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AIR RESONANCE NOISE REDUCTION OF POROUS PAVEMENT

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ABSTRACT
The porous asphalt pavement has been used as countermeasures for traffic noise reduction. In this paper tire/road noise generating mechanism on the porous pavement, especially pipe resonance on the porous pavement is discussed. At first the calculation method, acoustic FEM that has a porous pavement model, has been investigated. Then relationship between porous pavement design and the pipe resonance reduction has been examined by using acoustic FEM.

1 - INTRODUCTION
Initially porous pavement (Porous Asphalt Pavement) was introduced for traffic safety by draining water on the pavement through its pores. Its porous structure was also found to have air permeability, sound absorption effect and noise reduction effect [1]. The noise reduction effect is explained by the two mechanisms, i.e. (1) tire/road noise is reduced at the noise source by the reduction of air resonance noise (pipe resonance and air pumping noise) and (2) All the noise from vehicle is reduced during propagating over the porous pavement. In this paper tire/road noise generating mechanism especially pipe resonance is discussed. A relationship between porous pavement design and the pipe resonance reduction is investigated by using acoustic FEM for the porous pavement.

2 - ACOUSTIC FEM – HOW TO HANDLE THE POROUS PAVEMENT
Three parameters are introduced to formularize the FEM model of the porous pavement by taking into account the structural feature of porous pavement [2]. (1) The effective porosity V_e defined as the proportion of the voids where sound is able to propagate. Some of the voids are considered to contribute sound propagation. (2) Sound velocity in the porous pavement C_a(m/s) expresses the structural complication. (3) Sound propagating in the porous pavement is attenuated uniformly. Attenuation factor R (Pa s/m^2) is defined as sound pressure attenuation during unit distance. As mentioned above, steady state sound pressure in the porous pavement is expressed as eq. 1.

$$\nabla^2 P = \left(j\frac{\omega R}{\rho C_a^2} - \frac{\omega^2}{C_a^2} \right) P \tag{1}$$

where P: sound pressure in the porous pavement, ρ: density of the air.
Considering appropriate boundary conditions, eq. 2 is obtained by discretization (eq.1) using Galerkin Method [3].

$$\left([K] - \omega^2 [M] + j\omega \frac{R}{\rho} [M] \right) P = -\left(j\rho\omega + R \right) [F] \tag{2}$$

where

$$K_{ij} = \int\int\int \left(\frac{\partial N_i}{\partial x}\frac{\partial N_j}{\partial x} + \frac{\partial N_i}{\partial y}\frac{\partial N_j}{\partial y} + \frac{\partial N_i}{\partial z}\frac{\partial N_j}{\partial z} \right) dxdydz$$

$$M_{ij} = \frac{1}{C_a^2} \int\int\int N_i N_j dxdydz \qquad C_{ij} = \int\int_{s3} A_n N_i N_j dS \qquad F_i = \int\int_{s2} \bar{V_n} N_i dS$$

N: shape function, A_n: admittance on the boundary S_3, $\bar{V_n}$: velocity of the boundary S_2.
To consider that some of the voids contribute sound propagation, the range of integration must be limited. When calculating $[K]$ and $[M]$ matrices triple integration is calculated numerically by Gauss' method like eq. 3. The effective porosity V_e is multiplied to limit the integration range.

$$I_3 = V_e \sum_{i=1}^{n} \sum_{j=1}^{n} \sum_{k=1}^{n} H_i H_j H_k f\left(\varepsilon_i, \xi_j, \eta_k\right) \tag{4}$$

where I_3: triple integration, H: weight.

3 - VERIFICATION OF THE CALCULATING METHOD

Fig. 1 shows normal incident absorption coefficient that is calculated by FEM and measured. Test pieces are porous asphalt pavement that is 100mm diameter and 30mm thick. Calculated and measured data seems to be good fitting.

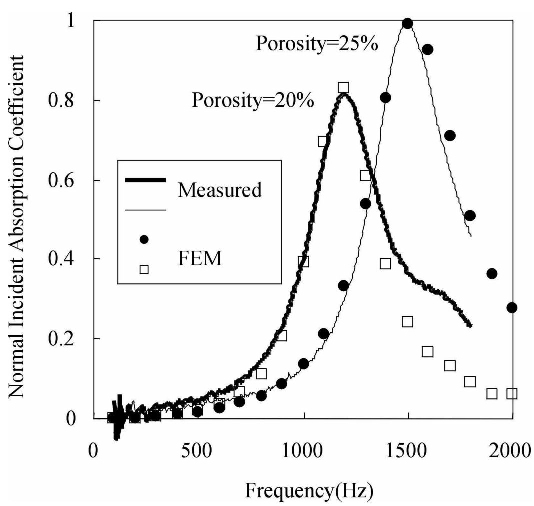

Figure 1: Absorption coefficient.

