25·29 August 2024
inter.noise
NANTES FRANCE

FEM simulation of vibrations in building: from volume to shell elements

Gautier Gillot[1]
Groupe Gamba
163 rue du Colombier, 31670 Labège

Tony Lethuillier[2]
Groupe Gamba
163 rue du Colombier, 31670 Labège

Bernard Laulagnet[3]
Institut National des Sciences Appliquées, Laboratoire Vibrations Acoustique
25 bis Avenue J. Capelle, 69621 Villeurbanne Cedex

ABSTRACT

The problem of vibrations in buildings situated in the proximity of railway tracks is a major concern for the resident's comfort. More and more studies focus on this problem using FEM models, with shell elements for the building's walls and floors. However, the validity of this simplification is never fully justified, and it raises questions concerning the dimensions to apply to the model.

The model of a building made of 3D elastic elements is compared to its simplified version made of shell elements. Three geometries with different dimensions are tested to find the one closer to the reference model. Different shell offsets are also tested. The results show great differences of floor vibration levels, mostly for high frequencies, depending on the dimensions of the geometry and the offset. The shell configuration with the closest results to the reference model is discussed.

1. INTRODUCTION

The accelerating development of railway transports in denser cities give rise to a major problem: the generation and propagation of annoying vibrations in buildings. The development of efficient solutions to treat these vibrations requires the use of numerical models.

Computationally efficient methods exists to treat railway vibrations problems, like the formulation in 2.5D [1]. But with the increasing use of complex materials for construction, like wood, the need for 3D models integrating the soil and buildings is greater [2, 3]. However, the large dimensions of buildings, associated with their complexity, give rise to heavy models with a huge computational cost. Therefore, simplification methods have to be used to reduce this cost.

In general, the Finite Elements Method (FEM) is used to study the dynamics of buildings. In 3D FEM models, building are often made of shell or plate elements for cost reduction [4, 5].

---

[1] gautier.gillot@gamba.fr

[2] tony.lethuillier@gamba.fr

[3] bernard.laulagnet@insa-lyon.fr

However, this choice is rarely justified, even for thick slabs, which are often met in buildings. This approximation is even more limited as the frequency bands studied are wide and may be sufficiently high for the plate approximation to no longer be valid

The use of shell element for 3D buildings also raises questions concerning the building dimensions. The shell elements having no geometrical thickness, it is not possible to keep both internal (floors and walls surfaces) and external dimensions of the 3D building.

This work compares several approaches to model a building with shell elements. A simple building geometry is studied, excited with a Rayleigh wave-like excitation. The reference model, made of volume elements, is compared to several models made of shell elements, with different dimensions and shell offsets.

2. NUMERICAL MODEL

A concrete building with 5 stories is studied, as shown in Figure 1, using Ansys software. The walls and floors are 0.2 m thick. The models are meshed with second order elements. The reference model is constituted of elastic volume elements, with a maximum size of 0.1 m. The test models are made of shell elements, with a maximum size of 0.1 m. Three dimensions are tested for the floors and walls, from the reference model dimensions as shown in Figure 2. For the first model, the interior dimensions are kept, meaning that the room volumes are the same as the reference model, but the global size of the building is smaller (Figure 2-b). The second model has the external dimensions of the reference building, so the rooms are wider than the reference model but the global building have the same size (Figure 2-c). The third model has intermediate dimensions, so the building has no common dimension with the reference but is the closest considering the shell thickness (Figure 2-d).

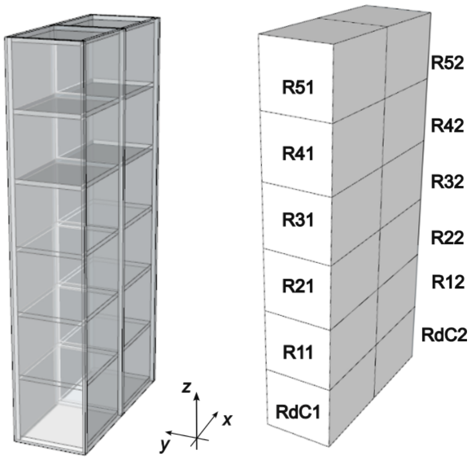

Figure 1: Geometry of the building for the FEM simulation, made of 3D elements (left) and 2D elements (right). The name given to the different floors is indicated on the right geometry.

