EXAMINATION OF OWN HUMAN COMFORT CRITERIA FOR FOOTBRIDGES IN CASE OF WIND-INDUCED VIBRATIONS

Andrzej FLAGA
Professor
Lublin and Cracow University of Technology, Cracow, Poland

Marek PAŃTAK
PhD
Cracow University of Technology
Cracow, Poland

Tomasz MICHAŁOWSKI
PhD
Cracow University of Technology
Cracow, Poland

Summary

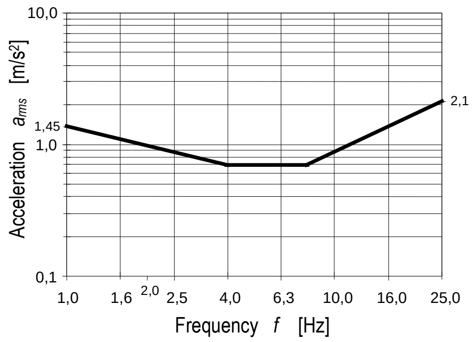
In the paper, analysis of wind-induced vibrations of a few footbridges built in Poland, with respect to new comfort criteria for pedestrians on footbridges elaborated by authors, have been presented.

Keywords: footbridges; dynamic; vibrations; wind; comfort criteria.

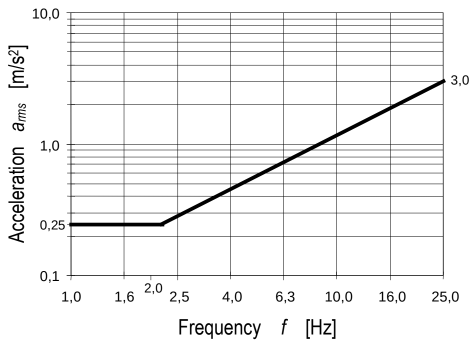
1. Authors' proposals of comfort criteria for pedestrians on footbridges in case of wind-induced vibrations

On the basis of different human comfort criteria encountered in several papers and standard documents – own proposals of comfort criteria for pedestrians on footbridges in case of wind-induced vibrations have been elaborated and presented in fig. 1 [1, 2].

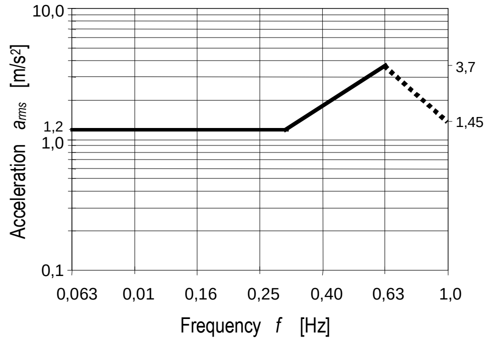
a) vertical vibrations 1,0 – 25,0 Hz



b) horizontal vibrations 1,0 – 25,0 Hz



c) vertical vibrations 0,063 – 1,0 Hz



d) horizontal vibrations 0,063 – 1,0 Hz

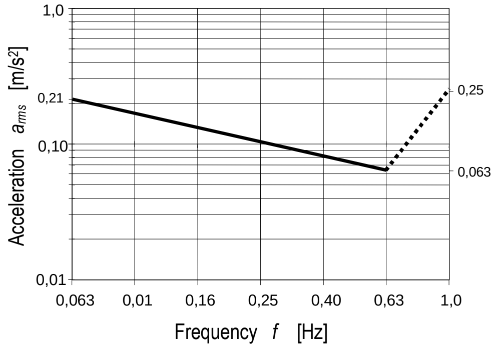


Fig. 1 Authors' proposals of human comfort criteria for footbridges in case of seldom occurring vibrations induced by wind (i.e. vibrations of stochastic character) [1, 2].

Proposed criteria take into account the courses of comfort criteria curves occurring in international standards ISO 2631 Part 2 and 3 [3, 4] and ISO 6897 [5] and have been formulated in terms of the effective acceleration (i.e. root-mean-square (*rms*) value of acceleration). In the frequency range 0,63 – 1,0 Hz, where diagram discontinuity occurs, due to lack of adequate investigation results, the propositions have been marked with a dashed line joining the border points of both ranges (below and above 1,0 Hz).

