inter•noise 96
25th Anniversary Congress – Liverpool

INCE: 31.1

THE PREDICTION OF COMBINED EFFECT OF ROAD NOISE BARRIER AND POROUS ROAD SURFACE BY B E M

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1. OBJECTIVES

The prediction of road traffic noise reducing devices has been extensively studied and the advantages of available methods (empirical, geometrical and numerical) are well known. But the prediction of the efficiency of road barriers still remains problematic as barriers are designed in more sophisticated shapes, with various materials of different acoustical properties. In parallel, the development of porous road surfaces is indirectly an interesting contribution to road traffic noise control because they bring sound absorption and reduce the emission of rolling noise. Because noise barriers performances are limited, such roadsurfaces are sometimes prescribed in conjunction, expecting that it will significantly reduce noise emission and propagation. However, this is still an empirical technique and there is a lack for a prediction of combined effect. Thus, the aim of this study is to develop a global model for individual or combined efficiency of these road noise reducing techniques, integrating all main parameters, i.e. geometry and acoustical properties of barriers, grounds and road surfaces. A 2-D Boundary Element Method (BEM) was developed in which diffraction effects and boundary conditions effects were validated, including local reaction and extended reaction type best adapted to porous road surfaces.

2. BRIEF DESCRIPTION OF BEM METHOD

Integral Formulation and Numerical Resolution

Boundary Element Method was found to be the most powerfull method to solve the 2-D problem, as any geometry or acoustical properties of both the barrier and the site can be easily integrated. The method used is a direct BEM. The sound pressure satisfies, without considering the conditions on the boundary S, the integral formulation :

$$\varepsilon(M)p(M) + \int_S \left(\frac{\partial G(M,M_s)}{\partial n_s} p(M_s) - G(M,M_s) \frac{\partial p(M_s)}{\partial n_s} \right) dS(M_s) = p_{inc}(M) \qquad \textbf{(1)}$$

where p_{inc} is the incident sound wave in free field, G the free field Green function, $\varepsilon(M)$ is set to 1 for $M \in V$ the air space and depends on the solid angle for $M \in S$ (1/2 for smooth points).

Using traditional techniques of discretization, interpolation and regularisation (see [1] for instance), the boundary integral equation set for $M \in S$ is solved numerically and when all the boundary elements are considered, the problem reduces to a system of linear equations :

$$[H]\{p\} - [G]\{q\} = \{p_{inc}\} \qquad \textbf{(2)}$$

The vectors of nodal pressure {p} and pressure gradient $\{q\}=\{\frac{\partial p}{\partial n}\}$ on the boundary are determined by addition of the boundary conditions. Subsequently, the application of the integral formulation (1) gives the sound pressure at any point M in the air medium V.

Boundary Conditions

For purely reflecting surfaces, the boundary condition {q} = {0} leads to an expression of the boundary equation only dependent on the pressure :

$$[H]\{p\} = \{p_{inc}\}$$

For locally absorbent boundaries, the boundary condition states that :

$\{q\} + \alpha \{p\} = \{0\}$ where $\alpha = - i\, k_0\, Z_0/Z_S$ is a constant over the boundary.

It is possible to follow the same steps of resolution as for perfectly reflecting case, by using an adequate change in coordinates. The system **(2)** becomes :

$$[H']\{p'\} - [G']\{q'\} = \{p_{inc}\}$$

$$\text{where } \{q'\} = \{0\}$$

$[H'] = [H] - \alpha [G]$

$[G'] = - [H] + \alpha [G]$

Assessment

Many comparisons of the model have been made with results from the literature. The simulations have been compared with analytical results for academic cases (thin reflecting screen) and with other numerical results for more complicated shapes. Very good agreement was found.

