Journal of Building Technology, 2026, Volume 8, Issue 1
DOI: 10.32629/jbt.v8i1.4719
ISSN Online: 2717-5103
ISSN Print: 2705-1390

Vibration periods of buildings

Mauricio Domínguez Caicedo

Universidad del Valle. Cali, Colombia

Abstract: The dynamic response of a building during an earthquake depends on the relationship between the period of vibration of the seismic waves and its own vibration frequency.

To the extent that the two periods match their values and their relationship was close to unity resonates building, significantly increasing deformations and accelerations of the building and therefore efforts in structural elements.

Knowing the value of the period is necessary to determine your response to the earthquakes that may occur in your area.

This article discusses the different periods of vibration having the structures and variation of fundamental period according to the characteristics of mass, stiffness and height have the building, according to results obtained from experimental work with scale models tested in seismic simulator.

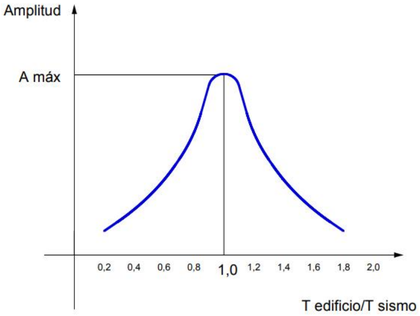


Figure 1. Variation in acceleration (or displacement) as a function of the ratio of the oscillation periods of the building and the earthquake

Key words: vibration period; buildings; earthquake

1 Development

The loads that affect buildings during a seismic event are the most critical test for their structures. For a short period of time, the earth vibrates due to the effect of energy that is suddenly released and transmitted through the strata of the ground. Ground vibration is transmitted to buildings through the foundation.

Buildings abruptly go from a state of rest, in which they mainly support vertical gravitational loads, to undergoing vibratory movement, which generates dynamic loads acting in all directions, with the horizontal components being the most critical, since in that direction the structures embedded in their foundations act as cantilevers.

Single-story buildings, having only one mass, vibrate in only one way, with the mass undergoing horizontal left-right vibration in the vertical plane.

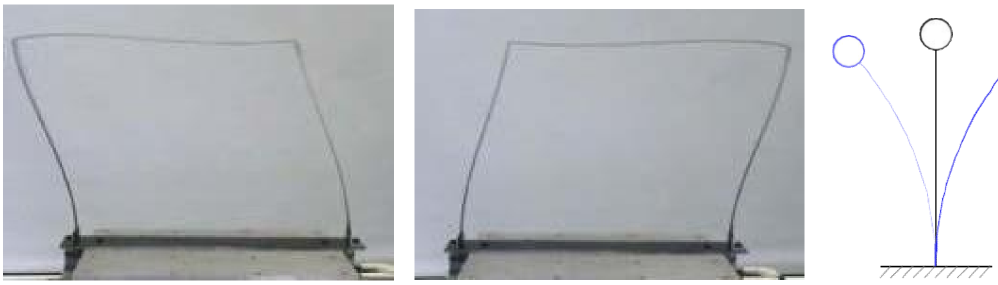
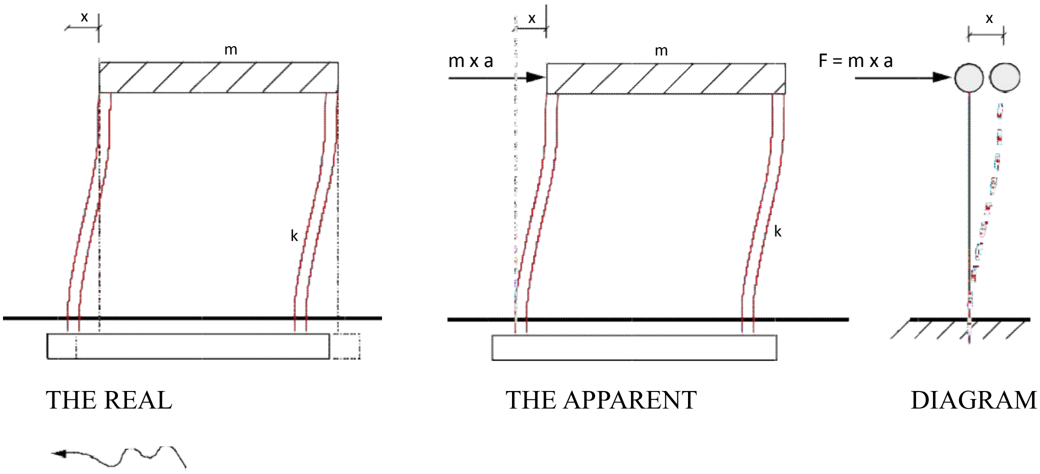


Figure 2. Vibration of a single-story frame or simple pendulum

When the base or anchorage point of the frame moves to one side, the mass of the frame tends to remain in place due to inertia, thereby causing the frame to deform. This is what actually happens. However, if we observe the image of the deformed frame (Figure 2), it can be interpreted as the frame being fixed to a rigid base, with a horizontal load applied to its top end causing deformation. This is the apparent effect. (Figure 3)

The magnitude of this inertial force will be given by Newton's formula, F = m x a, where F is inertial force, m is mass, and a is acceleration.



