Changes in the fundamental periods of buildings constructed with the great soviet panel

Cambios en los períodos fundamentales de edificaciones construidas con el gran panel soviético

Resumen

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After a visual inspection of 200 buildings built with the prefabricated great soviet panel system in Santiago the Cuba, factors leading to potential seismic damage were detected. These factors include pathological damage to structural elements and joints, with severe levels of damage. Likewise, changes in weight and / or rigidity, due to the violations of the residents. In order to forecast the seismic behavior of these buildings, the fundamental period is determined in 7 of them through environmental vibrations. Then, with these results, using linear analysis methods, the models of the buildings are calibrated. In the calibration, flexural stiffness modifiers are iteratively incorporated into the structural models. In addition, the properties of the materials are taken into account based on the results of destructive and non-destructive tests on concrete and steel. Both by instrumental and analytical means, similar values of the fundamental periods of oscillation are reached when faced with the earthquake of calculation. Changes in the seismic behavior of these buildings are envisaged as a result of increases in the fundamental periods of oscillation and the coupling of the oscillations.

Keywords: fundamental periods of oscillation; environmental vibrations; calibration; seismic behavior; stiffness modifiers.

Abstract:
Se detectaron, tras una inspección visual, a 200 edificios construidos con el sistema prefabricado Gran Panel Soviético en Santiago de Cuba, factores conducentes a daños sísmicos potenciales. Entre estos factores se pueden citar los daños patológicos en elementos estructurales y juntas, con niveles severos de afectación. Igualmente, transformaciones en el peso y/o la rigidez, a causa de las contravenciones de los moradores. Con el objetivo de pronosticar el comportamiento sísmico de estas edificaciones, se determinan en 7 de ellas los períodos fundamentales a través de las vibraciones ambientales. Luego, con estos resultados, empleando métodos de análisis lineal, se calibran los modelos de las edificaciones. En la calibración, se incorporan a los modelos estructurales, de forma iterativa, modificadores de rigidez a flexión. Además, se tienen en cuenta las propiedades de los materiales en base a los resultados de ensayos destructivos y no destructivos al hormigón y al acero. Tanto por vía instrumental como analítica se llegan a alcanzar valores similares de los períodos fundamentales de oscilación ante el sismo de cálculo. Se avizoran cambios en el comportamiento sísmico de estas edificaciones, como producto de incrementos de los períodos fundamentales de oscilación y al acoplamiento de las oscilaciones.

Palabras clave: períodos fundamentales de oscilación; vibraciones ambientales; calibración; comportamiento sísmico; modificadores de rigidez.

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1.Introduction

In the city of Santiago de Cuba, the area of greatest seismic danger in Cuba, buildings were built for a long period of time (1964-1991) with the prefabricated I-464 system, known as the Great Soviet Panel. This system became the main resource for solving housing problems in that city. It was implemented with two types, with balcony and without balcony, with 4 or 5 levels fundamentally. The buildings are developed vertically, very symmetrical in plan and elevation; with each building from one stairwell to six, but contemplating expansion joints at most every 2 stairwells.

The system is based on structures of large reinforced concrete panels joined by steel bars, where the joints are filled with concrete poured in situ (wet joints) to produce a unitary, rigid and homogeneous element. The vertical panels are located both transversely and longitudinally (crossed system). Also the horizontal joints between the slabs and the panels are wet joints, which allows the adequate work of the mezzanines and roof as a rigid disk. This has allowed to show good seismic behavior in countries where it has been implemented, such as Chile in 1985, 2010 and 2012 and Armenia in 1988.

However, there is concern about the seismic behavior of these buildings built in Santiago de Cuba. Recently Socarrás and Álvarez (2019) detected, after a visual inspection of a sample of 200 buildings, pathological damage to structural elements and joints, with severe levels of damage. Likewise, changes in weight and / or rigidity, due to the violations of the residents. The pathological damages have as their starting point humidity, as a result of the breakdown of the hydrosanitary facilities. Steel corrosion and concrete disintegration mechanisms were both noticeable. The weight transformations are due to the addition of water tanks in the service yards and the addition of masonry walls in the multipurpose areas. The transformations in rigidity are due to the opening of panels, elimination of panels and opening of slabs. Among the transformations of stiffness and weight are the lattices filling of the panels of the longitudinal facades.

