Researches on low noise pavement in Japan

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The research on low noise pavement in Japan started at the end of 80's. It was about ten years later than that of European countries. This paper historically and categorically included the researches concerning low noise pavement. When considering dense asphalt pavement as control pavement, the drainage asphalt pavement and porous elastic road surface are identified as low noise pavement. The author summarized the results of all the papers and acquired the following conclusions: (1) The result of the rough estimation through all the papers concerning initial noise reduction effect and the effect degradation indicates the amount of the performance of drainage asphalt pavement might be 3-5 dB(A) and the annual degradation is about 1 dB(A)/year. (2) The summary of the paper concerning the performance recovery gave us the reasonable explanation that the cleaning machine is only available to recovering the water drain effect but not to restore the noise reduction performance. (3) Porous elastic road surface showed the great improvement in the noise reduction performance. It also lets us expect that porous elastic road surface will give the fundamental solution to the highway noise problem in urban areas of Japan.

Keywords: Low noise pavement, Drainage asphalt pavement, Porous asphalt pavement, Porous elastic road surface, Tire/pavement noise, Sound absorption, Highway traffic noise

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1. INTRODUCTION

The origin of the researches concerning low noise pavement in Japan is the introduction of drainage asphalt pavement by Tokyo in 1988. The construction scale was 500 meters long for a 7.3 meters wide highway. The pavement has a quick drainage effect and noise reduction performance.

The origin in European countries goes back to about ten years. The originally expected effect of drainage asphalt pavement is fast water-drain effect. The porous structure enables the drainage asphalt pavement to drain off water through its porosity and prevents water from running on the pavement surface. Ordinary type of pavement drains off water by using their surface inclination and water runs on the surface. Water on the surface causes water splash when vehicles' tires pass-by and splash water decreases the sight distance of drivers. The water also causes the hydroplaning. Both of the splash and the hydroplaning are very dangerous phenomena for the traffic drivers to keep their traffic safety. The noise reduction performance is said to be an additional effect of drainage asphalt pavement.

There has been the difference of enthusiasm to apply drainage asphalt pavement for practical use even in European countries. France, Australia, and Belgium are aggressive. It is very interesting that their motivation is not the traffic safety but the noise reduction performance. The first pilot construction in Japan also expected the noise reduction performance. The researches of drainage asphalt pavement of Japan and European countries have been concentrated on the noise reduction performance. These two facts indicate us that we may consider the drainage asphalt pavement as low noise pavement.

Two reasons prevent other countries from apply-
ing it. First one is insufficient noise reduction performance of about 3 dB. Second one is more serious problem that the performance had been decreasing because of the destruction of porous structure by blocking and plastic deformation. For example, one of the representative countries is the United States of America. The Federal Highway Administration mentioned that it approves of the highway noise countermeasures that noise reduction effects are more than 5 dB(A).

The negative attitude of the highway administrators in Japan to the environment problem was one of other factors that prevent us from starting research concerning low noise pavement. The fact that highway administrators would not call the drainage asphalt pavement 'low noise pavement' after the first pilot construction also proves their attitude.

The most impressive incident that have drastically changed these negative attitudes must be the highway administrators’ loss of the noise pollution case of national highway route 43 at The Supreme Court on 7 July, 1995. After the loss, the highway administrators have been aggressively employing the drainage asphalt pavement as low noise pavement. They use the term ‘low noise pavement’ more than ‘drainage asphalt pavement’.

This paper historically and categorically collected the papers concerning low noise pavement. The author appreciates this honor to be requested to write the review on low noise pavement and expect this paper would give some contribution to the future research concerning low noise pavement.

2. REVIEW CONDITION

The Authors of the papers concerning low noise pavement belong to two groups. First one is a group of highway engineers and researchers. One of the representative pavements is named drainage asphalt pavement, open graded asphalt pavement, or porous asphalt pavement. The technology to construct these pavements has almost completed before the first test construction of Japan mentioned in the previous section. The great problems mentioned in the previous section have been attracting the great interest of highway engineers and researchers. They would like to develop the performance durability and the maintenance method. The another one is a group of acoustic engineers especially having a great interest in traffic noise. A great interest they commonly have is the mechanism of noise reduction performance. In order to cover the major papers printed in the journals and academic conference proceedings in Japan, the author decided to include the journals and proceedings for the paper collection as follows:

