FACTA UNIVERSITATIS
Series: **Architecture and Civil Engineering** Vol. 20, Nº 1, 2022, pp. 23-34
https://doi.org/10.2298/FUACE220301005S

Original scientific paper

MODELLING OF PEDESTRIAN-INDUCED LOAD IN SERVICEABILITY LIMIT STATE ANALYSIS OF FOOTBRIDGES

UDC 624.21.042

Marija Spasojević Šurdilović, Srđan Živković, Dragana Turnić, Marko Milošević

Faculty of Civil Engineering and Architecture, University of Niš, Serbia

Abstract. *The last few decades new trends in the design of pedestrian bridges have resulted in lighter and more slender structures. This leads to a reduction in natural frequencies and increased flexibility, and thus a greater possibility for structures to become more exposed to excessive vibrations caused by pedestrians. The lager amplitudes of vibrations occur if the pace frequency of excitation load approaches one of natural frequency of footbridge. The vibration of high proportions may cause pedestrians to feel uncomfortable, sick or unsafe while crossing the bridge. In modern pedestrian bridge design, human-induced vibrations have become an important issue. Footbridge vibrations occur in vertical, lateral and longitudinal direction, and torsion of the bridge deck is also possible. The main types of pedestrian action on the bridge are walking and running, while jumping, bouncing, swaying are considered to be intentional, or sometimes even vandal excitation. Pedestrian-induced loads are difficult to model since pedestrians may have different weight, various number in the groups randomly distributed over the bridge deck. Also, the walking velocity may vary from a pedestrian to a pedestrian. The load models appropriately set up are of great importance for understanding the response of the bridge. Principles of modeling of the human-induced load and some characteristic models of pedestrian loads, described in proposals and codes, are presented in this paper. Some results of Serviceability Limit State analysis, in terms of human-induced vibration, of the pedestrian bridge over the Nišava River in Niš, are also presented.*

Key words: *pedestrian-induced load, footbridge, dynamic load model, serviceability limit state*

Received March 1, 2022 / Accepted September 19, 2022
Corresponding author: Nenad Ćirić
Faculty of Civil Engineering and Architecture, Aleksandra Medvedeva 14, 18106 Niš, Serbia
E-mail: marija.spasojevic.surdilovic@gaf.ni.ac.rs

1. INTRODUCTION

The last few decades technical and technological developments, as well as the new trends in the design of pedestrian bridges resulted in more slender and flexible structures. This leads to a reduction in natural frequencies, and as a consequence, footbridges tend to be more sensitive to pedestrian-induced dynamic loads. The lager amplitudes of vibrations occur if the pace frequency of excitation load approaches one of the structural natural frequencies. The vibration of high proportions may cause pedestrians to feel uncomfortable, sometimes sick, or even unsafe while crossing the bridge, that is highly compromising the vibration serviceability limit state. Therefore, more detailed dynamic analyses have become inevitable in the design of footbridges. For good understanding of the bridge response, the load models have to be appropriately set up. Although pedestrian-induced loads are difficult to model, some of the current Codes and guides for practice are offering guidelines for their selection. Principles of modelling of pedestrian load and some characteristic models from existing literature are presented in addition.

2. PEDESTRIAN-INDUCED FORCES

Pedestrian-induced loads are results of human activities such as walking, running, jumping, bouncing, swaying in horizontal direction, jumping on the spot. Some of these actions are often characterized as intentional or vandal excitations.

Pedestrian-induced loading due to walking is a periodic excitation that depends on the pace frequency and body weight. The frequency range for loading due to walking is roughly between 1.5 and 2.5Hz, and for running above 2.5Hz. The force has three components: vertical, lateral and longitudinal. The vertical one is about 40% of body weight. While walking, the body weight changes position by shifting from one foot to the other. Load curves for each foot overlap (Figure 1).

