XLIII CILAMCE
21-25, November, 2022
FOZ DO IGUAÇU - PR - BRAZIL

Analysis of the modal response of a structure considering the periodic foundation effect

Jakeline Loureiro[1], Francisco A. A. Gomes[2], Paulo R. Novak[2], Rodrigo B. Santos[3]

[1]*Dept. of Civil Engineering, Federal University of Technology - Paraná*
[2]*Dept. of Mechanical Engineering, Federal University of Technology - Paraná*
Via do Conhecimento, Km 1, CEP 85503-390, Pato Branco, Parana, Brazil
jakelineloureiro@alunos.utfpr.edu.br, franciscogomes@utfpr.edu.br, novak@utfpr.edu.br
[3]*Dept. of Mechanical Engineering, Federal University - Grande Dourados*
Rua João Rosa Góes, nº 1761, Vila Progresso, CEP: 79825-070, Dourados, Mato Grosso do Sul, Brazil
rodrigobsantos@ufgd.edu.br

Abstract. The densification of the areas of urban structures has caused structures in general that are increasingly approaching road traffic and this scenario, with which the structures are presented in these environments as being the environment caused by the flow of traffic. studies that predict structures designed by traffic but do not address technical/intelligible isolation isolation from manipulation/insulation intelligibility. The vibrations generated by the impact cause discomfort to building users in addition to causing damage to buildings, including cracking or even more serious problems such as the collapse of the structure. Research shows that it can isolate the use of periodic structures as vibrations of a structure. The idea is that these periodic structures work like a filter, absorbing as frequency bands, not passing this vibration on to the rest of the structure. Periodic structures are being used in several areas of engineering, however, with limited use in civil engineering. In this context, this work intends a numerical modeling in finite elements of a structure with a periodic type foundation, to study the vibrational construction of the foundation, in comparison with a simple foundation structure. In other words, the model is based on the development of the soil-structure coupling of finite elements, adopting the contour structure as a basis for the study between conditions as foundations as well as between the foundation and the foundation. Numerical modeling in finite elements was performed in the free and open source software FreeCAD version 0.19 with analysis performed in the solver Calculix. The modal response will be used to verify the filtering of the structure's vibrational response.

Keywords: Periodic Foundation, Vibration Isolation, Modal Analysis, Finite Element Method.

1 Introduction

With the urban densification generated in recent years, the approach of buildings for road and rail traffic was inevitable, these two means of transport infrastructure, as they receive frequent loads from the passage of vehicles and trains, end up generating efforts on the ground, this energy is dissipated soil, passing loads to elements that are close to its propagation zone, so the foundation of buildings close to transport infrastructures ends up receiving these efforts. The loads in contact with the ground, generate transverse, longitudinal and vertical forces, these efforts propagate through the ground as waves so called vibration.

Soil vibration waves reach buildings through the soil-foundation connection, which is not yet a completely understood problem, as it varies with the interaction of road and rail loads, in addition, the wave propagation depends on the type of soil and its damping, vehicle speed, types of loads, among other factors that affect the amplitude and frequency of the generated vibrations.

This vibration generated in the ground ends up affecting buildings as a whole, be it in the form of cracks and cracks in the walls, auditory and visual discomfort for users, as well as more serious forms, generating a lot of discomfort for the occupants, affecting the safety of the building, It can even cause a structure to collapse. For this reason, authorities and bodies responsible for the supervision and execution of buildings are already trying to create solutions to reduce these damages Filho and Araújo [1].

Research shows that the use of periodic structures can isolate vibrations from a structure. The idea is that these periodic structures work as a filter, absorbing the frequency bands, not passing this vibration on to the rest of the structure. Periodic structures are being used in several areas of engineering, however, with limited use in civil engineering.

In this context, the work is motivated by the need for studies aimed at the isolation of vibration in civil structures due to road-rail traffic as shown in the figure 1 . Since these vibrations generate discomfort and irritation for people residing in buildings or residential constructions, in addition to bringing structural damage and financial losses.