Fig. 2 shows the test specimen to measure pipe resonance strength. A reflecting surface and porous asphalt pavements (porosity = 23%, aggregate size = 5 to 13mm, size = 300*300*50mm) are examined.

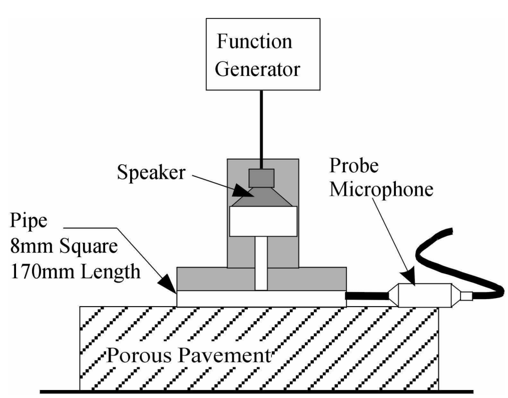

Figure 2: Test specimen for pipe resonance.

Fig. 3 shows the sound pressure level at the outlet of pipe that is calculated by FEM and measured. On the reflecting surface pipe resonance seems to be at 1kHz, on the porous pavement pipe resonance

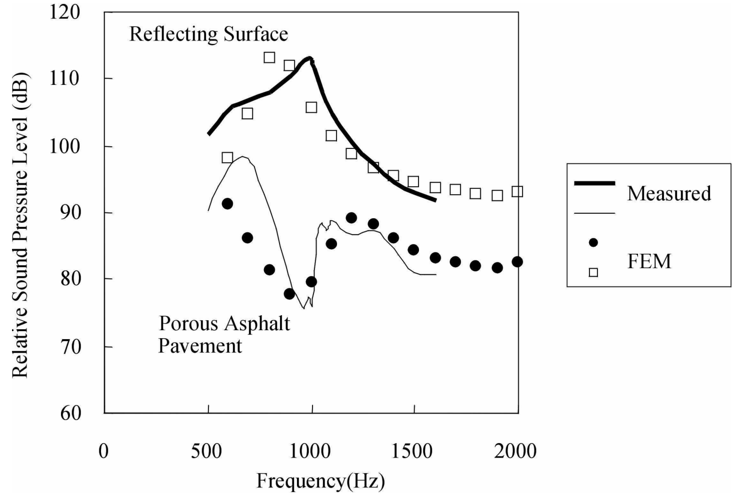

Figure 3: Sound pressure level at the outlet of the pipe.

disappears and both measured and calculated SPL seem to be good fitting. Above mentioned, the calculation method employed is applicable to calculation of acoustic problems of the porous pavement.

4 - PIPE RESONANCE STRENGTH ON POROUS PAVEMENT

Pipe resonance on various porous asphalt pavements (porosity is 14,17,20,23 and 25 %, aggregate size is 5 to 13mm that is most popular size used for porous asphalt pavement in Japan) examined by FEM. Fig. 4 shows the pipe resonance strength that is defined as sound pressure difference between the reflecting surface and the porous pavement at resonance frequency (1kHz). Fig. 4 shows that the pipe resonance decreases as the porosity and thickness increase when porosity is above 20%. Pipe resonance strength is almost same level at low porosity (14 and 17 %) and thickness is above 30mm.

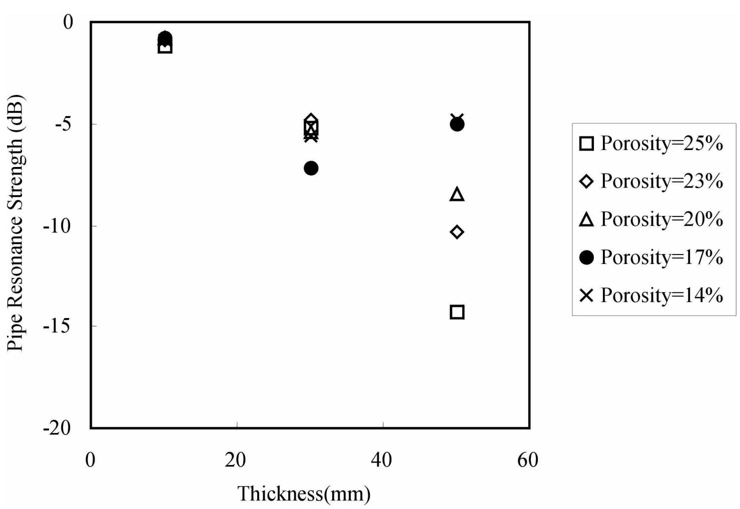

Figure 4: Pipe resonance strength (calculated by FEM).

5 - CONCLUSIONS

To evaluate pipe resonance strength the acoustic FEM model has been formularized taking into account the structural feature of porous pavement. Verification of calculating method has been investigated and it has been found this method is applicable to calculation of acoustic problems of the porous pavement. Pipe resonance strength on the porous pavement has been investigated by using this method and found to be affected by porosity and thickness of porous pavement.

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