For this reason, it is urgent to undertake structural seismic rehabilitation actions based on evaluations of seismic behavior. As the determination of the fundamental oscillation periods of a building, in each of its main directions, is the essential dynamic property that determines its seismic behavior, this research focuses on determining it in 7 buildings that were distinctive from the sample of buildings. There are 6 of these buildings that have 5 levels without balcony (A, B, C, E, F, G) and one has 4 levels with balcony (D). Buildings A, B, C, E, F have severe pathological damage in the structural elements and their joints, weight transformations, as well as rigidity and weight transformations. Although building D has a good technical-constructive state, it has weight transformations, rigidity transformations as well as rigidity and weight transformations. The transformations in stiffness are caused by an opening in a transverse panel on the 1st level of a corner apartment. In building G there are only pathological damages in the elements and joints.

To obtain the fundamental periods of oscillation, two methods are used, one experimental and the other analytical. Initially, the experimental method is used, which is based on measurements caused by environmental vibrations, mainly generated by human activity, the operation of industrial machinery and vibrations produced by the wind. This method is very simple and inexpensive; therefore, its use has increased in recent years. Researchers such as Peña (2010), Peralta, Sánchez & Arroyo (2014), Esquivel & Schmidt (2016), Díaz (2017), have used it to control and verify the quality of a rehabilitated work, control the damage caused by an earthquake, calibrate models structural, determine the characteristic period of a terrain, among others.

Specifically, Peralta et al. (2014), compare the fundamental periods of oscillation of two typical buildings, obtained by numerical models and by environmental vibrations. A building with cracks in the walls, damp tiles and collapse of an area; the other building without structural problems. The fundamental periods obtained by environmental vibrations (T_{VA}), in the damaged building, exceed between 12.4-33% the period values of the building without damage. At the same time, by calibrating the models with the reduction of the masonry modulus of elasticity, they achieve that the fundamental periods of oscillation of the models are equal to the T_{VA}.

For this reason, this research considers that the TVA reflect the possible deterioration suffered in the buildings, and can be chosen as a starting point for the calibration of the structural models when the analytical method is used, with the SAP 2000 v20 software. In this calibration flexural stiffness modifiers are used iteratively and the strength of concrete and steel is also reduced in elements with pathological damage, according to the results of destructive and non-destructive tests. At the same time, it is valued that during an earthquake the fundamental periods of oscillation of a structure can be much greater than those obtained through a vibration generator, as stated by Oliva (2018). For structures with shear walls (prefabricated in one direction), Chopra (2014) obtained increases between 2-48%. Polyakov (1974) considers in the case of large panel prefabricated structures that the increases are around 15%. Then, this research assumes in the calibration of the models that the fundamental periods of oscillation in the structural models (Tmodel), must comply with: (Tmodel) ≈ (1.02-1.15) T_{VA}.

Finally, the values of the fundamental periods of oscillation obtained experimentally and analytically, are compared with each other and with empirical values. These empirical values are obtained through expressions that essentially relate the type of material, the structural system, the type of soil, the plan dimensions and the total number of floors. This analysis allows to conclude that, both by instrumental and analytical means, changes in the seismic behavior of instrumented buildings are envisioned. Increases in the fundamental periods of oscillation are observed with the consequent increase in deformations and coupling of the oscillations. This behavior is influenced by pathological damage to structural elements and joints, as well as weight transformations and rigidity transformations.

2. Methods

2.1. Experimental method

To determine the fundamental period of oscillation in an experimental way, of the buildings built with the Great Soviet Panel, the environmental vibrations are taken as a source of excitation. 7 representative buildings are chosen from a sample of 200 buildings, which were inspected. Table 1 shows the dimensions of the buildings in plan and elevation.

