Vibration in Pre-Manufactured Floor Used in Steel Structure Buildings

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Abstract. *The floor vibrations occurrence is not a new phenomenon, however, the new concepts and constructive techniques have become the structures lighter and slender, resulting in lower natural frequencies and damping levels, mainly in the case of steel structures. Therefore, resonance can occur with a harmonic of the step frequency due to the vibration induced by walking. Then, it is important the floor dynamic response calculation for amplitude of acceleration in order to check its performance relating to human comfort. In this work, the evaluation of the performance concerning of the vibration criterion for four hypothetical situations of floors configurations is presented. In order to check the floor performance relating to human comfort, floors have been modeled by finite elements using the software Ansys. The response in terms of acceleration for each floor have been obtained by means a transient dynamic analysis, taking into consideration the locations where the vibration level is greatest, normally at those points that have presented the greatest static displacements. By confronting those values of acceleration obtained through numerical simulation with those presented in the graphics based on the base curves, multiplied by parameters as recommended by the International Standard Organization – ISO/2631, it is possible to check if the floor attends the criterion regarding the human comfort. The methodology presented in this work, using numerical simulations applying the finite element method, constitute itself in a convenient procedure to assessment situations where more complexes floor arrangements in steel structures are found.*

Keys words. *Pre-manufactured floors, vibration floors performance*

1. Introduction

Most of the structures are projected appropriately for static loads, but cases exist where it is done necessary to take into account the effects of the dynamic loads. The dynamic loads can produce high vibration levels, the ones which so much can commit the structural safety as causing human discomfort. With the metallic construction a tendency exists in projecting structures more and more slender, besides using new materials in the building site. This tendency does with that there is a reduction of the natural frequencies of the structures leaving them more susceptible to a series of dynamic loads, since their natural frequencies start to be more and more close of the one of excitement. Therefore, it becomes more and more important to verify the dynamic behavior of the structures and to describe with detail the dynamic loads that can act.

The vibration induced in floors is classified in external and internal sources. There is great diversity of possible dynamic excitement causes in floors. Of a source for other, it happens variations of the important characteristics of the excitements, so that processes different from evaluation they can be valid in agreement with the more important potential cause. As examples of external sources of vibration, the road traffic and the railway man can be mentioned, that depending on the conditions of the envelop of the construction, they provoke vibrations in the structure of this. Such problem is usually treated through the isolation between the source and the building, since the objective is to obstruct the transmission of the vibratory wave.

In relation to internal sources of vibration, the one that happens in larger number and also the most important is the pedestrians' traffic. A pedestrian walking regularly applies a repeated force periodically to the floor, could provoke a pick in its structural answer. Daily they are found other types of internal excitements, as for instance a group of people practicing rhythmic gymnastics in academies. The effect of the walk is the form of more common excitement. In an approximate way, the geometry of the human body walking is an organized movement of legs that provokes an ascent and a descent of the mass of the body for each walking, Fig. (1). That ascent movement and descent is of approximately 50 mm, of pick the pick, but it is dependent of the angle among a leg and other completely stretched, in other words, to the length of the walking that the pedestrian is accomplishing in his walk.

The human perception of the vibrations is of difficult characterization, could be very sensitive for low levels of vibration of the floor, and on the other hand, almost insensitive, when happen quantitative changes in a substantial way in the vibration width. The great oscillation widths for frequencies in the range of 2 Hz to 20 Hz can provoke significant deformations in the human body, including resonance of specific organs, increasing the discomfort sensation, harming the ability to develop mechanical tasks and even provoking lesions. There is also the subjective factor, since the people possess differentiated perceptions some of the other ones. The human reaction at the vibration levels is substantially psychological; depending partially on the activity that is being carried out. That reaction is usually affected by other incentives, as the sound. Although the vibration level in floors can induce some people to an insecurity sensation, in most of the cases, that doesn't mean that some risk of structural collapse exists (SCI, 1989; Sales et all, 2001).

