Structural Dynamics and Acoustics

Case-study 3

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Key points of the TP

1. Compute the dynamic response of a 3D multi-story building with `COMSOL Multiphysics`®
2. Export the `Results` into the support notebook `mdof_comsol_todo.ipynb` for further analysis and comparison with a simplified MDOF (see Case-study 2)
   - Compare the Eigen-frequency and Eigen-modes of simplified 1D MDOF and the 3D multi-story building designed in `COMSOL Multiphysics`®
   - Compare the Participation factors of simplified 1D MDOF and the 3D multi-story building designed in `COMSOL Multiphysics`®
   - Compute the simplified dynamic response of the MDOF to earthquake loading, using the Participation factors of the 3D multi-story building designed in `COMSOL Multiphysics`®

Problem setting: Global Definitions

- MDOF_EigenFrequency_solved.mph
  - Global Definitions
    - Parameters
    - Default Model Inputs
    - Materials

Parameters

Settings Properties

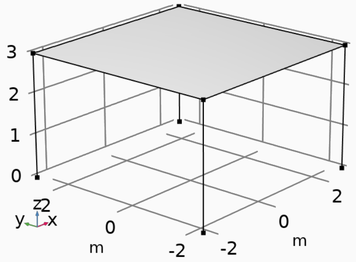
Parameters

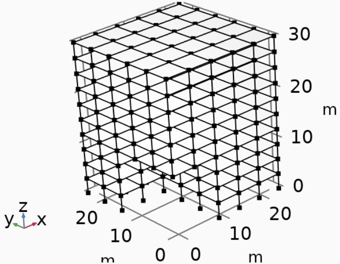
Label: Parameters

Parameters

Name	Expression	Value	Description
bb	30 [cm]	0.3 m	Cross sectional base for beam elements
bc	30 [cm]	0.3 m	Cross sectional base for column elements
c1x	-Lx/2	-2.5 m	Origin of master frame in the x direction
c1y	-Ly/2	-2.5 m	Origin of the master frame in the y direction
c1z	0 [m]	0 m	Origin of the master frame in the z direction
E_beam	28.3e9 [Pa]	2.83E10 Pa	Beam/Column concrete Young's modulus
E_floor	25e9 [Pa]	2.5E10 Pa	Floor concrete Young's modulus
ft	hb	0.3 m	Thickness of the floor
hb	30 [cm]	0.3 m	Cross sectional height for beam elements
hc	30 [cm]	0.3 m	Cross sectional height for column elements
Hf	3 [m]	3 m	Floor's height
Lx	5 [m]	5 m	Intercolumn distance in the x direction
Ly	5 [m]	5 m	Intercolumn distance in the y direction
Mf	0	0	issing frames in the z direction
Mx	0	0	Missing frames on the x direction
My	0	0	Missing frames in the y direction
Nf	3	3	Number of floors
Nx	1	1	Number of frames in the x direction
Ny	1	1	Number of frames in the y direction
rho_beam	500 [kg/m^	500 kg/m³	Beam/Column concrete unit mass density
rho_floor	2300 [kg/m	2300 kg/m	Floor concrete unit mass density

Problem setting: component `Frame3D`





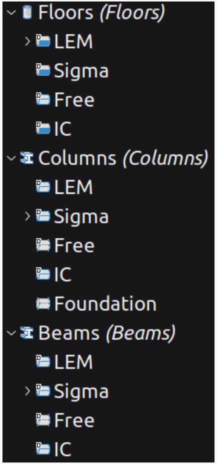
`MasterFrame`:

- 1D Vertical concrete beams of height H_f (`Columns`)
- 1D Horizontal concrete beams of length L_x and L_y (`Beams`)
- 2D Horizontal concrete shells of area $L_x \times L_y$ (`Floors`)

`MultiStoryBuilding`:

- Array of $N_x \times N_y \times N_f$ `MasterFrames`
- $M_x \times M_y \times M_f$ missing frames

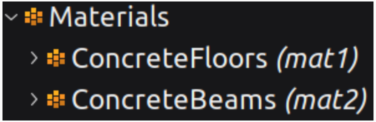
Problem setting: component `Frame3D`



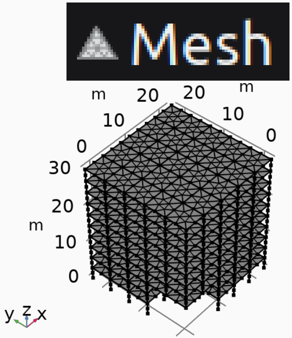
Physical entities: `Floors`, `Columns`, `Beams`:

- `LEM`: Linear Elastic Material
- `Sigma`: Cross-Section properties
- `Free`: Free boundaries/edges
- `IC`: Initial Conditions

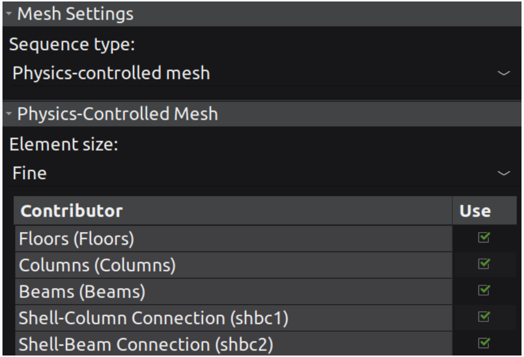
`Materials` (from `COMSOL multiphysics`®library) are assigned to each component



Problem setting: component `Frame3D`

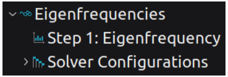


Each physical entity is meshed according to `Settings`:

