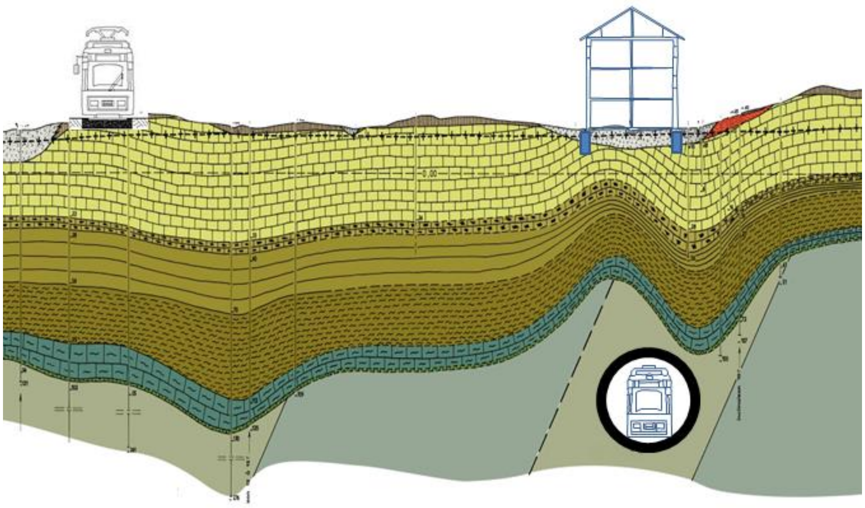
MEFISSTO

The software dedicated to environmental vibrations and ground-structure interaction

MEFISSTO is a numerical software dedicated to the prediction of vibration propagation in the ground and in structures. It is based on two complementary numerical methods (FEM and BEM) which makes it the ideal tool to address many different kinds of problems related to environmental vibrations and ground-structure interaction. It can be used for instance to design reduction systems for vibrations induced in buildings or to predict surface vibration levels due to the pass-by of an underground train.

In MEFISSTO, it is assumed that all domains are isotropic and homogeneous, and that propagation effects are linear. This tool therefore solves linear elastodynamics equations in the frequency domain.



Cross sectional view of the physical problems adressed by MEFISSTO

2D versus 2.5D modelling

MEFISSTO allows 2D as well as 2.5D calculations.

In 2D modelling, all physical aspects of the problem (geometry, source, etc.) are described in a vertical cross section and are considered invariant in the third horizontal direction. Consequently, in 2D, the excitation can be viewed as an infinite coherent line source, which is very rarely encountered in real situations.

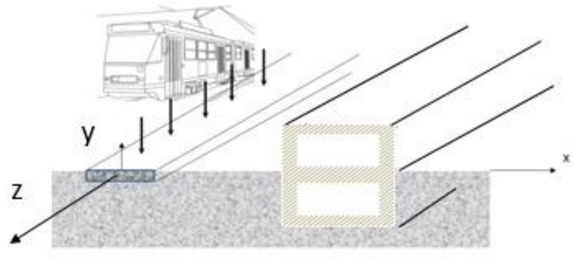
In 2.5D modelling, the geometry remains invariant along the horizontal direction (an infinite tunnel for instance) but the excitation is no longer considered invariant. One can therefore model one or several point forces in 3D, anywhere in space, which clearly is a much more realistic model for real vibration sources. The description of the geometry remains simple however since it is made only in a vertical plane (in 2D).

Comparisons between calculations and measurements have shown that in many cases (vibration impact on buildings during train pass-bys for instance), 2.5D calculations yield significantly better results than 2D calculations. In fact, 2D calculations typically tend to overestimate vibration levels and therefore can induce oversized foundations or protections, and therefore important extra cost. 2.5D modelling therefore allows to design vibration reduction systems more accurately and more economically.