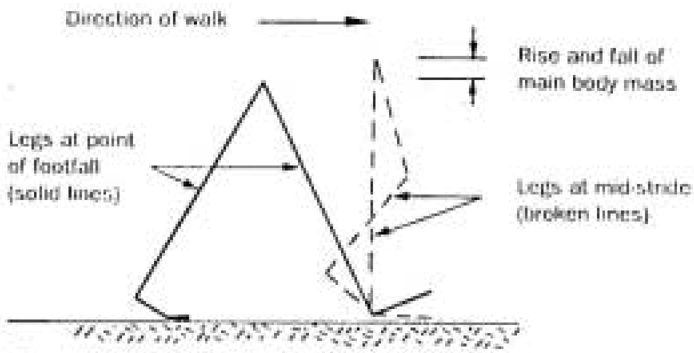


Figure 1. Simplified Geometry of walking. (Ohlsson, 1982)

The acceptability of floors of the point of view of the vibration depends on three factors: characteristics of the floor, type of excitement action in the floor and acceptable limits of vibration (Rainer et all, 1988). In that way, the study here accomplished proposes a vibratory evaluation, through numeric simulation. Such evaluation takes into account pedestrians walking as excitement source, the characteristics of four types of floors structured in steel and the criteria of minimum comfort recommended by standard, for four hypothetical structural situations.

2. Used Methodology

2.1. The dynamic problem of vibration of floors

For the description and characterization of the dynamic problem, involving vibrations of floors, it is important that are appraised the characteristics of each floor, as their outline conditions, mass, natural frequency, rigidity and capacity of reduction; as for the characteristics of the excitement loads, as their variability with the time, their excitement frequency and their magnitude; and as for the acceptability level and human perception, in terms of factors of answer lifted up statistically.

In this work only the dynamic load is considered generated on the floors by human activities. The load induced in the floors of the constructions due to the human activities as running, to jump, to dance and to walk, mainly this last one, it can be faced as being a load with characteristics of the harmonic and impulsive load.

The load in function of the time for activities that involve human activities, how to walk, to jump, to run and to dance, it can be described through a series of Fourier of harmonic n, given by the Eq. (1) (Vasconcelos, 1998).

$$F(t) = G_{st} + \sum_{i=1}^{n} Gst \cdot \alpha_i \cdot sen(2\pi \cdot i \cdot f_T \cdot t - \phi_i) \tag{1}$$

where G_{st} is the load density (forces for unit of area); f_T is the frequency of excitement of the force (fundamental frequency of the human activity); ϕ_i is the relative phase of the excitement force and α_i are the coefficients of the series. In the people's case walking on the floor and considering important just the harmonic first three for the description of the force, it is obtained for G_{st} = 700 N/m^2 (weigh of a person); $\alpha_1 = 0.4$; $\alpha_2 = 0.1$; $\alpha_3 = 0.1$; i = 1, 2 e 3; f_t = 2 HZ (adopted); range of fundamental frequency for people walking among 1.6 to 2.4 Hz and $\phi_1 = 0$; $\phi_2 = \pi/2$; $\phi_3 = \pi/2$, Eq. (2):

$$F(t) = 70 + \left\{ [280 \cdot sen(4\pi t)] + \left[70 \cdot sen\left(8\pi t - \frac{\pi}{2}\right)\right] + \left[70 \cdot sen\left(12\pi t - \frac{\pi}{2}\right)\right]\right\} \tag{2}$$

2.2. Analysis method

To proceed to the assessment of a floor of a given construction with relation for the comfort criterion it is necessary to make a dynamic characterization of the floor in terms of their modal parameters (frequencies and natural modal shapes and the damping ratio), besides to obtaining the dynamic response of the floor, in general, in terms of its acceleration. The evaluation of the floor with relation to the human comfort criterion due to the vibrations imposed by human activities, for instance, it is accomplished by confronting the accelerations obtained as a dynamic response of the floor with those limits established by the Standards and International Recommendations, as for instance ISO 2631/1 and to 2631/2 (1985). As the Standards present the results in curves that are functions of the frequency of vibration of the structure versus a percentile of the acceleration of the gravity, it is important to know which the predominant frequency of vibration of the structure. For a correct description of the dynamic behavior it is indispensable the knowledge of the applied dynamic loading. In the case in study, this corresponds to the description of the loading imposed by human activities, as walking.

