Calculations with BEM in a refracting atmosphere

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Introduction

Being able to predict outdoor sound propagation is important in order to design road and railway infrastructures to improve the acoustic environment. One of the main problems with outdoor sound propagation is related to the meteorological conditions. In numerical acoustics, the Boundary Element Method (BEM) is a powerful tool, widely used but in its classical form only for quiescent media. In this article, a method is presented to deal with meteorological effects in BEM calculations. Firstly, the theory is detailed, secondly numerical validations are presented and finally numerical results are compared to experimental data.

Theoretical formulation

To handle with outdoor sound propagation over irregular terrain, conformal mapping can be used [1]: propagation over a concave/convex surface becomes equivalent to downward/upward refraction. Thus, propagation for linear effective sound speed profile above a flat surface is transformed into propagation with a constant sound speed profile above a cylindrical surface [2]. As a result, meteorological effects can be taken into account in BEM calculations.

Studied configuration

The studied 2D geometrical configuration is described Figure 1: the source is located at (0, 0.5m) and the receiver at (82m, 1.5m). The ground under the source is rigid and the surface under the receiver is absorbent. The impedance of the absorbent part is described by the Delany and Bazley model [3] with a flow resistivity σ=180 000 MKS and an infinite thickness. There is an impedance discontinuity located at (7m, 0). A 3 meters rigid barrier is fixed at (7m, 0). Two sound speed profiles have been studied:

- Downward refracting profile: $c(z) = c_0(1 + 0.0049z)$
- Upward refracting profile: $c(z) = c_0(1 - 0.0049z)$

The choice of these sound speed profiles corresponds to a wind speed of $v_{10} = 16{,}7\ m.s^{-1}$ at ten meters high which does not correspond to a realistic sound speed profile but has been chosen to clearly point out the refraction effects.

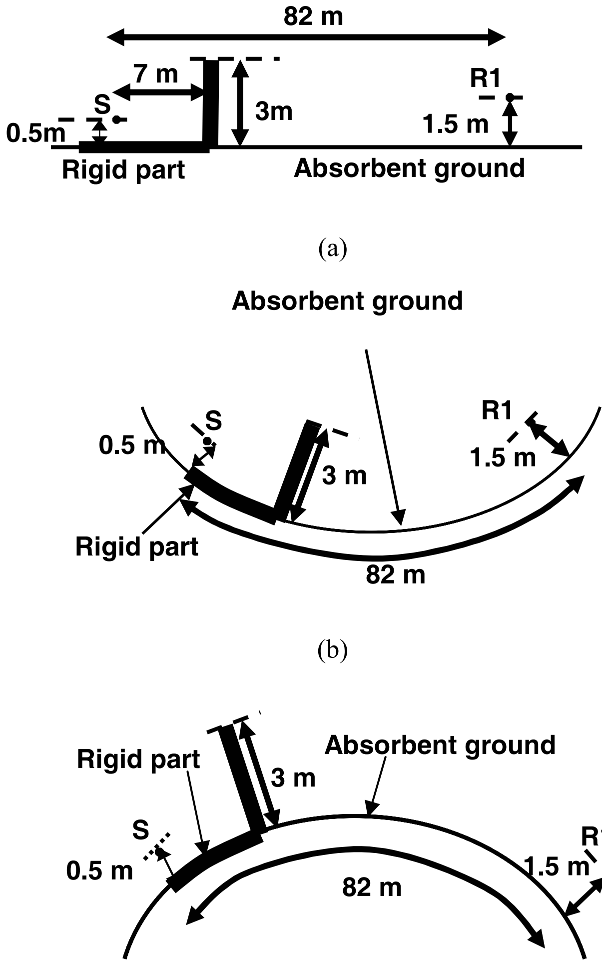
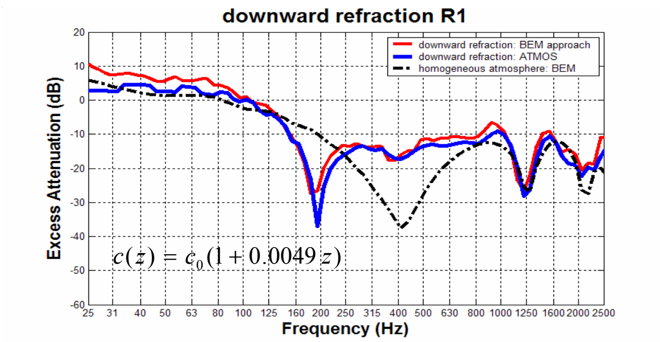