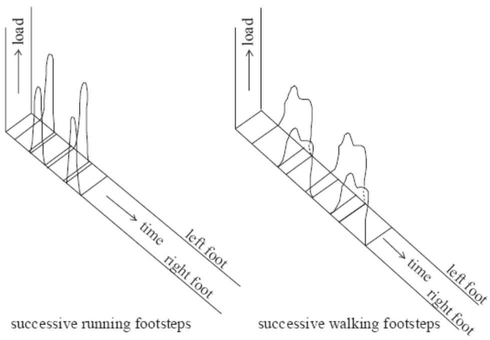


Fig. 1 Changes of the force due to a) running; b) walking [1]

2.1. Vertical component

Normal walking induces a vertical force of a double hump shape. The curve has two force maximums, where the first one comes from the heel impact, and the second one is due to push off. The ground reaction is shown on (Figure 2).

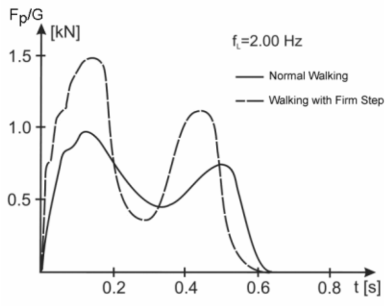


Fig. 2 Vertical ground reaction forces: normal walking and walking with firm step [2]

2.2. Transverse and longitudinal components

The frequency of the transverse component of the force induced by walking is half the vertical component and is about 1 Hz. This force is caused by the lateral body oscillation. The longitudinal component has the same magnitude as the lateral one. The main characteristic of the longitudinal force is the retarding and pushing walking period. Their pattern is shown on Figure 3.

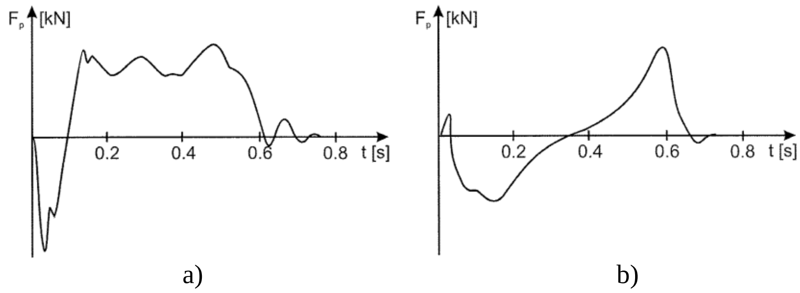


Fig. 3 Ground reaction forces from walking: a) lateral; b) longitudinal [3]

3. PEDESTRIAN-INDUCED FORCES

It is difficult to mathematically represent the dynamic force induced by a single pedestrian since it is essentially a narrow-band phenomenon that is poorly understood [4]. Modelling of the walking load is more complex than modelling of the running one. Yet, walking is a more common activity on footbridges, and only the basis of modelling of time domain load induced by walking will be given below.

3.1. Vertical load model

Due to periodic nature of the pedestrian-induced force, this load can be divided into a set of sinusoidal oscillations by using the Fourier transformation:

$$F(t) = F_0 + \sum_{i=1}^{n} F_i \cdot \sin(2\pi \cdot i \cdot f_s \cdot t - \varphi_i) \qquad (1)$$

where:

F_0 is mean or static load
F_i is load component for frequency $i \cdot f_s$
f_s is step frequency
φ_i is phase angle of load component F_i

The number of harmonics that have to be considered depends on their amplitude and their dynamic influence. Usually, the first three harmonics are taken into account. The ratio of the force amplitude to the person's weight that is the static load, is defined as the dynamic load factor. The loading coefficients according to different authors are given in Table 1.

Table 1 Recommended dynamic load factors (DLF) for vertical loads

DLF	$F_{1,v} / F_0$	$F_{2,v} / F_0$	$F_{3,v} / F_0$
Bachmann [2]	0,4 for f_s = 2 Hz 0,5 for f_s = 2,4 Hz	0.1	0.1
Kerr [5]	Freq. dependent	0.07	0.06
Young [6]	$0.37(f_s-0.95) \leq 0.5$	$0.054+0.0044\, f_s$	$0.026+0.0050\, f_s$