The evaluation of the performance of the floor in relation to the vibration criterion for industrialized floors used in the steel structure building is accomplished through the computational simulation using Ansys (ANSYS, 2001). Four hypothetical situations of different arrangements (structuring) of floors they are evaluated. The dimensions of the chosen spans for the floors are close of those dimensions more commonly found at the market.

For the description of the finite element model, it was used two types of elements for all of the computational simulations accomplished. An element of spatial frame was used for the beams, described by Ansys as BEAM4, and a plate element, referred as SHELL63. The element BEAM4 is a unidirectional element constituted by two nodes. The element has six degrees of freedom for node: three translations in the X, Y and Z directions and three rotations around the X, Y and Z axes. The element formulation takes into consideration hardening tensions and large deformations. The element SHELL63 is a shell element constituted of four nodes. The element has six degrees of freedom for node: three translations in the X, Y and Z directions and three rotations around the X, Y and Z axes. For the element SHELL63 is possible to enter with normal and parallel loading to the plan, besides the consideration of hardening tensions and large deformations.

Static, modal, harmonic and transient analyses, for all of the hypothetical situations of arrangement of floors, were accomplished. Through the static analysis it was possible to obtaining the values of the nodal displacements, in order to compare with those values obtained by a simplified process of calculation, besides the obtaining of the area of the floor that comes with the largest displacements, with the objective of monitoring the dynamic response of the floor (Sales et all, 2001).

With the objective of evaluating which the predominant frequency of vibration for the floors, a harmonic analysis was accomplished in order to verify the importance of the vibrations mode shape in the dynamic response of the structure and to facilitate in the process of the establishment of the modal damping ratio to accomplish the transient analyses. For all of the accomplished transient analyses, the function of descriptive load of human activities was used. The accomplishment of the transient analysis seeks the determination of the values of displacements and nodal accelerations for those nodal points of the floor that presented the largest static displacements.

Once computed the accelerations, in terms of their peak values, the root mean square (r.m.s) values of acceleration equivalent to those peak values are computed, in order to using Standard's prescriptions. In this work, the base curves presented in International Standard ISO 2631-1/2 (1985) multiplied by a weighted factor has been used, in agreement with the destination of the floor, and as having suggested by Standard. The root mean square values and the values of peak of the acceleration are obtained through Eq. (3),

$$a_m = \frac{\Gamma \cdot a_{rms}}{\Lambda} \qquad (3)$$

where, a_m is the maximum peak of acceleration; a_{rms} is the root mean square and it represents the acceptable value of the acceleration obtained through the curves of ISO; Γ is the constant that depends on the analyzed case, being defined for each limit as: = 1/3–it limits I; = 1–it limits II; = 2 - it limits III. The constant, Λ, used for conversion between the RMS value and the peak value, considering a simple harmonic, it is given by $\Lambda = \sqrt{2} / 2$.

The curves of peak of acceleration to frequency induced in the floor by human activity are shown in Fig. (2). For those situations in which the points representing the computed acceleration are located above certain values of a given limit curve implies that the environment (place) are not attending the comfort criterion.

2.3. Floor vibration criteria related to human comfort

The criteria appropriate to residences and offices are associated with intermediate levels of vibration at which the physiologic effects take second place to the psychological factors. The importance of the psychological factors makes it difficult to quantify human reaction at these vibration levels. Reactions at these vibration levels may be influenced by several factors. In that way, statistical studies and collection of data were carried out in order to arrive to qualitative evaluations of the human reaction to vibrations and to comfort criteria for vibrations in floors (ISO 2631, 1985).

Because the wide range of frequency to be covered is large, it is common to plot contours indicating human reaction on logarithmic scales of frequency and amplitude of response. This structural response can be expressed in terms of displacements, velocity or acceleration (Fig. 3).

