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DYNAMIC RESPONSE OF A PEDESTRIAN BRIDGE TO TRAFFIC LOAD

ODPOWIEDŹ DYNAMICZNA KŁADKI DLA PIESZYCH O ROZPIĘTOŚCI 120 M NA OBCIĄŻENIE DYNAMICZNE GENEROWANE PRZEZ ŚRODKI TRANSPORTU

Abstract

In the paper, a detailed analysis of the dynamic response of the pedestrian and cyclist footbridge to traffic loads typical for trucks, trains, metro and trams was presented. The representative time histories registered in the further cases were used as ground motion data in calculations of the dynamic response of the footbridge. The results of numerical analysis were checked with the criteria of vibration comfort for footbridges. The ABAQUS software was used for the dynamic calculations.

Keywords: footbridge, dynamics, footbridge vibrations

Streszczenie

W artykule zaprezentowano wyniki analizy dynamicznej kładki dla pieszych i rowerzystów w Pcimiu poddanej oddziaływaniom komunikacyjnym przenoszonym przez grunt. W tym celu wykonana została analiza modalna w pakiecie ABAQUS. Do przyczółków kładki zostało przyłożone obciążenie kinematyczne zarejestrowane dla oddziaływań komunikacyjnych. Wyniki analizy zostały porównane z kryteriami komfortu wibracyjnego kładek dla pieszych.

Słowa kluczowe: kładki dla pieszych, komfort wibracyjny, dynamika budowli

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1. Introduction

1.1. Footbridges – definition, task and basic requirements

Footbridges are constructions, whose main task it is to carry pedestrians over a physical obstacle [2, 6, 9]. Currently, in addition to the safe conduct of traffic on the other side of the obstacle, pedestrian bridges are – for their users – a kind of an opportunity to enjoy the advantages of the environment with which they are associated.

Footbridges differ significantly from conventional bridges in how they influence the users. Footbridges' users are located directly on the object deck, staying there longer than when traveling by car across the bridge and feel its behavior directly. Users are exposed to a greater feeling of structural behavior [2, 6].

The application of advanced solutions makes the currently designed footbridges longer, lighter and more slender than the older ones [4, 11]. The new approach has a contrary effect on the dynamic properties of these objects. Sometimes, the lowest natural frequency of a structure coincides with the frequency of pedestrian steps (while walking or running). This situation may cause a resonance phenomenon and contribute to the failure of the structure. It should be noted that not only the pedestrians are the source of a dynamic load for footbridges. These structures can also be exposed to kinematic excitation originating from seismic or paraseismic phenomena, like mining tremors and traffic load [9].

In the paper, the comparison of the maximal acceleration obtained for the following types of traffic loads was presented. The results were summarized for loads generated by trucks, trains, metro and trams.

1.2. Traffic load [8]

The development of means of transport is the cause of an increase in the number of sources of vibration. This type of a load is transmitted via the ground [7]. They are outside of the construction. In particular, the effect of dynamic impact generated by traffic should be emphasized. One of the major conditions of sustainable development is also ensuring the safe, efficient and as rapid as possible movement between different places. The development of urban space causes the quality of people's life in cities to be disrupted by noise and vibrations. In the city space, the most common and troublesome source of vibration are movements of different vehicles. An interesting and poorly recognized issue is the effect of traffic loads which are source of vibration on footbridges [10].

This type of vibration is outside of the analyzed object. The vibrations are transmitted to the foundations of the structure by the ground. It should also be noted that the vibration which are generated by traffic have its own specific characteristics: during their lifetime their accretion and then decrease takes place [10]. It is shown in Fig. 1.