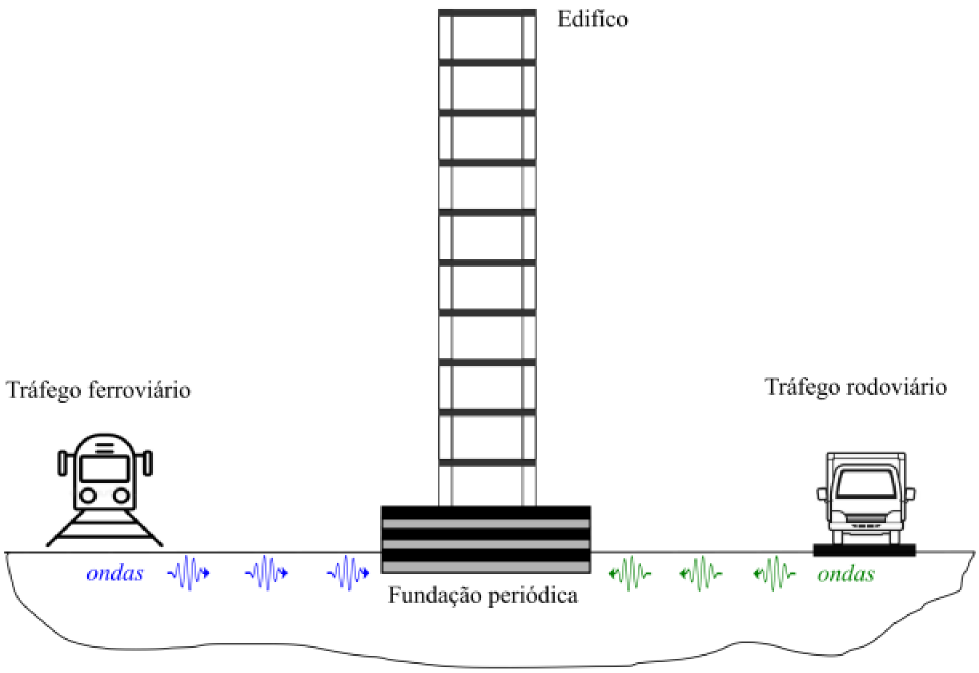

Figure 1. Periodic Foundation Model in Building

2 Mechanical vibrations

Vibration is defined as a periodic motion, that is, an oscillation of a particle, a system of particles, or a rigid body around an equilibrium position [2]. According to Rao (2008), any movement that is repeated within a time interval can be called vibration or oscillation, as the swing of a pendulum is an example of vibration. In vibration theory, it deals with the study of oscillatory movements of bodies and forces associated with them [3].

3 Periodic Foundation

The concept of periodic structure was proposed in the 1980s, and many researchers used these structures to control the flow of light in the field of optics, and these materials are also called [4] photonic crystals. This concept was and is also being applied to the field of acoustics using the Floquet principle to solve the wave equation directly, Mead [5] obtained the curves of propagation and attenuation constants related to quasi-one-dimensional periodic beams and plates and cylindrical shells.

Periodic materials called phononic crystals exhibit a unique ability to manipulate the propagation of elastic waves. This is achieved by deliberately structuring and organizing the phase or geometry of materials to take advantage of wave-material interactions, including standing wave modes resulting from the superposition of incident and reflected waves and local resonances in substructural systems [4].

The existence of frequency band gaps is well predicted by the Floquet Bloch theorem, which can be used to prevent any kind of wave from propagating within periodic materials [6]. Therefore, the unique property of frequency band gaps has resulted in numerous potential applications in engineering, periodic structures can aid in thermal insulation [7], noise reduction [8] and vibration isolation [9]. In the figure 2 we can observe the basic formulation of the periodic structure composed by layers, the same one to be used in this work.