THE REAL

THE APPARENT

DIAGRAM

Figure 3. Single-story building as a simple pendulum

A model of three simple pendulums with different lengths and equal conditions of mass and stiffness of the bar allows us to observe that each pendulum has its own period of vibration, such that the longer the length, the greater the period. The period of each pendulum will be the period of vibration of the base that causes it to resonate, reaching maximum deformation values.

Long pendulum Ta = 0.65 sec

Intermediate pendulum Ta = 0.33 sec

Short pendulum Ta = 0.15 sec

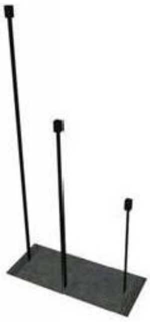


Figure 4. Model of 3 simple pendulums

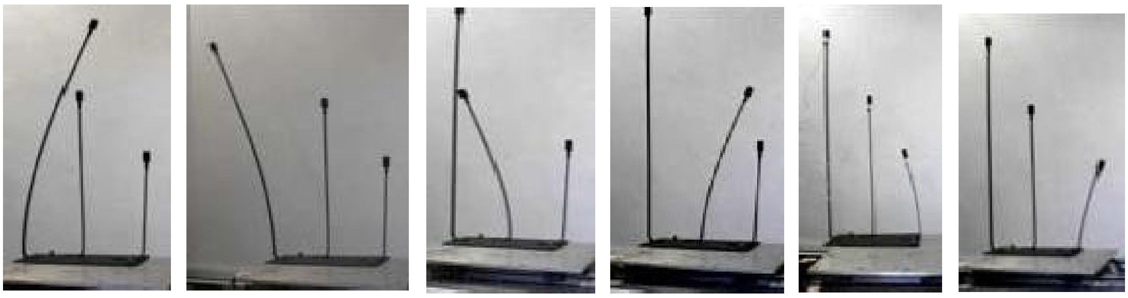


Figure 5. Resonance of each pendulum for different soil vibration periods

Multi-story buildings are multiple pendulums that can vibrate in different ways: all masses on one side of the vertical or some masses on one side of the vertical while the other masses move to the other side of the vertical.

For example, a three-story building will behave like a three-mass pendulum with three different modes of vibration.

Of the three modes of vibration of the three-mass pendulum in Figure 6, the largest shear at the base of the structure (basal shear) corresponds to the fundamental mode for which the inertial forces have the same direction, while in the other two modes the directions of these forces alternate, resulting in a lower basal shear, resulting from the vector summation.

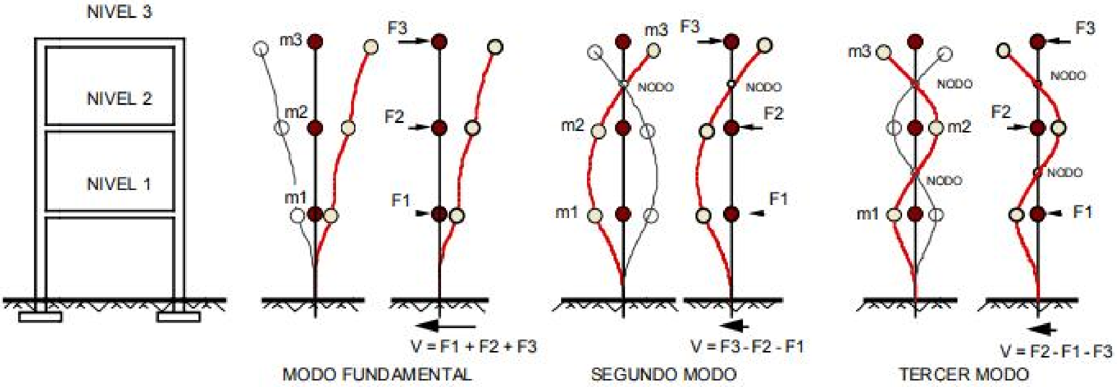


Figure 6. Three-story building and its modes of vibration as a three-mass pendulum

To verify this, a plate with three masses is installed on the vibrating table (Figure 7).

When subjected to vibration, we observe three different modes of oscillation, each corresponding to a different period, with the fundamental mode having the longest period, which is 1.5 seconds for model T= 1.5 sec. The second mode of vibration occurs for a period T = 0.17 sec, and the third mode of vibration for a period T = 0.68 sec.