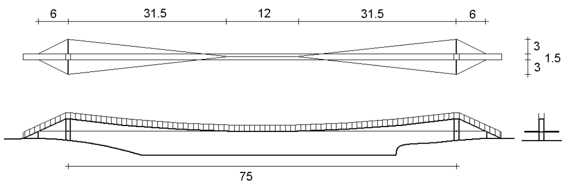
2. Characteristics of analysed footbridges

New structural materials are characterized by its better and better mechanical and resistance parameters, what – against to older structures – leads to: grater spans and smaller cross sectional dimensions (i.e. more slender structures), smaller stiffnesses, smaller unit masses and lower damping in contemporary structures. All of such structures become more susceptible to dynamic actions.

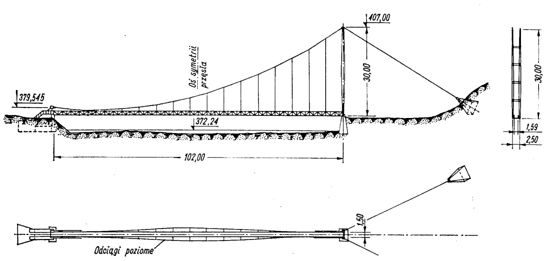
Fundamental vibration frequencies of the lightweight and slender footbridges often appear in a frequency range of human and wind actions.

In fig. 2 several different suspension and cable-stayed footbridges analysed in the paper are presented. Fundamental vertical and horizontal frequencies obtained from numerical calculations as well as in-situ measurements of them are given in fig. 3 [6, 7].

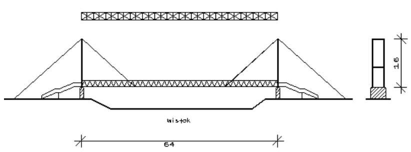
a) footbridge in Myslenice main span 75 m (ribbon footbridge)



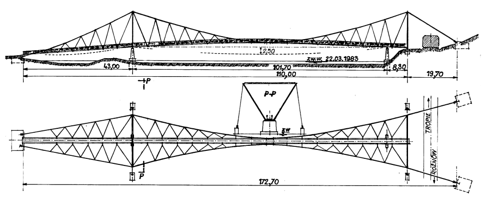
b) footbridge in Piwniczna main span 102 m