Taking into account the first three harmonics, Bachmann [2] described the vertical load as:

$$F_v = F_0 + F_{1,v} \cdot \sin(2\pi \cdot f_s \cdot t) + F_{2,v} \cdot \sin(4\pi \cdot f_s \cdot t - \varphi_2) + F_{3,v} \cdot \sin(6\pi \cdot f_s \cdot t - \varphi_3) \quad (2)$$

where:

F_0 is dead load of the pedestrian (800 N)
F_i is participation of the *i*-th harmonic to the resulting load
f_s is step frequency
φ_i is phase angle of the *i*-th harmonic ($\varphi_2 = \varphi_3 = \pi/2$)

3.2. Horizontal load model

Horizontal load can also be represented by the Fourier transformation. The frequency of the lateral load is half of the vertical load. Considering the first 3 harmonics of the Fourier coefficients the lateral force is:

$$F_h = F_{1,h} \cdot \sin\left(2\pi \cdot \frac{f_s}{2} \cdot t\right) + F_{2,h} \cdot \sin\left(4\pi \cdot \frac{f_s}{2} \cdot t - \varphi_2\right) + F_{3,h} \cdot \sin\left(6\pi \cdot \frac{f_s}{2} \cdot t - \varphi_3\right) \quad (3)$$

where:

$F_{i,h}$ is participation of the *i*-th harmonic to the resulting load
f_s is step frequency
φ_i is phase angle of the *i*-th harmonic ($\varphi_2 = \varphi_3 = \pi/2$)

Table 2 Recommended dynamic load factors (DLF) for lateral loads

DLF	$F_{1,h} / F_0$	$F_{2,h} / F_0$	$F_{3,h} / F_0$
Sétra [7]	0.05	0.01	0.05
Bachmann et al. [8]	0.1 for f_s=2 Hz	/	0.1

Running or walking, load induced by pedestrians has been extensively studied and is expressed as a point force exerted to the support, as a function of time and pedestrian position. The load of a pedestrian moving at constant speed v can be described as the product of a time component $F(t)$ by a space component $\delta(x - vt)$, δ being the Dirac operator and x being the pedestrian position in relation to the footbridge centerline [7], that is:

$$P(x,t) = F(t)\delta\,(x - vt) \tag{4}$$

4. LOAD MODELS IN CODES AND GUIDES FOR PRACTICE

Even after twenty years of intensive study in the area of human-induced vibration, there are still no sufficiently reliable load and response models to evaluate the vibration serviceability of footbridges under the human-induced excitation, particularly in view of crowded conditions [9]. The dynamic phenomenon of footbridge behavior under the human-induced load is yet not well understood. That is why many codes and standards differ in their approach to this topic. Some proposal and recommendations for dynamic load models are given in ISO 10137:2007 [10], Australian Standard AS 5100.2-2004 [11], British Standard BS 5400 [12], Ontario Highway Bridge Design Code OHBDC ONT 83 [13], UK National Annex to EN 1991-2:2003 [14], Guidelines for the design of footbridges FIB [15], Design of Lightweight Footbridges for Human-Induced Vibration-JRC Scientific and Technical Reports [16], Footbridges-Assessment of vibrational behavior of footbridges under pedestrian loading SETRA [7] etc.

4.1. Eurocode

Eurocode is a set of building codes developed by the European Committee for Standardization. There are three parts of Eurocode dealing with human-induced loads and structural requirements. Comfort criteria, defined in terms of maximum acceptable acceleration, are given in EN 1990:2002 "Basis of structural design" [17] while EN 1991-2:2003 "Action on structures" [18], instead of giving dynamic loads which should be applied, proposes that complementary load models, with associated combination rules, may have to be defined for the individual project. According to Eurocode, National Annexes are supposed to propose appropriate load models for dynamic analysis of footbridges. Performance criteria are contained in EN 1993-2:2006 "Design of steel structures" [19].