Figure 7. Three-mass pendulum vibration modes

A multi-story building can have several modes of vibration, as many as it has floors, where the first mode of vibration corresponds to the longest period and each subsequent mode of vibration occurs for an increasingly shorter period.

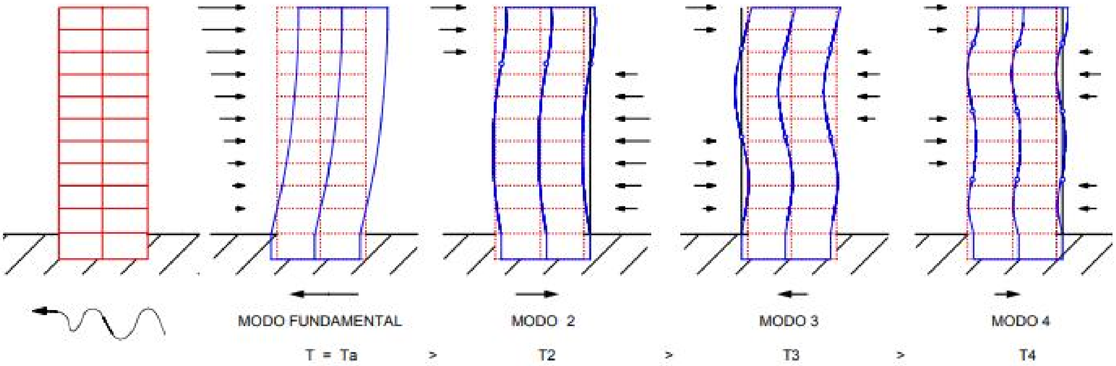


Figure 8. First vibration modes of a multi-story building

An 8-story model is tested in the seismic simulator by installing two accelerometers, one on the top floor (red signal) and the other halfway up (blue signal). The acceleration and displacement versus frequency graphs (frequency is the inverse value of the period f=1/T) in Figure 10. When the model is subjected to a frequency sweep, the frequencies corresponding to the acceleration amplitudes of the first three vibration modes are shown. The first vibration mode occurred for Ta=0.37 sec (f=2.7 Hz), while for the second mode T= 0.12 sec (f=8.4 Hz) and for the third mode the period T= 0.07 sec (f=14.5Hz).

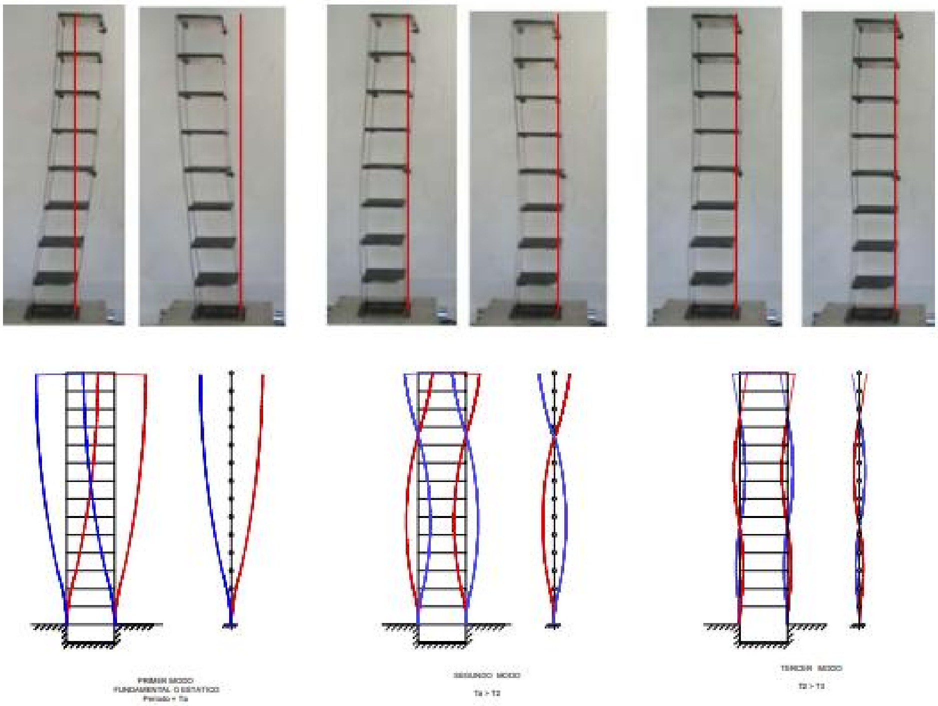


Figure 9. First three vibration modes of the eight-story model

The other higher vibration modes do not appear due to limitations of the vibration table, as they occur at frequencies higher than those for which it is rated (20 Hz).

