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VERIFICATION OF EXCESSIVE VIBRATIONS ON UNIDIRECTIONAL PRECAST RIBBED SLAB FLOORS

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Abstract. The ribbed slabs (RS) are one of several types of precast slabs. This type of slab is suitable for any work, but is very much used in small housing and commercial buildings. The construction system, composed of reinforced concrete ribs, stands out economically when compared to structures cast in loco, whether they are solid or ribbed, since they require a smaller amount of framework and shoring, and reduce the consumption of concrete. From the design point of view, these slabs are often only verified in relation to the ULS and the SLS of deflection, however when the verification of this SLS of vibration is neglected, it results in vibration comfort problems and, in some cases, may cause malfunction of machines and equipment. In this context, this work aims to study the static and dynamic behavior of the RS's by means of a parametric analysis that evaluates the influence of the useful height, topping slab thickness and characteristic strength of the concrete (f_{ck}) in the natural frequency variation, through an analytical and numerical approach (via SAP2000®). The results were discussed comparing the analytical prediction of the limit values proposed by ABNT NBR 6118:2014 and PCI Design Handbook (2010). The results show that with the adoption of additional reinforcement, RS's present worse results for vibration SLS in relation to deflection SLS, fortifying the need to verify the dynamic behavior.

Keywords: Vibrations, Ribbed slab, Serviceability limit state

1 Introduction

The ribbed slabs, that will be discussed in this work, are, as shown in Figure 1, basically consisting of:

- Precast linear elements, which are the ribs, arranged spaced apart in one direction;
- Hollow blocks interposed between the precast elements;
- Topping layer of cast-in-place concrete.

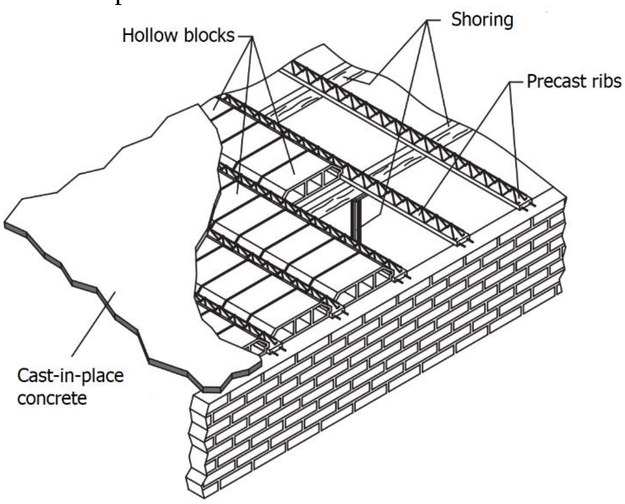

Figure 1. Ribbed Slab. Source: El Debs [1]

The ribbed slabs are one of several types of precast slabs. This type of slab is suitable for any work, but is very much used in small housing and commercial buildings. The construction system, composed of reinforced concrete ribs, stands out economically when compared to structures cast in loco, whether they are solid or ribbed, since they require a smaller amount of framework and shoring, and reduce the consumption of concrete.

From the design point of view, these slabs are often only verified in relation to the ULS and the SLS of deflection, however when the verification of this SLS of vibration is neglected, it results in vibration comfort problems and, in some cases, may cause malfunction of machines and equipment.

Many factors contribute to the fact that dynamic structural analysis should be incorporated into the day-to-day in the development of structural projects, such as the rigorous in-service requirements of modern equipment that generate actions that, by their nature and intensity, cannot be regarded as static; the proliferation of buildings whose height and slenderness forces the designer to develop a structural analysis that takes into account the dynamic effects generated by the action of the wind and other actions; the seismic risk associated with each region, which requires the understanding and application of methodologies related to earthquake resistant projects.

From this perspective, the technology of precast concrete, while on the one hand offers interesting alternatives to the construction strategy, among them the fast assembly, lightness and excellent quality of the structure. This slenderness associated with greater difficulty in the execution of rigid connections leads to more flexible structural systems when compared to those of cast-in-place concrete. In particular, slabs and other floor structures are very susceptible to dynamic loads, since they often have a large span and small thickness.

In order to provide an example of verification of SLS of vibration recommended by the standards PCI Design Handbook [2] e ABNT NBR 6118 [3] and to provide data regarding the dynamic behavior of ribbed slabs, this paper presents simplified dynamic analysis procedures in articles and standards related to precast concrete, as well as the simplified modeling through the SAP2000® computer program, comparing the results obtained by the methods suggested by standard, with the results obtained through numerical modeling.

In this context, this work aims to study the static and dynamic behavior of the RS's corresponding to the SLS of deflection and vibration, respectively, by means of a parametric analysis that evaluates the influence of the useful height, topping slab thickness and characteristic strength of the concrete (f_{ck}) in the natural frequency variation, through an analytical and numerical approach (via SAP2000®). The results were discussed comparing the analytical prediction of the limit values proposed by PCI [2] and ABNT [3].

2 Theoretical background

It can be said that the vibration of a human body is any movement it executes relative to a fixed point. This movement may be regular, sinusoidal or irregular, when it does not follow any particular pattern. The vibration is defined by three variables: the frequency (Hz), the maximum acceleration suffered by the body (m/s²) and the direction of movement.

Whenever the natural frequency of any structure approaches the frequency of the excitation source, it may resonate. In the resonance, there is a marked amplification of the deflections of the structure, which makes the movement perceptible and often uncomfortable. To avoid the situation of the resonance, it is necessary to adopt procedures of prevention, adjustment or control of vibrations. Some of these procedures are described below:

- Reduction of actions;
- Mass reduction;
- Increased rigidity of the structure;
- Increased damping level;
- Mechanical passive control devices;
- Active control systems.

As for the procedures for modifying mass and rigidity characteristics, the Frequency Adjustment Method is based on the premise that, in order to avoid the proximity of the resonance, it is necessary to increase the natural frequencies of the structure. This method is the most used in design practice and indicated by technical standards. From an estimate of the natural frequency of the structure (f_n), its value is compared with the minimum natural frequency required (f_{min}), which is directly related to the type of excitation expected for the service condition of the building.

When $f_n \geq f_{min}$ is present, this means that the structure is suitable for such use, with no risk of resonance or excessive vibration. Otherwise, modification of the mass characteristics and rigidity of the structure should be promoted.

Considering that the minimum frequency specified is the parameter to be met from the point of view of vibration sensitivity, different expressions of calculation of the minimum frequency in floor structures are presented here. Assuming that the variables involved in the problems differ according to the actions that cause the vibration, they can be classified in:

- Vibrations induced by walking people;
- Vibrations induced by rhythmic activities;
- Vibrations induced by machines and equipment.

2.1 Natural Frequency

When the floor structure exhibits predominantly unidirectional behavior, a frequent situation in the case of precast concrete elements, the possibility of analyzing the floor as a set of adjacent beams makes the calculation simpler. For this, there are in the literature simple expressions for estimating the natural frequency of beams, for several types of bonding. For example, the expression of the natural frequency (f_n) of a beam considered as a continuous system with uniformly distributed load is shown in equation (1):

$$f_n = R\sqrt{\frac{EIg}{wL^4}} \tag{1}$$

At where,

R is the constant that varies with the type of the beam based in the supports from analytical expressions of continuous systems vibration calculation, being adopted as 0.56; 1.57; 2.45 and 3.56 for cantilever, simply supported, propped cantilever and fixed beam, respectively.