Building	Building length (L)	Building width (A)	Balcony width (b)	Building height (H)
A,B, C, E, F, G	32m	9.6m		14.33m
D	32m	9.6m	1m	11.63m

Table 1. Dimensions of buildings in plan and elevation
Source: Authors (2020)

The buildings are made up of 12 cm thick transverse interior panels, spaced 3.20m apart, and 15 cm thick interior longitudinal panels, spaced 4.80m apart. All the outer panels are 15 cm thick in both directions, in their central area, but at the edges they increase to 25 cm. The mezzanine and roof slabs are 12 cm thick. The foundations of the buildings are straight, with rectangular section cast in situ beams on which small panels called baseboards are placed. All the elements that make up the system are prefabricated.

The criteria to be taken into account in the selection of the 7 buildings were the state of conservation, the number of floors, as well as the weight and / or rigidity transformations. These criteria are described below:

- The buildings A, B, C, E, F have 5 levels without balcony, they present severe pathological damages in the structural elements and their joints, weight transformations, as well as rigidity and weight transformations.
- Building D, has 4 levels with balcony, although it has a good technical-constructive state, it shows weight transformations, rigidity transformations as well as rigidity and weight transformations. The changes in rigidity in this building are due to an opening in a transverse panel on the 1st level of a corner apartment.
- Building G has 5 levels without balcony and only presents pathological damage to the elements and joints.

The weight transformations of the instrumented buildings are due to the addition of water tanks and masonry walls. In the case of rigidity and weight transformations, they are due to the fillings of the lattices of the longitudinal façade panels.

In each building three measurement points are selected. These points were located in the center of the rooftops and at the opposite ends, to measure the longitudinal and transverse fundamental periods and to assess the torsion. For their location, it was considered:

- Easy access.
- The distance from sources that generate noise and the movement of people.
- The coincidence with the lines of symmetry of the building, in plan and elevation.

In Figure 1, the location of the three measurement points in each instrumented building is shown. The north of the team is also indicated.

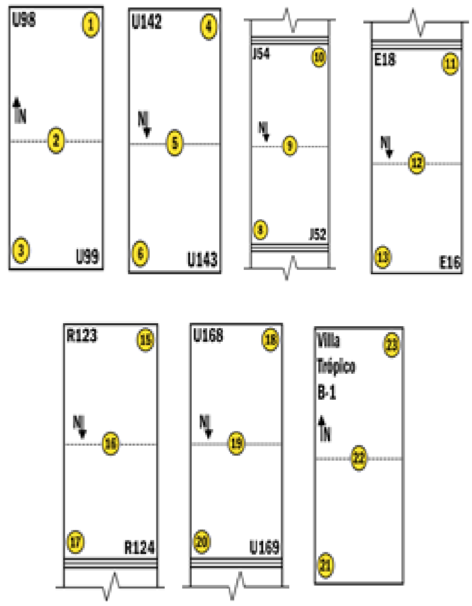


Figure 1. Measurement points in the 7 buildings
Source: Authors (2020)

The measurements were made on the roofs of the buildings in a time period of 5 minutes each. A medium period seismometer (Marslite) and a digitizer (EDAS-3M) were used. The registration of the digital signals obtained is processed with the GEOPSY program (Wathelet, 2011), which is a software for processing signals recorded by seismological stations and geophysical sensors. This program allows spectral analysis through the "Discrete Fourier Transform" (DFT) using the "Fast Fourier Transform" (FFT) algorithm. Basically, this program applies the fast Fourier transform to a signal in the time domain to convert it to the frequency domain. The registration of digital signals is considered discrete. These input and output signals are processed by the program on the previously windowed data, determining:

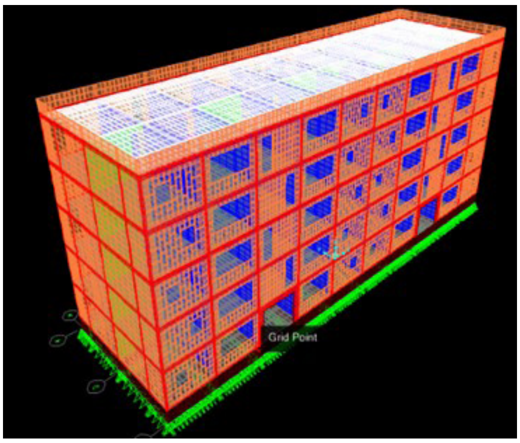
- The arithmetic mean of the sample.
- The variance.