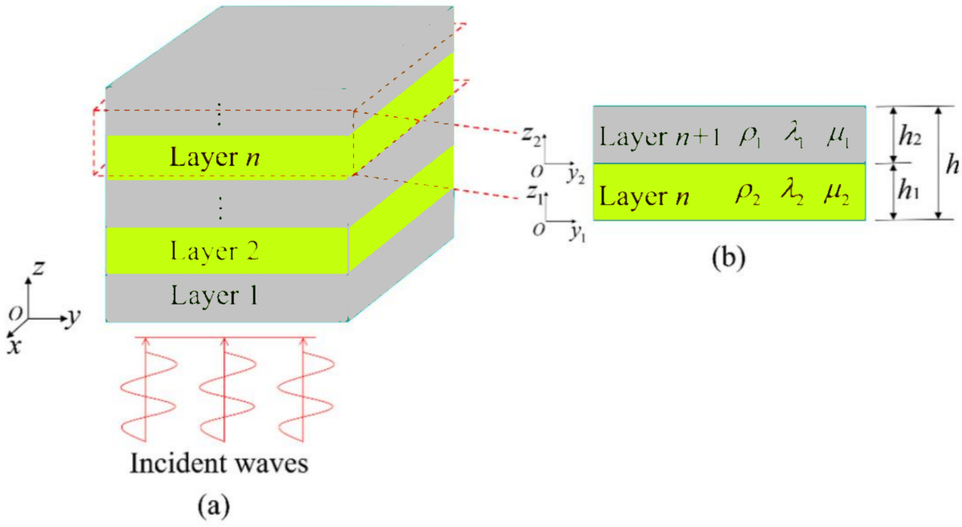

Figure 2. Periodic foundation. (a) Periodic foundation composition and vibration propagation in the z axis. (b) Periodic foundation layers.

4 Modeling in FreeCad

FreeCAD is an open source parametric 3D modeler made mainly to design real life objects [10], used in this work for modeling 2 structures, which are composed of soil, foundation and building (pillar). In order to analyze how the foundations isolate/absorb from vibration present in the ground, generated by external loads.

For this study, 2 different types of foundation were analyzed, a simple and/or more usual concrete shown in Figure 3 , and a periodic foundation, with five layers alternating between concrete and rubber with different dimensions, their configuration and dimensions. are shown in Figure 4. And in the table 1 are presented the data used in the materials used.

The ideal periodic layered structure is periodically composed of two homogeneous, isotropic, well-bonded materials at the interface. For the analysis, boundary conditions were applied so that the modeling could simulate a real structure. It is worth remembering that the simulation was carried out only with a portion of what would be a complete building, but we understand that if the structure is homogeneous and symmetrical in the x and y axes (vertical and horizontal) the energy dissipation, and/or energy absorption will happen.

Table 1. Soil properties and simple and periodic foundation materials

Material	Young's modulus (MPa)	Density (kg/m³)	Poisson's ratio
Solo	200.000,00	7850	0,4
Concreto	40,00	2300	0,2
Borracha	1,58	1277	0,46

4.1 Boundary Conditions

After modeling the structures to be analyzed, the boundary conditions were defined for the numerical study, the conditions imposed on the element serve to make the numerical model implemented as faithful as possible to what we have in reality. As previously described, this study works with three elements, soil, foundation and structure. To analyze how much the vibrations propagated by the soil affect the structure, the first boundary condition was established.

The ground is locked at its base, sides and top, restricting the movement in the x, y and z axes of all its faces, as we can see in the figure 5 - (c).