1. The years when the papers are published are after 1988, because considering the first introduction of drainage asphalt pavement in Japan.
2. The definition of low noise pavement is a relative idea. For example, tire/pavement noise measured at asphalt pavement sections seems to be smaller than that at concrete sections. The asphalt pavement could be considered as a low noise pavement in this case. The noise at fine concrete pavement section is smaller than that of grooved/tined concrete pavement section. The smooth concrete pavement may be a low noise pavement. One of the great problems to define low noise pavement is the type of control pavement. The most common type of pavement in Japan is dense asphalt pavement and the author would like to choose it as a control pavement. When considering this definition, the drainage asphalt pavement and porous elastic road surface are selected as low noise pavement.
3. The author selected all the papers1-114 from the following journals and proceedings, considering the engineers and researchers related to the low noise pavement.
   1) Pavement published by Construction Library Inc.
   2) Journal of the Acoustical Society of Japan
   3) Journal of INCE of Japan
   4) Applied Acoustics
   5) Traffic Engineering
   6) Proceedings of Japan Road Conference
   7) Proceedings of Japan Society of Civil Engineers’ Annual Conference
   8) Proceedings of Inter-Noise
   9) Proceedings of Acoustical Society of Japan Conference
   10) Proceedings of INCE of Japan Conference
   11) Civil Engineering Journal

3. REVIEWED PAPER

The total number of the reviewed papers was 114. Almost all the papers were those on the drainage asphalt pavement. The number of the papers concerning porous elastic road surface (PERS) was very
small because it had not successfully constructed in real highway, yet. Figure 1 shows the classification of all the papers.

The four categories, initial performance, performance degradation, performance recovery and performance improvement attracts the great interest of highway engineers and researchers. The noise reduction mechanism is also an important issue for acoustic engineers and researchers. The author gave some comment and reported the reviewed result concerning the papers classified to the above categories.

3.1 Initial Performance

There are several methods to identify the performance of drainage asphalt pavement on noise reduction. One of the most popular method is the measurement of exterior noise of test vehicles peak noise levels, $L_{50}$, and $L_{eq}$. The other method is the measurement of adjacent tire noise. The original method is the measurement of car cabin noise. The pavement surface condition should be dry when we define the noise reduction levels without mentioning the surface condition.

The most important point to identify the noise reduction performance of drainage asphalt pavement is the condition of control pavement. The most popular asphalt pavement in Japan is dense asphalt pavement. If we would like to measure the initial noise reduction performance of drainage asphalt pavement, we have to choose the brand-new dense asphalt pavement as control pavement. The result of the rough estimation through all the papers concerning initial noise reduction performance indicates the amount of the effect of drainage asphalt pavement might be 3-5 dB(A). There is great difference of tire/pavement noise between old and new dense asphalt pavement because of the difference of surface roughness.

The previous research on tire pavement noise measured by close-proximity method also gave the same amount of noise reduction levels as test vehicles peak noise level, $L_{50}$, and $L_{eq}$. There are two different result concerning the car cabin noise reduction performance. Some of them agree to the existence of the performance, however the other does not. Some of them have introduced new indexes, for example, loudness, sharpness, roughness of sound in order to estimate the difference between car cabin noise of dense asphalt pavement and drainage asphalt pavement.

3.2 Performance Degradation

The author has first mentioned that performance degradation is one of the serious problems on the drainage asphalt pavement in the introduction. Doiuchi reported the noise reduction levels of the first pilot construction in Japan. He mentioned that the initial effects are 3.0-7.0 dB(A) in $L_{50}$, however the effects after 9 months usage reduced to 0.5-3.0 dB(A). This durability in the noise reduction performance seems to be too short by comparing that of drainage asphalt pavement composed of high viscosity asphalt. The reason of the discrepancy in the durability is the insufficient performance of the asphalt used for the first pilot construction. Uchida tried to reproduce the degradation of noise reduction performance and ensured the degradation by applying of test vehicle noise measurement and sound absorption coefficient. The lack of objectivity in his reproduction made it impossible to quantitatively estimate his result. Ohnishi aimed at identify the change in porosity of drainage asphalt pavement. Adding to the amount of the porosity, he traced the noise reduction performance and sound absorption coefficient. He concluded that all the indexes had been degrading as the time passage.