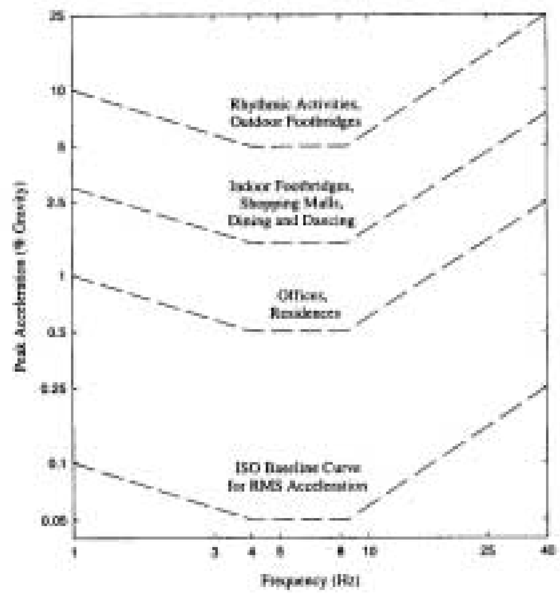


Figure 2. Values of peak of acceleration for check the human comfort due to vibrations generated by human activities – SOURCE - ISO2631-2, 1985.

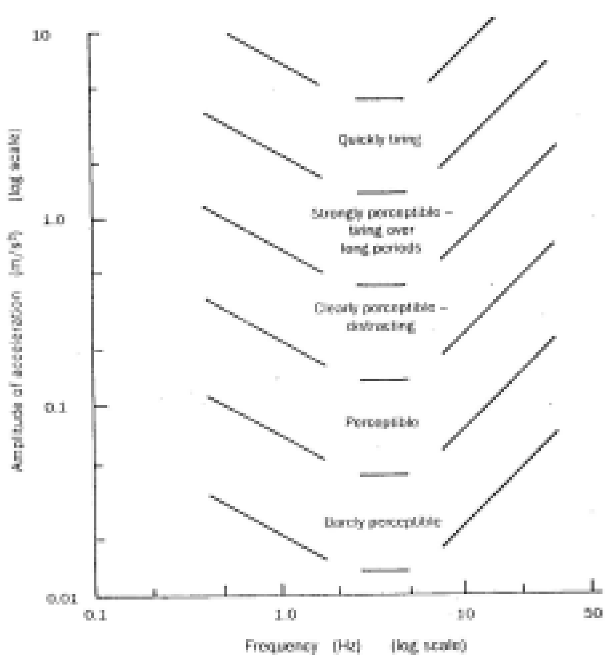


Figure.3. Qualitative description of human reaction to sustained steady oscillation. SOURCE–OHLSSON, 1982.

International Standard ISO 2631/1 (1985) defines the range of parameters of human comfort in three boundaries concerning to human sensation, the exposure time and level of acceleration for which a person may be exposed:

Limit I – Limit of the reduced comfort – it is related with the level of vertical acceleration from which the people are annoyed by the vibration, having more difficulties to execute tasks that demand certain concentration, such as eating, to read and to write.

Limit II – Limit of fatigue-decreased proficiency – it specifies the boundary beyond which exposure during a long period to vibration can bring a significant risk of impaired working efficiency in many kinds of tasks, particularly those in which time-dependent effects, fatigue, are known to worsen performance. The limit associated to the fatigue-decreased proficiency is defined by ISO 2631/1 (1985) as being three times larger than the limit associated to the reduced comfort.

Limit III – Limit of exposure time – is the limit in terms of values of maximum acceleration that a person can be exposed in a safe way, for any frequency condition, duration and direction, in a such way that their limit values are obtaining by doubling the values allowed according to the criterion of to the fatigue-decreased proficiency.

3. Case studies

All structural situations were analyzed as concrete slab molded in site, being considered a medium thickness of 10 cm, specific mass of the concrete and steel of 2500 kg/m3 and 7850 kg/m3 respectively, concrete and steel Young module of 29 GPa and 210 GPa respectively and coefficient of Poisson equal to 0,20 for both materials.

For each structural situation, three types of prefabricated floors were analyzed ("Steel deck", panels of concrete cellular autoclaved and alveolar panels of concrete extruded) besides the concrete slab molded in site, with the objective of comparing the performance of the prefabricated systems with the conventional ones.

The definition of dimensions of steel cross section, for each situation, was done starting from a previous basic proportioning, considering the most robust cross section to be adopted as pattern, for the four floor types studied. Starting from the minimum dimensions of steel cross section initially chosen, their characteristics could be varied in order to observes the influence degree for each studied floor assembly (Sales, 2001).