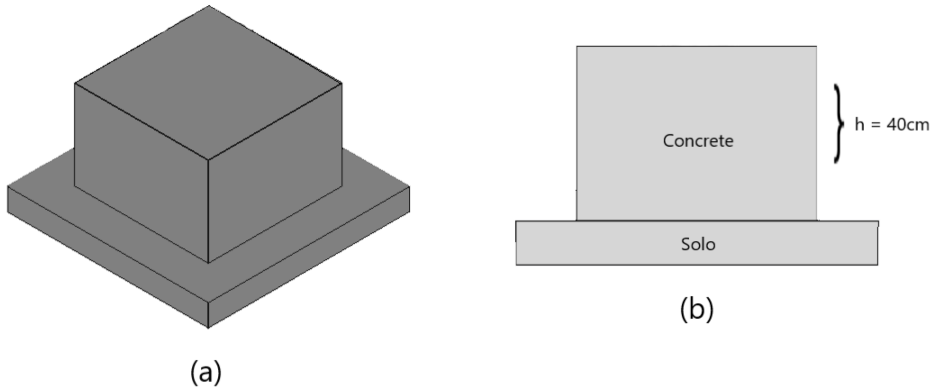

Figure 3. Simple foundation. (a) Simple foundation: Concrete block. (b) Dimension of foundation used.

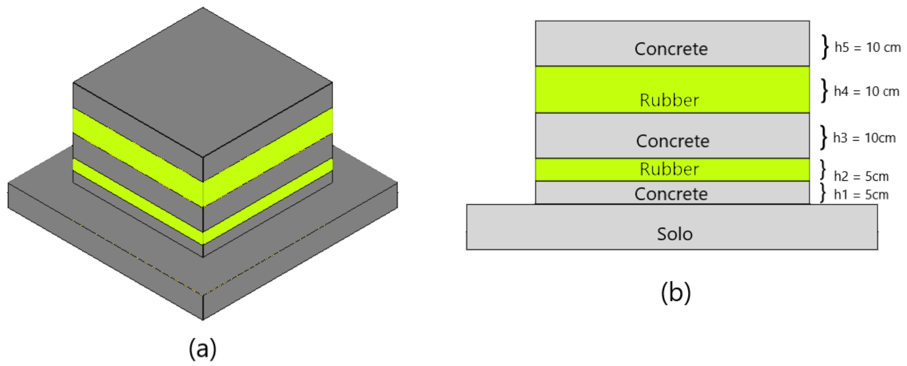

Figure 4. Periodic Foundation. (a) Periodic foundation: Block with 5 layers - concrete and rubber. (b) Dimension of each layer.

The foundation element, simple or periodic, is fixed on all sides and base, restricting movements in the x, y and z axes, on the situated faces, so its top is only set with the pillar (building) in its region of contact, also shown in figure 5 - (c).

The Pillar Element (building) is locked at its base and top, restricting the movement along the x, y and z axes on the situated faces, as shown in the figure 5 - (b) and (c).

4.2 Modal Analysis

Modal analysis is the determination of the effects of vibrations. This analysis uses the type of mass and stiffness of a structure to find the modes of natural frequencies of a component.

For this work we used modal analysis to analyze the vibration isolation of a periodic foundation compared to a simple foundation structure. The analysis was performed using the software formerly FreeCAD [10], with the aid of Solver Calculix [11] .

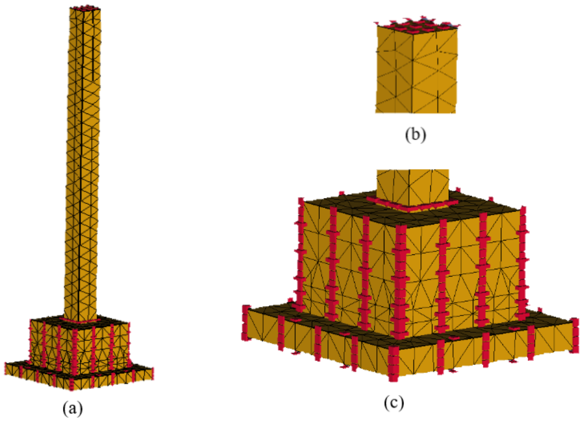

Figure 5. System boundary conditions. (a) model analyzed with mesh and boundary conditions applied. (b) Boundary condition applied to the top of the column (building). (c) Boundary condition imposed on soil and foundation..