There is great discrepancy in the annual degradation of the noise reduction performance reported in previous papers, because of the several difference in the comparison conditions. If it is allowed to roughly summarize all the result of collected papers, it can be said that the annual degradation of the noise reduction effect is about 1 dB(A)/year.
3.3 Performance Recovery

Almost all the papers concerning development of performance recovery machines for drainage asphalt pavement considered the index of the efficiency as water permeability coefficient, excluding Meiarashi\(^\text{32}\) that used sound absorption coefficient and noise reduction levels as the index. It seems that there are two main factors on reducing the initial performance of water drain and noise reduction. One is plastic deformation of porous structure because of the plasticity of high viscosity asphalt used for the pavement. Another one is the blocking porosity by sand and soil. The principals of the machines indicate that they are available only for the blocking.

Masuyama,\(^\text{27}\) Fukui,\(^\text{28}\) and Fujita\(^\text{29}\) artificially reproduced the condition of porosity blocking by fine sand and measured the water permeability coefficient of before and after the cleaning by each machine. Masuyama,\(^\text{27}\) Hiyoshi,\(^\text{30}\) and Ishida,\(^\text{31}\) also used their machine for the actual pavement cleaning and compared the water permeability coefficient of before and after the cleaning by each machine. All of their results identified the effectiveness of their machines on recovering the coefficient.

Meiarashi,\(^\text{32}\) that adopted the noise reduction levels and sound absorption coefficient as the indices, found there were no influence of its machine cleaning on recovering these indexes. Meiarashi\(^\text{70}\) directly analyzed the porous structure of drainage asphalt pavement and concluded half of the effective porosity was lost within half a year after its opening to traffic because of the elastic deformation of the porous structure. The porosity ratio of usual drainage asphalt pavement is about 20 %. His result indicated that the porosity ratio of the pavement soon became 15 % because of elastic deformation. After this degradation, the deformation seemed to stop and the blocking decreased 1 % of porosity by every one year. Meiarashi\(^\text{70,74}\) have also mentioned more than 20 % of porosity ratio would be required for expecting the sufficient amount of noise reduction performance of passenger cars and trucks. These results enables us to understand the reason why the cleaning machine is only available to recovering the water drain effect but not to restore the noise reduction performance.

3.4 Noise Reduction Mechanism

One of the most important factors of drainage asphalt pavement on noise reduction is sound absorption effect.\(^\text{34–59}\) Almost all of the papers concerning the noise reduction mechanism of drainage asphalt pavement have mentioned the sound absorption coefficient of the pavement. Because of the easiness of measurement, many researchers measured the normal incidence sound absorption coefficient by using tube method. There are two methods of measuring the coefficient. One is standing wave pattern measurement method indicated in JIS A 1405. The other way is so called 'two microphone method,' which has not been described in any standards like JIS or ISO. Comparing the accuracy of measured data, the latter way is better than the former way. Meiarashi\(^\text{70}\) indicated the reverberation sound absorption coefficient and oblique incidence absorption coefficient. Some papers\(^\text{56–59}\) have also devised the new on-site method for measuring sound absorption coefficient because of the request for detecting the most suitable period for highway cleaning.

The another seems to be the reduction of tire/pavement noise, for example tread-air-pumping noise. Some researchers\(^\text{15–67}\) conducted the measurement of tire/pavement noise by close-proximity method and detected the noise reduction of the tire/pavement noise. Iwai\(^\text{67}\) took a very unique experimental method to prove the horn effect of drainage asphalt pavement is one of the noise reduction mechanism of tire/pavement noise.

Shima\(^\text{68,72}\) and Meiarashi\(^\text{69–71,73,74}\) have been approaching for identifying the noise reduction mechanism of drainage asphalt pavement in the integrated manners. Shima\(^\text{68}\) first measured the power-by noise and the coast-by noise of test vehicles. Meiarashi\(^\text{69–71}\) formulated the simple sound propagation model to explain the part of the noise reduction performance caused by the sound absorption effect of drainage asphalt pavement. Shima\(^\text{69–71}\) and Meiarashi\(^\text{73}\) also set up a qualitative hypothesis concerning the total noise reduction. Meiarashi\(^\text{74}\) has finally proved his hypothesis with conducting the sophisticated field test. According to the hypothesis, the noise reduction performance of drainage asphalt pavement is brought both by the reduction of tire/pavement noise and the sound absorption effect. The results proved the hypothesis. It also showed that the contribution of the sound absorp-
tion effect was relatively larger than that of tire/pavement noise reduction. Suzuki\(^75\) indirectly gave the proof to Meiarashi’s diffusion model\(^74\) that explained the noise reduction levels caused by the sound absorption effect of the drainage asphalt pavement. The hypothesis requires both of the improvement in sound absorption effect and the reduction of tire/pavement noise at the same time for additional total noise reduction of drainage asphalt pavement.