3.1. Configuration 01

Floor of 18,00 m x 12,00 m, spacing between beams of 3,00 m and boundary conditions as indicated in the Fig. (4). According with the pre-proportioning, the minimum dimensions of the beams are: V1– external beam (cross section 350x38), V2 – external beam (cross section 350x38), V 3– internal beam (cross section 400x78).

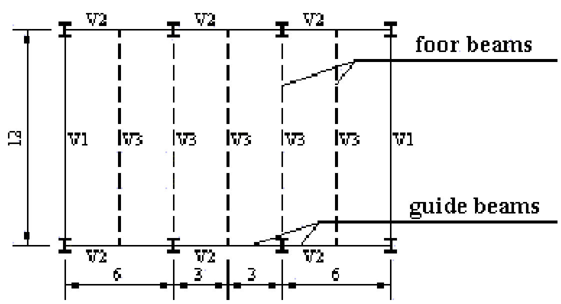


Figure 4– Schematic view of floor structural arrangement – configuration 01 (measures in m)

3.2. Configuration 02

Floor of 36,00 m x 12,00 m, spacing between beams of 3,00 m and boundary conditions as indicated in the Fig. (5). According with the pre-proportioning, the minimum dimensions of the beams are V1 – external beam (cross section 350x38), V2 – external beam (cross section 500x97), V3 – internal beam (cross section 500x86).

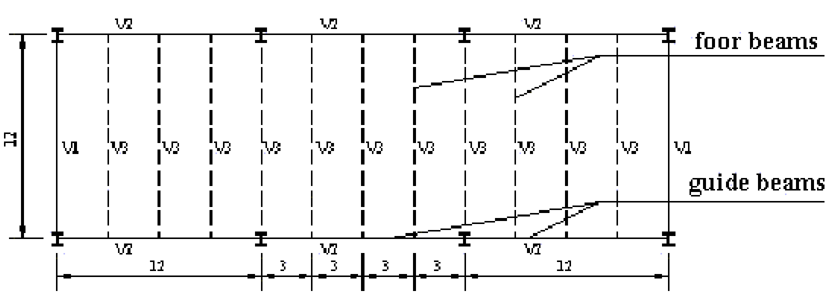


Figure 5. Schematic view of floor structural arrangement – configuration 02 (measures in m)

3.3. Configuration 03

Floor of 24,00 m x 12,00 m, spacing between beams of 3,00 m and boundary conditions as indicated in the Fig. (6). According with the pre-proportioning, the minimum dimensions of the beams are V1 – external beam (cross section 200x19), V2 – external beam (cross section 400x68), V3 – internal beam (cross section 250x27), V4 – internal beam (cross section 550x100).

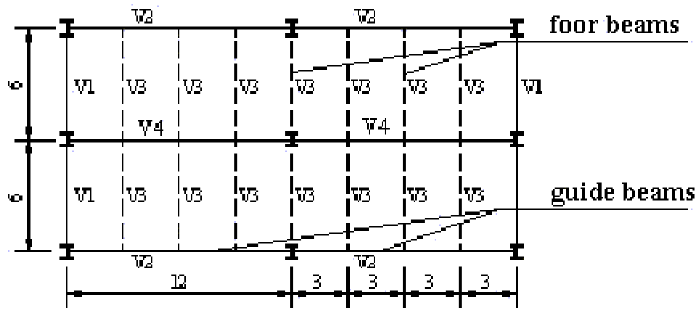


Figure 6. Schematic view of floor structural arrangement – configuration 03 (measures in m).

3.4. Configuration 04

Floor of 24,00 m x 24,00 m, spacing between beams of 3,00 m and boundary conditions as indicated in the Fig. (7). According with the pre-proportioning, the minimum dimensions of the beams are V1 – external beam (cross section 200x19), V2 – external beam (cross section 600x95), V3 – internal beam (cross section250x27), V4 – internal beam (cross section 650x155).

