USING FINITE ELEMENTS TO MODEL POROUS MATERIALS IN BUILDINGS

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Abstract
Several situations have shown the need of considering finite sizes when modeling porous materials in building applications. Prior to this study, matrix transfer models with windowing techniques or equivalent fluids in BEM approaches have been employed at CSTB. In order to widen the range of application of the existing tools, the well known (U,P) FEM formalism (Atalla & all) has been programmed and validated against the NOVAfem software. The first application concerns the modeling of absorbent material placed in openings or air-inlets. When grazing incidence occurs in small volumes it seems necessary to correctly model the porous medium. A second example concerns a flocking system sprayed on the underside of a concrete floor slab for which contact can be only partial. In this situation the use of a transfer matrix approach is not sufficient and the FEM model can deal with this problem in the low and mid frequency ranges.

Keywords: Porous materials, Finite Elements, flocking, air-inlet.

1 Introduction
The modeling of poro-elastic media has, in recent years, strongly progressed both by means of semi-analytic models and FEM-based approaches. Although applications for transport noise have been at the origin of many numerical developments, one should not forget that such materials are also well employed in buildings. In many building situations, the use of ‘approximate’ approaches, such as the transfer matrix method gives very precise results [6]. Such techniques usually assume simple flat shapes made of the piling of uniform materials of infinite extend; size effects are taken into account partially with a windowing technique which acts as a wave filter on both the excitation and the radiation. Modal behavior due to finite size is therefore not included but is often found to be negligible. Last but not least, such approaches are found to be relatively fast.
However, there are building problems which require finer models. The problem of partial contact between two layers or 3D situations such as treated air inlets will need other approaches. Past work at CSTB has made use of the matrix transfer approach [6] or even of BEM [4]. In 2009, a FEM model based on published formalisms as been developed and this paper presents first applications to the above mentioned problems.

2 The FEM Model

The FEM formalism proposed en [1,2,3] has been employed. N. Atalla and others have proposed two (U,P) models for poro-acoustic media were the displacement U describes the solid phase and the pressure P describes the fluid phase. Standard 3D finite elements have been programmed for porous and acoustic media (8 and 20 nodes hexahedric elements) or eventually for thick structures. In addition, 3 or four-nodes shell elements have been implemented for plate-like structures where the thickness need not be discretized. An integrated simple mesh generator is included and is based on a 3D original grid where cells can be attributed to different materials or taken out as illustrated in Figure 6. Baffled components can be handled with a BEM approach as described in [3]. We should point out that both formalisms proposed in [1] and [2] have been implemented; one major difference is that in the first formalism there is no coupling term between porous and acoustic media and conversely in the second formalism there are no coupling terms between solid and porous media. Both formalisms are equivalent and give identical results. The computer code named PANAM (Poro-Acoustic Numerical Assessment Model) has been validated against the NOVAfem code developed at GAUS, Sherbrooke.

3 Application1: Air inlets

The modeling of air inlet has first been carried out with a multi-domain BEM model where the porous media are modeled as equivalent fluids. It has been judged necessary to assess the important of solid phase vibrations neglected when using equivalent fluids.

![Figure 1 – A rectangular air inlet set in a thick wall](image-url)
3.1 Large opening

We first consider the case of a large 200 x 150 mm² rectangular and rigid opening set in a 330 mm thick wall. The Dn,e index is computed; it is defined as

\[ Dn,e = -10 \log(\tau \cdot S / A_{ref}) \]

where S is the area of the inlet, \( A_{ref} = 10 \) m² and \( \tau = W_{ray}/W_{inc} \) ratio of radiated to incident acoustic power. The diffuse exciting field is obtained as a sum of decorrelated incident plane waves. Figure 2 compares the measured and computed Dn,e, both with the BEM and FEM. This first test confirms that both models give very similar results also very close to the measurements [7].

![Figure 2 – Comparison of Dn,e for a rectangular rigid opening.](image)

Next, a slightly larger opening (260x210 mm²) is considered. The four sides of the cavity are covered with 15 mm of a porous material (PM) which consists of either foam (FO) or fiber glass (FG) (the inner cavity is therefore 230x180 mm²).

<table>
<thead>
<tr>
<th>Material</th>
<th>E</th>
<th>( \eta )</th>
<th>( \rho )</th>
<th>( \nu )</th>
<th>( \sigma )</th>
<th>( \phi )</th>
<th>( \alpha_{\infty} )</th>
<th>( \Lambda )</th>
<th>( \Lambda' )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foam</td>
<td>800 k</td>
<td>0.256</td>
<td>30</td>
<td>0.4</td>
<td>24 k</td>
<td>0.90</td>
<td>7.8</td>
<td>226 ( \mu )</td>
<td>226 ( \mu )</td>
</tr>
<tr>
<td>Fiber Glass</td>
<td>14 k</td>
<td>0.05</td>
<td>30</td>
<td>0</td>
<td>15 k</td>
<td>0.95</td>
<td>1.4</td>
<td>93.2 ( \mu )</td>
<td>93.2 ( \mu )</td>
</tr>
</tbody>
</table>

