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ON SUBSTRUCTURE BOUNDARY ELEMENT TECHNIQUES TO ANALYZE ACOUSTIC PROPERTIES OF AIR-DUCT COMPONENTS

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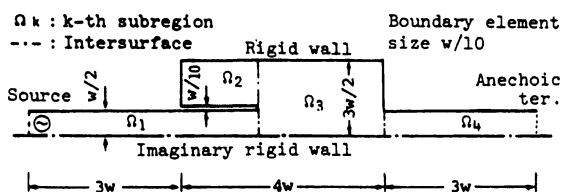
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INTRODUCTION

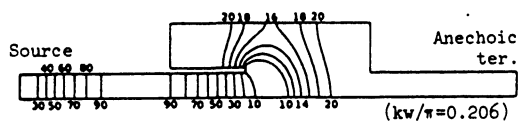
A direct BEM (boundary element method) has been employed combining with the substructure techniques to analyze duct acoustic fields which contain thin plates and porous materials. The results by this BEM have been compared with those by experimental, FEM (finite element method) and theoretical for silencers and duct open ends.

NUMERICAL METHOD

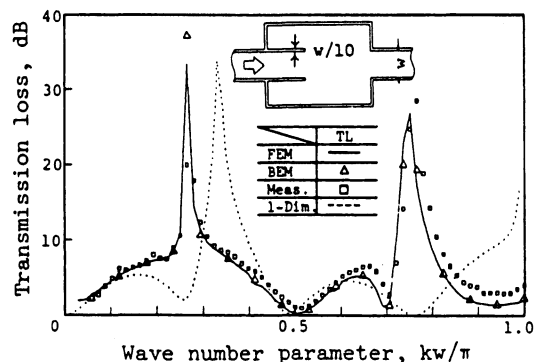
In this method, acoustic field are divided into subregions by introducing intersurfaces. A linear equation system is constructed by discretizing Helmholtz integral formula governing an individual subregion, employing plane quadrilateral constant boundary element and Gaussian quadrature formulae to perform numerical integrations over boundary elements including singular elements. A set of simultaneous equation is reconstructed, reduced and solved linking the subregions one after another.