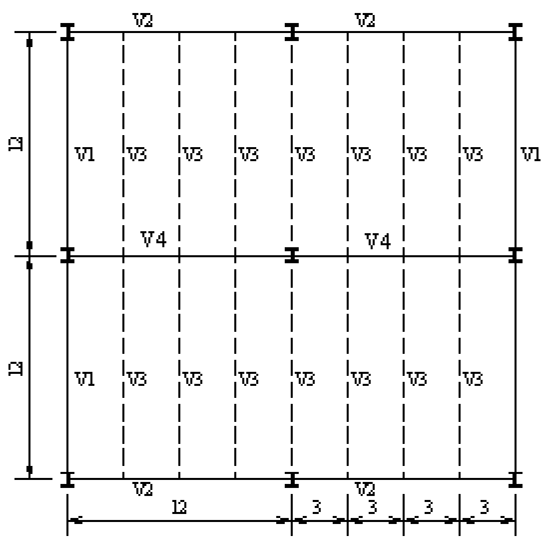


Figure 7. Schematic view of floor structural arrangement – configuration 04 (measures in m).

4. Result analysis

With the objective of determining the modal contribution in the response of the floor, i.e., those mode shapes that contribute in an effective way to structural response, in order to verify the susceptibility of the floor related to resonance due to the load induced by people walking, a harmonic analysis was carried out. In this analysis, a force of the type F(t) = F0 sen (t) was applied, with the force amplitude, F0 = 1000N, and making her to oscillate in a range of certain frequency. This force was applied in those nodal points submitted to the largest displacements verified in static analysis. In Figs. 8, 9, 10 and 11 are showed the nodal displacements amplitude in function of frequency of the force F(t).

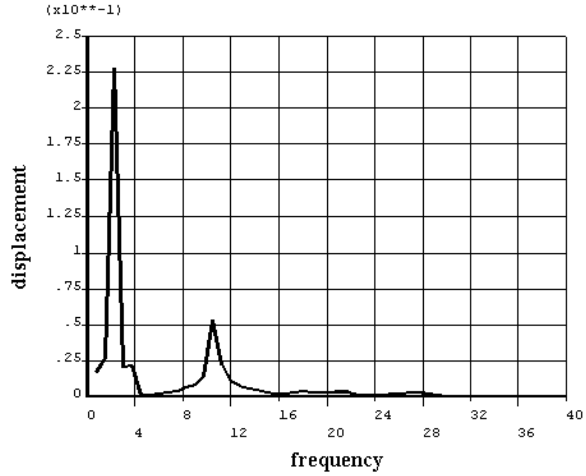


Figure 8. Nodal displacement in function of frequency (Harmonic analysis) – Configuration 01

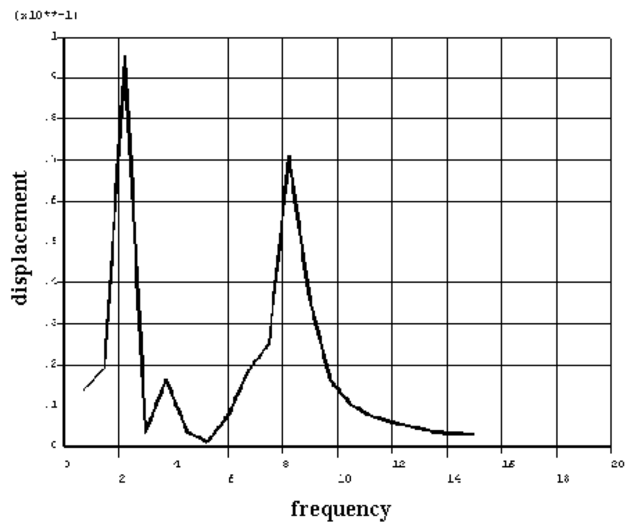


Figure 9. Nodal displacement in function of frequency (Harmonic analysis) – – Configuration 02

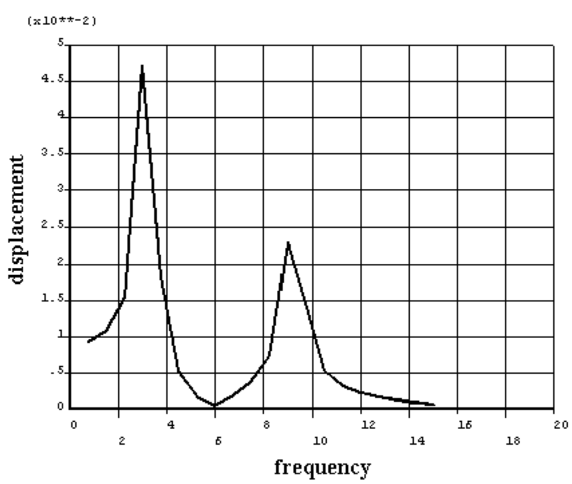


Figure 10. Nodal displacement in function of frequency (Harmonic analysis) – Configuration 03