4.2. ISO 10137:2007

According to ISO 10137:2007 [10] dynamic pedestrian action on footbridges can be described as:

- *Single pedestrian dynamic action*

The dynamic force $F(t)$ induced by a person of weight, Q, doing repeated, coordinated activities can be expressed as a function of time t by a series of pulses:

$$F_v(t) = Q\left(1 + \sum_{n=1}^{k} \alpha_{n,v} \sin\left(2\pi nft + \phi_{n,v}\right)\right) \text{ in vertical direction} \tag{5}$$

and

$$F_h(t) = Q\left(1+\sum_{n=1}^{k}\alpha_{n,h}\sin(2\pi nft+\phi_{n,h})\right) \text{ in horozontal direction} \quad (6)$$

where: $\alpha_{n,\mathrm{v}}$ and $\alpha_{n,\mathrm{v}}$ are numerical coefficients corresponding to the n_{th} harmonic for vertical and horizontal direction, respectively; Q is the static load of the participating person; f is the frequency component of repetitive loading and f is half the activity rate in the case of walking or running for determining transverse horizontal vibrations; $\phi_{n,\mathrm{v}}$ and $\phi_{n,\mathrm{h}}$ are the phase angles of the n_{th} harmonic, for vertical and horizontal direction, respectively; n is the integer designating harmonics of the fundamental; k is the number of harmonics that characterize the forcing function in the frequency range of interest. The number of harmonics k required to effectively model the time history of the load will vary depending on how complex it is.

- *Dynamic action of groups of participants*

The main factors that determine the dynamic action induced by groups of participants are the weight of the participants, the maximum number of people per unit floor area that can be accommodated for the pedestrian activity, and the level of participant coordination. Considering that there is some variation in the frequency f, the phase angle ϕ_n, and the numerical coefficient α_n in a group of people representing general population, the dynamic response of the structure will be less than it would be in a group with perfect coordination. This reduced response of the structure can be approximately described by applying a coordination factor $C(N)$ to the forcing function:

$$F(t)_N = F(t)\cdot C(N) \quad (7)$$

where N is the number of participants.

4.3. Guidelines for the design of footbridges FIB

Even it has not ever been officially approved, Proposal Annex C to EN 1991-2:2003 "Action on structures" [20,21] proposed three dynamic load models that were subsequently recommended by guidance for footbridge design of Féderation internationalle du béton (FIB) [15]. Those models are:

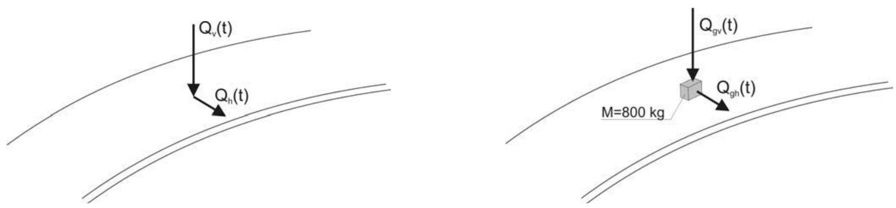
- *Single pedestrian dynamic load model*

The dynamic load model of a single pedestrian (Fig.4a), also contained in British Standard BS 5400, Part 2 [12] is limited to the first harmonic of the force F(t). It consists of a pulsating stationary force with two components. That considers the effect of pedestrian weighing 700 N and moving with speed equal [m/s] to 0.9 times the walking frequency f_s, considering the first harmonic of the reaction force and dynamic factor for vertical direction according to Blanchard [22].

$$\text{vertical component: } Q_{pv} = 180\cdot\sin(2\pi\cdot f_v\cdot t)\ [\mathrm{N}] \quad (8)$$

$$\text{lateral component: } Q_{ph} = 70\cdot\sin(2\pi\cdot f_h\cdot t)\ [\mathrm{N}] \quad (9)$$

where f_v is the natural vertical frequency of the bridge that is the closest to 2 Hz, and f_h is the natural horizontal frequency of the bridge that is the closest to 1 Hz.



a) b)

Fig. 4 Dynamic load model: a) single pedestrian; b) group of pedestrians [15]

- *Group of pedestrians dynamic load model*

The dynamic load model of a group of pedestrians (Fig. 4b) has a stochastic approach and describes the effect of a group (8-15 persons) of unsorted walking persons. The synchronisation of a frequencies and phases is taken into account by the coefficient k_v and k_h. This pulsating stationary force has two parts:

$$\text{vertical component: } Q_{gv} = 180 \cdot k_v(f_v) \cdot \sin(2\pi \cdot f_v \cdot t) \text{ [N]} \quad (10)$$
$$\text{lateral component: } Q_{gh} = 70 \cdot k_h(f_h) \cdot \sin(2\pi \cdot f_h \cdot t) \text{ [N]} \quad (11)$$

where f_v is the natural vertical frequency of the bridge that is the closest to 2 Hz, f_h is the natural horizontal frequency of the bridge that is the closest to 1.5 Hz, and k_v i k_h are synchronisation factors.

