buick GL8 reached 80km/h, the relative augment of the braking distance between porous asphalt pavement road surface and stone matrix asphalt road surface was 9.19m; when the speed reached 100 km/h, the relative augment of the braking distance between porous asphalt pavement road surface and stone matrix asphalt road surface was 11.49m. It indicates that the water film thickness of porous asphalt pavement road under heavy rainfall is less than that of stone matrix asphalt road surface. With the increase of vehicle speed, this influence factor can be reflected through the relative augment of braking distance between the two roads.

3.2. Study on Noise Reduction Performance

When the car driving noise mainly by time and compression effect between pavement and tire air, generated by the porous asphalt pavement is big pore structure, the structure of the tire in high speed air pumping and pressure provides the connectivity for the channel, compared with the traditional dense gradation impermeable pavement, porous asphalt pavement has the role of absorption and reduce the tire rolling noise [13-14]. Therefore, porous asphalt pavement is also called "porous noise reduction asphalt pavement" or "low noise road surface".

Although the noise-reducing function of porous asphalt pavement has been recognized by the industry. At present, due to the lack of standardized noise testing equipment and testing methods in China, there is still a lack of measured data related to the noise-reducing effect of porous asphalt pavement road surface, as well as the comparative study on the traffic noise of other asphalt pavement. In this paper, the noise reduction effect of porous asphalt pavement and stone matrix asphalt pavement was studied by field noise test.

In the field noise test, we adopted the type SL-401 noise meter and the roadside test method to install the noise meter on the uniform section of the road before the test vehicle enters the simulated precipitation area. The noise detection results of porous pavement and stone matrix asphalt pavement were shown in Table 5.
Table 5. Field noise test results

| Vehicle type | Pavement type | Driving speed | Noise detection data (dB) | Average |
|--------------|---------------|---------------|---------------------------|---------|
| Magten       | PAC           | 80km/h        | 74.8 73.8 76.7           | 75.1    |
|              |               | 100km/h       | 78.4 77.7 79.1           | 78.4    |
|              | SMA           | 80km/h        | 79.5 80.3 79.9           | 79.9    |
|              |               | 100km/h       | 83.1 85.2 82.8           | 83.7    |
| Buick GL8    | PAC           | 80km/h        | 76.1 77.9 78.2           | 77.4    |
|              |               | 100km/h       | 80.3 82.8 79.1           | 80.7    |
|              | SMA           | 80km/h        | 79.7 80.4 77.7           | 79.3    |
|              |               | 100km/h       | 84.5 87.6 84.5           | 85.3    |

By observing the field noise test data, it could be found that the noise generated by porous asphalt pavement was smaller than that generated by stone matrix asphalt pavement. Taking Volkswagen Magten as an example, when the driving speed was 80km/h, the noise generated when driving on porous asphalt pavement was lower than that generated by stone matrix asphalt pavement. In addition, the noise level is related to the driving speed and the size of vehicles. The faster the vehicle travels on the same road, the higher the noise generated. Traveling at the same speed and on the same road, the buick GL8 made more noise than the Volkswagen magten.

In addition, when the vehicle speed of Volkswagen Magton increased from 80km/h to 100km/h, the average increase of noise on porous asphalt pavement was 3.3db, and that on stone matrix asphalt pavement was 3.8dB. When the vehicle speed of buick GL8 increased from 80km/h to 100km/h, the average increase of noise on porous asphalt pavement was 3.3dB and that on stone matrix asphalt pavement was 6dB. This shows that the increase of noise on porous asphalt mixture pavement road surface is relatively less than that on stone matrix asphalt road surface with the increase of vehicle speed. This was due to the increase of the speed of the vehicle, the increase of the air compression and release between the tire and the road surface lead to an increase in noise. For the porous asphalt pavement, the pumping effect was also relatively fastened by the interconnected pores. When the tire compressed the air, the air could quickly dissipate through the connected pores, reducing the noise generated by the air squeeze. When the tire released air, the air pressure in the pores at the contact between the tire and the porous asphalt pavement was substantially consistent with the external air pressure due to the existence of the connected pores, and the probability of noise generated by the difference between the inside and outside of the pores was greatly reduced. In general, the connection of large pore structures can quickly reduce the pumping effect and reduce the noise, but the ability to connect the large pore structure to reduce the pumping effect is not unlimited, and the pumping speed increases as the driving speed increases. When it exceeded the ability of the connected pore structure to reduce the pumping effect, the noise generated by the porous asphalt pavement was increased. However, the stone matrix asphalt pavement has a larger structural depth than the ordinary asphalt pavement (AC-20), and this structural depth can be approximated as a semi-connected pore. When the same vehicle travels on the two roads at the same speed, the tire compresses the same volume of air into the semi-connected pores of the semi-connected pore, and the pressure generated in the semi-connected pore of the asphalt pavement (AC-20) is less than the pressure generated in the semi-connected pore of the ordinary asphalt pavement (AC-20). So the noise of stone matrix asphalt pavement is lower than that of ordinary asphalt pavement (AC-20) in pump suction effect. However, the ability to reduce noise by using semi-connected pores has a certain limit compared with the connected pores. With the increase of pumping effect and beyond this limit, the noise of drained asphalt pavement will increase less than that of stone matrix asphalt pavement. Further analysis shows that when the vehicle speed increase is consistent with the growth rate, the noise generated by ordinary asphalt pavement increases the most, followed by stone matrix asphalt pavement, and the least is drainage asphalt pavement.
In summary, the results of comparison and analysis show that porous asphalt pavement has very obvious noise reduction effect, especially at higher speed, the noise reduction effect in rainy days is more significant than that in stone matrix asphalt pavement, and it can be approximately reduced by 2 ~ 6 dB.