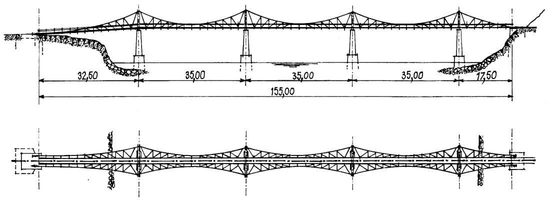
c) footbridge in Rzeszow main span 64 m



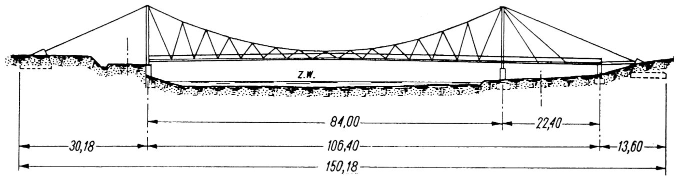
d) footbridge in Tropie main span 110 m



e) footbridge in Roznow main span 35 m



f) footbridge in Tylmanowa main span 84 m



g) footbridge in Tylmanowa main span 78 m

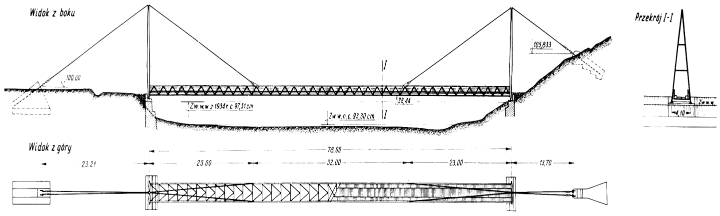
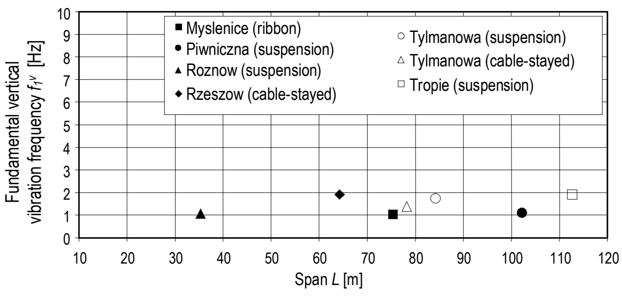


Fig. 2 Structures of the analyzed footbridges in: Myslenice (a), Piwniczna (b), Rzeszow (c), Tropie (d), Roznow (e), Tylmanowa (f, g).

a)



b)

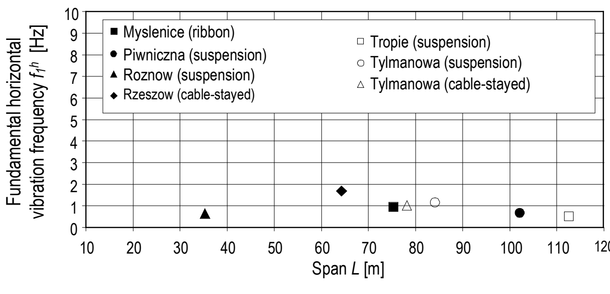


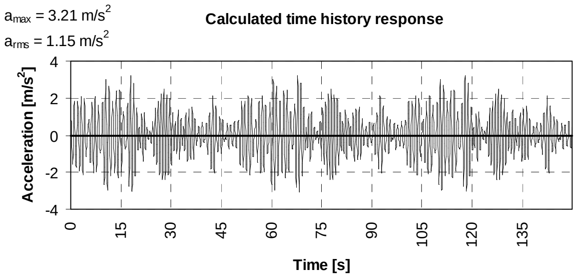
Fig. 3 Fundamental vertical (a) and horizontal (b) vibration frequencies (f_{1v}, f_{1h}) of some suspension and cable-stayed footbridges in Poland as a function of the span L [6, 7].

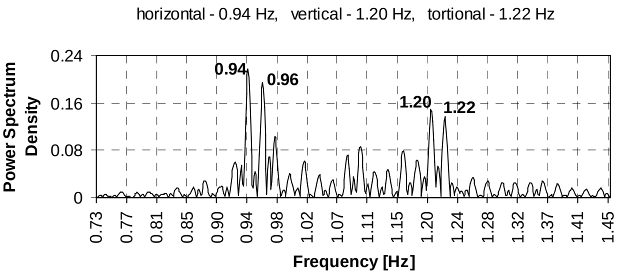
3. Results of aerodynamic calculations

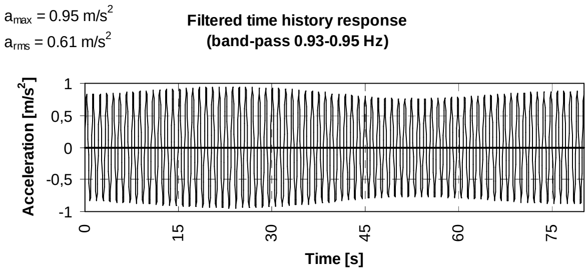
Examples presented below (Fig. 4) shows results of aerodynamic analyses of aforementioned footbridges. For all analysed footbridges, calculations have been performed at power wind profile exponent α = 0,24 and at mean wind velocity $\bar{v}_{max} = 28{,}4$ m/s.

