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Analysis of the Vibrations in Walk Bridges

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Abstract: This report looks for to present a research carried out, related to the area of analysis of vibrations in structures taking into account the importance of these in our daily lives. The dynamics of the structures bring about the movement of people, which cause harmful vibrations for the structure and unpleasant for users. We call this dynamic of rhythmic movements, taking into account the frequency with which they are performed. Each structure has expected rhythmic movements and its corresponding frequency, which is taken into account at the time of its projection, thus being adapted for each function it supports. It is worth mentioning that users, as soon as they perceive this frequency, tend to synchronize themselves accordingly, intensifying the submitted vibrations, making their effects more intense.

Keywords: Vibrations; walkways; bridges.

1 Introduction

Walkways are important constructions of the modern world, today it is almost impossible to make a metropolis viable without dozens of them. Population-giant cities with limited territory need bridges and walkways to stay active. This constrютions enable better mobility for cyclists and pedestrians, in addition to preventing accidents and shortening distances. Given this importance, ensuring the safety of these is also necessary, since they are structures with high cost and widespread use, being fundamental researches on materials, structures, frequency and environment, before considering their construction.

2 Methodology

2.1 Materials and Methods

The theoretical part of the work was based on three main literatures: *Introdução à Dinâmica das Estruturas, Para a Engenharia Civil* [1]; *Experimental evaluation of the effect of geometric nonlinearities in structural resonances* [2]; *Vibration problems in structures, practical guidelines*[3]. Based on them, spreadsheets and individual research were created to understand and justify the basic requirements. Analysis of formulas was one of the main topics under the theoretical part. In consequence, from them, the first procedures could be followed: not only knowing how to read them but also knowing how to translate them proved to be essential:

For the calculation of the dimensions that govern under a structure we have some formulas, such as:

$$M\ddot{u} + C\dot{u} + Ku = P(t) \qquad (1)$$

$$f_i = Mu_t = M(\ddot{u}_s + \ddot{u}) \; ; \qquad f_e = Ku; \qquad f_d = C\dot{u}$$

$$f_i = P(t) - f_e - f_d \qquad (2)$$

Where:

P(t)= vertical force;
u= displacement;
u̇= speed;
ü= acceleration;
f_d*= dissipation force;*
f_e *= elastic restorative force;*
f_i*= force of inertia;*
M= relative mass;
K= elastic capacity.

Formula (1) is important for the deduction of other model formulas with one degree of freedom:

$$M\ddot{u} + C\dot{u} + Ku = p_0 sin\Omega\, t \quad (3) \quad \text{or}$$

$$\ddot{u} + 2\xi\omega\dot{u} + \omega^2 u = \frac{p_0}{M} sint \qquad (4)$$

To calculate the displacement:

$$u(t) = \rho sin\Omega\, t - \theta) \qquad (5)$$

Where:

p_0*= amplitude of harmonic loading;*
ξ *= damping rate;*
ω= first natural frequency of vibration;
θ*=lag.*

Formula (5) allows us to deduct the equation used to calculate the response to forced vibrations (vibrations caused by people's rhythmic movement):

$$F(t) = G[\ 1 + \alpha_1 sin(\ 2\pi f_p t\ ) + \alpha_2 sin(\ 4\pi f_p t\text{-}\phi_2\ ) + \alpha_3 sin\ (\ 6\pi f_p t\text{-}\phi_3\ ) + \ldots \qquad (6)$$

Where:

f_p*= fundamental excitation frequency;*
G =weight of the people in motion;
α_i*= proportion of total weight corresponding to each harmonic;*
ϕ_i *= phase of a harmonic in relation to the first..*

Based on these calculations, a table on the tolerance for the accelerations to which the structure is subjected is pre-established:

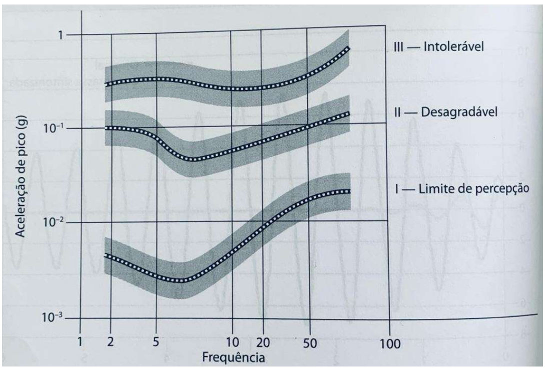


Figure 1. Acceleration x Frequency Chart[1]

3 Results and discussion of results

A hypothetical walkway was created with the following configurations: base 0.5 radius m x 1.2 m; slab 0.2 m x 2 m x 20 m. This passerelle served as a base for the creation of several others, differing by the size of the base or length. All of them were subjected to loads that simulate the walking of people and from that, graphs were generated to understand the behavior of the structure with each configuration. At the end, the grafics were compared, under the vibration tolerance criteria established in *Shock and Vibration Handbook*[4], to adequacy of each of them. For a better explanation, we will show first the results presented by the base catwalk, such as drawing and graphics, then the comparison between them.