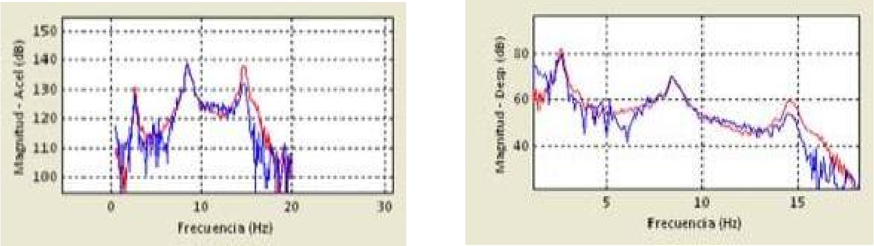


Figure 10. Acceleration and displacement versus frequency graphs for the eight-story model

The displacement graph shows that the highest values occur when the model enters resonance in the first mode, they decrease in the second mode and smaller displacements occur in the third mode. In contrast, the acceleration graph shows that the peak acceleration in the first mode is lower than in the other two vibration modes.

The level of damage that a building may suffer is related to the magnitude of the lateral displacements; the greater the lateral displacement, the greater the deformations in the structural elements and the greater the internal stresses.

In the static interpretation, the magnitude of lateral forces is linked to accelerations, which would lead us to believe that vibration modes with higher acceleration values (compared to the fundamental mode) are more critical. However, these acceleration values do not persist over time; instead, they vary rapidly, decrease, change direction, and reach a maximum value of the opposite sign before starting a new cycle. The most critical mode will be the fundamental mode, for which the greatest deformations occur, even if they do not correspond to the greatest accelerations. However, the whiplash effect, as recognized by the fact that large accelerations and displacements occur in modes other than the fundamental mode at the top of the building, starting the upper node, can result in the generation of large forces and stresses that cause the upper levels of the structure to collapse.

1.1 Influence of the soil on the vibration period of buildings

The value of the fundamental vibration period of buildings varies with the type of soil on which they stand. A building founded on rock or hard soil will behave like a cantilever perfectly embedded in the base and will have its shortest vibration period, but when the soil is soft, it deforms with vibrations, the soil-building assembly becomes more flexible, and the period increases as it behaves as partially embedded due to the deformation of the embedding.

A model of a simple pendulum in Figure 11 tested on a vibrating table allows us to observe the change in period as the characteristics of the fixed base are modified.

To simulate different ground conditions, the pendulum is embedded on three different bases: wood (rocky ground), high-density foam (semi-soft ground), and low-density foam (soft ground).

Although the three pendulums are identical, different vibration periods are recorded, with the model embedded in wood having the shortest period and the pendulum embedded in low-density foam having the longest period.

a) Hard ground, rock b) Intermediate hardness ground c) Soft ground

Figure 11. Model simulating three different ground conditions

The period values for the tested model recorded vibration period values of Ta= 0.38 sec, 0.42 sec, and 0.50 sec for the three types of soil simulation described.

1.2 Response and seismic design spectrums

The vibration movement record is characterized by the values of Amplitude A and period T, where A is the highest value of the displacement, velocity, or acceleration record, and T is the time in seconds of an oscillation.

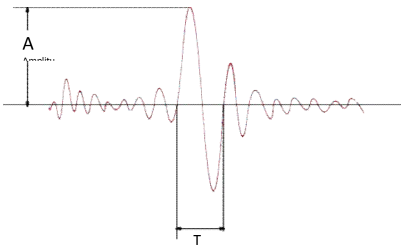


Figure 12. Amplitude and period of seismic motion

The vibration period of seismic waves increases as they move away from the epicenter, while the amplitude decreases as the released energy dissipates.

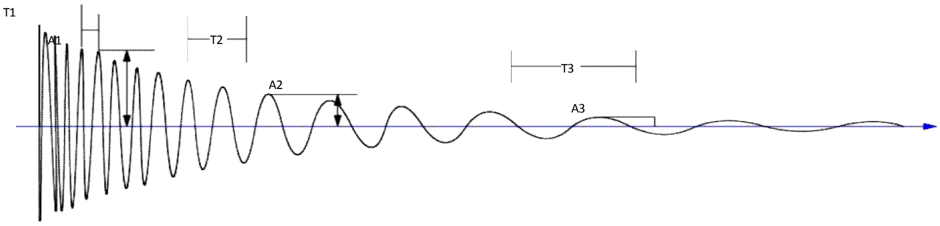


Figure 13. Variation of amplitude and period with epicentral distance

Since the fundamental vibration period of buildings varies with their height (the Colombian NSR standard establishes an approximate fundamental vibration period of Ta=0.1N, where N is the number of floors, applicable to buildings with braced frame systems and floor heights not exceeding 3.0 m), the resonance between ground and building vibrations varies with distance from the epicenter:

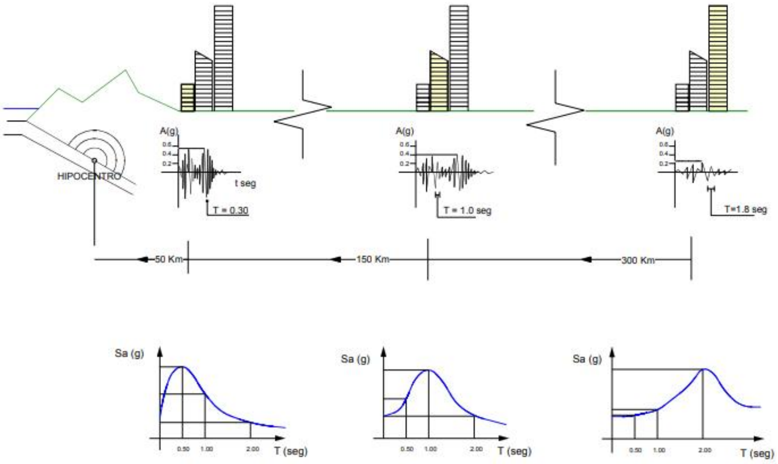


Figure 14. Variation in amplitude, period, and response spectra with distance from the epicenter

Near the epicenter, the ground vibrates at high frequency, with short periods of a few tenths of a second, where low-rise buildings enter into resonance. As you move away from the epicenter, seismic waves produce longer period ground vibrations, which can be close to 1.0 sec at distances between 100 and 150 km, where buildings of around 10 stories are most likely to resonate. and at distances of 300 km or greater, the ground vibration period will be close to 2.0 seconds, with buildings around 20 stories high being those that can reach resonance with their fundamental period.

However, during a nearby earthquake, a tall building may resonate at a vibration mode higher than the fundamental mode.

If this physical phenomenon is plotted on a coordinate system of building vibration period T versus building acceleration, the so-called Response Spectra are obtained, which will have different expressions for different epicentral distances, as shown in Figure 14.

It is important to note that the amplitude of ground motion increases when soft soil deposits are encountered, reaching values similar to those corresponding to nearby distances, as occurred in Mexico City during the 1985 earthquake.

Since soft soil deposits also modify the vibration period of buildings by increasing its value, for the example of the city located at a great distance from the epicenter, resonance will occur for buildings of intermediate to high heights, as shown in Figure 15.

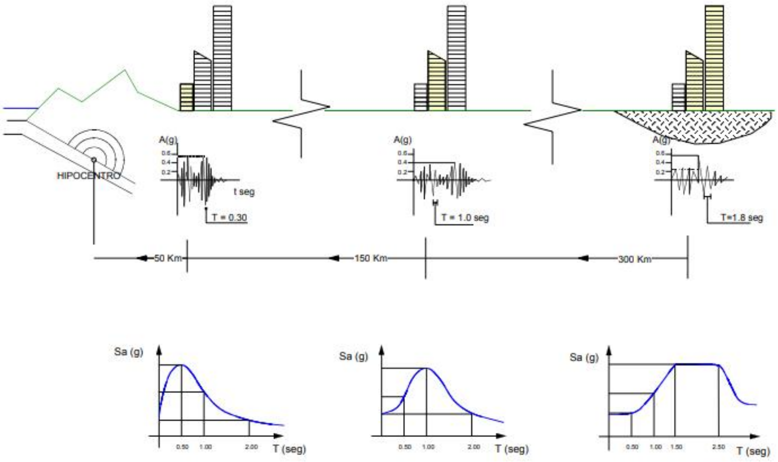


Figure 15. Amplification of amplitude and variation in the response spectrum for soft soil deposits at a great distance from the epicenter

Building regulations determine design spectra that establish the expected acceleration value based on the fundamental vibration period of the building analyzed.

Since the energy released during an earthquake dissipates with distance, it will be much greater in locations close to the epicenter. Given the need to assume the design for the most critical seismic load conditions, design spectra are established for nearby earthquakes. As an example, the design spectrum of the Colombian standard NSR-10 in Figure 16.