- *Dynamic load model of continuous stream of pedestrians*

The dynamic load model for a continuous stream of pedestrians considers the excitation forces due to a continuous stream of pedestrians with a density of 0.6 pers/m^2 and has to be used separately from the dynamic load model of a pedestrian group. This load is applied as a uniformly distributing two component pulsating area load. The total number of pedestrians is N=0.6BL, where B is the effective bridge width and L is the bridge length.

$$\text{vertical component: } q_{s,v} = 12{,}6 \cdot k_v(f_v) \cdot \sin(2\pi \cdot f_v \cdot t) \text{ [N/m}^2\text{]} \quad (12)$$
$$\text{lateral component: } q_{s,h} = 3{,}2 \cdot k_h(f_h) \cdot \sin(2\pi \cdot f_h \cdot t) \text{ [N/m}^2\text{]} \quad (13)$$

where f_v is the natural vertical frequency of the bridge that is the closest to 2 Hz, f_h is the natural horizontal frequency of the bridge that is the closest to 1.5 Hz and k_v and k_h are synchronization factors.

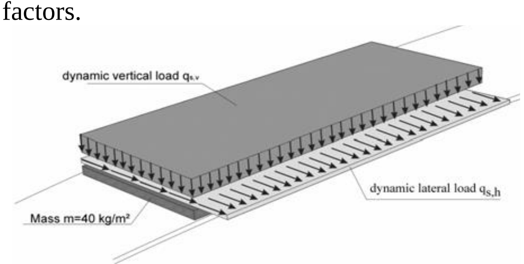


Fig. 5 Dynamic load model of a continuous stream of pedestrians [15]

5. APPLICATION EXAMPLE -VIBRATION ANALYSIS OF THE PEDESTRIAN BRIDGE OVER THE NIŠAVA RIVER IN NIŠ

5.1. Structural information

The pedestrian bridge over the Nišava River in Niš (Fig.6, 7) is a cable-stayed bridge that has been opened in 2003. The total footbridge lenght is 78 meters. The bridge has two spans 14.00 + 56.00 = 70.00 meters. The bridge consists of a composite deck (steel-concrete), steel pylon 20.443 meters high, and stay cables SPB SUPER. The bridge is supported on three different places: at each end and at the pylon (see [23], [24] for more structural information).