For the three geometries, different offset settings for the shell elements are tested. The offset is used to define the thickness distribution compared to the surface. For a middle offset, the thickness is equally distributed on both sides of the surface (Figure 3-b). The interior offset corresponds here to a distribution of thickness entirely toward the inside of the building (Figure 3-a). The exterior offset corresponds to a distribution of thickness entirely toward the outside of the building (Figure 3-c).

The different buildings are excited on the lower floors with a surface force of 1N on the x and z directions, with an phase shift of $\pi/2$ for the vertical excitation. This excitation is chosen to reproduce movements similar to the one imposed by the Rayleigh wave. The mean velocity levels

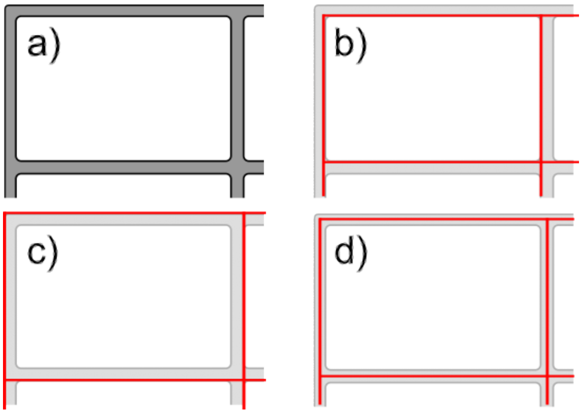

Figure 2: Cross-section view of the building geometry made with a) 3D elements, b) shell elements with interior dimensions, c) shell elements with exterior dimensions and d) shell elements with intermediate dimensions.

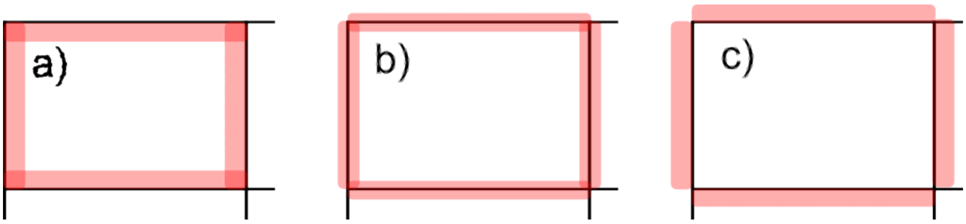

Figure 3: Cross-section view of the building shell geometry. Red rectangles show the shell offset: a) interior offset, b) middle offset and c) exterior offset.

are calculated on the different floors, from the ground level (RdC1 and RdC2) to the fifth floor (R51 and R52). The results are presented in third octave, integrated from a narrowband spectra.

3. RESULTS

First, the three shell models with a middle offset are compared to the reference model. The mean velocity levels of different floors are compared in Figure 4. In low frequencies, until 40 Hz, there is a little difference between the different models, with the intermediate dimensions having the smallest gap with the reference model. Above 40 Hz, when the building starts to exhibit a modal behaviour, differences appears between the shell models and the reference model. Overall, the model with intermediate dimensions shows the smallest differences.

For each geometry, the offset setting for the shell elements is modified to get closer to the reference model's behaviour. It means that for the geometry with exterior dimensions, the interior offset is applied (because the faces represent the exterior of the walls), and for the geometry with interior dimensions, the exterior offset is applied (because the faces represent the interior of the walls). The geometry with intermediate dimensions is let with middle offset as the faces represent the walls' mid-surface plane.

The absolute difference of floor velocity levels with the reference model is compared in Figure 5. Once again, only small differences are visible between the models at low frequencies below 40 Hz, but with the smallest gap for model with intermediate dimensions. Above 40 Hz, both the model with intermediate and interior dimensions exhibit floor levels closer to the reference, depending on the stage and the frequency. The squared error summation over the entire frequency band show that the model with interior dimensions is the closest to the reference model, when the same operation over the third octave results show the closest results with the