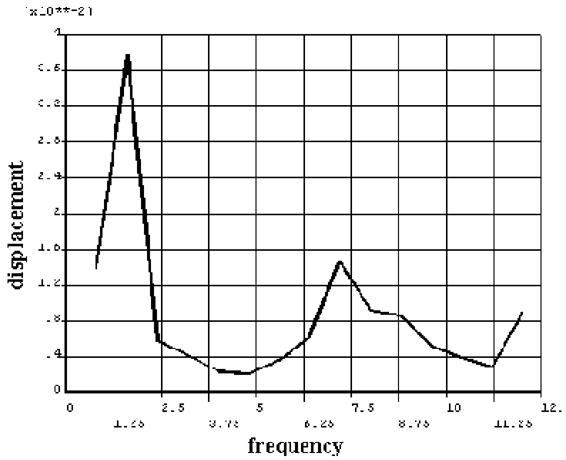
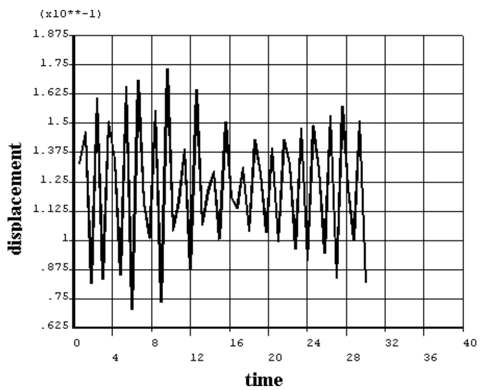
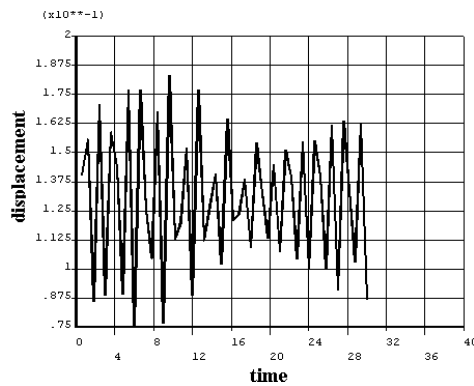


Figure 11. Nodal displacement in function of frequency (Harmonic analysis) – Configuration 04

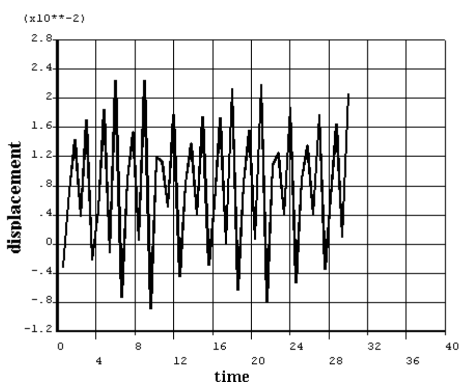
Through a transient analysis, the nodal displacements and accelerations for those points of the floor that presented the largest static displacements were computed, as seen before. In Figs. 12 and 13 are presented the displacements and accelerations computed for each analyzed floor configuration.