E is the dynamic modulus of elasticity, in N/m²;

I is the moment of inertia of the gross section in m^4;

g is the acceleration of gravity, 9.81 m/s²;

w is the distributed load (dead and live loads) per unit length in N/m;

L is the span length, in m.

Important points to note when using the above expressions are:

- The total load w to be considered should be carefully estimated taking characteristic values, without taking into account any dynamic coefficient or other similar magnification factor. Murray et al. [4] suggest values for variable loads, for example, 500 N/m2 for office floors and 250 N/m2 for residential floors. For walkways, gymnasium and shopping mall floors, the authors recommend zero, or something close to it. The adoption of these load values should be done with caution, because the lower the load to be adopted, the higher the natural frequency obtained, thus causing the illusion that the structure will behave satisfactorily in the excessive vibrations;
- As for the modulus of elasticity, it is recommended to adopt the dynamic modulus of elasticity Edin instead of the usual static modulus E, where it can be arbitrated as an increase of the static modulus by approximately 20%. This procedure is not conservative, because with a higher value of E, a more rigid structure is obtained and, therefore, more natural frequency.

2.2 Standard recommendations

Considering that the specific Brazilian standard for precast concrete structures, NBR 9062 [5] does not make any consideration, regarding the dynamic effects of people activities, the recommendations of the PCI [2] are presented. In addition, the considerations of the Brazilian standard NBR 6118 [3], regarding the SLS of vibration, will be presented. For concrete structures (precast or not), so far, is the criterion to be followed.

It is noteworthy that, in general, frequencies below 3 Hz are not recommended for floors, as this is the main excitation range in which people move in synchronized activities or that may intentionally excite the structure.

- PCI – Precast/Prestressed Concrete Institute [2]

For PCI Design Handbook [2], the assessment of structural behavior is based on the types of vibrations to which the structure is subjected, therefore dependent on the type of excitation, whether it comes from walking, rhythmic activities or mechanical equipment.

For vibrations caused by walking, the minimum frequency to be reached by the floor is given by equation (2):

$$f_{\min} = 2{,}86\left[\ln\left(\frac{\mathrm{K}}{\beta \mathrm{W_e}}\right)\right] \tag{2}$$

At where,

$f_{\min}$ is the minimum fundamental natural frequency of the structural system in Hz;

K is the floor loading constant indicated in Table 1;

β is the modal damping rate indicated in Table 1;

W_e is the effective weight, equivalent to the total weight of the floor area influenced by concentrated loading, in kN.

This effective weight shall be considered as the permanent load plus the variable load of the precast floor panel multiplied by the span (L) and an effective width (B_{ef}). For continuous spans, the effective weight can be increased by 50%.

According to Chen and Aswad [6], for double-tees, it is recommended that W_e vary from 0.8 of the span for 18 in. double-tees with 2 in. to 3 in. topping to 0.6 of the span for 32 in. double-tees with 2 in. to 3 in. topping.

Table 1 - Values for K and B [2]

Occupancies affected by the vibrations	k (kN)	**β**
Offices, residences, Churches	58	0,02[1]
		0,03[2]
		0,05[3]
Shopping malls	20	0,02
Footbridges	8	0,01

¹ For floors with few non-structural components (ceilings, ducts, partitions, and the like) and furnishings, open work area, and churches.

² For floors with non-structural components and furnishings, but with only small, demountable partitions, typical of many modular office spaces.

³ For floors with full-height partitions.

For vibrations generated by rhythmic activity, when a group of people move in a synchronized manner, such as dance classes, aerobics, music concerts, sports events, among others, the PCI Design Handbook states that the minimum fundamental frequency is given by equation (3:

$$f_{mín} = f.\sqrt{1 + \frac{k}{a_{máx}/g} . \frac{\alpha_i . w_p}{w_t}} \tag{3}$$

At where,

f is the frequency of the excitation force, ($f = i.f_{exc}$), in Hz;
i is the harmonic number of the excitation force (1, 2 or 3), indicated in Table 2;
f_{exc} is the base frequency of the excitation force, shown in Table 2, in Hz;
k is the dimensionless constant dependent on the type of floor activity: 1.3 for dance, 1.7 for concerts or sporting events, and 2.0 for aerobic activity;
α_i is the dynamic action coefficient given in Table 2;
w_p is the weight of participants distributed on the floor (N / m²);
w_t is the total weight distributed on the floor (N / m²);
$a_{máx}/g$ is the ratio between maximum tread acceleration and acceleration due to gravity, the limits of which are given in Table 3.

Table 2 - Estimated loading during rhythmic events. PCI [2]

Activity	$\mathbf{f_{exc}}$ (Hz)	w_p(KN/m²)	α_i
Dancing:			
First harmonic	1,5 a 3,0	0,6	0,5
Lively concert o sports event:			
First harmonic	1,5 a 3,0	1,5	0,25
Second harmonic	3,0 a 5,0	1,5	0,05
Jumping exercises:			
First harmonic	2,0 a 2,75	0,2	1,5
Second harmonic	4 a 5,5	0,2	0,6
Third harmonic	6,0 a 8,25	0,2	0,1

Table 3 - Recommended acceleration limits for rhythmic activities. PCI [2]

Occupancies affected by the vibrations	$a_{máx}/g$
Office or residential	0,004 a 0,007(0,4 a 0,7%)
Dining	0,015 a 0,025 (1,5 a 2,5%)
Weightlifting	0,015 a 0,025 (1,5 a 2,5%)
Rhythmic activity only	0,04 a 0,07(4,0 a 7,0%)

According to Diogenes et. al [7], some considerations regarding equation (3) should be raised, such as: The values of w_p may be higher than those presented in Table 2, provided that they are consistent with what was introduced in equation (3).If the structure has more than one type of activity, it will be necessary to calculate the natural frequency considering different values of w_t and also to estimate the minimum natural frequencies required and it should be noted that for each type of activity, the calculation of the minimum fundamental natural frequency of structural system (f_{min}) should be made for all harmonics they may excite according to Table 2.

- ABNT NBR 6118 [3]

The referred standard, which deals with concrete structures, in its item 23.3 – Limit State of Excessive Vibrations, presents the critical (minimum) frequencies f_{crit} according to the type of use of the building in a way that meets and ensures the satisfactory behavior of the buildings. structures for vibration sensitivity (Table 4). So the Brazilian code recommends that to ensure satisfactory behavior of structures subject to vibration, their natural frequency (f) must be at least 20% higher than the f_{crit}.