5 Results

The present study intends to analyze the natural frequencies obtained for the simple foundation and periodic foundation in order to verify their vibration isolation. By the modal analysis we found the natural frequency modes of the structure, being it composed of soil foundation and building, for the structure containing periodic foundation we have the first natural frequency 0.1062 Hz being the first mode of vibration of the structure with simple foundation in concrete 0.0336 Hz. The second vibration mode for the structure with periodic foundation increased to 0.1063 Hz and the one with simple foundation remained the same, in the third vibration mode we have a significant increase for the simple foundation to 0.0891 Hz and a decrease for the structure with periodic foundation for 0.0282 Hz. The natural frequencies found for the structure with periodic foundation had a greater variation, in addition to having the highest vibration mode found.

6 Conclusions

The present study sought to analyze the vibrational isolation of a periodic foundation, for which two structures were modeled: a periodic foundation with different layers of materials and a simple/usual foundation for data comparison purposes. A modal analysis of these structures composed of soil, foundation and floor of the building was carried out, in order to find the natural frequency of these structures, the frequencies found were presented in the table of chapter 4, for the foundation period we obtain frequencies higher than those found for a foundation of the same size made with only one material, so understand that this difference makes for the structure to suffer some damage it is necessary to apply external forces to have more energy, so to speak even with a small difference the periodic foundation works better insulates waves propagated on the ground.

Acknowledgements. The first author gratefully acknowledge the financial support from Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES - Brazil) in form of master's scholarship - Financial Code001.

Authorship statement. The authors hereby confirm that they are the sole liable persons responsible for the authorship of this work, and that all material that has been herein included as part of the present paper is either the property (and authorship) of the authors, or has the permission of the owners to be included here.

References

[1] C. G. B. Filho and T. D. P. Araújo. Estudo analítico sobre velocidade de vibração de solos próximos a linhas ferroviárias. *XLI Ibero-Latin American Congress on Computacional Methods in Engineering*, vol. 1, n. 1, 2020.

[2] S. Silva. Vibrações mecânicas. Notas de aulas - 2.o versão, Universidade Estadual do Oeste do Paraná - UNIOESTE, Notas de Aulas - 2.o Versão. Universidade Estadual do Oeste do Paraná - UNIOESTE. Foz do Iguaçu - PR, Brasil, 2009.

[3] S. S. Rao. *Vibração Mecânica*. Pearson Prentice Hall, 2008.
[4] G. T. S. F. W. W. Kley Ernst-B.. Hartung H. and T. A.. Ultra thin high index contrast photonic crystal slabs in lithium niobate. *Optical Materials*, vol. 3, n. 2, pp. 19–21, 2010.
[5] D. Mead. Wave propagation in continuous periodic structures: Research contributions from southampton, 1964–1995. *Journal of Sound and Vibration*, vol. 190, n. 3, pp. 495–524, 1996.
[6] K. F. V. S. G. M. Chalmers L.. Elforda D. P. Matryoshka locally resonant sonic crystal. *The Journal of the Acoustical Society of America*, vol. 130, n. 5, 2011.
[7] Y. N. L. B. Chen J.. Yang L. Significant reduction of graphene thermal conductivity by phononic crystal structure. *International Journal of Heat and Mass Transfer*, vol. 91, pp. 428–432, 1996.
[8] Y. D. Y. D. L. Z. Z. J. W. Y. T. F. K. Zheng C.. Hu L. A hollow-core photonic band-gap fiber based methane sensor system capable of reduced mode interference noise. *Infrared Physics Technology*, vol. 97, pp. 105–107, 2019.
[9] E. E. N. K. M. P. I. E. S. W. Kushwaha M. S.. Sigalas M. Classical vibrational modes in phononic lattices: theory and experiment. *Oldenbourg Wissenschaftsverlag, Mu nchen*, vol. 220, pp. 765–809, 2005.
[10] FreeCAD. Version 0.19. Available - https://www.freecadweb.org/downloads.php?lang=pt$_B R$, 2021.
[11] CALCULIX. A free software three-dimensional structural finite element program - version 2.19 is. Available - http://www.calculix.de/, 2021.