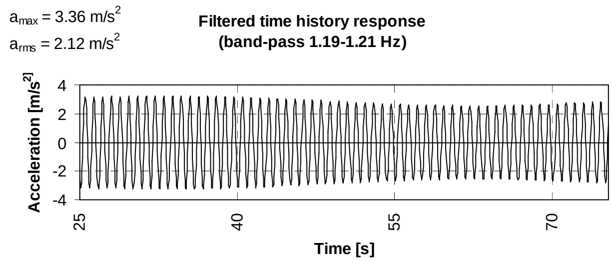
There are four graphs for each footbridge: upper left – exemplary calculated time history response; upper right – power spectrum density of it; bottom left and right – maximal, filtered time history responses.

a) footbridge in Myslenice (ribbon footbridge)

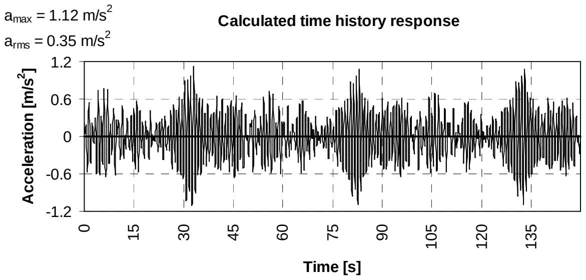


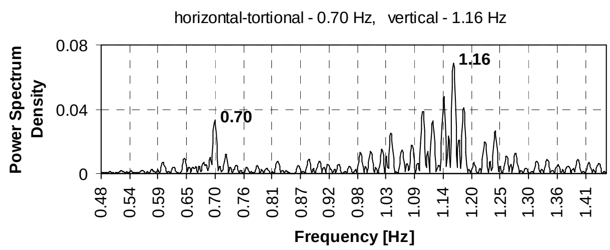


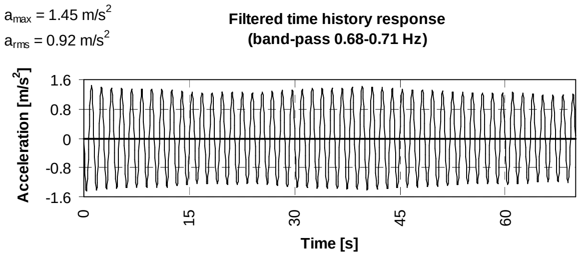


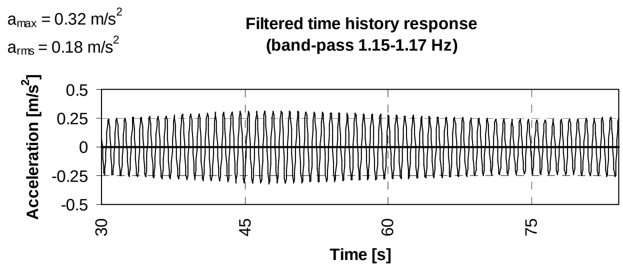


b) footbridge in Piwniczna

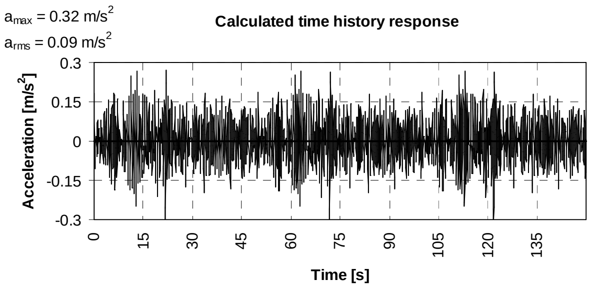


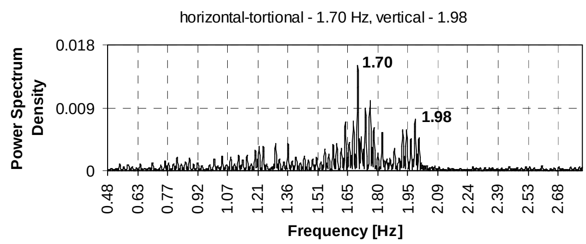


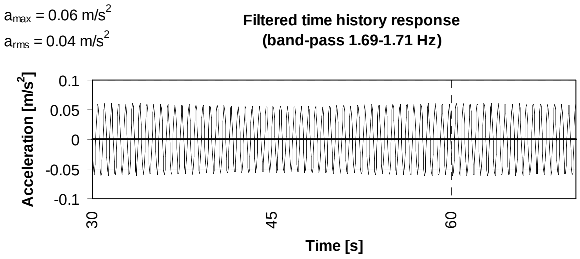