Table 4 - Critical Frequency in function of the type of building occupancy. ABNT [3]

Case	f_{crit}(Hz)	f(Hz)
Sports gym and fitness center	8,0	9,6
Dance or concert halls without fixed chairs	7,0	8,4
Pedestrian or cyclist walkways	4,5	5,4
Offices	4,0	4,8
Concert Halls with Fixed Chairs	3,5	4,2

When the critical action originates from a machine, the critical frequency becomes that of machine operation. In this case, ABNT 6118 [3] warns that it may not be sufficient to move away from the two frequencies, proper and critical. For this case, you need accurate information about machine operation, so this case will not be dealt with in this work.

In special cases the standard suggests that more accurate dynamic analyzes be performed based on international recommendations, as long as there is no specific Brazilian standard that addresses this issue.

3 Case study

The sections chosen were according to the heights of the commonly sold trusses, in this work the trusses with the heights of 8, 12 and 16 cm. It was decided to use EPS to fill the slabs, due to the tendency of the market to adopt this material for lattice slabs, due to its lower weight and less loss due to the breakage of the material in relation to the ceramic blocks. It is important to know the material that will be used, because it changes the weight of the structure and, consequently, the natural frequency.

The used reinforcements for the static evaluation were according to Figure 2 and Table 5.

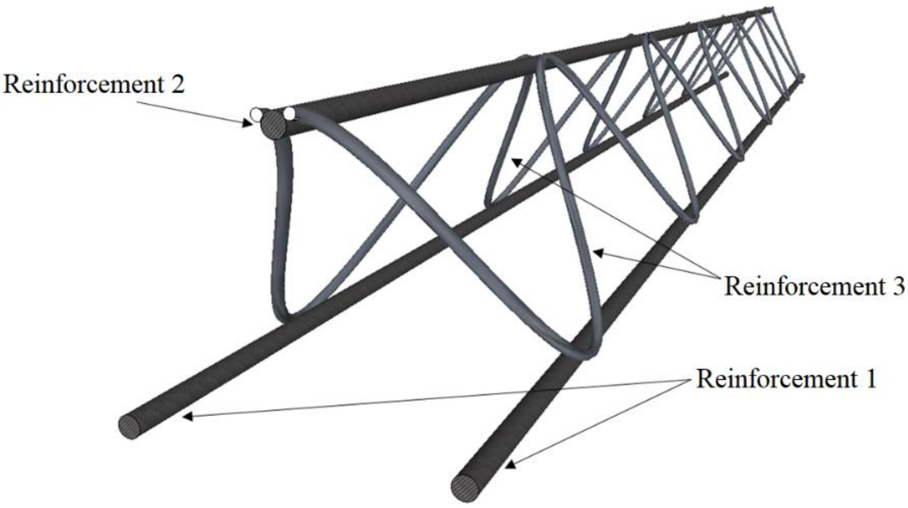

Figure 2 - Used truss.

Table 5 - Used trusses properties

Used trusses properties according to their heights			
Height	Reinforcement 1	Reinforcement 2	Reinforcement 3
8 cm	2Ø5	1Ø6	2Ø4.2
12 cm	2Ø6	1Ø6	2Ø4.2
16 cm	2Ø6	1Ø6	2Ø4.2

In relation to the topping of the slab, according to the objective of the work two heights of 4 and 8 cm were used, in order to observe the alteration in the frequencies of the studied slabs. The cross sections of the slabs studied in this work are shown in Figure 3.

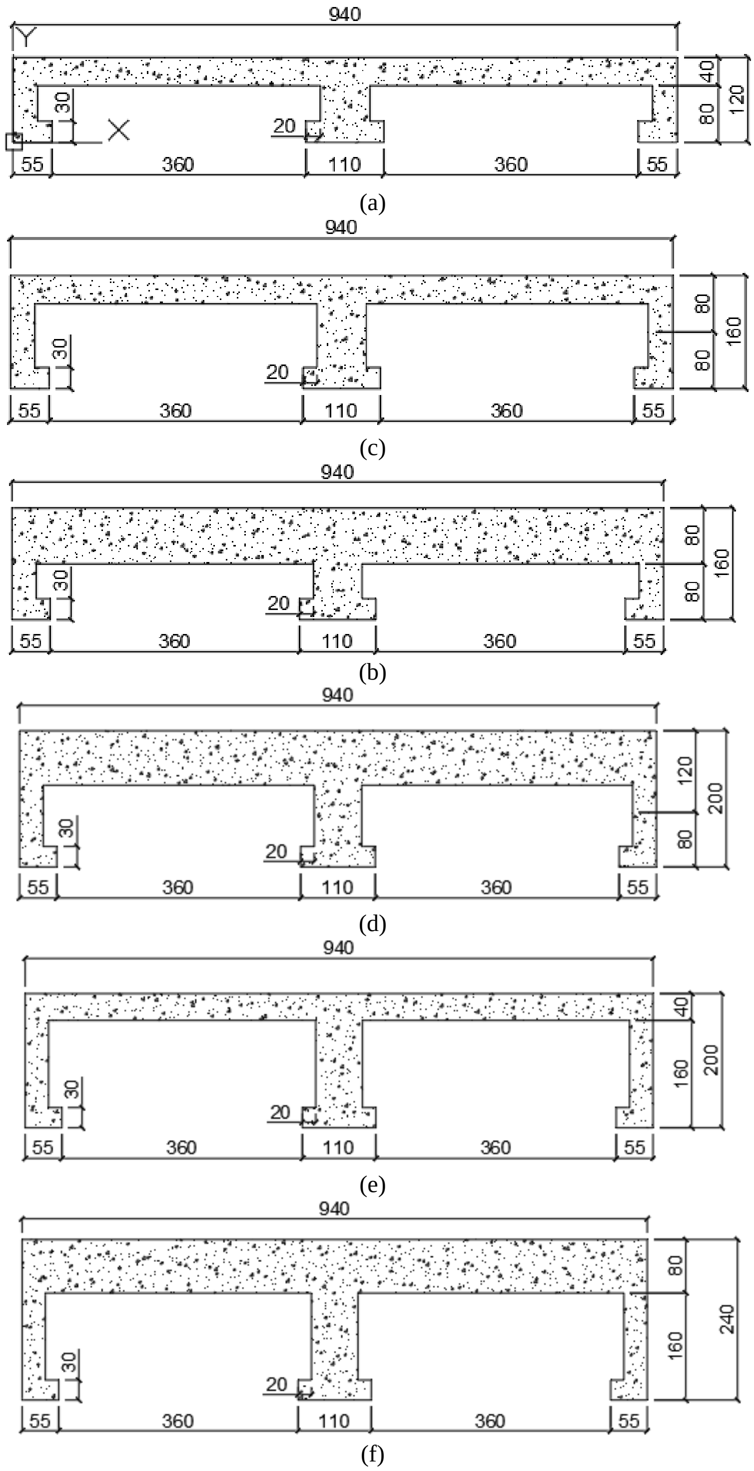

Figure 3 - Cross sections of slabs: (a) RS 08+04; (b) RS 08+08; (c) RS 12+04; (d) RS 12+08; (e) RS 16+04; (f) RS 16+08. Dimensions in mm.