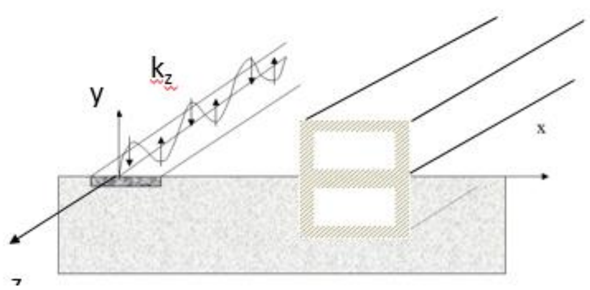
Besides, another asset of 2.5 modelling compared to full 3D modelling, apart from the inherent simplicity, is that many 3D problems are well-approximated by 2.5D modelling. In fact, it turns out that in many cases, 2.5D calculations – which assume infinitely extended geometries in one dimension – yield very similar results than performing full 3D calculations – which takes into account finite extent effects. This is due to the fact that dissipation is rather high in the ground, and therefore even 10 m-long structures essentially behave as infinitely long structures (which is what the 2.5D approach assumes).

Theoretical and computational aspects of 2.5D calculations

From a theoretical point of view, a 2.5D computation is achieved by solving a set of 2D sub-problems, each solved for a given horizontal wavenumber k_z. To get to the 2.5D solution, one then needs to perform an integration over the different values of k_z for all positions of point forces (see the image below).



2.5D problem : multiple point forces



2D sub-problem for a given wavenumber k_z

The extra computation time required to perform a 2.5D calculation is much smaller than what would be required for a full 3D calculation. Besides, calculations for each wavenumber and for each frequency are independent and can easily be run in parallel.

Numerical methods: FEM and BEM

Two complementary numerical methods are implemented in MEFISSTO, FEM and BEM.

The FEM (Finite Element Method) is based on the fact that each domain is broken down into small surface elements. The field variables inside each domain are then described by their nodal values of the mesh.

In the BEM (Boundary Element Method) approach, the field variables are described based only on the boundary values of each domain. Field values defined on line contours only are therefore required to describe a domain entirely.

By definition, FEM cannot handle unbounded domains, whereas the BEM is well-suited for unbounded domains. Bounded and thin domains (such as the structure of a building or a tunnel) are however best modelled with the FEM but can nevertheless be modelled with the BEM as well.

In both FEM and BEM, the maximum element size must be a fraction of the smallest wavelength involved, which depends on frequency and the physical properties of the different domains. This is easily handled in MEFISSTO since a meshing criterion is specified for each segment in the geometry.

Acoustic pressure calculation inside volumes

When one wants to predict a structure-borne noise level, it is also possible in MEFISSTO to define rectangular volumes in which a post-treatment calculation of the pressure field radiated by vibrating walls will be made. An original method – known as 2D3/4 calculation - combining 2.5D results and 3D modal coupling calculations hence allows to obtain a quick and precise estimation of structure-borne noise level inside buildings.

Input parameters

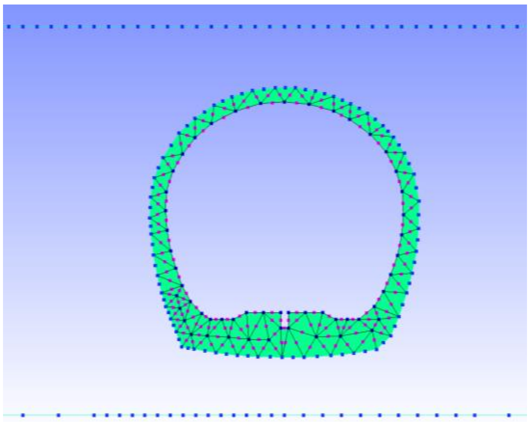
(1) Geometry

In MEFISSTO, the geometry is simply described by a list of straight segments or by portions of circles, which are the boundaries of all domains (whether they are described with FEM or BEM). At each frequency, the meshing is done automatically by splitting all segments according to the shortest wavelengths involved. The implementation of a geometry is therefore very simple.

When entering the geometry, one can also define a set of acoustic “ducts”, which can be used to calculate structure-borne noise levels (as a post-treatment). A duct has to be defined by 4 segments delimiting a closed rectangle.