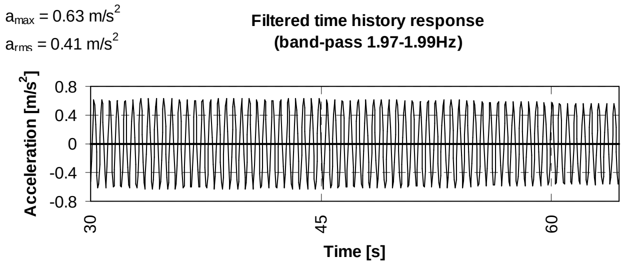


c) footbridge in Rzeszow

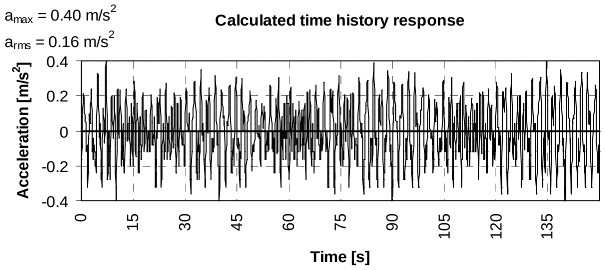


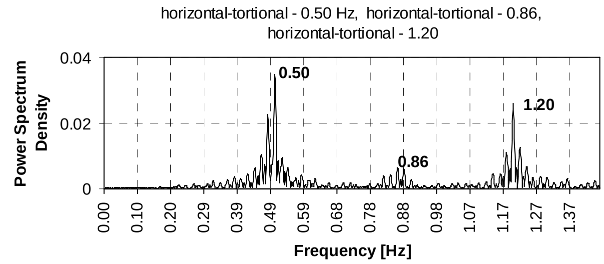


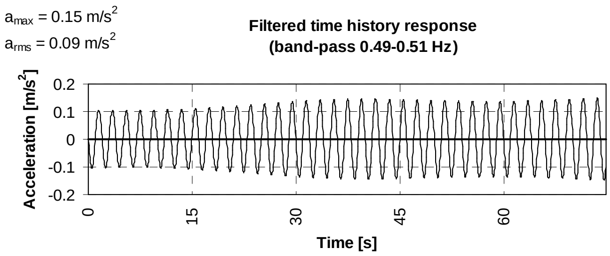


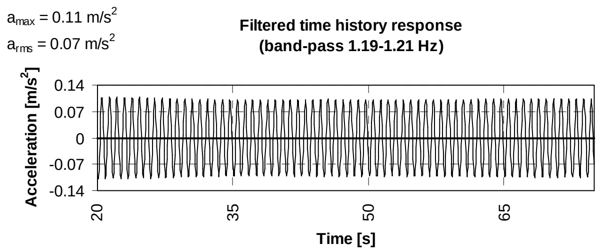


d) footbridge in Tropie

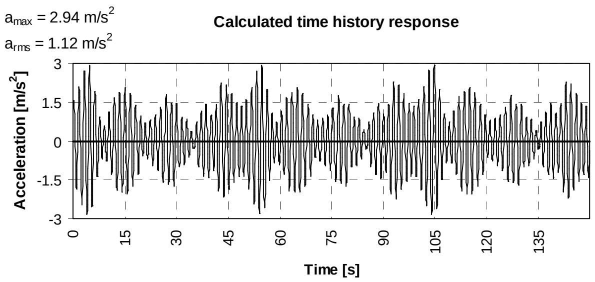


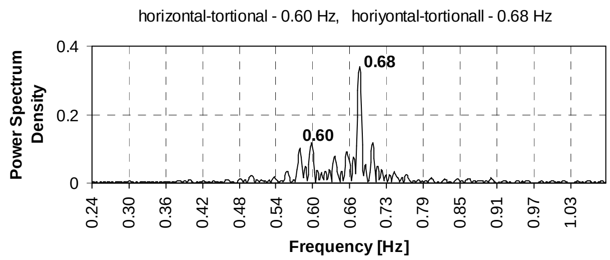


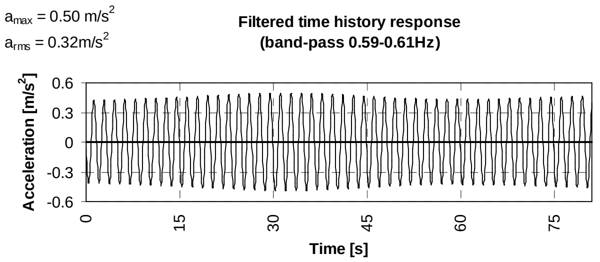


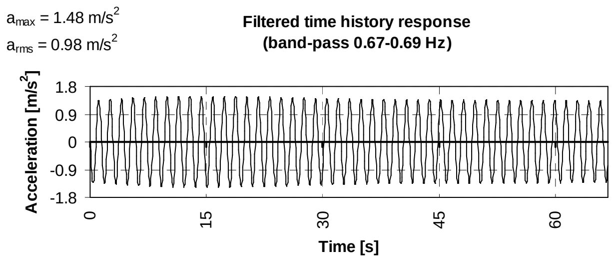


e) footbridge in Roznow

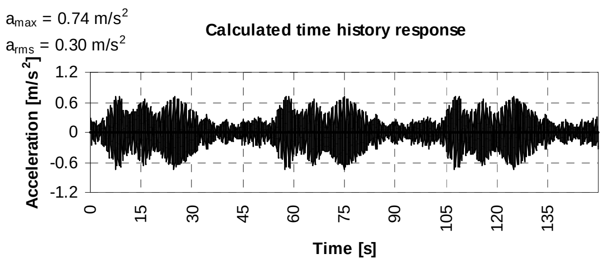


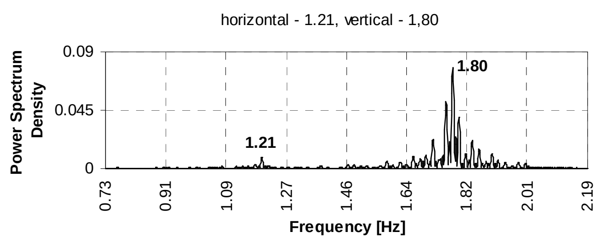






f) footbridge in Tylmanowa span 84 m (suspension)