- The auto-correlation function or the power spectral density.
- Estimation of the power spectrum.

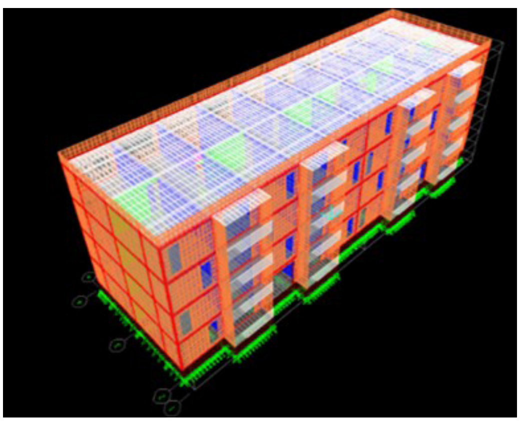
Thus, for each measurement point, the time series and their corresponding frequency spectra are obtained. After obtaining the natural frequency for each measurement point, its inverse is calculated, which corresponds to the fundamental period of oscillation.

2.2. Analytical method

Multi-mass models of buildings were developed for dynamic analysis with SAP 2000 v20, reflecting the properties of materials, geometry and the links between component elements. The panels are modeled like the slabs, as finite elements type "Shell", joined continuously to each other to produce a rigid and homogeneous structural system. Likewise, stair slabs are modeled as "Shell" type finite elements connected to panels and slabs. Figure 2 shows the isometrics of the geometric models.



A) Building A, B, C, E, F, G



B) Building D

Figure 2. Geometric models
Source: Authors (2020)

The strengths of the materials are obtained from destructive and non-destructive tests on concrete and steel, according to table 2. Socarrás et al. (2020a) and Socarrás et al. (2020b) detail the results of the concrete tests that were carried out both on elements that are still in the warehouse area of the precast plant and on elements that are forming the buildings.

Material characteristics			
Steel	Diameter (mm)	fy in elements without pathological damage (MPa)	fy in elements with pathological damage (MPa)
Corrugated	9.5	328.72	205.45
	12	324.43	202.76
Smooth	3	948.58	592.86
	6	397.40	248.37
	8	554.62	346.63
	f´c (MPa)	Modulus of elasticity E (MPa)	
Precast concrete in elements without pathological damage	16.00	13536.00	
Precast concrete in elements with pathological damage	12.79	12102.23	
Lattice filled concrete	10.00	10701.14	

Table 2. Characteristics of the materials
Source: Authors (2020)

The modulus of elasticity of precast concrete is calculated using the expression recommended by the American Concrete Institute (ACI 318-19), but with a reduction greater than 40%, as recommended by Lewicki (1968) for buildings made of precast panels. On the other hand, it increases by 20% because it is the seismic action of short duration, totaling a penalty of 28%. The shear modulus G is obtained from the modulus of elasticity E, assuming a Poisson's ratio v = 0.17 for concrete.

To reflect the degree of cracking and inelastic action that occurs in the elements immediately before creep, stiffness modifiers are used iteratively, proposed by the Federal Emergency Management Agency (FEMA-273) and the American Concrete Institute (ACI: 318-19). Table 3 summarizes the flexural stiffness modifiers used in the calibrated structural models. For the filling of lattices, 0.15 EI is used, because it is assumed that they provide instantaneous stiffness.

In the calibration of the models, an increase between 2-15% of the T_{VA} values is assumed, because according to Chopra (2014) only under small oscillations the fundamental period of a linear system is equal to the elastoplastic one; but at higher amplitudes of movement when an earthquake occurs, the fundamental period increases. In turn, Chopra (2014) for a structure made up of shear walls cast in situ and prefabricated, obtained increases before an earthquake, of the instrumented periods, between 2-48%. Polyakov (1974) obtained increases of 15% for buildings built with the precast I-464 AC system. Therefore, the calibration range of the fundamental periods of the models is: Tmodel ≈ (1.02-1.15) T_{VA}.