3.1 Determination of natural frequencies

For the purposes of determining the natural frequencies, a model was developed using bar element in the SAP2000® program (Figure 4), aiming at comparing the values of the model with the values obtained through the analytical models proposed previously in this paper using equation (1). The minimum value considered for the natural frequencies was 3 Hz, considering that for values below this, simple activities such as walking, could lead to discomfort. The slab data used to obtain natural frequencies is in Table 6.

Figure 4 - 1D model

Table 6 – Mechanical Properties

Element	I (m^4)	$W_{element}$ (kN/m)
RS8+4	0,0000538389	2,653863
RS12+4	0,0001227900	2,794342
RS16+4	0,0002309659	2,925639
RS8+8	0,0001295587	3,576003
RS12+8	0,0002353390	3,716482
RS16+8	0,0003946791	3,847779
Concrete: for f_{ck}= 30 MPa , $E_{s,din}$=31.286 Mpa and for f_{ck}= 40 MPa , $E_{s,din}$=36.126 MPa		

It is shown in Table 1, the comparative table of the values obtained of natural frequency of the elements, for the length of 5 meters, simply supported and f_{ck} = 30MPa. Evaluating via finite element of bar, as well as the analytical calculation for pre-shaped unidirectional ribbed slab elements. The value obtained in the modeling of the bar element via MEF was used as reference for evaluating the variation of the natural frequency value, according to the resolution method.

Table 7 - Comparison of methods of resolution

Element	f_n (Hz) MEF-Bar	f_n (Hz) Analytical	Δ (%)
RS8+4	4,957	4,955	0,03
RS12+4	7,295	7,293	0,03
RS16+4	9,777	9,775	0,02
RS8+8	6,624	6,622	0,03
RS12+8	8,757	8,755	0,02
RS16+8	11,144	11,143	0,01
Δ (%) Average	-	-	0,02

Considering that the analytical calculation when compared to numerical modeling presents practically the same values, besides not requiring the use of sophisticated computational tools, this method was chosen for the purpose of determining the natural frequencies of the elements studied. The graphs of the respective natural frequencies are shown below, according to the boundary conditions and span length (from Figure 5 to Figure 16).