The design of the base walkway:

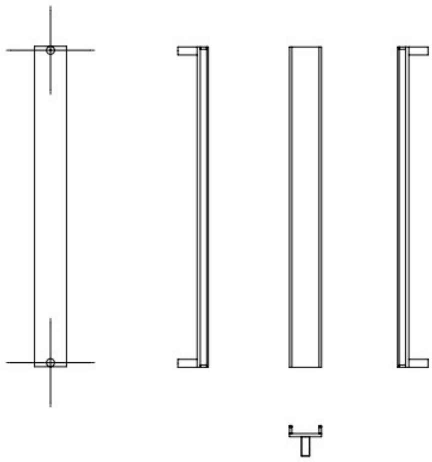


Figure 2. Base design of the main walkway.

Along with the drawing, a spreadsheet was created to predict the harmonic loading of the structure. On this spreadsheet we have the graphs related to the three harmonics and on the sum of the accelerations, all of them are in function of time:

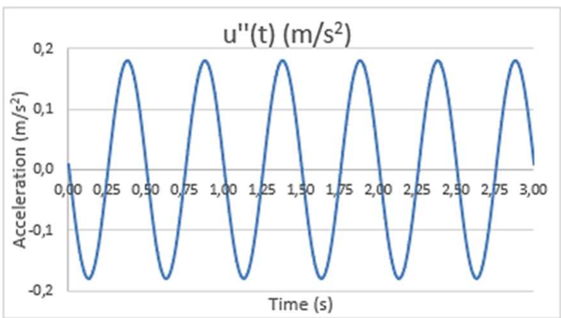


Figure 3. Acceleration X Time in the first Harmonic

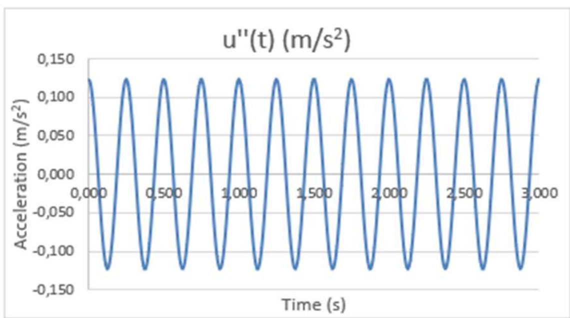


Figure 4. Acceleration X Time in the third Harmonic

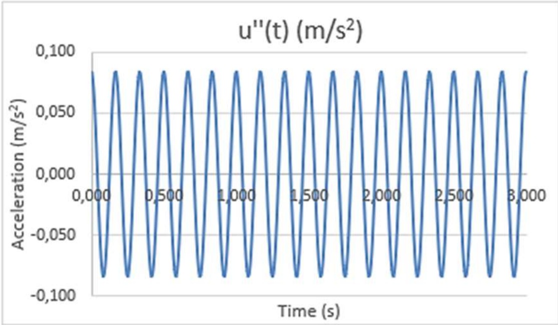


Figure 4. Acceleration X time in the second Harmonic

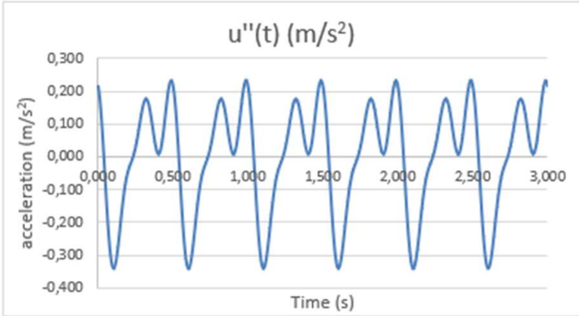


Figure 5. Sum of accelerations X Time

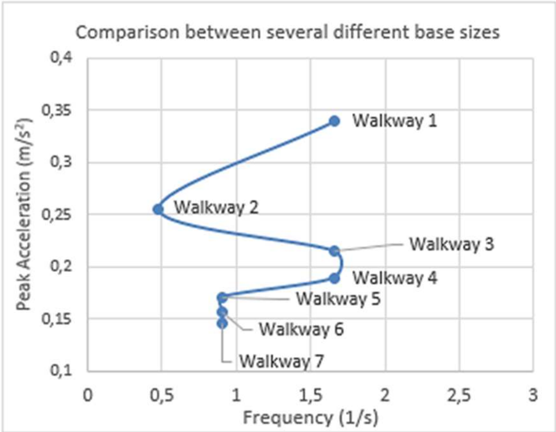
Now, the search for the acceleration of peak, or the greatest absolute number of the sum of accelerations of each structure become the focus of the work. Along with that, grafics of acceleration X frequency were build, aiming to compare the structures along themselves, and, in the end, compare with the grafics in the Figure 1. That last step was made in order to know where each one of the passerelles fall in.