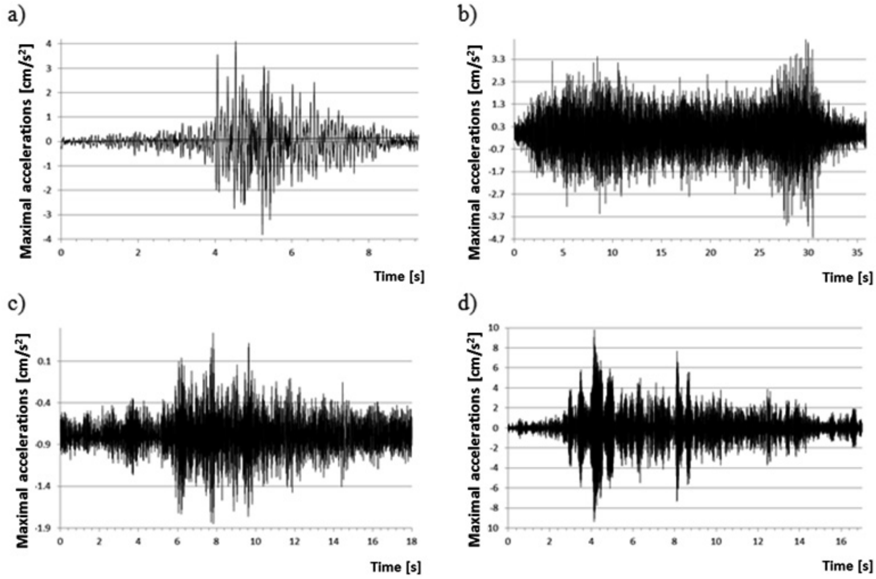

Fig. 1. Time histories of ground motion accelerations [cm/s^2] registered in the urban space in az (vertical) direction for transit: a) truck, b) train, c) metro and d) tram [10]

2. Dynamic response of a pedestrian and a cyclist footbridge to traffic load

2.1. Main data and the numerical model of the footbridge

The calculations of the dynamic response of a pedestrian and cyclist footbridge to traffic load were performed for an existing footbridge located in Pcim, Southern Poland [1]. The primary purpose of the structure is to carry pedestrians and cyclists across the Raba river [8, 9].

In the work the model (see Fig. 2) presented in [9] has been used. The model was created in the ABAQUS software on the basis of the existing technical documentation [8]. The suspended structure of the footbridge consists of three spans: the middle one is 60.00 m long, whereas two extreme ones are 25.50 m long. The total theoretical length is 120 m. The footbridge's plat is composite with steel girders. The modulus of elasticity of steel girders and cross-bars was taken as 210 GPa. The Poisson's ratio was assumed as 0.29. The superstructure has been suspended from steel pylons 11.80 m high. The pillars and abutments are founded on reinforced concrete piles with a diameter of 100 cm [8, 9].

The footbridge is equipped with elastomeric bearings as linking elements between the deck and the piers. Usually, a two-coefficient Mooney-Rivlin model is used as a constitutive model of hyperelastic nonlinear elastomeric material of bearings. However, the parameters of the Mooney-Rivlin material: C_{10} and C_{01} can be replaced with equivalent elasticity modulus: $E = 6\ (C_{10} + C_{01})$. In this work, the parameters of the Mooney-Rivlin model, assumed as $C_{10} = 0.292$ MPa and $C_{01} = 0.177$ MPa [3], were replaced with the equivalent elasticity modulus of 2.814 MPa. Such simplification is commonly used in calculations of bridges with elastomeric bearings [3, 5]. The Poisson's ratio of elastomeric material was taken as 0.49.

2.2. Dynamic response of the footbridge to traffic loads

Firstly, the natural frequencies of the footbridge were evaluated. The first natural frequency f_1 = 1.94 Hz is associated with vibrations in the vertical direction, whereas the second natural frequency, f_2 = 2.29 Hz, corresponds to the horizontal mode of vibrations.

Then, for the assessment of the influence of dominant frequencies of the traffic loads on the dynamic response of the structure, full time history analysis (THA) was carried out. The time history analysis (THA) was carried out with the Hilber-Hughes-Taylor time integration algorithm provided in the ABAQUS software. Modal dynamic analysis was implemented for the solution, since the problem was assumed to be linear-elastic. The calculations of the dynamic responses were performed using time histories of the selected vibration generated by traffic load registered in three directions in the urban space. Rayleigh model of damping was introduced in the calculation. Rayleigh damping coefficients were determined based on: $\alpha = 0.1862$, $\beta = 0.00113$ [8].