Where \((E, \eta, \rho, \nu)\) are data for the solid phase (Young’s modulus, losses, density, Poisson ratio) and \((\sigma, \phi, \alpha_{\infty}, \Lambda, \Lambda')\) are data for the fluid phase (resistivity, porosity, tortuosity, viscous and thermal lengths).
Figure 3 reports for each material a comparison of Dne spectra obtained with 4 different computations:

A) the BEM approach for the inner cavity with impedance conditions (Z obtained from the 1D simulation of the impedance tube using the full FEM description of the PM,

B) FEM computations where the PM is replaced by an equivalent fluid based on the Delany & Bazley model (D&B)

C) as in B where the equivalent fluid is obtained from [5]

D) full FEM modeling for the PM.

First, one sees that the impedance approach starts to deviate from other computations above 1600 Hz.

For Fiberglass, models C and D give very close results. This corresponds to the well known fact that equivalent approaches are usually sufficient for PM with rigid soft phases. Also, model B with the simple D&B model gives quite acceptable results. However, in the case of the foam (50 times more rigid), the four computations show differences above 1600 Hz. The C approach may differ from the full model by more than 5 dB. Consequently one already observes the importance of fully modeling the porous materials.

![Figure 3 – Different models for porous media. Left) Foam Right) Fiber Glass](image)

### 3.2 Air-inlet

Small standard 172x12 mm² air inlets are now considered. The depth of the cavity is 60 mm. Comparing both the BEM and FEM models with measurements for rigid cavities (Figure 4) shows a good agreement [4].
Although, not measured the FEM model has been used to try to improve the Dne by adding a 10 mm layer of porous material (PM). The overall cavity is therefore enlarged so that the inner dimensions remain 172x12 mm². One notices that the minimum at 2000 Hz which corresponds to the resonance of the first longitudinal mode is shifted to 1250 Hz. Consequently, below 2000 Hz, the sound isolation is reduced; it is increased at higher frequencies. For both materials the A approach with an impedance condition gives unreliable results above 2000 Hz. Again, an equivalent fluid approach can be sufficient for the fiber glass (even using a simplified D&B model) whereas in the case of Foam the full FEM model appears to be necessary.

In order to reduce the transmission of noise, a more complex zigzag shape is tested within the same wall. The openings on both sides still have internal dimensions of 172x12 mm². Figure 6 shows a vertical cut and an example of meshing.
Figure 6. Air inlet with a zigzag shape. Left) Vertical cut Right) Mesh example (yellow for air)

Figure 7 shows a comparison of Dne spectra computed both for straight and zigzag inlet profiles, either rigid or treated with 10 mm of both porous materials. Changing the shape is more beneficial for the treated inlet, above 1250 Hz.

4 Application 2: sprayed flocking system with partial contact

We consider the case presented in [6] which consists of a 160 mm concrete slab with sprayed flocking on the underside. In order to improve the performance of the system, by avoiding contact between slab and flocking, a metallic lattice is inserted in-between. Measurements reported in [6], have shown that full uncoupling could not be achieved and that the performance of the system lies somewhere between full and no contact simulations. Figure 8 shows a comparison of sound reduction index spectra computed with CASC (transfer matrix approach) and PANAM (FEM), both for 0% and 100% contact cases. Good agreement can be observed between both models, CASC being much faster than FEM.
Figure 8. Comparison between CASC (transfer matrix) and PANAM (FEM)

As FEM allows the modeling of partial contact, PANAM has been tested against this problem by computing partial contact situations. One cannot hope to obtain exactly the measured situation as the position and exact percentage of contact is not known although it was estimated to be between 10 and 30 \% of the total area. As contact occurs on a small area around the fixation points (7/8 per m²) two cases have been considered as illustrated in the captions of Figure 8 (each red square corresponds to a 10x10 cm² contact). Despite a poor knowledge of the contact zones, these computations manage to approximate the measured sound reduction index (red curve against black) up to 1600 Hz. Above 1600 Hz, the measured reduction index decreases: this may be attributed either to background noise or more likely to lateral transmission.
Varying the amount of contact between 0 and 100 % gives varying values of R. However, peripheral and central contacts give different progressions; the former seems more apt at describing the measured values, especially around 400 Hz. A contact between 20 and 30 % seems to approach measured data. Naturally, one would require a more precise knowledge of contact zones to better recover reality. Nevertheless, these computations show that the main effects observed in the measurements can be predicted with a FEM approach. Further computations will be carried in the future.

5 Conclusions

The FEM formalism proposed in [1,2,3] I for poro-acoustic media has been implemented in order to model specific building applications for which the matrix-transfer formalism is not adequate. The case of air inlets has confirmed that the full two-phase model is required for porous materials such as foam. On the other hand, porous materials such as fiber glass, with a much less rigid skeleton can be modeled with an equivalent fluid approach.

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References