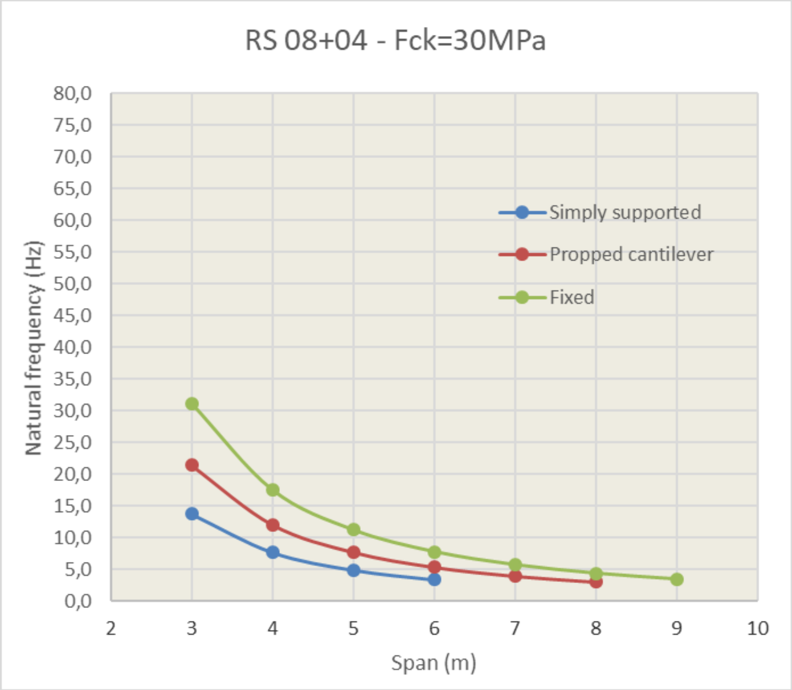

Figure 5 - Natural Frequency- RS 08+04 - Fck =30MPa

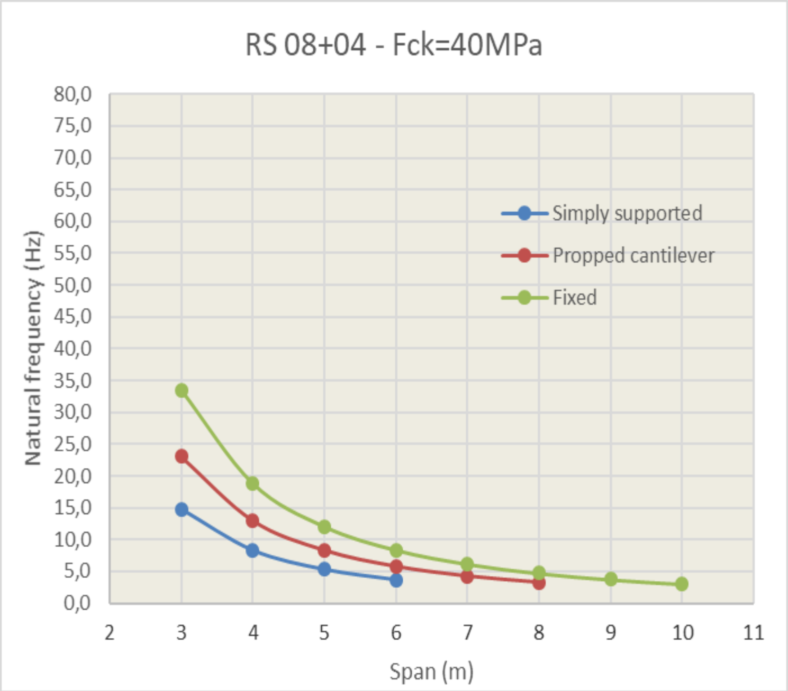

Figure 6 - Natural Frequency- RS 08+04 - Fck =40MPa

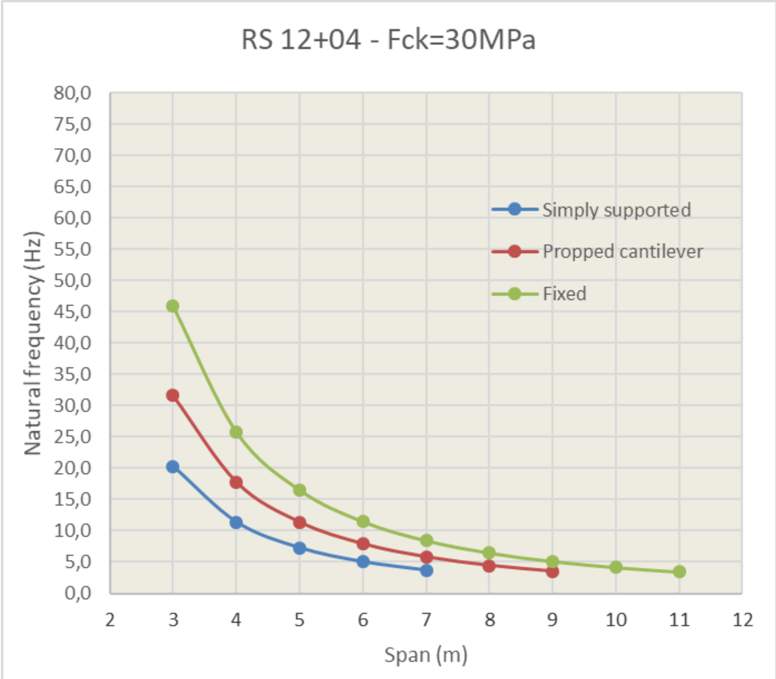

Figure 7 - Natural Frequency- RS 12+04 - Fck =30MPa

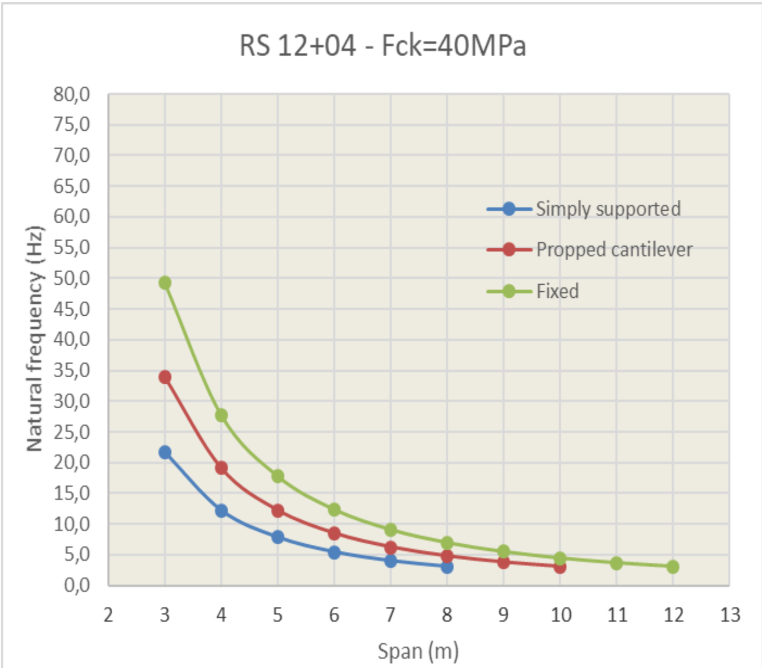

Figure 8 - Natural Frequency- RS 12+04 - Fck =40MPa

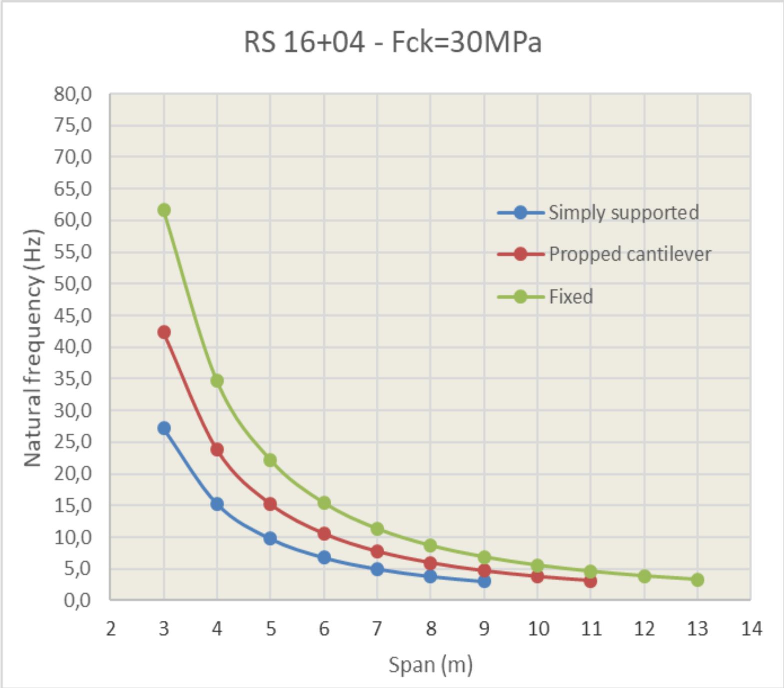

Figure 9 - Natural Frequency- RS 16+04 - Fck =30MPa

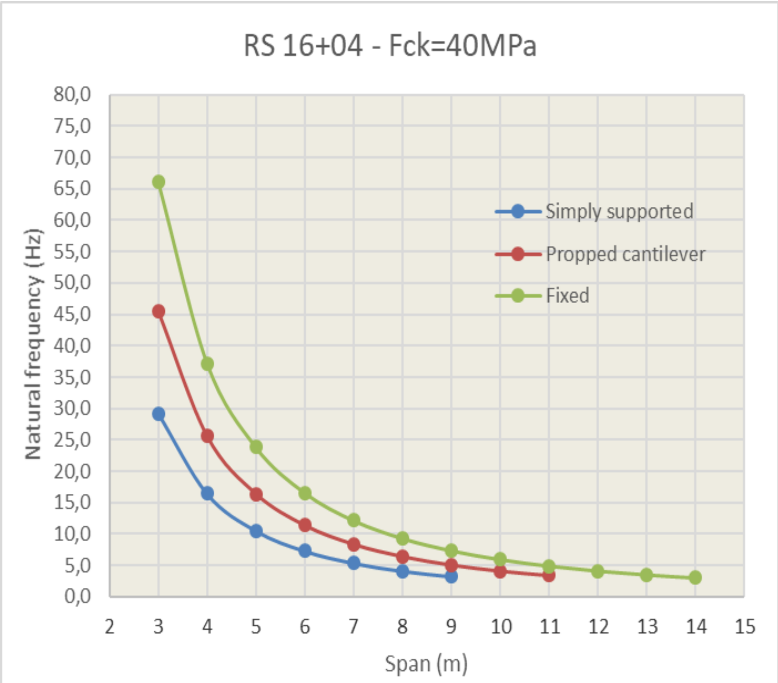

Figure 10 - Natural Frequency- RS 16+04 - Fck =40MPa

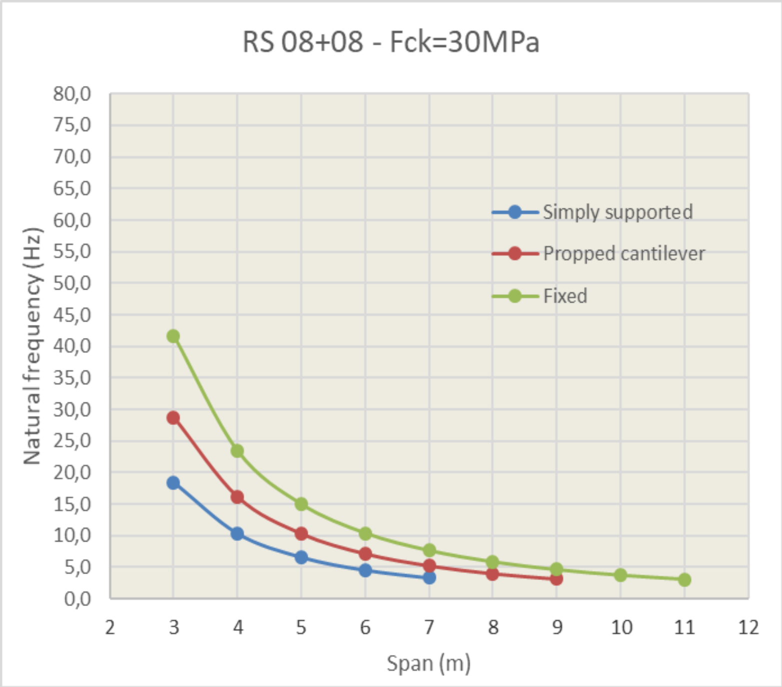

Figure 11 - Natural Frequency- RS 08+08 - Fck =30MPa

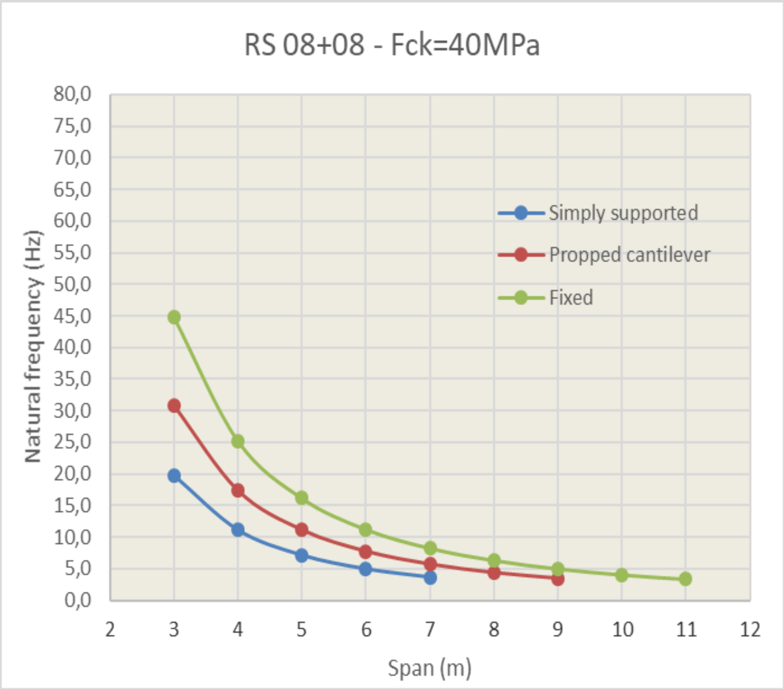

Figure 12 - Natural Frequency- RS 08+08 - Fck =40MPa

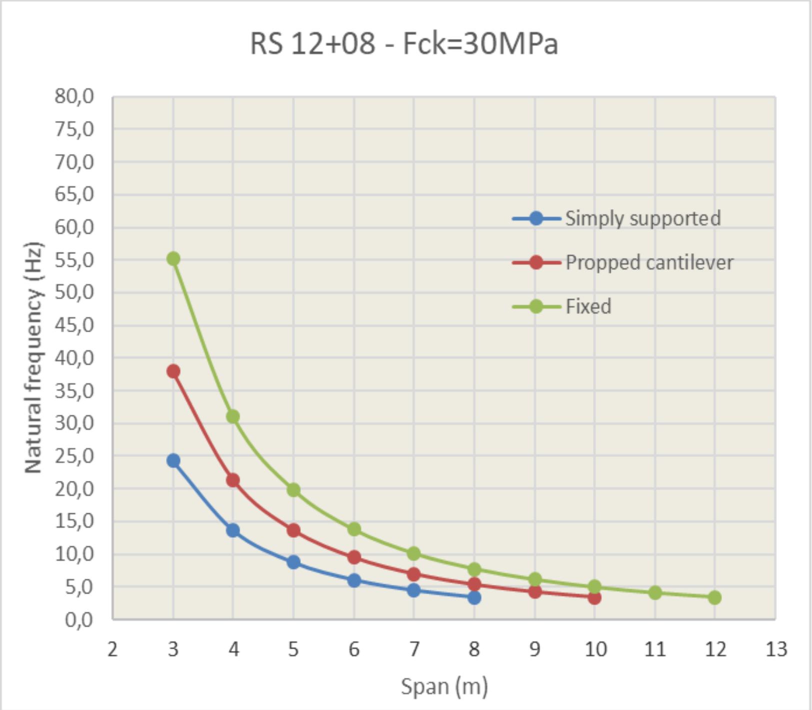

Figure 13 - Natural Frequency- RS 12+08 - Fck =30MPa

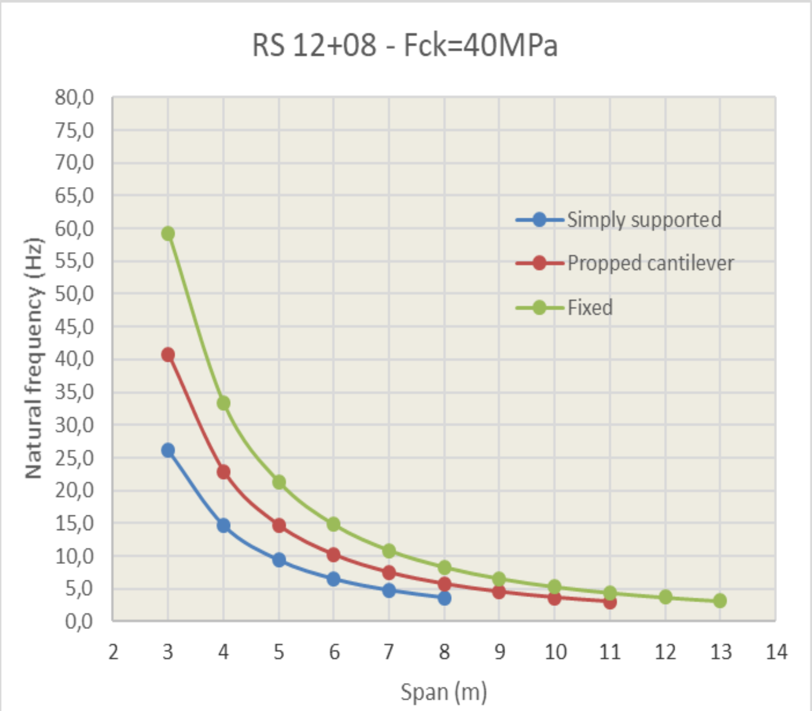

Figure 14 - Natural Frequency- RS 12+08 - Fck =40MPa

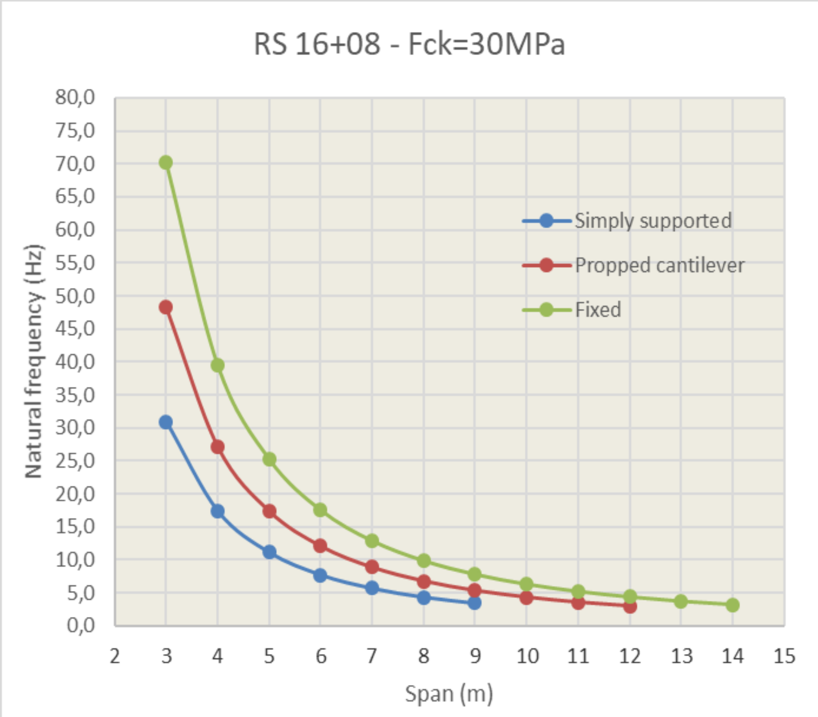

Figure 15 - Natural Frequency- RS 16+08 - Fck =30MPa

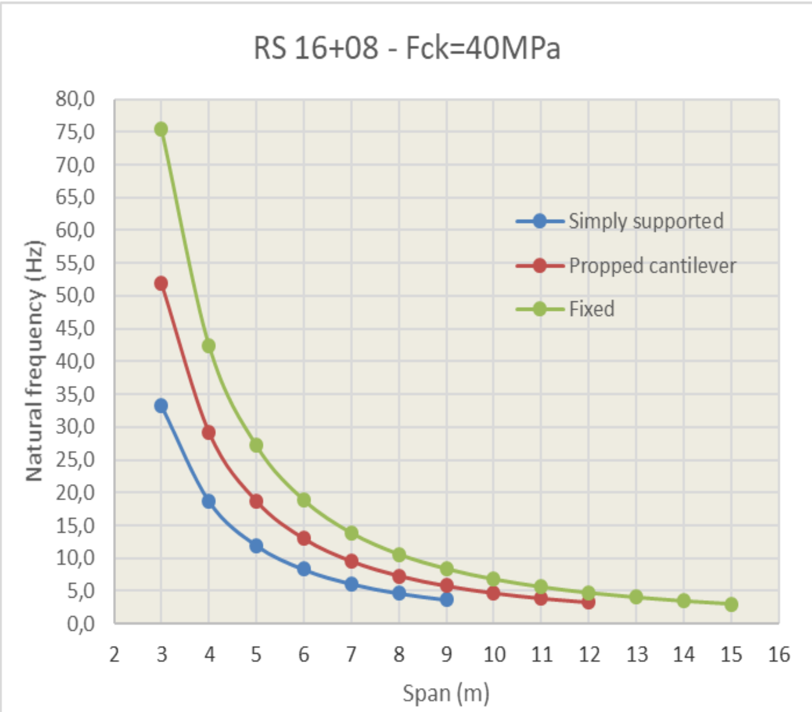

Figure 16 - Natural Frequency- RS 16+08 - Fck =40MPa

3.2 Determination of minimum natural frequencies

Recalling that the ELS-VE check was made for sports gymnasium, dance hall or concert hall without fixed chair, walkways or cyclists, offices and concert halls with fixed seats, which are situation determined by [3].