3.3. Temperature Variation Study

The porous asphalt pavement has the function of cooling [15-16], and the stone mastic asphalt pavement also has a relatively stable effect. In order to compare the cooling effects of the two road surfaces, we buried the temperature sensor in the same position on the two pavement layers during the road construction. This is used to monitor the temperature changes of both roads for a long time. As shown in Fig.3 and Fig.4.

**Figure 3.** Embedding process of temperature sensor

**Figure 4.** Temperature Monitoring Test Points for Two Types of Bridge Deck Pavement

The temperature change of the two pavement was studied by setting the temperature sensor at the same position of porous asphalt pavement and stone matrix asphalt pavement. The position of sensors is the inner track position (monitoring the temperature of the roller position). And the midline position of the lane (monitoring the temperature of the unrolled position of the tire).

Through the study of the monthly temperature data of March 20th solstice on April 20th, we found that the temperature changes of all structural layers were basically the same. Therefore, we analyzed the data of March 25th solstice 27th, which represented the temperature changes of the two roads in
spring and autumn season, as shown in Fig.5 and Fig.6.

**Figure 5.** Curve of temperature change of porous asphalt pavement on March 25th solstice 27th

**Figure 6.** The curve of stone matrix asphalt pavement temperature on March 25th solstice 27th

We found that the drainage asphalt mixture on the inside layer of belt and the lane center line of the wheel track location of temperature data had certain gap, at noon, the inside temperature was higher than middle temperature 1.3℃. The temperature data of the inner wheel-track of the upper layer of stone matrix asphalt was basically consistent with the position of the middle line of this lane, as the figure showed that the two temperature curves basically coincide. This is because the drainage asphalt mixture is a large-porosity connected structure. When the wheels act on the inside track zone, they generate a certain amount of heat energy through the pump suction effect. Part of the heat energy dissipate through the connected pores, and the heat energy that does not dissipate is transferred to the mixture. However, although stone matrix asphalt pavement has a deep structural depth, it does not connect pores, and the heat generated by the pumping effect cannot be transferred inward. Therefore, there is no significant difference between the location of the inner wheel track of stone matrix asphalt pavement and the temperature of the middle line of this road.

The temperature data of the lower layer of AC-20 were basically consistent, and the temperature of the upper layer was higher than that of the lower layer during the day, and the temperature of the upper layer was 3℃ higher than that of the lower layer. The temperature of upper and lower surface layer was basically the same at night, and the temperature of surface layer was always higher than that of external layer, which was 7℃ higher than that of outside layer.

The temperature law of each structure layer of stone matrix asphalt pavement was similar to that of porous asphalt pavement. Taking the data of 12:15 on March 27 as an example, the average temperature of two kinds of pavement at the same time was 23℃, while the average temperature of stone matrix asphalt pavement at the same time was 26.4℃, the difference was 2.4℃. At this time, the temperature difference between the two kinds of pavement was less than 0.5℃, but the temperature of
the lower layer was higher than that of the top layer at night.

![Figure 7. Curve of temperature change of porous asphalt pavement on July 26th solstice 28th](image1)

![Figure 8. The curve of stone matrix asphalt pavement temperature on July 26th solstice 28th](image2)

By comparing and analyzing the temperature variation data of porous asphalt pavement and stone matrix asphalt pavement (Fig. 3 and 4), it could be seen that the temperature difference between the two pavements was large when the temperature was high. For example, at 12:30 on July 28, the temperature of the porous asphalt pavement was 34.6 ℃, while that of the stone matrix asphalt pavement was 42.4 ℃, and the temperature of the porous asphalt pavement was reduced by 7.8 ℃, and the data at 00:30 on 28 July was taken as an example. The temperature of drainage asphalt pavement and stone matrix asphalt pavement were both 21.7 ℃.

The comparison showed that the higher the temperature, the better the cooling effect of porous asphalt surface on stone matrix asphalt pavement, and the maximum could be reduced by 6~8 ℃.

4. Conclusion
(1) By comparing the high and low temperature performance and water stability of drainage asphalt mixture and stone matrix asphalt mixture, it was found that porous asphalt mixture still has good performance, although it was a macro porous structure.

(2) It was found by field noise test that the connected macro porous structure had better noise reduction performance. Compared with stone matrix asphalt pavement, it could reduce the noise of 2~6dB, and with the increase of speed, the noise reduction effect of porous asphalt pavement was more prominent than that of stone matrix asphalt pavement. By comparing the traffic noise data of sunny and rainy days, it was found that water film could increase the road noise. In this case, the noise reduction effect of porous asphalt pavement was more significant than that of stone matrix asphalt pavement.

(3) By comparing the braking distance between porous asphalt pavement and stone matrix asphalt pavement, it was found that the braking distance on porous asphalt pavement was shorter than that on
stone matrix asphalt pavement, and the average braking distance could be reduced by 4m~6m in sunny
days. Moreover, the more rainfall, the better the braking performance of the porous asphalt pavement,
the maximum could reduce the braking distance of 6m~8m.

(4) The cooling effect of drainage asphalt pavement on stone matrix asphalt pavement is better.
Moreover, the higher the external temperature, the better the cooling effect of drainage asphalt
pavement. In spring and autumn, the temperature of porous asphalt pavement could be reduced by
2~4℃ compared with stone matrix asphalt pavement, while in summer it could be reduced by 6~8℃.

(5) Considering the anti-skid performance and noise reduction performance of porous asphalt
pavement, it is recommended that porous asphalt pavement be used in highway or urban expressway
with high speed and noise.

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