a) BEM model



c) Relative sound pressure distribution



b) Transmission loss

Fig.1 2D expansion chamber

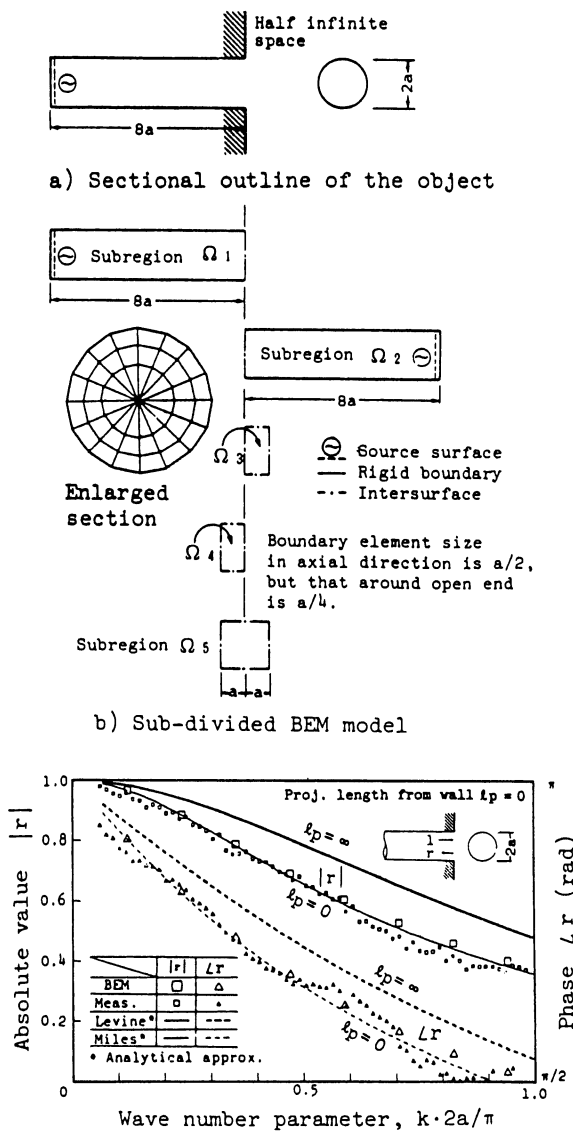
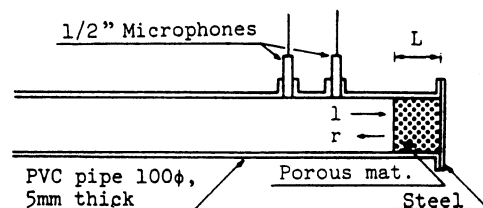
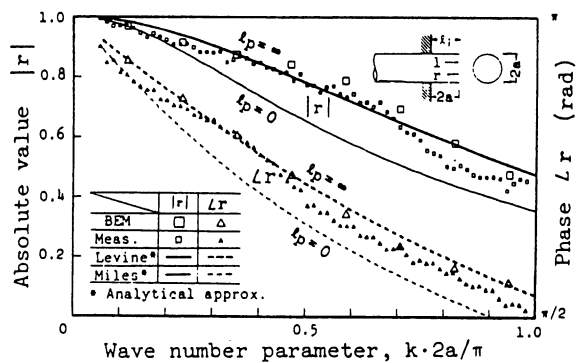
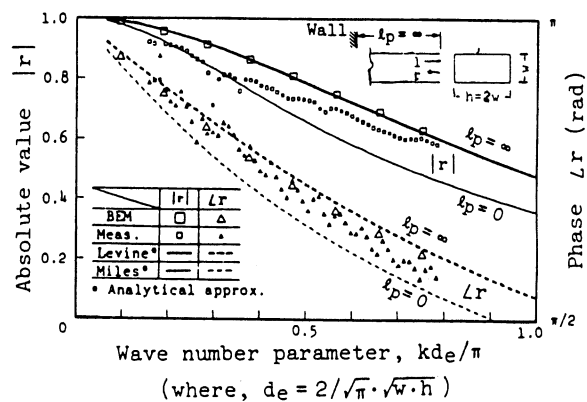


Fig.2 Reflection factor of circular duct open end with flush wall.



APPLICATION TO ACOUSTIC FIELDS WITH THIN OBSTACLES

2D expansion chamber with thin plates

Silencers with inner projections have been studied. Typical substructurized BEM model and results are shown in fig.1. This BEM using constant boundary elements agrees well with FEM using quadratic quadrilateral elements. The discrepancy between these numerical and experimental in the higher frequency range is caused by incomplete hard wall construction in the experiment. The results implies that this substructurization enables to analyze acoustic field with thin obstacle for which singularity arises when direct BEM is used without subdivision.

3D open end of circular and rectangular duct

Reflection at open end with a finite projection from a wall to semi-infinite field has been studied. Typical results are shown in fig.2 to 4. The equivalent diameter of