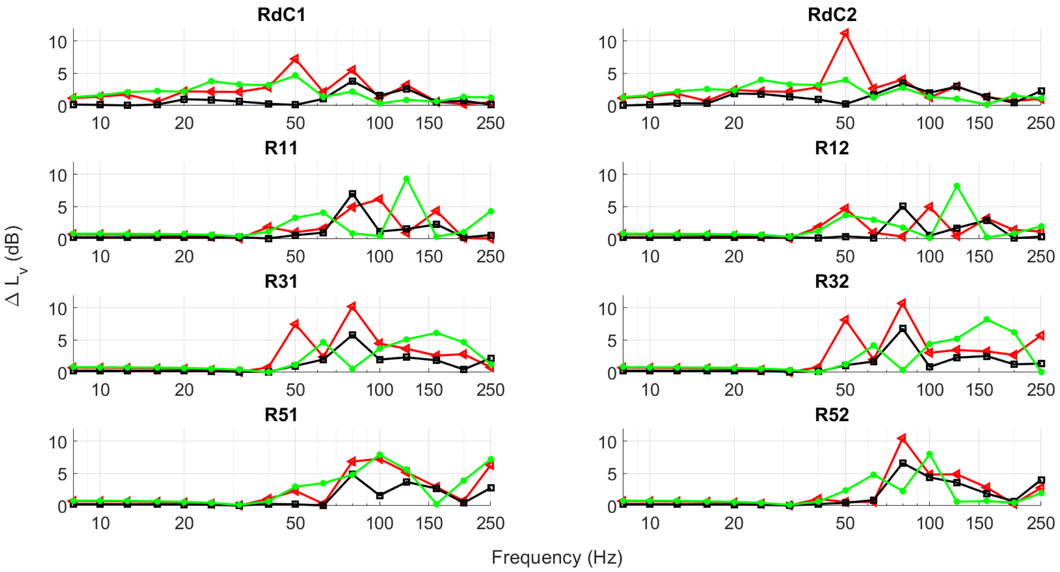

Figure 4: Absolute difference of velocity level ΔL_v between the model made of 3D elements and the models made of shell elements with exterior dimensions (red), with intermediate dimensions (black) and with interior dimensions (green).

model with intermediate dimensions.

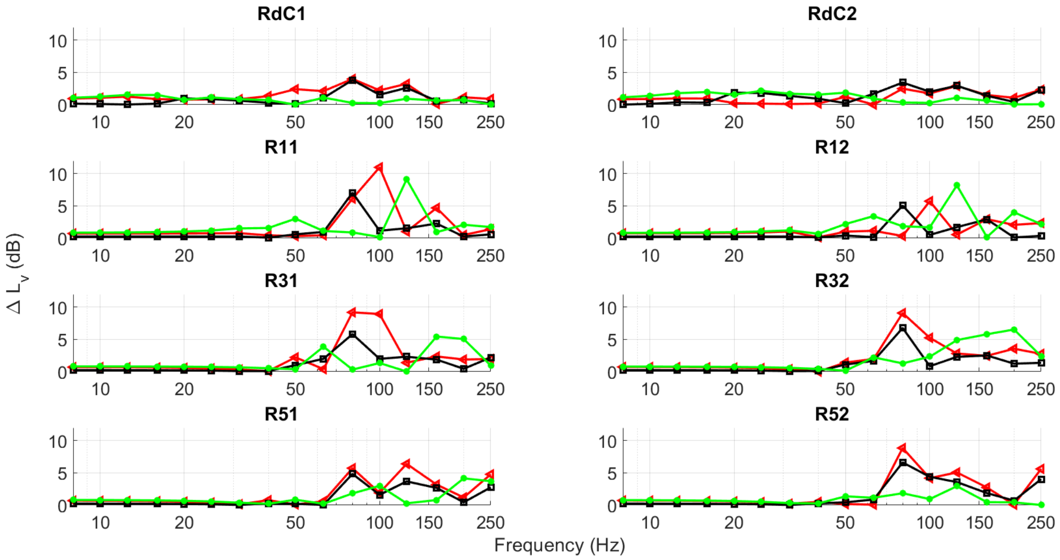

Figure 5: Absolute difference of velocity level ΔL_v between the model made of 3D elements and the models made of shell elements with exterior dimensions and interior offset (red), with intermediate dimensions and middle offset (black) and with interior dimensions and exterior offset (green).

4. DISCUSSION

The results show that the geometry with intermediate dimensions is the closest to the reference model when the offset is not considered. Indeed, comparing the total mass of the geometries, the model with intermediate dimensions is the closest to the reference, with only 3% of difference, when the other two geometries have a mass difference of 9% (the model with interior dimensions is lighter and the one with exterior dimensions is heavier than the reference). Thus the global mobility of the intermediate model is close to the reference.

When the offset are adapted to the geometry, the model with interior dimensions and exterior offset gives a closest response to the reference than the intermediate model. This is due to the geometry which keeps the same floor and walls dimensions as the reference, thus giving almost the same local modes. The differences remains in the boundary conditions on the floors' edges, which are stiffer for the shell models. The exterior offset also reproduces the moment created at the floor edges by the walls in the reference model, which does not exist with a middle offset [6, 7].