Building	Stiffness Modifiers			
	Plinths	Long interior panels	Long exterior panels	Transv Interior panels
A	0.70EI	0.35EI	0.35EI	0.35 EI
B	0.70EI	0.35EI	0.35 EI	0.35 EI
C	0.70EI	0.70 EI	0.70EI	0.35 EI
D	0.70EI	0.70EI	0.70EI	0.35 EI
E	0.70EI	0.35 EI	0.35 EI	0.35 EI
F	0.70EI	0.35 EI	0.35 EI	0.35 EI
G	0.70EI	0.35 EI	0.35 EI	0.35 EI
Building	**Transv Exterior panels**	**Panels with severe pathological damage**	**Slabs**	**Slabs with severe pathological damage**
A	0.35EI	0.15EI	0.25EI	0.10EI
B	0.35EI	0.15EI	0.25EI	0.10EI
C	0.35EI	0.15EI	0.25EI	0.10EI
D	0.70EI	-	0.25EI	-
E	0.35 EI	0.15 EI	0.25EI	0.10EI
F	0.35 EI	0.15 EI	0.25EI	0.10EI
G	0.35 EI	0.15 EI	0.25EI	0.10EI

Table 3. Bending stiffness modifiers in the calibrated structural models
Source: Authors (2020)

The permanent and utilization loads were defined respecting the considerations of the original projects. As permanent loads, three layers of gravel asphalt (0.28 kN / m^2) are considered on the roof; on the mezzanines, the floor filling (0.180 kN / m^2 / cm), the mortar (20.00 kN / m^3) and the mosaic (0.230 kN / m^2 / cm). For the loads of use, the roof takes into account the drainage by drain (2,000 kN / m2) and in the mezzanines, rooms of common homes (1,500 kN / m^2) are assumed. The self-weight of all the elements is generated by the SAP2000 v20 software from the specific weight of the material (25 kN / m^3).

Within the permanent loads on the modeled buildings, the following were also added:

- Water tanks in the service yards.
- Masonry wall in multipurpose areas.
- Filling with concrete the lattices that have some panels.

Seismic loads are modeled as stipulated by the Cuban National Standardization Office (NC 46: 2017), with the Response Spectrum Method (MER) and the Equivalent Static Method (MEE) using the fundamental periods of modal analysis. The three fundamental components of an earthquake are considered, the two horizontal and the vertical, combining 100% of the seismic load in one of the main directions, simultaneously with 30% in the remaining directions. The seismic load in the vertical direction is modeled as an increase in the total permanent load that includes the self-weight of the structure. This increase is estimated as 20% of the permanent load mentioned above by the response acceleration for a short period determined in the Design Spectrum for the considered soil profile. Also in each one of the floors the accidental eccentricities of the mass centers with respect to the rigid centers were considered. For the proposed model, it is verified that the centers of stiffness of each of the floors coincide approximately with their centers of mass, hence their position was assumed the same for all floors. For the MER, the CQC was used as the modal superposition formula.

The design response spectrum used was elaborated for residential buildings built in Santiago de Cuba, considering the location of the buildings studied and reductions in the spectral ordinates for the energy dissipation of the prefabricated Great Soviet Panel system assumed in the research. See figure 3. The considerations for the elaboration of this spectrum are detailed below:

- Seismic danger zone: Very high (zone 5), where the maximum horizontal accelerations from the ground (0.3g).
- Basic Earthquake: which for periods of useful life of 50 years and an accepted exceedance probability of 10% correspond to a return period of 475 years from the design earthquake.
- Type of soil: profile D.
- Structural system: E2 (Wall system) o Ductility reduction factor R = 1.5, assuming quasi-elastic response. It is valued that they are prefabricated structures designed by repealed codes, with little ductility of the steel of the structural elements and inadequate detailing of the sections of the elements.