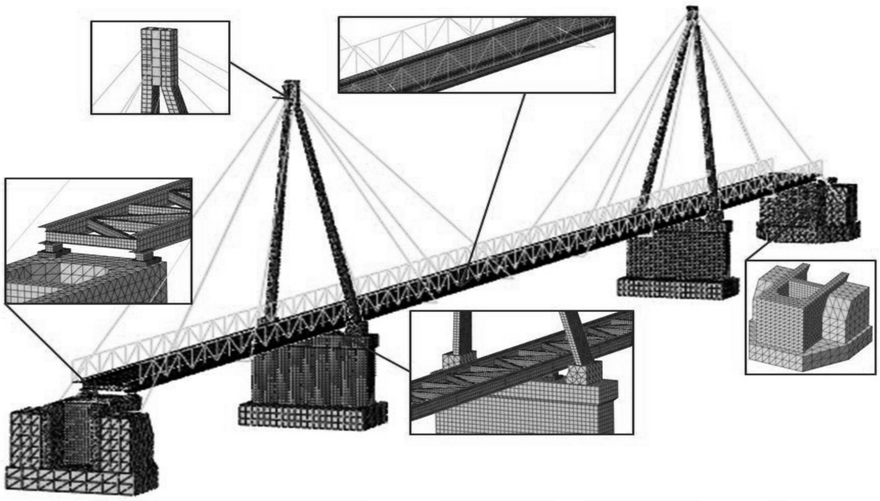

Fig. 2. The FE model of the footbridge [9]

The dynamic response of the footbridge to the selected traffic loads were evaluated for the whole model, but in the comparative analysis of the obtained responses, maximal acceleration was compared only for a point in the middle span of the footbridge (see Fig. 3). The relation between maximal acceleration and different type of traffic load obtained from the THA methods for traffic load from urban space is presented in Fig. 3. Taking into account the results of the numerical analysis, the vibration comfort criteria were checked for the footbridge. The results are summarized in Table 1, and compared with the selected comfort criteria (according to the literature). In all types of traffic load (truck, train, metro and tram), the vibration comfort criteria are met.

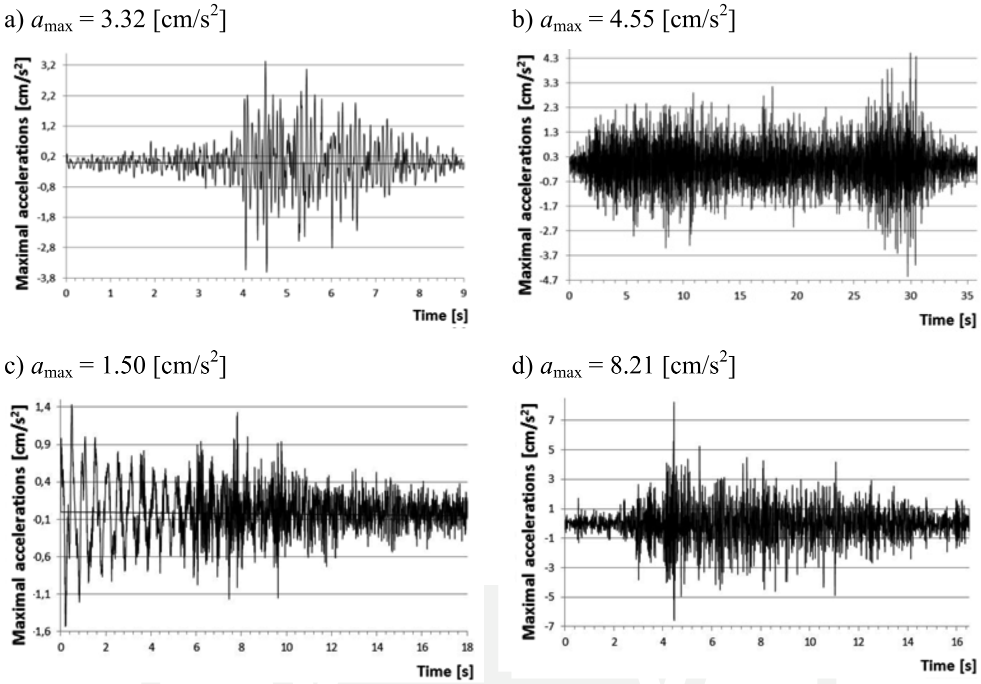

Fig. 3. The maximum accelerations [cm/s²] in the middle span of the footbridge in a_z (vertical) direction for transit: a) truck, b) train, c) metro and d) tram

Table 1

The vibration comfort criteria for the footbridge

Standard	Acceptable acceleration [m/s²]
BS 5400 [10]	0.63
The paper [4]	0.70–1.0
The paper [9]	0.65
SETRA [2]	0.50
PN-EN 1990/A1 [11]	0.70

3. Conclusions

The numerical analysis showed that the vibrations generated by the traffic load and transmitted via the ground (abutments) on the footbridge do not disturb the comfort of its use. For all checked cases of traffic loads: truck, train, metro and tram, the vibration comfort criteria which are summarized in Table 1 are met. What is more, the vibrations are practically imperceptible by the users of the footbridge.

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