The ground surface and any interface between horizontal layers, which are infinitely long lines, are modelled with the BEM as a line of finite extent with a length that is automatically adapted to the frequency. This approximation is done without any loss of accuracy.

The picture below shows an example of a hybrid mesh for a tunnel placed in a ground layer. The BEM meshing will consist of the two horizontal interfaces plus the external tunnel contour. The tunnel is a FEM surface meshing made of six-node triangles.



Example of a hybrid mesh: FEM mesh for the tunnel structure and BEM mesh for ground layers

(2) Material properties

The material which each domain is made of is described with four parameters which are user-provided: Young's modulus (E), density (ρ), loss factor (η) and Poisson's ratio (ν).

(3) Propagation media

A propagation medium is defined with a number, a material, a numerical method (FEM or BEM) and a set of segments defining the boundary.

(4) Source positions

In MEFISSTO, point sources only are allowed. One should keep in mind that thanks to 2.5 modelling one point position provided in the definition geometric plan can describe a set of incoherent point sources in the third horizontal direction (along a train track for instance).

(5) Receiver positions

Receivers can be defined as individual points, axes, averaging zones or maps in any direction, in vibration propagation domains as well as acoustic volumes.

Output data

The user may choose as output data the vibration field (displacement, velocity or acceleration) or the acoustic field (inside the volumes defined as acoustic volumes) at the different receiver locations. All three components are calculated and stored. MEFISSTO generates text files as well as GMSH files.

The two mains kind of results are:

- Spectra: solutions at chosen receiver points, depending on frequency
- Field maps (see examples below)

The user can then apply any kind of post-treatment to the results: third-octave integration, curve plotting, 3D visualization of maps, etc.

Scilab Package Scilab for Mefissto

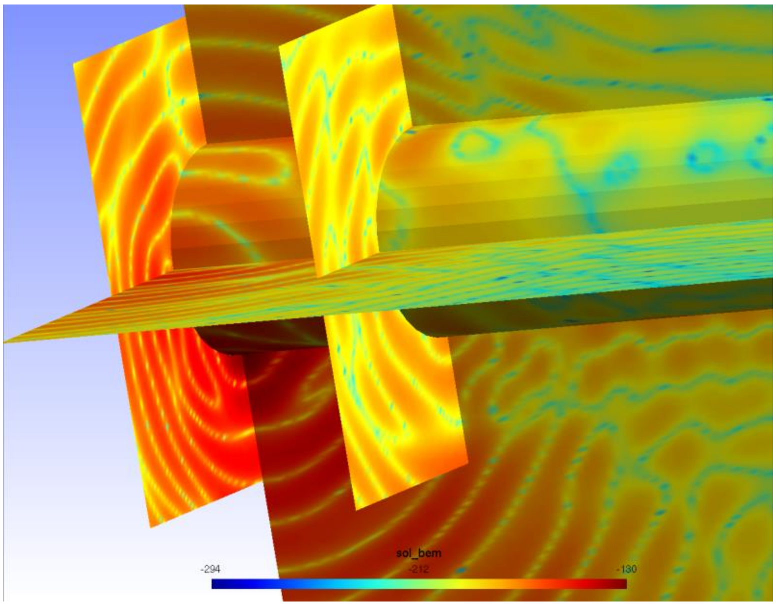
In order to ease input data entry as well as the post-treatment of the generated text files, a set of functions usable in the numerical calculation freeware Scilab[1] has been developed and is freely distributed with Mefissto. Using those functions, you can easily:

> Read a well-formatted DXF file and export the geometry so that it can be used in Mefissto
> Plot the geometry that has been defined to make sure it has been entered properly
> Plot generated mesh files (using the freeware GMSH[2])
> Run Mefissto at several frequencies in parallel
> Read Mefissto's output files and load them as Scilab variables (which allows you to make all the calculations you want)
> Plot graphs (frequency dependent response curves, structure-borne noise levels…)