3. AIR / POROUS MEDIUM INTERACTION

Description of the Propagation Inside the Porous Medium

As our purpose is to study the effect of porous road surface such as drainage asphalt, different available models were considered. The phenomenological model was selected, in which the porous medium is regarded as an homogeneous compressive and dissipative fluid. In this model developed in ref. [2], the propagation in the medium is described by the complex wave number and characteristic impedance :

$$k_p = k_o \sqrt{K\gamma}\left(1 + i\frac{f_\mu}{f}\right)^{1/2}\left(1 - \frac{1 - 1/\gamma}{1 + i\, f_\theta/f}\right)^{1/2}$$

$$Z_p = Z_o \sqrt{\frac{K}{\gamma}}\,\frac{1}{\Omega}\left(1 + i\frac{f_\mu}{f}\right)^{1/2}\left(1 - \frac{1 - 1/\gamma}{1 + i\, f_\theta/f}\right)^{-1/2}$$

where f_μ and f_θ are frequencies defined by :

$$f_\theta = \frac{R_s}{2\pi\rho_o N_{pr}} \qquad \text{and} \qquad f_\mu = \frac{R_s\,\Omega}{2\pi\rho_o K}$$

Ω, R_s, K are respectively the porosity, air flow resistivity, and shape factor of the porous medium, γ=1.4 the specific heat ratio, N_{pr} the Prandtl Number. All the subscripts "0" refer to the air medium, and "p" refer to the porous medium (a "$e^{-j\omega t}$" time variation has been assumed).

The Problematic of Non-Local Type Reaction at the Interface with B.E.M.

Absorption effects on porous surfaces like drainage asphalts road surfaces, can not be taken into account by a local reaction model. In this case, the acoustic attenuation is not only due to surface reaction but the layer with all its thickness do participate to the absorption. This effect of extended reaction is commonly described by an equivalent surface impedance, derived from geometrical theory by analogy with refraction theory in optics :

$$Z_{eq} = \frac{Z_p}{\cos\theta_r}\coth(-i\, k_p\, d\cos\theta_r)$$

where d is the thickness of the layer and θ_r the refraction angle in the porous medium. θ_r is linked to the incident angle (θ_i) according to Snell-Decartes equation :

$$\cos\theta_r = \sqrt{1 - \left(\frac{k_o}{k_p}\right)^2 \cos^2\theta_i}$$

But the concept of angle is not appropriate in a BEM model, especially if several sources have to be considered, and an alternative had to be found for extended type of boundary reaction.

Resolution of 2 Coupled Integral Equations

To introduce the precise interaction air/porous medium, the option was taken to formulate the problem in terms of 2 coupled integral equations, the first one is expressed in the air, the second one is deriving from the propagation problem in the porous medium. Let us consider the problem of an plane interface S separating the space into 2 media : air and porous :

- for M in the air : see equation (1)
- for M_i in the porous medium : the following boundary integral is satisfied, where n_s is the normal unit vector outside the air medium :

$$\varepsilon_p(M_i)p_p(M_i) + \int_S \left(\frac{\partial G_p(M_i,M_s)}{\partial n_s} p_p(M_s) - G_p(M_i,M_s)q_p(M_s)\right) dS(M_s) = 0 \qquad (3)$$

The coupling between the two media results from the condition of continuity fo pressure and particule velocity at the interface :

$$p_p = p \quad \text{and} \quad q_p = \frac{k_p Z_p}{k_0 Z_0} q = -\alpha\, q \qquad (4)$$

From equations (1), (3), and (4) a complete coupled system is derived :

$$[H]\{p\} - [G]\{q\} = \{p_{inc}\}$$
$$[H_p]\{p\} - [G_p]\{q\} = \{0\} \qquad (5)$$

An experimental validation was performed of sound propagation above a porous asphalt road section. The physical parameters of the porous medium were evaluated from absorption measurements : R_s = 2 10^4 MKS Rayls/m, Ω=0.15, K=4, e=0.038 m and the sound attenuation was measured, simulated with BEM and simulated with an analytical method [3]. The results presented on Fig.1. show good agreement for a source placed at 0.3 m above the road, and a receiver 4 m distant from the source at the same height.

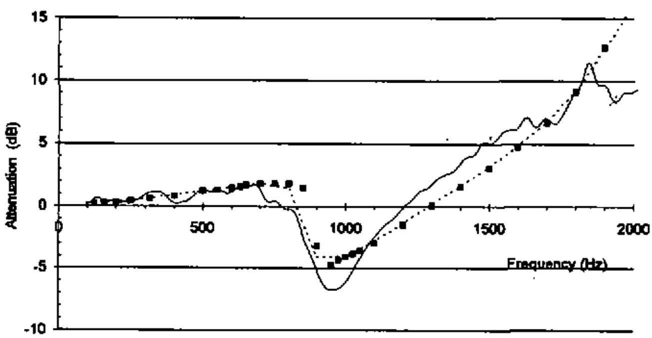

Fig. 1. : Sound attenuation above a porous asphalt ; experiment (—), BEM model (■), analytical model (- - -)

4. COMBINED EFFECT OF BARRIER AND POROUS ASPHALT

The BEM model (the software developed is called CESAR-LCPC) is now ready for the simulation of interaction problems. On Fig.2. the result of simulation is represented for a flat reflecting screen erected on grass with a porous asphalt road on the source side. The insertion loss obtained with

BEM is compared with analytical solution adapted from Koers model [4]. Very good agreement is found.