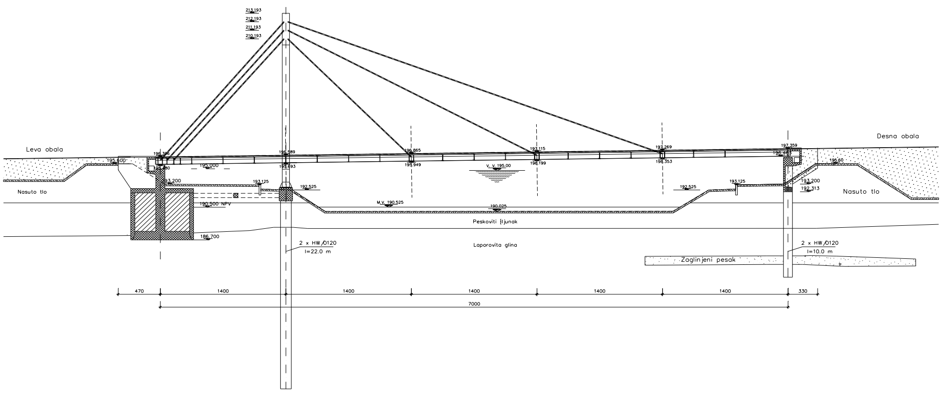


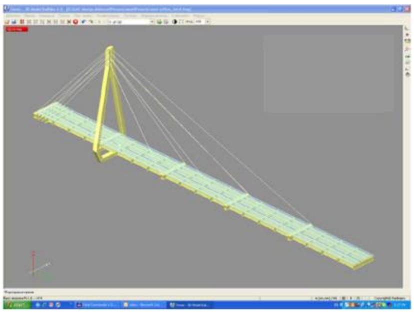
Fig. 6 Layout of the bridge

a) bridge view from the right river bank b) traffic on the bridge

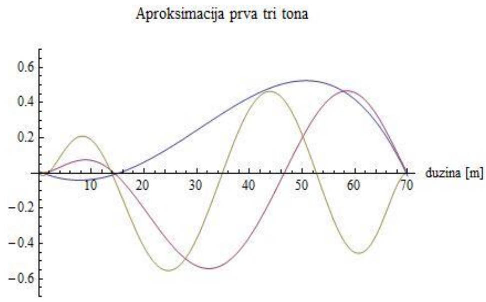
Fig. 7 Pedestrian bridge over the Nišava River in Niš

5.1. Vibration analysis

Vibration analysis is performed according to the solutions, algorithms and Wolfram Mathematica® programmes, developed within research in thesis [24]. In addition, some results of footbridge resonant vertical vibration due to single pedestrian excitation are presented.



a)



b)

Fig. 8 a) FE Model of the bridge superstructure; b) approximation of first three vertical modes shapes

Eurocode 1990:2002 proposes to check vertical vibrations in the case that at least one of the Natural Frequencies lies below 5 Hz. The frequency that is the most nearby to 2 Hz should be considered for the analysis.

Table 3 Natural Frequencies of the bridge superstructure

Natural Frequency	Mode shape 1	2	3	4	5	Direction
f_y [Hz]	1.396	3.32	5.77	9.15	11.68	vertical
f_z [Hz]	3.40	7.06	10.93	19.23	26.04	transversal
f_x [Hz]	10.92	13.77	32.05	33.11	37.31	longitudinal

The damping ratio ζ is an important input parameter for the bridges and this value can only be estimated. For composite bridges, Eurocode proposes using a logarithmic decrement (δ) of 0.04 for steel and concrete composite structures, which represents a damping ratio ($\zeta=\delta/(2\pi)$) of 0.006. The dynamic single walking pedestrian force is modelled as the moving harmonic concentrated load [24].

Figure 9 shows a three-dimensional simulation of bridge response (acceleration along the span of the bridge), in the case of vertical damped vibrations, induced by the force $P(t)= 0.18\sin(2\pi f_0 t)$, representing a moving pedestrian. Analyzing the output for resonant vibrations, when the pace frequency f_p is equal to the vertical natural frequency of the bridge f_0=1.396 Hz (Table 3), and the pedestrian velocity is $c = 0.9f_p = 1.2564$ m/s, it was concluded that the maximum acceleration occurs at the section $x = 52$ m, and at the time $t = 50$ s, when the force position is $x = c \cdot t = 62.82$ m. The maximum acceleration is 0.121 m/s^2.

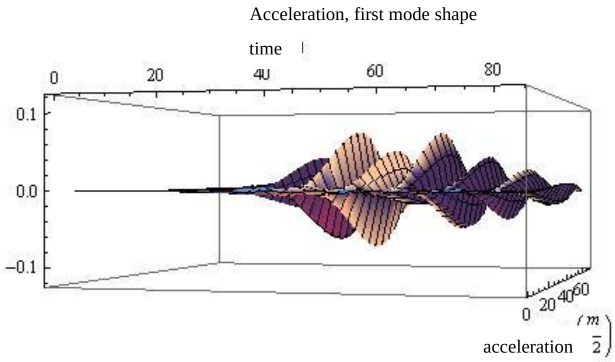


Fig. 9 Mathematical simulation of the bridge response due to a single pedestrian moving excitation force P(t)=0.18sin(2πf$_0$t)

Figures 10 a) and 10 b) show the time-histories of deflection and acceleration in the critical section x=52 m, for the case of vertical vibrations due to the same action as in the previous case. The maximum deflection is 1.58 mm and the acceleration is 0.121 m/s^2.