For the determination of the minimum natural frequencies, we chose the criterion used by [3] and the criterion proposed by [2], expressed by equations (2) and (3), to obtain the minimum values of natural frequency for walking situations and rhythmic activities, for the evaluation of the Limit State of Excessive Vibrations. The minimum natural frequency values by [3] have already been shown in Table 4, and the PCI values [2] are in the tables Table 8 to Table 12. For pedestrian or cyclist and office walkways, it was considered walking-induced vibration, in which case the minimum frequency varies along with the span, either for sports gymnasium, dance hall or concert with no fixed chair and rooms concert with fixed chairs that the vibrations are induced by rhythmic activities, the frequency is independent of the length of the span.

Table 8 - Minimum frequency for sports gym according to PCI

f_{min} - sports gym					
RS 08+04	RS 12+04	RS 16+04	RS 08+08	RS 12+08	RS 16+08
11,92	11,64	11,40	10,40	10,22	10,07

Table 9 - Minimum frequency for dance halls or concerts without fixed seats according to PCI

f_{min} - dance halls or concerts with fixed seats (Hz)					
RS 08+04	RS 12+04	RS 16+04	RS 08+08	RS 12+08	RS 16+08
9,20	9,00	8,83	8,13	8,01	7,90

Table 10 - Minimum frequency for pedestrian or cyclist walkways according to PCI

f_{min} - pedestrian or cyclist walkways (Hz)						
Span (m)	RS8+4	RS12+4	RS16+4	RS8+8	RS12+8	RS16+8
1	19,80	19,63	19,47	18,78	18,65	18,53
2	17,43	17,25	17,09	16,40	16,27	16,15
3	16,03	15,86	15,70	15,01	14,88	14,76
4	15,05	14,87	14,71	14,02	13,89	13,77
5	14,28	14,10	13,95	13,26	13,12	13,01
6	13,65	13,48	13,32	12,63	12,50	12,38
7	13,13	12,95	12,79	12,10	11,97	11,85
8	12,67	12,49	12,33	11,64	11,51	11,39
9	12,26	12,09	11,93	11,24	11,11	10,99
10	11,90	11,72	11,57	10,88	10,75	10,63
11	11,57	11,40	11,24	10,55	10,42	10,30
12	11,28	11,10	10,94	10,25	10,12	10,00