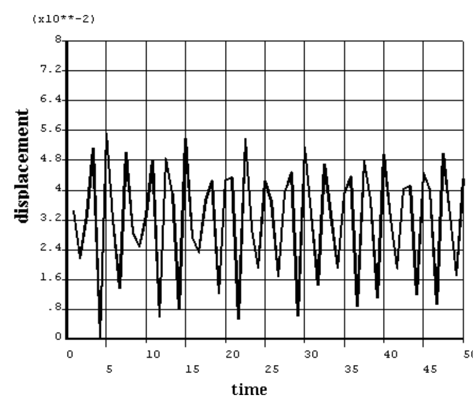
(a) Configuration 01



(b) Configuration 02

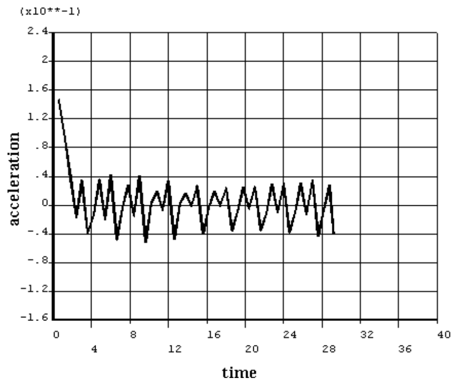


(c) Configuration 03

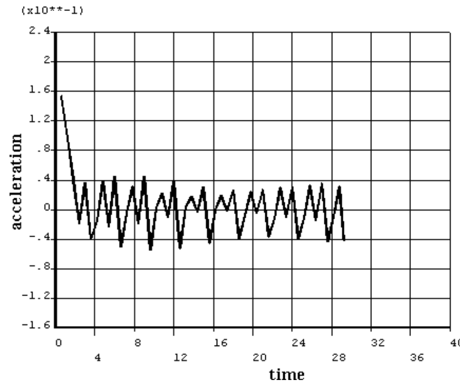


(d) Configuration 04

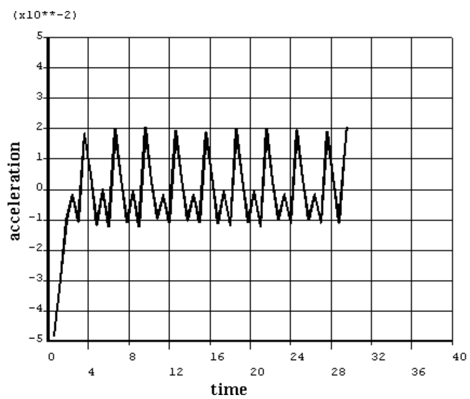
Figure 12. Time response of nodal displacement



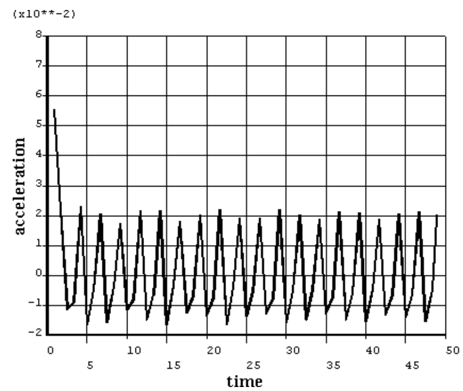
(a) Configuration 01



(b) Configuration 02



(c) Configuration 03



(d) Configuration 04

Figure 13. Time response of acceleration

In Tab. (1), the values of the accelerations obtained for the four situations of floors analyzed are presented. A dynamic load given by Eq. (2) was applied and it was considered an oscillation frequency around 2 Hz. The value of RMS acceleration was obtained through Eq. (3).

Table 1. Values of accelerations for the configurations of floors analyzed.

Acceleration (m/s^2)	Configuration 01	Configuration 02	Configuration 03	Configuration 04
a_{max}.	$4{,}75 \times 10^{-2}$	$5{,}48 \times 10^{-2}$	$2{,}03 \times 10^{-2}$	$2{,}31 \times 10^{-2}$
a_{RMS} (Limit I)	$1{,}01 \times 10^{-1}$	$1{,}16 \times 10^{-1}$	$4{,}31 \times 10^{-2}$	$4{,}90 \times 10^{-2}$
a_{RMS} (Limit II)	$3{,}36 \times 10^{-2}$	$3{,}87 \times 10^{-2}$	$1{,}44 \times 10^{-2}$	$1{,}63 \times 10^{-2}$

The values of Tab. (1) are compared with the curves shown in the Fig. (3). It is verified that the floor of situation 01is adapted for the use as residence and office, just when is considered the limit II. In the same way, the floor of situation 02 is adapted for the use as residence and office just for the Limit II. On the other hand, the floors of situations 3 and 4 are adapted for the use as residence and office as much for Limit I as for the Limit II.

5. Final considerations

The obtained results, for the vibratory behavior of the floors, through numerical simulation, were shown coherent when compared to those presented by Standard. This proves that this calculation procedure is a good tool to check the condition of comfort of floors in relation to the vibration even in the early project phase.

6. References

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