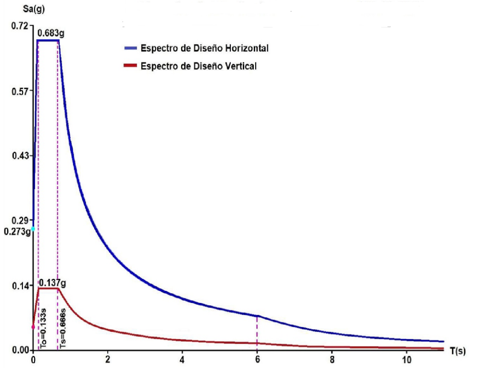


Figure 3. Design spectrum for horizontal and vertical loads according to NC 46-2017
Source: Authors (2020)

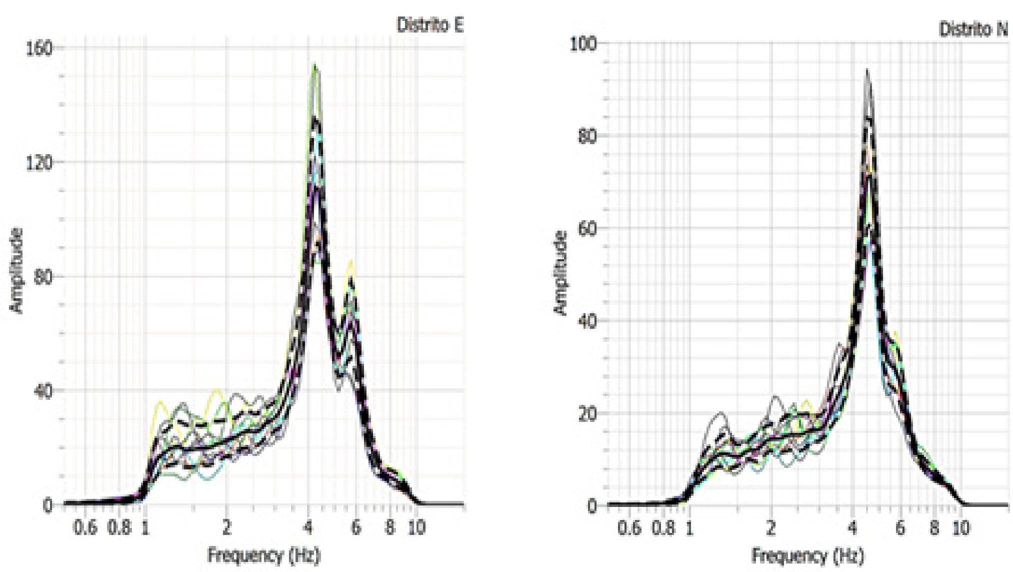
3. Results

3.1. Experimental method

For each of the selected points of the 7 buildings, the time series and their frequency spectra are processed, which allow obtaining the values of the fundamental periods of oscillation. Table 4 summarizes the frequency (W) and fundamental oscillation period (T) values for each measurement point. Figure 4 shows the frequency spectra corresponding to point 4 of building B.

Buildings	Points	W E - O (Hz)	W N - S (Hz)	T E-O (s)	T N - S (s)
A	1	4.64	4.43	0.215	0.225
	2	4.55	4.48	0.220	0.223
	3	4.95	4.55	0.202	0.220
B	4	4.59	4.28	0.217	0.234
	5	4.62	4.26	0.226	0.235
	6	4.72	4.68	0.212	0.213
C	8	5.50	5.27	0.182	0.189
	9	5.79	5.35	0.172	0.187
	10	6.11	5.53	0.164	0.181
D	11	7.45	7.20	0.134	0.139
	12	7.57	7.14	0.132	0.140
	13	7.90	7.38	0.127	0.135
E	14	4.83	4.68	0.210	0.210
	15	5.04	4.88	0.200	0.200
	16	5.17	5.04	0.190	0.200
F	18	4.95	4.23	0.200	0.240
	19	4.58	4.33	0.220	0.230
	20	4.58	4.39	0.220	0.230
G	21	5.65	4.17	0.180	0.240
	22	5.22	4.15	0.190	0.240
	23	5.19	4.15	0.190	0.240

Table 4. Period values at each measurement point
Source: Authors (2020)



A) North-South (Longitudinal) Direction

A) East-West (Transverse) Direction

Figure 4. Frequency spectra corresponding to the time series of point 4, building B
Source: Authors (2020)

3.2. Analytical method

Table 5 shows the fundamental periods obtained through the analytical models.