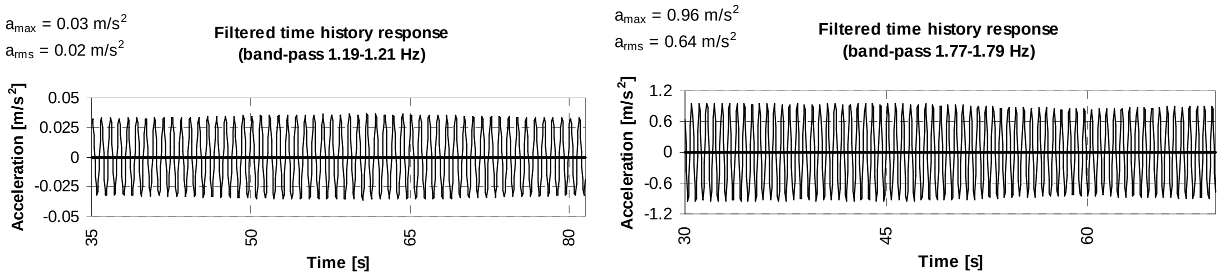


Fig. 4 Results of aerodynamic analysis of footbridges in: Myslenice (a), Piwniczna (b), Rzeszow (c), Tropie (d), Roznow (e), Tylmanowa (f).

In first approximation, it can be assumed that dynamical component of footbridge response depends linearly on mean wind velocity $\overline{\upsilon}$. Evaluation of fulfilment of comfort criteria for the analysed footbridges have been performed at assumption that $\overline{\upsilon} = 14{,}0$ m/s ≈ $\frac{1}{2}\overline{\upsilon}_{max}$ i.e. when pedestrian movement on footbridges is still possible.