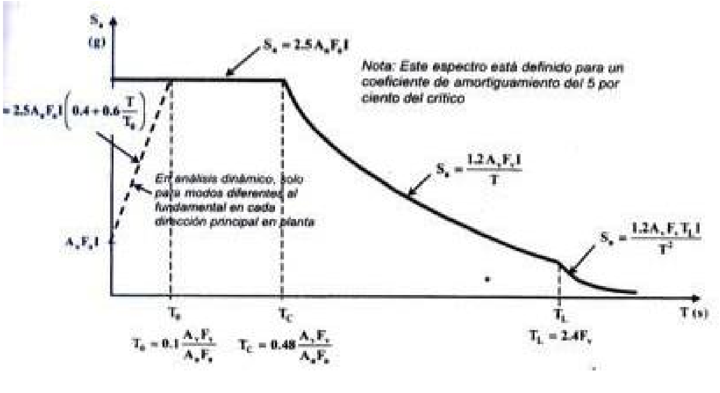


Figure 16. Design spectrum of the Colombian standard NSR-10

The importance of determining the vibration period of structures with relative precision can be estimated from the following paragraph extracted from NSR-10: "The fundamental vibration period of structures allows us to predict the forces to be applied to the structure in order to dimension its seismic resistance system" (NSR 10 -A.4.2.3.). The seismic shear at the base, Vs, is obtained from the equation Vs= Sa g M "(A.4.3.1.) where the value of Sa corresponds to the value of the acceleration read in the spectrum for the period T of the building.

1.3 Effect of non-structural brick masonry walls attached to the structure

The use of non-structural brick masonry elements when they are not isolated from the structure increases the stiffness of the structure, reducing its vibration period. This is most noticeable in buildings with a structural frame system that need to deform in order to resist seismic loads. If the wall completely blocks the space between columns and beams, it prevents lateral displacement, and when it comes into contact with the wall, it produces the effect of a diagonal or brace, altering its flexibility and giving it the stiffness of a building with a structural wall system. As long as the masonry resists seismic loads for which it was not designed, it will break and detach, and the structure will regain its flexibility (Figure 17).

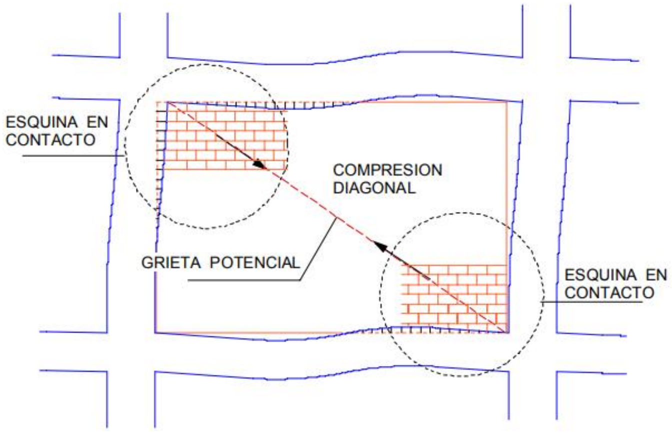


Figure 17. Effect of equivalent diagonal produced by non-structural masonry wall attached to the structure.

As a result, the actual structure will be completely different from the calculated structure, and its vibration period will be shorter than that used in the design spectrum to estimate its acceleration. As the period decreases, it falls into the area of the spectrum with higher accelerations, and the structure will take on greater seismic loads than those estimated in the design.

1.4 Influence of mass characteristics, column stiffness, and building height on the value of the fundamental vibration period of buildings.

Given the importance of accurately determining the fundamental vibration period of buildings in order to determine the magnitude of the inertial forces that will affect them during seismic events that may occur, research has been conducted at the Structures Laboratory of the School of Architecture of the University of Valle in the city of Cali, Colombia, using shaker table simulations of reduced-scale models of frame-structured buildings.

The research seeks to experimentally determine, using reduced-scale models, the influence that parameters such as the masses of the floors that make up a building, the stiffness of its structural elements, and the height of the building have on the fundamental period of a building, establishing relationships between the values obtained in models with different characteristics, analyzing combinations of three heights, two masses, and two different stiffnesses, for a total of 12 models with different characteristics.

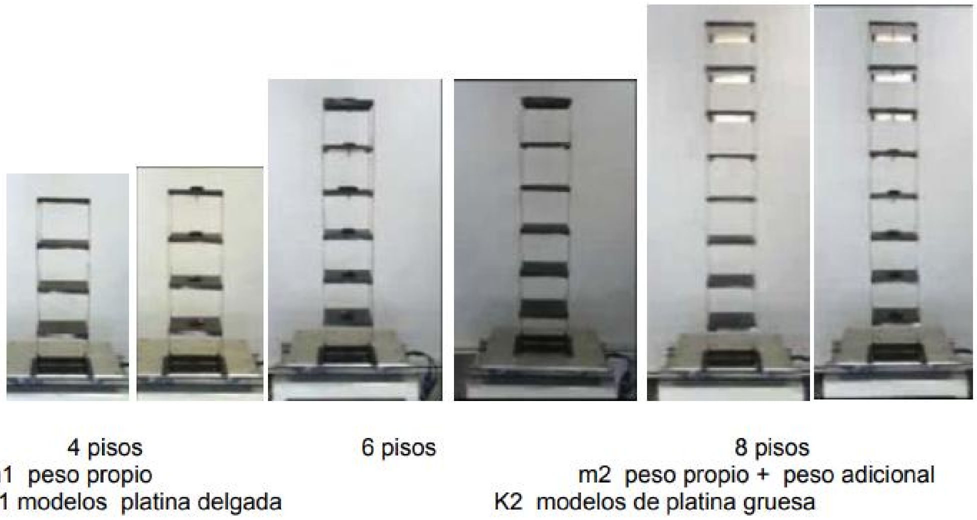
The fundamental vibration period is determined using accelerometers installed on reduced-scale models subjected to unidirectional oscillations based on the recording of accelerations versus frequencies provided by the data acquisition system. By establishing relationships between the values obtained, the influence of the mass, stiffness, and height of the building on the fundamental vibration period is determined graphically.