T (s)	Buildings						
	A	B	C	D	E	F	G
Long.	0.252	0.270	0.213	0.171	0.233	0.269	0.273
Trans.	0.219	0.219	0.193	0.139	0.228	0.233	0.211
Torsion	0.210	0.188	0.189	0.124	0.219	0.231	0.160

Table 5. Period values at each measurement point
Source: Authors (2020)

4. Discussion

Figure 4 shows that the maximum frequency values are 4.2812 Hz in the north-south direction (longitudinal) and 4.5928 Hz in the east-west direction (transverse). In other words, the frequency values are greater in the transverse direction, in turn the periods in the longitudinal direction are greater, as shown in table 5.

In all buildings, the cross-panel area per structural level is 268.32 m^2. In buildings A, B, C, E, F and G; the area of longitudinal panels on the first level is 132.00 m2 and on the remaining levels 149.00 m^2. On the other hand, in building D, the area of longitudinal panels on the first level is 121.44 m2 and on the remaining levels 138.72 m^2. For this reason, these buildings have more rigidity in the transverse direction because the area of the longitudinal panels at all levels is less than the area of the transverse panels. However, the plan dimensions of these buildings, length (16 m) and width (9.6m), would imply, taking into account an adequate conceptual design, that the longitudinal fundamental periods are smaller than the transversal ones. In fact, according to the formulations to determine the empirical periods of buildings based on shear walls provided by Karnan and Kahm (s, f., Cited in Polyakov, 1974) as well as Sandy and Serbanescu (s, f., Cited in Polyakov, 1974), the values obtained from the transversal periods are greater than the longitudinal ones. This is the case with the use of formulations that consider the dimensions of the building in the direction considered.

When comparing the results, of the periods of the corner points in relation to the central point in each of the buildings and in each of the directions (longitudinal and transverse), two cases are delimited:

Case I: In the three points equal values are reached. Example: Building G

Case II: At the corner points, values that differ from the center are reached. Examples: Buildings A-F.

These cases are associated with the following behaviors: In case I there is no rotation and therefore there will be no possibility of coupling the oscillations. However, in case II buildings, there are possibilities of rotation with coupling of the oscillations, therefore there is risk of negative effects that increase the shear in the structural elements.

When the differences between the longitudinal and transversal periods, are evaluated, three cases are specified:

Case I: Differences between 0-1.80%, in buildings A-E.

Case II: Differences between 1.00-4.00%, in building F.

Case III: Differences between 5.00-6.00%, in building G.

As the differences are shortened, it is shown that the decrease in stiffness in the transverse direction is greater than in the longitudinal one. The causes of this decrease in stiffness in the transverse direction, taking into account the evaluation of the selection criteria, are the openings of transverse panels (building D) and pathological damage to structural elements and joints, without ruling out weight transformations (buildings A, B, C, E, F and G). In the longitudinal direction, stiffness increases, although this can be considered "instantaneous" at the time of the earthquake; since the filling of the lattices can come off quickly. However, the longitudinal periods increase, due to the increases in weights.

When analyzing the results of table 5, in relation to the number of floors, logical values are obtained. The 5-level buildings have values of fundamental periods of oscillation, obviously higher. Esquivel & Schmidt (2016), argue in this sense that the deformation corresponding to mode 1 is similar to that of a cantilevered beam, so the displacements increase as we move away from the base.

Table 6 shows the empirical period values of the Great Soviet Panel precast system, according to different sources. The highest values are obtained, using the formula proposed by the NC: 46-2017 and they increase in the order of 55% in relation to the average periods (0.2422 s for 4 levels and 0.290 s for 5 levels). This research considers that the expressions of Polyakov (1974) and Oliva (2001) are more suitable to take them as references, because they are specific for buildings of this same prefabricated system. In particular, that of Oliva (2001), was obtained from the measurement of the fundamental periods of oscillation of a sample of buildings built in Santiago de Cuba with this system.