Figure 1: The 2D geometrical configuration.
S (0, 0.5m); R(82m, 1.5m); 3 meter rigid barrier
absorbent : σ = 180 000 MKS, infinite thickness

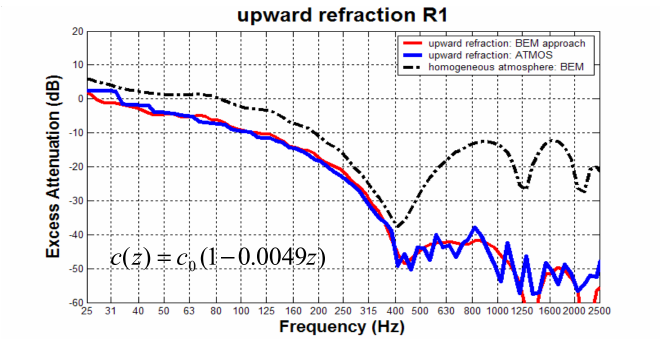
(a): homogeneous atmosphere
(b): downward refraction, $c(z) = c_0(1 + 0.0049z)$
(c): upward refraction $c(z) = c_0(1 - 0.0049z)$

Numerical validations

In this section, BEM calculations [4] are compared to Atmos numerical simulations [5, 6]. Atmos is a code based on the parabolic equation method in which sound can propagate with various effective sound speed profiles. In Figure 2 (a), BEM results obtained for the geometrical configuration described in Figure 1 (b) are compared with Atmos calculations for the upward refracting profile. In Figure 2 (b), BEM results obtained for the geometrical configuration described in Figure 1 (c) are compared to Atmos calculations for the downward refraction. Comparisons with homogeneous atmosphere results enhance the importance of meteorological effects.



(a)



(b)

Figure 2: Comparisons between BEM and Atmos calculations

Sound pressure levels relative to free field obtained for the configuration detailed in Figure1

S (0, 0.5m); R(82m, 1.5m; 3 meter rigid barrier

absorbent :σ= 180 000 MKS, infinite thickness

(a), downward refraction : concave surface

(b), upward refraction : convex surface

: BEM calculations in a refracting atmosphere

: GFPE calculations in a refracting atmosphere

: BEM calculations in homogeneous atmosphere

The agreement between BEM and Atmos results is very good. In the following section devoted to scale experiments, BEM results and experimental data are compared.

Scale experiments

A series of model experiments has been conducted at a scale of 1:20 above curved surfaces (which radius of curvature is Rc=10.2m). The sound pressure levels relative to the free field have been measured in narrow bands in the frequency range [1000, 20000Hz], corresponding at full scale to [50, 1000 Hz], with a sine sweep method. In Figure 3, BEM results are compared to scale experiments measurements. The interference pattern is well described by experimental and numerical results.

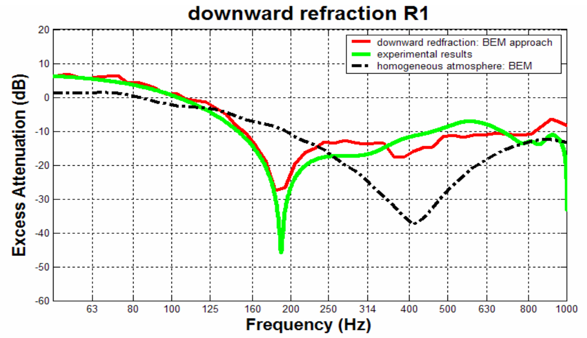


Figure 3 Sound pressure levels relative to free field obtained with the BEM approach and compared with experiments

S (0, 0.5m); R(82m, 1.5m), 3 meter rigid barrier

absorbent : σ = 180 000 MKS, infinite thickness

downward refraction : concave surface

: BEM calculations in a refracting atmosphere

: experimental measurements

: BEM calculations in a homogeneous atmosphere

Conclusion

The BEM approach using the above mentioned analogy accounting for refraction effects gives very good results when compared to other numerical simulations and to experimental data. A work is in progress to use the same approach for more complex topographies.

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