Figure 5 presents results of all analyses with reference to human comfort criteria proposed by the authors.

a) vertical vibrations 1,0 – 25,0 Hz

b) horizontal vibrations 0,063 – 1,0 Hz

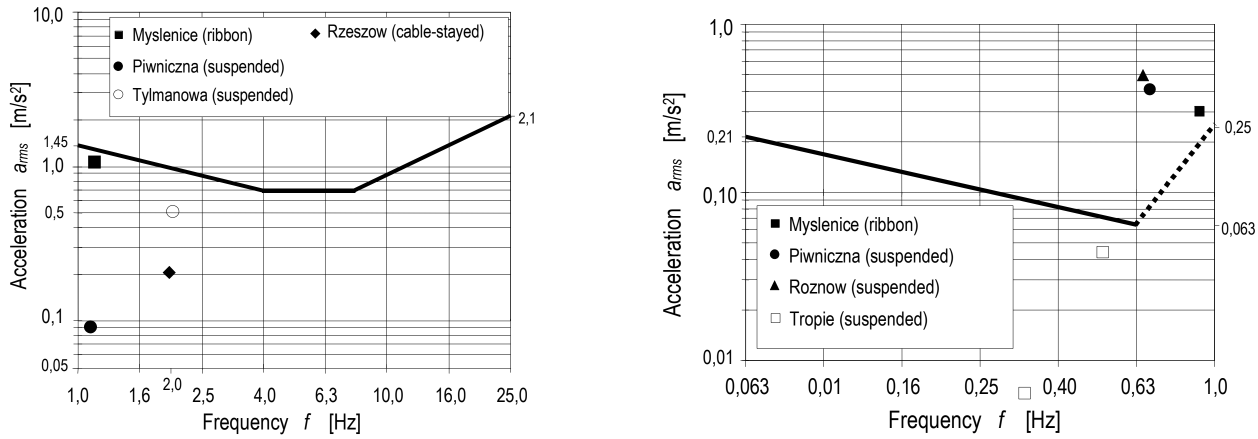


Fig. 5 Results of human comfort analysis for several suspension and cable-stayed footbridges in Poland in case of wind-induced vibrations.

4. Conclusions

Basing upon the obtained results, following general conclusions can be formulated:

1. Human comfort criteria are a serious problem in case of slender and lightweight footbridges. In case of wind-induced vibrations it relates to horizontal vibrations of low frequencies (below 1,0 Hz).
2. Dynamic analysis is necessary during design of modern footbridges. Static analysis is insufficient.
3. Footbridges without proper lateral bracing are prone to vibrations caused by dynamic wind action (as well as men-induced vibrations).
4. For some slender structures the static angle of torsion of a span is very big and does not fulfil the requirements.
5. In case of susceptible structures its upgrade is indispensable. The following preventive measures can be undertaken: application of flaps on a bridge girder, thickening of the slab, altering the length of the span(s), changing the mass of the structure or application of vibration absorbers (tuned mass dampers, tuned liquid dampers, viscous dampers).

Proposed comfort criteria have been partially verified on the basis of in situ observations of analyzed footbridges behaviour. It seems that these criteria are quite reasonable.

5. References

[1] FLAGA A, PAŃTAK M, "Vibration comfort curves with respect to footbridges according to ISO/CD 10137:2005 and own proposals", *Inzynieria i Budownictwo*, No. 10/2006, Warsaw, 2006, pp. 541-547, (in Polish).

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[4] *ISO 2631 Part 3* "Evaluation of human exposure to whole-body vibration. Evaluation of exposure to whole-body z-axis vertical vibration in the frequency range 0,1 to 0,63 Hz", International Standard Organization, 1985.

[5] *ISO 6897* "Guidelines for the evaluation of the response of occupants of fixed structures, especially buildings and of-shore structures, to low-frequency horizontal motion (0,063 to 1 Hz)", International Organization for Standardization, 1984.

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