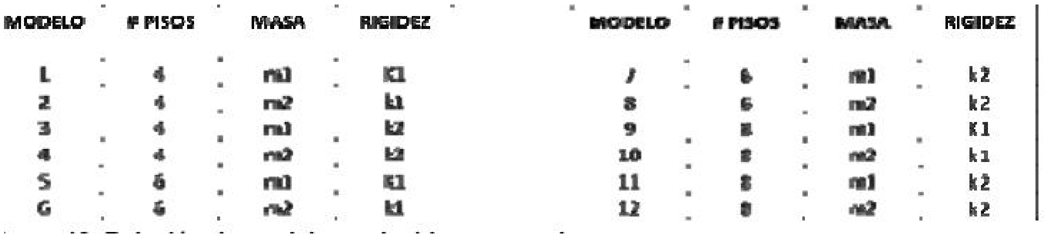
The material used in the manufacture of models is aluminum sheets and aluminum plates. The columns are simulated with plates and the floors are simulated with sheets.

Models of three different heights were manufactured: 4, 6, and 8 stories. To obtain two different stiffness values for each height, sheets of two different stiffnesses were used for each of the heights, resulting in six types of models.

To obtain two mass values at each level of the six models of different heights and stiffness, additional weights can be installed, resulting in 12 types of models, 6 with their own weight 8 (m1) and 6 with their own weight + additional mass (m2).

The models were tested in a seismic simulator or uniaxial vibrating table that operates by magnetic fields, with a platform for the embedding of the models of small dimensions (50x50 cm), controlled by software that allows the programming of constant frequency vibrations or frequency sweeps from f=0 Hz to f=20 Hz during the time desired, with a displacement range of up to 20 mm and a weight of up to 20 kg.





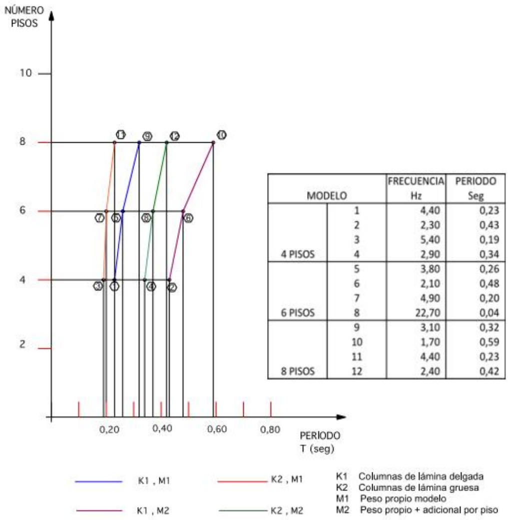
MODELO	# PISOS	MASA	RIGIDEZ	MODELO	# PISOS	MASA	RIGIDEZ
1	4	m1	K1	7	6	m1	k2
2	4	m2	k1	8	6	m2	k2
3	4	m1	k2	9	8	m1	K1
4	4	m2	k2	10	8	m2	k1
5	6	m1	K1	11	8	m1	k2
6	6	m2	k1	12	8	m2	k2

Figure 18. Relationship of tested reduced-scale models

The results of the research are expressed in three graphs that relate the vibration period versus the height of the building linked to the number of floors (Figure 19), the vibration period versus the stiffness of the vertical elements (Figure 20), and the vibration period versus the mass (Figure 21).

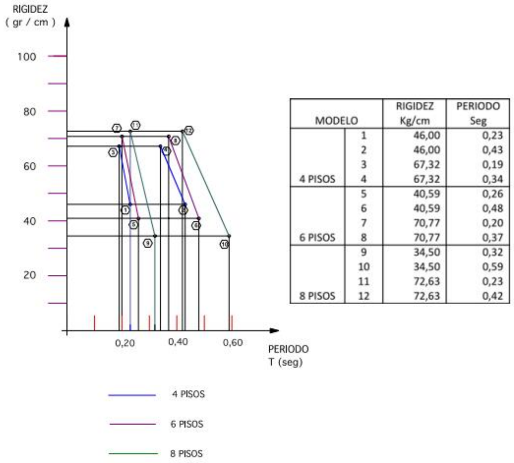
The conclusion is that:

- The greater the height (or number of floors), the longer the vibration period
- The greater the rigidity, the shorter the vibration period
- The greater the mass, the longer the vibration period.