While both models with interior and intermediate dimensions give the closest approximation of the reference model, this can be different for larger buildings. Indeed, by keeping only the interior dimensions, the overall building is smaller (and also lighter) than the reference geometry. This is due to the additional length brought by the walls and floors thickness, as shown in Figure 6. Therefore, a larger building with many floors and walls can lead to a great difference on the overall size, thus a greater gap in the results. This additional length in taken into account for the geometry with intermediate dimensions, thus its good results may not be affected by the building size.

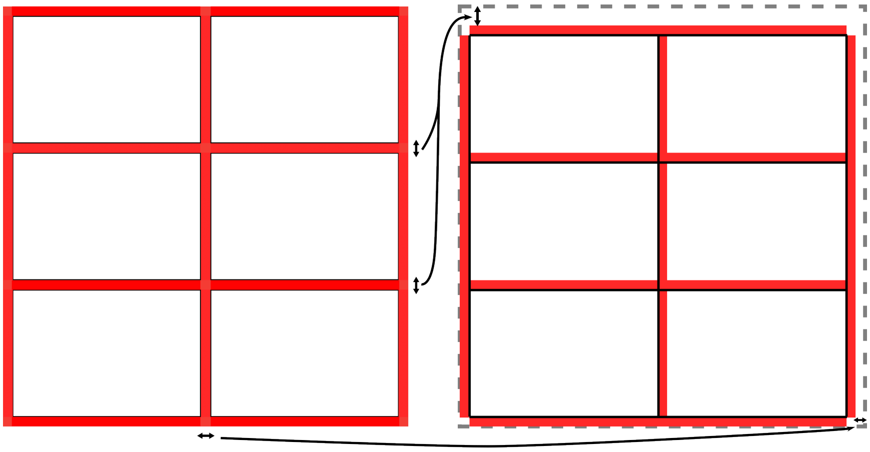

Figure 6: Cross-section view of the geometry of the reference model (left) and the model with interior dimensions with the shell thickness represented in red (right). The dashed line show the global dimensions of the reference building.

5. CONCLUSION

The comparison between building models with volumic elements and shell elements shows that the simplification from one to the other is not straightforward. The walls thickness, which is only implicitly considered for shell elements, gives rise to questions considering the dimensions to use for the geometry to have the closest behaviour to the fully volumic model.

Comparing different approach, it was shown that using intermediate dimensions, by adding to each floor and wall an additional length corresponding to half the plate thickness, and defining a middle offset for the shells, gives the closest results to the full volumic element model. While the solution of keeping the walls and floors interior dimensions and defining an 'exterior' offset for the shells also gives results close to the reference model, this method might give worst results as the building size increases, by underestimating the building total size and mass.

It remains to study how the different model behave when coupled to a soil. The mass and dimensions problems might be even more pronounced because of the soil/structure interactions.

REFERENCES

1. Philippe Jean. Computing vibration transfer from trains to buildings by means of 2d1/2 and 2d3/4 models. In *INTER-NOISE and NOISE-CON Congress and Conference Proceedings*, pages 2070–2081, Hambourg, Germany, August 2016.
2. Blaž Kurent, Boštjan Brank, W Kei Ao, Aleksandar Pavic, and Manuel Manthey. On finite element modelling and model updating of multi-storey timber buildings. In *World Conference on Timber Engineering (WCTE 2023), Oslo 19-22 June*, pages 2892–2897, Oslo, Norway, June 2023.
3. Yasser E Ibrahim and Marwa Nabil. Finite element analysis of multistory structures subjected to train-induced vibrations considering soil-structure interaction. *Case Studies in Construction Materials*, 15:e00592, 2021.
4. Scott Breneman and Reid Zimmerman. Us mass timber floor vibration design guide, 2021.
5. JA ALOMARI and FR MARAOA. Floors modelled as thick shells, rigid diaphragm. *Journal of Engineering Science and Technology*, 17(5):3211–3223, 2022.
6. Nader G Zamani, Nima Gharib, and PN Kaloni. Two case studies for the effect of beam offset in finite element calculations. *International Journal of Mechanical Engineering Education*, 37(2):87–97, 2009.
7. David Klarholm. Offset modeling of shell elements: a study in shell element modeling using nastran, 2016.