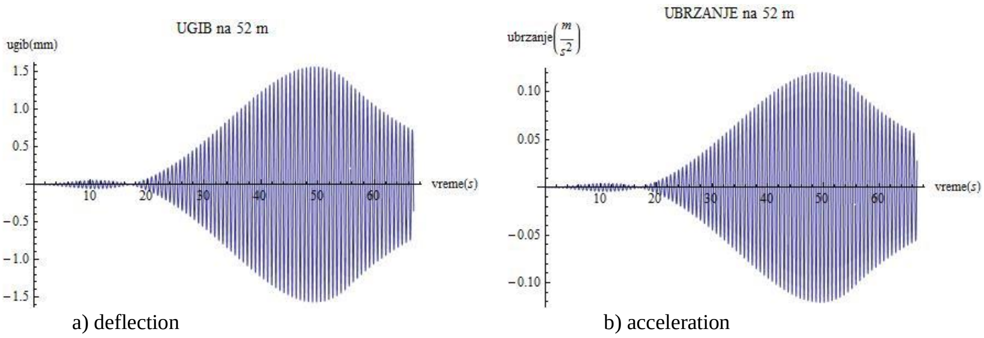


Fig. 10 Time-history due to a single pedestrian moving excitation force $P(t) = 0.18\sin(2\pi f_0 t)$: a) deflection; b) acceleration.

Comparing the obtained results of dynamic analysis, it was concluded that the response of the bridge for single pedestrian load in terms of acceleration stays within the limits recommended in relevant Code of practice as EN 1990:2002 ($a_{\text{lim}} < 0.7$ m/s^2) [14].

6. CONCLUSION

New trends in footbridge design, mainly arising from demanding aesthetic criteria and possibility of using modern construction materials, have led to more slender and flexible structures. As a consequence, lightweight pedestrian bridges are more prone to vibrate with amplitudes of high proportions, and that way cause pedestrians to feel uncomfortable.

Therefore, the dynamic analysis of footbridges has become inevitable, and load model determination is necessary for its implementation. The basis of modelling of time domain pedestrian loads using the Fourier transformation and their use in Codes are presented. It should be emphasized that the extensive research on this topic is still ongoing in order to improve the existing dynamic load models and to propose more reliable and accurate ones. Some of presented results of the dynamic analysis in terms of serviceability of the pedestrian bridge over the Nišava River in Niš, have shown that the bridge response stayed within limits recommended by EN 1990:2002.