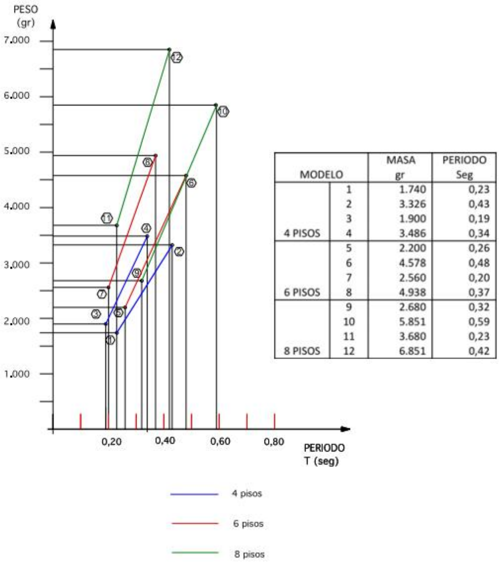
MODELO		FRECUENCIA Hz	PERIODO Seg
4 PISOS	1	4,40	0,23
	2	2,30	0,43
	3	5,40	0,19
	4	2,90	0,34
6 PISOS	5	3,80	0,26
	6	2,10	0,48
	7	4,90	0,20
	8	22,70	0,04
8 PISOS	9	3,10	0,32
	10	1,70	0,59
	11	4,40	0,23
	12	2,40	0,42

Figure 19. Variation in period in relation to the number of stories for different mass and stiffness conditions



MODELO		RIGIDEZ Kg/cm	PERIODO Seg
4 PISOS	1	46,00	0,23
	2	46,00	0,43
	3	67,32	0,19
	4	67,32	0,34
6 PISOS	5	40,59	0,26
	6	40,59	0,48
	7	70,77	0,20
	8	70,77	0,37
8 PISOS	9	34,50	0,32
	10	34,50	0,59
	11	72,63	0,23
	12	72,63	0,42

Figure 20. Variation in period in relation to stiffness for models with different numbers of stories



MODELO		MASA gr	PERIODO Seg
4 PISOS	1	1.740	0,23
	2	3.326	0,43
	3	1.900	0,19
	4	3.486	0,34
6 PISOS	5	2.200	0,26
	6	4.578	0,48
	7	2.560	0,20
	8	4.938	0,37
8 PISOS	9	2.680	0,32
	10	5.851	0,59
	11	3.680	0,23
	12	6.851	0,42

Figure 21. Variation in period in relation to mass for models with different numbers of floors

2 Conclusion

Buildings have different modes of vibration, each corresponding to a different vibration period.

Buildings enter into resonance during a seismic event for one of their vibration modes when the vibration period of the ground coincides with the period of that vibration mode.

Of the different modes of vibration that structures have, the most important for structural analysis is the so-called Fundamental mode, as it corresponds to the greatest deformations and, therefore, the greatest stresses on its structural elements.

Seismic-resistant building regulations establish the magnitude of the inertial forces generated by the vibration of structures based on the fundamental vibration period.

The fundamental vibration period of buildings depends on their height, stiffness, and mass characteristics

The type of soil is also a determining factor; soft soils deform with vibration, making the soil-building complex more flexible and increasing its vibration period.

The presence of rigid non-structural walls (masonry) attached to the structure without allowing free deformation significantly varies its vibration period, decreasing it, which is more critical for nearby earthquakes. If non-structural walls are not isolated from the structure and are not taken into account in the analysis, the calculated structure will be very different from the actual structure, and an error will have been made in determining the inertial forces of the earthquake.

The results of research carried out with reduced-scale models show the direct relationship between the fundamental vibration period and the characteristics of height and mass, and the inverse relationship with stiffness.

Conflicts of interest

The author declares no conflicts of interest regarding the publication of this paper.

References

[1] Colombian Seismic Resistance Standard NSR-10

[2] Wave propagation. Article: 8, published on: 2011-05-31 University of Costa Rica Seismic Engineering Laboratory Institute of Engineering Research (INII)

[3] Sarria Molina, A. Seismic Engineering. Colombia, Editorial Uniandes, 1995

[4] Long-period vs. short-period earthquakes: How do they affect buildings? National Geographic video. Retrieved from: www.ingcivilperu.blogspot.com