Calculation expressions	Source	Values of the empirical period (s)	
T= 0.045 N N is the number of floors	Polyakov (1974)	4 floors 5 floors	0.180 0.225
T=0.033 N N is the number of floors	Oliva (2001)	4 floors	0.132
		5 floors	0.165
$T= C_TH^{0,75}$ CT = 0.020 and H is the total height in feet	Housing and Building Research Center (EGC-2012)	4 floors	0.307
		5 floors	0.359
$T=C_T(h_n)^x$ hn is the total height of the building (m) from the base, $C_T = 0.047$, x = 0.85	NC: 46-2017	4 floors	0.378
		5 floors	0.452
$T=C_TH^{0,75}$ C_T = 0.014 and H is the total height in feet	Mohamed y Magdy (2017)	4 floors	0.214
		5 floors	0.251
Average values of the fundamental periods of oscillation		4 floors	0.242
		5 floors	0.290

Table 6. Expressions to calculate the fundamental period empirically
Source: Authors (2020)

When the values of the fundamental periods of oscillation obtained by the environmental vibrations are contrasted with the empirical periods offered by Oliva (2001), it can be seen that the former are larger for all buildings. In Building D, the maximum increases are 6%. In buildings A, B, C and E the increases are between 14.00-42.00% and in building G, they are greater than 45.45%. From this analysis we conclude the higher incidence of pathological damage in the increments of the fundamental oscillation periods, because building G, which does not present changes in weight or stiffness, nor in stiffness and weight, only presents pathological damage in the elements and structural joints, the largest increases are obtained.

If increases between 2-15% of the periods obtained through environmental vibrations are assumed, considering the contributions of Polyakov (1974) and Chopra (2014); In the 4-story building, periods from 0.154s to 0.161s can be reached before the calculation earthquake, which represent increases of at most 22.00% in relation to the empirical period. On the other hand, in buildings with 5 levels, periods from 0.209s to 0.276s can be reached, which represent increases from 31.72% to a maximum of 67.27%, also in relation to the empirical period. It can then be confirmed that changes in the seismic behavior of these buildings are foreseen.

On the other hand, when estimating the results of table 7, it can be seen that the periods that the buildings reach before the considered earthquake are greater than the empirical periods obtained by applying the expression of Oliva (2001).

When the differences obtained between the fundamental longitudinal and transverse oscillation periods, presented in Table 7, are evaluated, similar behaviors are observed than by the instrumental route. In buildings A-E, there are differences between 0.50-5.10%, in F of 3.60% and in G of 6.2%. The differences between the transversal and torsion periods are small, which in building G reach 5.1%, in the remaining cases they are between 0.20-3.10%. It is also evident by the analytical way, the possibility of coupling of the oscillations, even for the same causes.

Then, analytically, in the event of an earthquake, maximum increases in the fundamental periods of oscillation of buildings in relation to the empirical period are also expected, from 29.09% to 65.45% in buildings with 5 levels and 26.00% in buildings with 4 levels.

From all the previous analysis it can be concluded that:

- Both instrumentally and analytically, changes in the seismic behavior of instrumented buildings are envisaged, as a result of increases in the periods of oscillation with the consequent increase in deformations and coupling of oscillations. In this change in behavior, pathological damage to structural elements and joints has a greater impact, followed by weight transformations and rigidity transformations.

- In the calibration of the analytical models, it was taken into account that Tmodel ≈ (1.02-1.15) T_{VA} and rigidity modifiers are applied iteratively and also the reduction of the resistance of concrete and steel in the elements with pathological damage.

- By instrumental means, in 5-story buildings, maximum increases are expected in the longitudinal periods of oscillation of buildings in the event of an earthquake, in relation to the empirical T, from 31.72% to 67.27%; 22% in the 4-level building. Analytically, from 29.09% to 65.45% in buildings with 5 levels and 26.00 % in buildings with 4 levels

5. Recommendations

In subsequent studies, also taking as a starting point the measurement of the period by environmental vibrations, the structural models can be calibrated using other ways such as:

- Consider uncoupled sections in the elements or joints with pathological damage.
- Release of degrees of freedom of some elements or joints with pathological damage.

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