REFERENCES

1. F. W. Galbraith, M. V. Barton, "Ground loading from footsteps", Journal of the Acoustic Society of America 48, Vol. 5, pp. 1288–1292, 1970.
2. H. Bachmann, W. Ammann, "Vibrations in structures induced by man and machines", Structural Engineering Document Nr.3, IABSE, 1987.
3. M. Schneider, "Ein Beitrag zu fußgängerinduzierten Brückenschwingungen", Dissertation, Lehrstuhl für Baumechanik, Technische Universität München, München, 1991.
4. S. Zivanovic et al., "Vibration serviceability under human-induced excitation: a literature review", Journal of Sound and Vibration 279, pp. 1–74, 2005.
5. Y. Matsumoto, T. Nishioka, H. Shiojiri, K. Matsuzaki, "Dynamic design of footbridges", IABSE Proceedings, No. P-17/78, pp. 1–15, 1978.
6. S.C. Kerr, N.W.M. Bishop," Human induced loading on flexible staircases", Engineering Structures 23, pp. 37–45, 2001.
7. Sétra Guide métodologique passerelles piétones., Sétra. Service d'etudes techniques des routes et autoroutes, Paris, 2006.
8. H. Bachmann, A.J. Pretlove, H. Rainer, "Dynamic forces from rhythmical human body motions", in: Vibration Problems in Structures: Practical Guidelines, Birkha¨ user, Appendix G, Basel, 1995.
9. V. Fiammetta, T. Federica, "Human-induced loading and dynamic response of footbridges in the vertical direction due to restricted pedestrian traffic", Structure and Infrastructure Engineering, Volume 17, 2021-Issue 10, p.1431-1445, doi:10.1080/15732479.2021.1897630
10. ISO 10137:2007, Bases for design of Structures- Serviceability of buildings and pedestrians walkways against vibration, International Standardization Organization (ISO), Geneva, Switzerland, 2007.
11. Australian Standard 5100.2-2004 Bridge design - Part 2: Design loads, 2004.
12. British Standards Institution: British Standard 5400 Steel, Concrete and Composite Bridges: Specification for Loads, Part 2, Appendix C, 1978.
13. OHBDC, Ontario Highway Bridge Design Code, Highway Engineering Division, Ministry of Transportation and Communication, Ontario, Canada, 1983.
14. UK National Annex to EN 1991-2:2003
15. Guidelines for the design of footbridges. Guide to good practice (155 pages ISBN 2-88394-072-X), Féderation internationalle du béton (FIB), Lausanne, 2005.
16. C. Heinemeyer et al.," Design of Lightweight Footbridges for Human Induced Vibration", JRC Scientific and Technical Reports, European Commission, pp. 98, Luxembourg, 2009.
17. European Committee for Standardization CEN: EN 1990-2002+A1-2005+Corrigenda 2008, Eurocode 0-Basis of structural design, 2010.
18. European Committee for Standardization CEN: EN 1991-2+Corrigenda 2004 and 2010, Eurocode 1 - Actions on structures - Part 2: Traffic loads on bridges, 2010.
19. European Committee for Standardization CEN:EN 1993-2:2006 +Corrigendum 2009, Design of steel structures - Part 2: Steel Bridges, 2009.
20. Proposal Annex C (not published) to EN 1991-2:2003
21. M. Imke, "Human induced vibration on footbridges-Application and comparison of load models", Master thesis, Faculty of Civil Engineering and Geoscience, Delft University of Technology, 2009.
22. J. Blanchard, B.L. Davies, J.W. Smith, "Design criteria and analysis for dynamic loading of footbridges", in: Proceedings of the DOE and DOT TRRL Symposium on Dynamic Behaviour of Bridges, Crowthorne, UK, May 19, 1977, pp. 90–106.

23. Main design of pedestrian bridge over the Nišava river in Niš, Institute for Civil Engineering and Architecture, Faculty of Civil Engineering and Architecture, University of Niš, Niš, 2000.
24. M. Spasojević Šurdilović, "Analysis of serviceability limit state of pedestrian bridges regarding vibrations induced by pedestrians", PhD thesis, Faculty of Civil Engineering and Architecture, University of Niš, Niš, 2014, 139p. (in Serbian)

MODELIRANJE PEŠAČKOG OPTEREĆENJA U ANALIZI GRANIČNOG STANJA UPOTREBLJIVOSTI PEŠAČKIH MOSTOVA

Novi trendovi u projektovanju pešačkih mostova, koji uglavnom proizilaze iz zahtevnih estetskih kriterijuma i mogućnosti korišćenja savremenih građevinskih materijala, doveli su do vitkih i fleksibilnijih konstrukcija. Kao posledica toga, lagani pešački mostovi su skloniji da vibriranju sa amplitudama velikih proporcija i na taj način izazivaju nelagodnost kod pešaka. S toga je dinamička analiza pešačkih mostova postala neizbežna, a određivanje modela opterećenja je neophodno za njeno sprovođenje. U radu su date osnove modeliranja vremenski zavisnog opterećenja pešaka korišćenjem Furijeove transformacije i prikazana je njihova upotreba u važećoj regulativi. Treba naglasiti da je opsežno istraživanje na ovu temu još uvek u toku, kako bi se poboljšali postojeći i predložili pouzdaniji modeli dinamičkog opterećenja. Prikazan je i deo analize graničnog stanja upotrebljivosti pešačkog mosta preko Nišave u Nišu. Pokazano je da je odziv konstrukcije za opterećenje izazvano kretanjem pešaka u granicama preporučenim važećom regulativom.

Ključne reči: *opterećenje indukovano pešacima, pešački most, dinamički model opterećenja, granično stanje upotrebljivosti*