[1] https://www.scilab.org/en
[2] http://gmsh.info/

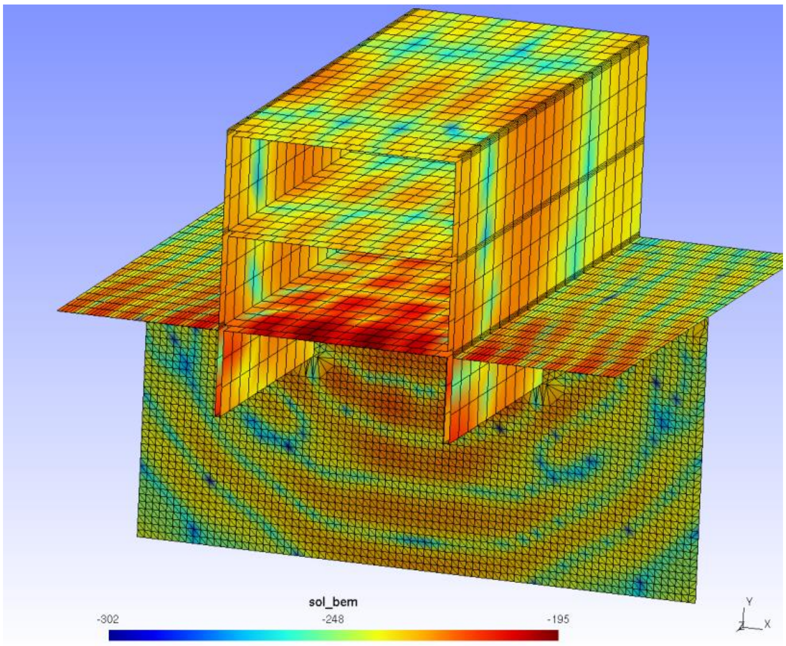
Example 1: a tunnel set in an infinite ground excited by a point force

In this example, the level of vertical displacement at 100 Hz is plotted both on the tunnel but also in different planes. Visualization is done with the software GMSH.



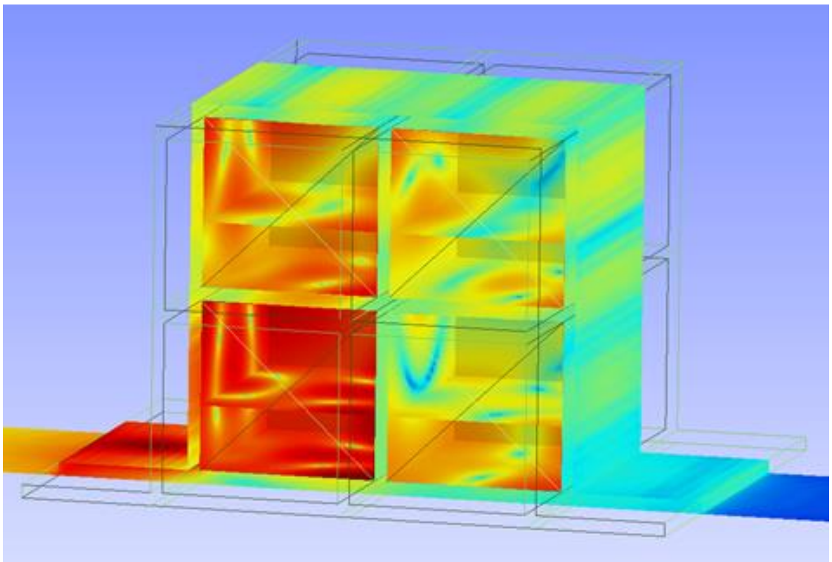
Example 2: vibrations of a building by a surface excitation

A two level building with vertical foundations is excited at ground level by a vertical force. The following picture shows the vertical displacement at 100 Hz on the structure, on the ground surface and in a vertical plane, 10 m away from the source.



Example 3: acoustic field radiated by vibrating walls (structure-borne noise) in a building

A two-storeys building with quatre volumes is excited by a vertical force at the surface level. RThe calculation of the vibration field is achieved in 2.5D, and the computation of the acoustic field within the four volumes with 3D modal coupling (2D3/4 calculation).



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