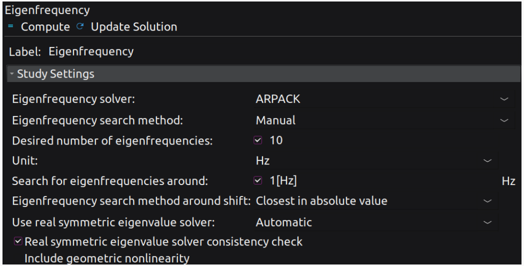


- `Extremely coarse`
- `...`
- `Extremely fine`

Problem setting: Study

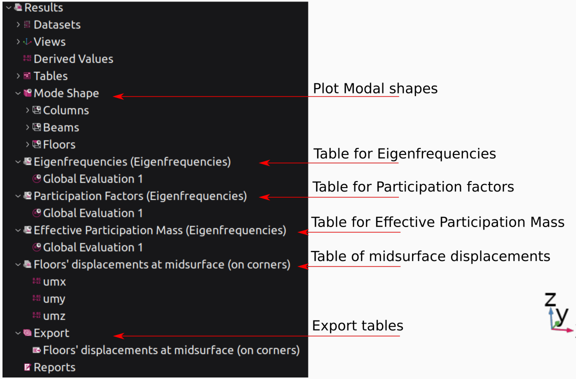


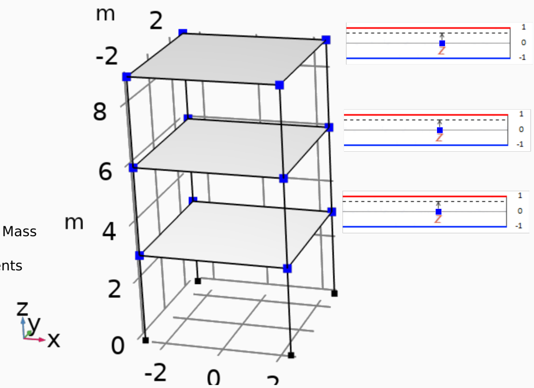
Tune the solver:



- `Real symmetric eigenvalue solver consistency check`
- No `Include geometric nonlinearity`
- `Compute` every time the model is modified

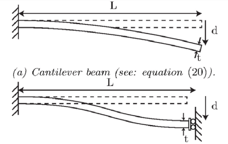
Problem setting: Results





[TASK #1]: `COMSOL Multiphysics` Modal Shapes and Eigen-frequencies

- In the `Global Definitions`, select `Nx`=`Ny`=1 and `Nf`=3, with no missing frames (`Mx`=`My`=`Mf`=0)
- Rebuild the Geometry by building all the entities (in `Form Union (fin)`)
- **Story Shear Building Model**
  - Constrain the structure in the $x-z$ plane
    - For each physical entity `Floors`, `Columns`, `Beams`, introduce the adequate kinematic constraints
      (*Hint*: Right click on the component → `Prescribed`...)



(a) Cantilever beam (see: equation (20)*).*

(b) Doubly clamped beam (see: equation (21)*).*

  - Constrain `Columns` to pure shear
  - (*Hint*Right click on the `Columns` component → ...)
  - `Compute` the `Eigenfrequencies` study for 10 eigen-frequencies (real) around 1 Hz and report the corresponding Modal Shapes in the `jupyter` notebook `mdof_comsol_todo.ipynb` (snapshots to be placed in the cell *Report the Modal Shapes Eigen-frequencies from `COMSOL Multiphysics`*)

[TASK #2]: Compare the Eigen-frequencies

- In the `jupyter` notebook `mdof_comsol_todo.ipynb`, compute the approximate mass and stiffness matrices of each story of the `COMSOL Multiphysic)` model
  Nota Bene: Do not consider the masses of the beams and columns (double clamped beam)
- In the `jupyter` notebook `mdof_comsol_todo.ipynb`, compute the eigen-frequencies and eigen-modes of the MDOF system. What are the natural frequencies? Do they correspond to the `COMSOL Multiphysics`®ones?
- Plot the eigen-modes of MDOF system and compared them to the `COMSOL Multiphysics` ones (evaluated on at the midsurface of each floor)
  (*Hint*: Export `umx`, `umy` and `umz` from `COMSOL Multiphysics`®and import the files in the notebook).

[TASK #2]: Compare the Eigen-frequencies

- Compute the Participation Factors Γ_{ij} and compare them to those from `COMSOL Multiphysics`®((from Export Groups `Participation Factors (Eigenfrequencies)`).
  Nota bene: Using modal participation factors is a way to characterize how much a certain mode will be excited by a rigid body acceleration $\boldsymbol{d}_j$ in a certain direction j.
  The *normalized participation factor* with respect to mode i and excitation direction j, is defined as:

$$\tilde{\Gamma}_{ij} = \frac{\langle \boldsymbol{\phi}_i, \boldsymbol{M}.\boldsymbol{d}_j \rangle}{\langle \boldsymbol{\phi}_i, \boldsymbol{M}.\boldsymbol{\phi}_j \rangle} = \frac{\Gamma_{ij}}{m_i}$$

  with $\Gamma_{ij} = \langle \boldsymbol{\phi}_i, \boldsymbol{M}.\boldsymbol{d}_j \rangle$ the Participation Factors and $m_i = \langle \boldsymbol{\phi}_i, \boldsymbol{M}.\boldsymbol{\phi}_j \rangle$ the i^{th} modal mass.