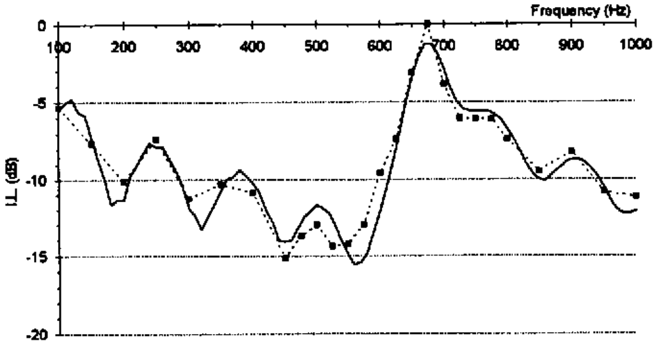

***Fig. 2.** : Insertion Loss of a flat reflecting screen on grass with porous asphalt road on the source side ; BEM (- ■ -) ; Analytical (—)*

The advantage of the BEM model is then to investigate more complicated shapes of barriers. An example is shown of a 3 m high flat reflecting barrier, installed either near a traditional reflecting road surface or near a porous road surface. A tilted absorbent element is then added on the top of the barrier (Fig. 3.), and both configurations of road surfaces are tested.

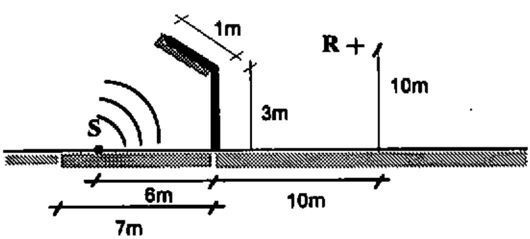

Fig. 3. Configuration of the complete barrier considered

The results of insertion loss are presented on Fig. 4. For the configuration under study, the addition of the top absorbent element increases the total height of the barrier, and in consequence, the receiver passes from the nearly illuminated zone to the shadow zone. The effect of the porous surface is mainly significant for frequencies above 1 kHz. This effect is more sensitive for the simple flat reflecting barrier than for the barrier with the top absorbing element, where the insulation of the barrier predominates.

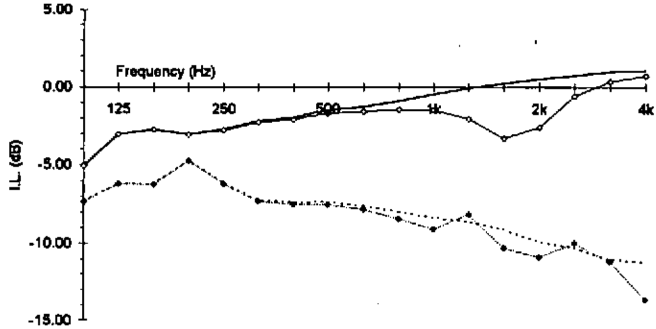

Fig. 4. : Prediction of Insertion Loss of a barrier with traditional road surface : simple barrier (—), barrier+absorbent element on top (-◊-) ; with porous road surface : simple barrier (- -), barrier+element (- ♦ -).

It has to be noted that the results of insertion loss only account for sound absorption of porous road surface. But this type of road surface also reduces the rolling noise emitted by vehicles. This reduction in noise emission should be added to get the effective effect of changing the road surface into a porous one.

5. CONCLUSION

A BEM model was developed and validated for the prediction of the effect of road noise reducing devices. The advantage of the method is to permit various shape of barriers to be studied in vue of their optimization. As it is also possible to integrate specific boundary conditions such as porous road surfaces, the optimization can be performed in terms of combination of noise control techniques.

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