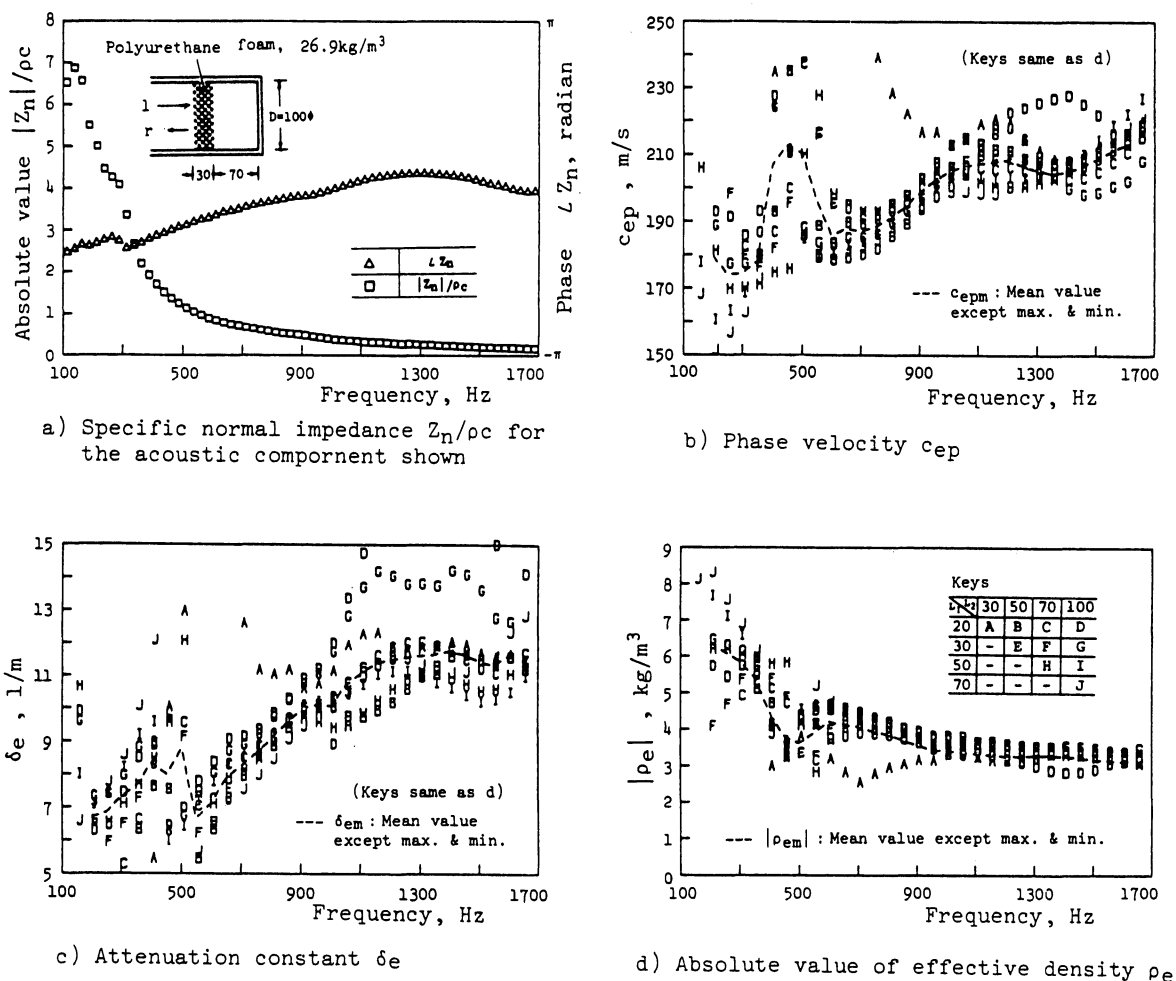


Fig.6 Acoustic properties of the porous polyurethane foam (26.9kg/m³) measured.

square duct is found to be what has the same sectional area as that of square. Levine's case($\ell_p=\infty$)[1] and Miles' case($\ell_p=0$)[2] can be roughly applied when the wave length of interest is smaller than 6 and larger than 12 times the projection length ℓ_p from the wall respectively.

APPLICATION TO ACOUSTIC FIELD WITH POROUS MATERIALS

Required acoustic properties for porous materials

To calculate the free field Green's functions in the integral formula, effective sound velocity c_e or wave number $k_e=\omega/c_e=\omega/c_{ep}-j\delta_e$ in the porous material[3] must be explicitly given. Where, $j=\sqrt{-1}$, ω denotes angular frequency, c_{ep} phase velocity, and δ_e attenuation constant.

Furthermore, to satisfy the equation of continuity $q/q_e=-\rho/\rho_e$ at the intersurface between air and the material, effective density ρ_e in the material must be known. Where, q denotes pressure gradient in the outward normal to the surface. Symbols with and without subscript (e) indicate quantities for porous material and for air respectively.