Table 1. The first 7 walkways and their values for peak acceleration.

Changing the Base Size					
Walkways	Base (m)	Time (s)	Frequency (1/s)	Maximum Absolute Acceleration (m/s^2)	Peak Acceleration (m/s^2)
1	**0,5**	**0,603**	**1,658374793**	**-0,339650748**	**0,339650748**
2	0,75	2,1	0,476190476	-0,255560914	0,255560914
3	1	0,603	1,658374793	-0,215028012	0,215028012
4	1,25	0,603	1,658374793	-0,189265582	0,189265582
5	1,5	1,104	0,905797101	-0,171014939	0,171014939
6	1,75	1,104	0,905797101	-0,157097411	0,157097411
7	2	1,104	0,905797101	-0,145942119	0,145942119

Table 2. The last 6 walkways and the base, together with their peak acceleration values.

Changing the Length					
Walkways	Length (m)	Time (s)	Frequency (1/s)	Maximum Absolute Acceleration (m/s^2)	Peak Acceleration (m/s^2)
1	**20**	**0,603**	**1,658374793**	**-0,339650748**	**0,339650748**
8	17,5	0,096	10,41666667	-0,999813711	0,999813711
9	15	0,495	2,02020202	0,357355426	0,357355426
10	12,5	1,089	0,918273646	-0,128043496	0,128043496
11	10	0,09	11,11111111	-0,030985874	0,030985874
12	7,5	1,59	0,628930818	-0,00841206	0,00841206
13	5	0,09	11,11111111	-0,001582811	0,001582811
14	2,5	0,09	11,11111111	-9,78745E-05	9,78745E-05



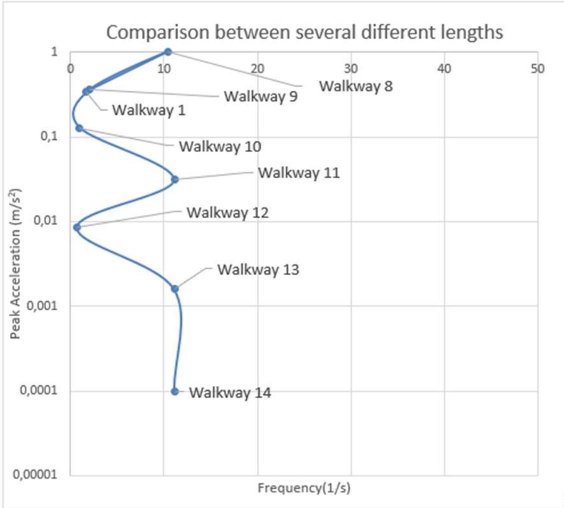


Image 7. Comparasion between several differnet base sizes and Image 8. Comparison between several diferente lenghts.

Comparing this graphic from Image 7 to that in Image 1. it is possible to defer that all structures are between levels of unpleasant and intolerable, which means that just by changing the size of the base is not enough to make them pleasant or safe. Making the same comparison with Image 8. is possible to notice the walkways were only below the level of unpleasant when cutting their length in half. A possible solution for that the reduction wouldn't be necessary would be to place dampers or insert another support column in some points to guarantee the safe dissipation of the loads.

4 Conclusions

The research project concluded the initial objectives and presented satisfactory results. It created hypothetical walkways, subjected them to loads that exemplified the walking of people, tested them, analyzed them, found problems and was able to promoted a solution. Walkways have to be sturdy, safe and comfortable - ensuring this is essencial. Therefore, walkways 1, 2 3, 4, 5, 6, 7, 8, 9 and 10, didn't achieve the minimum characteristics of vibration, because the greatest acceleration presented in each one was superior to the levels of unpleasant. However, the catwalks, 11, 12, 13 and 14, reached good levels of acceleration even at their highest peaks.

References

[1] M. A. Silva and R. M. Brasil *Introdução à Dinâmica das Estruturas, Para a Engenharia Civil*.
[2] M. A. Silva and A. M. Wahrhafitg *Experimental evaluation of the effect of geometric nonlinearities in structural resonances*.
[3] H. Bachmann. *Vibration problems in structures, practical guidelines*.
[4] C. M Harris. *Shock and Vibration Handbook.*