3.5 Performance Improvement

There are two purposes to develop the noise reduction performance of drainage asphalt pavement. First one is to increase the continuous porosity and improve the durability of noise reduction performance.\(^76,77\) The another one is to increase the initial noise reduction performance.\(^78-99\) The development of higher viscosity asphalt binder for drainage asphalt pavement is one of the most effective efforts, however, the viscosity of the present one is unfortunately very close to the limit for the construction and there is no room for improvement.

Tokumasu\(^76\) and Hokari\(^77\) proposed to use the uniform size and shapes of coarse aggregate for the drainage asphalt pavement because it increase the continuous porosity more than the usual coarse aggregate. These efforts have no relation to the increase of the initial noise reduction performance.

Meiarashi\(^78\) tried to increase the initial performance through using the smaller size of uniform aggregate with reflecting his hypothesis mentioned in the previous section. The usual drainage asphalt pavement uses 13–5 mm coarse aggregate. He proposed to use 10–5 mm coarse aggregate. He formulated that this devise reduced the generation of tire/pavement noise and had no effect on the sound absorption. As the result, total noise reduction of test vehicles changed from 3–5 dB(A) to 5–8 dB(A). There is some pilot construction example to use more fine aggregate, which size is 5–2.5 mm. It does not seem to be practical because the pavement has less water drainage effect and more plastic deformation of surface figure than the usual one. Ichihara\(^81\) took the same kind of method as Meiarashi\(^87\). Two layer types of drainage asphalt pavement\(^82,83\) composed of different size of aggregate layer is one of the application of the improved drainage asphalt pavement mentioned in the previous section. The aggregate size standards are prescribed in Japanese Industrial Standards (JIS). The size range of the aggregate is too wide for the drainage asphalt pavement to keep the continuous porosity structure. In order to increase the use efficiency of aggregate, it is one of the ingenious methods.

Porous elastic road surface (PERS) is an epoch-making device of low noise pavement first proposed by Nilsson. That was first introduced by Meiara\(shi\(^87\) in Japan. The noise reduction performance of PERS is much higher than that of drainage asphalt pavement. If we consider the drainage asphalt pavement as low noise pavement, we should call PERS a silent pavement. Unfortunately it has not been in practical use in Japan because of other reason, for example, relatively low skid resistance and the construction method. Tachibana\(^92\) mentioned that PERS had already developed in Sweden with referring to the same paper referred by Meiarashi\(^87\). The author is afraid that he misunderstands the state of arts on PERS and would like to emphasize that PERS has never successfully applied to the practical highway. Of course, they took great efforts to use PERS for actual highway in Sweden but all had ended in failure.

According to recent results by Ohnishi\(^95\) the noise reduction level of PERS is about 15–20 dB(A) for a passenger car and about 5–10 dB(A) for trucks. This result lets us expect that PERS will become the fundamental solution of the highway noise problem in urban areas of Japan.

4. CONCLUSION

The research on the drainage asphalt pavement in Japan started at the end of 80’s. It was about ten years later than that in European countries. The state of arts of Japan in this area has already reached to that of European countries.

The result of the rough estimation through all the papers concerning initial noise reduction performance indicates the amount of the effect of drainage asphalt pavement might be 3–5 dB(A).

If it is allowed to roughly summarize all the result of collected papers, it can be said that the annual degradation of the noise reduction effect is about 1 dB(A)/year.

The major theme of the research in Japan changes from the initial performance, noise reduction mechanism, and the degradation of the performance to the performance improvement and the development of
performance recovery method.

The summary of the paper concerning the performance recovery gave us the reasonable explanation that the cleaning machine is only available to recovering the water drain effect but not to restore the noise reduction performance.

Porous elastic road surface showed the great improvement in the noise reduction performance. It also lets us expect that Porous elastic road surface will become the fundamental solution of the highway noise problem in urban areas of Japan.

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