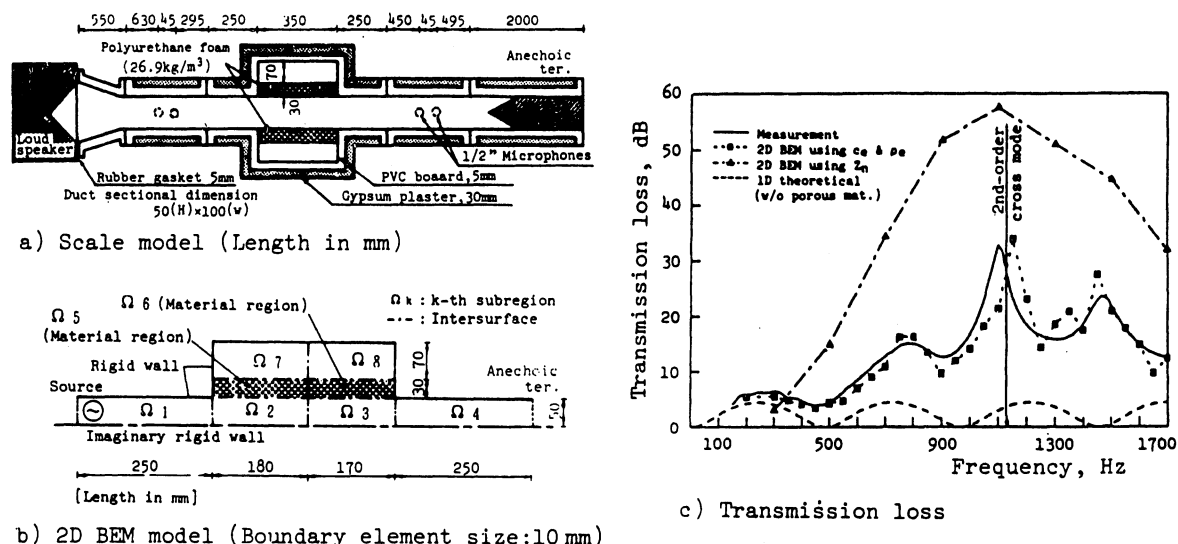


Fig.7 Expansion chamber with porous materials.

Method to determine the properties

To determine c_e and ρ_e , reflection factor r at the air adjacent to the material surface is measured employing the two microphon method as shown in fig.5. The following eq.(2) is employed for this method instead of normal impedance z_n by eq.(1) for conventional:

$$z_n^* = z_n / \rho c = (1+r)/(1-r) \quad (1)$$

$$\rho_e c_e / \rho c = z_n^* \{1 - \exp(-2jk_e L)\} / \{1 + \exp(-2jk_e L)\} \quad (2)$$

Supposing that a set of materials tested have the same properties, $\rho_e c_e / \rho c$ has constant value independent of the length; accordingly measuring r or z_n for two test pieces with different length L , one can determine k_e or c_e and ρ_e solving eqs.(2).

The properties of the material used

The measured properties are shown in fig.6. All the test pieces were cut from a lump of porous polyurethane foam (26.9 kg/m^3), nevertheless there is difference in the determined properties with the lot of the length pair because of difficulty of keeping uniformity in inserting test pieces.

Numerical results for a silencer with porous materials

The expansion chamber studied and the results are shown in fig.7. Using 2D BEM and the mean values c_{epm} , δ_{epm} and ρ_{epm} except max. and min. at every frequency, the validity of this method by means of c_e and ρ_e has been confirmed.

CONCLUSIONS

The effectiveness of the substructurized direct BEM employed has been confirmed by comparing with experimental, FEM and theoretical for duct open ends and for silencers with thin plates and porous materials.

REFERENCES

- [1] H. Levine et al, Physical Review, Vol.73, No.4, 1948.
- [2] J.W. Miles, J.A.S.A., Vol.20, No.5, 1948.
- [3] Morse and Ingard, Theoretical Acoustics, McGrawhill, 1968.