13	11,00	10,82	10,67	9,98	9,85	9,73
14	10,75	10,57	10,41	9,72	9,59	9,47
15	10,51	10,33	10,18	9,49	9,35	9,24

Table 11 - Minimum frequency for offices according to PCI

f_{min} – Offices (Hz)						
Span (m)	RS8+4	RS12+4	RS16+4	RS8+8	RS12+8	RS16+8
1	24,22	24,05	23,89	23,20	23,07	22,95
2	21,85	21,67	21,51	20,82	20,69	20,57
3	20,45	20,28	20,12	19,43	19,30	19,18
4	19,47	19,29	19,13	18,44	18,31	18,19
5	18,70	18,52	18,37	17,68	17,54	17,43
6	18,07	17,90	17,74	17,05	16,92	16,80
7	17,55	17,37	17,21	16,52	16,39	16,27
8	17,09	16,91	16,75	16,06	15,93	15,81
9	16,68	16,51	16,35	15,66	15,53	15,41
10	16,32	16,14	15,99	15,30	15,17	15,05
11	15,99	15,82	15,66	14,97	14,84	14,72
12	15,70	15,52	15,36	14,67	14,54	14,42
13	15,42	15,24	15,09	14,40	14,27	14,15
14	15,17	14,99	14,83	14,14	14,01	13,89
15	14,93	14,75	14,60	13,91	13,77	13,66

Table 12 - Minimum frequency for concert halls with fixed seats according to PCI

f_{min} - Concert halls with fixed seats (Hz)					
RS8+4	RS12+4	RS16+4	RS8+8	RS12+8	RS16+8
14,42	14,08	13,78	12,56	12,34	12,15

3.3 Span limit for SLS of deflection

Table 13 present the limit values for the span lengths of the unidirectional ribbed slabs considering the SLS of excessive deflection according to [3]. For the calculations it was considered two possibilities, with or without camber. In ABNT NBR 6118, the limit for deflection is L/250, where L is the length of the span, but it is possible to use a camber of L/350, for a better performance of the structure. The calculations were made meter by meter and the results are shown in Table 13. In regard of the complementary reinforcement, it was used 2 bars of 6.3 mm.

Table 13 - Limit span for SLS of deflection according to [3]

Element	Limit Span (m)							
	Without complementary reinforcement				With complementary reinforcement			
	f_{ck} 30		f_{ck} 40		f_{ck} 30		f_{ck} 40	
	Without camber	With camber	Without camber	With camber	Without camber	With camber	Without camber	With camber
RS8+4	2,00	2,00	2,00	2,00	2,00	3,00	2,00	3,00
RS12+4	3,00	3,00	3,00	3,00	3,00	4,00	3,00	4,00
RS16+4	4,00	4,00	4,00	4,00	4,00	4,00	4,00	5,00
RS8+8	2,00	3,00	3,00	3,00	3,00	3,00	3,00	3,00
RS12+8	3,00	4,00	3,00	4,00	3,00	4,00	4,00	4,00
RS16+8	4,00	4,00	4,00	4,00	4,00	5,00	4,00	5,00

3.4 Span limit for SLS of vibration

Table 14 and Table 15 present the limit values for the spans of the unidirectional ribbed slabs considering the minimum frequencies of the normative codes mentioned in this paper, considering only the simply support beam situation, since the design is done for the contour condition simply supported. The calculation was made meter by meter. Also in these tables, the results filled in red represents the cases where the performance in the static behavior according to the SLS of deflection were better that in the dynamic behavior represented here by the SLS of vibration, for the comparison it was used the static results with complementary reinforcement and camber.

Table 14 – Limit span for unidirectional ribbed slab - ELS - Excessive vibrations (according to NBR 6118 [3] and PCI [2]) - (f_{ck}=30MPa)

Element	Limit span (m)									
	Sports gym		Dance halls or concerts without fixed seats		Offices		Concert halls with fixed seats		Pedestrian or cyclist walkways	
	PCI	ABNT	PCI	ABNT	PCI	ABNT	PCI	ABNT	PCI	ABNT
RS8+4	3,00	3,00	3,00	3,00	2,00	5,00	2,00	5,00	2,00	4,00
RS12+4	3,00	4,00	3,00	4,00	2,00	6,00	3,00	6,00	3,00	5,00
RS16+4	4,00	5,00	4,00	5,00	3,00	7,00	4,00	7,00	3,00	6,00
RS8+8	3,00	4,00	3,00	4,00	2,00	5,00	3,00	6,00	2,00	5,00
RS12+8	4,00	4,00	4,00	5,00	3,00	6,00	3,00	7,00	3,00	6,00
RS16+8	5,00	5,00	5,00	5,00	3,00	7,00	4,00	8,00	3,00	7,00

Table 15 - Limit span for unidirectional ribbed slab - ELS - Excessive vibrations (according to NBR 6118 [3] and PCI [2]) - (f_{ck}=40MPa)

Element	Limit span (m)									
	Sports gym		Dance halls or concerts without fixed seats		Sports gym		Concert halls with fixed seats		Sports gym	
	PCI	ABNT	PCI	ABNT	PCI	ABNT	PCI	ABNT	PCI	ABNT
RS8+4	3,00	3,00	3,00	3,00	2,00	5,00	3,00	5,00	2,00	4,00
RS12+4	3,00	4,00	4,00	4,00	2,00	6,00	3,00	6,00	3,00	6,00
RS16+4	4,00	5,00	4,00	5,00	3,00	7,00	4,00	7,00	3,00	6,00
RS8+8	3,00	4,00	4,00	4,00	2,00	6,00	3,00	6,00	2,00	5,00
RS12+8	4,00	4,00	4,00	5,00	3,00	6,00	4,00	7,00	3,00	6,00
RS16+8	5,00	5,00	5,00	5,00	3,00	7,00	4,00	8,00	3,00	7,00

In that was, for the cases where the results are filled in red, it is necessary even after a static evaluation of the structure, it would be necessary also a dynamic evaluation. It can be observed that for the criteria used in ABNT 6118 [3], there is no need to be done a dynamic evaluation after the static one, because it showed an inferior performance for all cases, but for PCI [2], that are some cases that there is the need of dynamic evaluation, showing that the PCI [2] is more conservative in this subject than the ABNT 6118 [3].

4 Conclusion

From the analysis of the Table 14 and Table 15, it is noticed that the parameter to be varied, when we need to increase the natural frequency is the inertia, the difference between the values for the increase of the section in relation to the whole height or height of the topping presented similar results, but due to the lower expense of concrete in the increase of the height of the rib in relation to the increase of the topping, makes the first option more advantageous. But changing only the modulus of elasticity of the material, by increasing f_{ck}, in many cases is not enough.

Also in Table 14 and Table 15, it was possible to observe the difference between the range obtained by PCI [2] and ABNT 6118 [3], PCI [2] is much more conservative with respect to the minimum frequencies required for a satisfactory performance of the structure, in addition to the vibration induced by rhythmic activities, vary these values according to the span of the structure.

It was verified that the results obtained by the application of the equations indicated in the mentioned standards and by the modeling by the Finite Element Method of bar were very close, indicating the feasibility of using any of the methods.

It is important to analyze vibration in pre-cast floors because they are more flexible structures and therefore more susceptible to excessive vibrations. But according to the results in this paper, for ABNT 6118 [3], when the static evaluation in done for the SLS of deflection, there is no need to perform the dynamic analysis for the SLS of vibration, however that is not the same for PCI [2], that is more conservative. What leads for the need of experiments that could show what code is more representative to the criteria of human comfort in regard of vibrations.

4.1 Suggestions for future work

As the work did not take into account, the composite section of the ribbed slab, where it was studied as a monolithic section, the effect of the cold joint between the base of the rib and the topping of the section can decrease the rigidity of the part and can decrease the frequency natural slabs. Therefore, it is necessary to verify the interference of this type of connection, in order to bring the model closer to reality.

It is important to observe the interference when the panels are interconnected, in this work it was not possible to observe difference, since the load was equally distributed throughout the section, thus, the natural frequency obtained is the same, but with different loads on the same slab, different responses would be obtained, approaching the experimental results, in the case of a person walking through the panels. For this it is necessary, a 3D modeling in order to apply different loads in the surface area.

It is also important to relate the frequencies obtained with those required by performance standards beyond the codes studied in this work, such as ISO standards. Finally, it is important to do experimental results that could show what code is more representative to the criteria of human comfort in regard of vibrations.

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