Evaluation of Dissipative Characteristics of Pedestrian Spans with Bearings Exhibiting Viscoelastic Properties

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Abstract. the use of polymer bearings with a given shear rigidity and viscoelasticity in the spans of pedestrian bridges makes it possible to effectively control the dynamic characteristics of the span. At the same time, taking into account the viscoelasticity of the bearings is not an easy task, since the attenuation coefficient that characterizes the dissipative properties of the span structure can only be calculated experimentally. In this paper, the dependencies between the basic parameters of span vibrations and the attenuation coefficient are specified. The similarity test is defined for the presented hypothesis. To compare the practical results with theoretical calculations, the materials of the R&D report "Dynamic parameters evaluation of a pedestrian bridge span on the Station 156 +32 at the object: Reconstruction of the road from the airport "Knevichi" to St. Sanatornaya on a hack of the highway M-60 "Ussuri" Khabarovsk-Vladivostok between 747-750 km" were used.

1. Introduction

There is no need to describe in detail the role of pedestrian bridges as a part of the road or urban infrastructure that provides the necessary balance of traffic capacity for cars and pedestrians, as well as the architectural role of these structures in organization of the city image as a part of modern urbanism.

In the works [1,3,4,5], the possibilities of improving and regulating the dynamic characteristics of spans of pedestrian bridges are considered. As you may recall, the spans of pedestrian bridges are relatively light in comparison with road spans, which makes them sensitive to various dynamic influences by their nature.

We believe that the most effective way to regulate the dynamic characteristics of a pedestrian bridge span is to use polymer bearings with viscoelastic elastomer properties at the base of their structure. However, in this case, at the design stage, it is difficult to build a design model of the span, which would reflect the rigidness characteristics of the polymer bearings, with viscoelastic properties of the elastomer. It should be noted that few studies in this area do not allow obtaining the necessary physical and mechanical characteristics of polymers for calculations as "background information". Thus, one of the most important dynamic properties of a span system with polymer bearings will be the attenuation coefficient, which characterizes the dissipative characteristics of this system.

The use of polymer bearings can be considered, in some sort, a way to change the attenuation coefficient in the integral sense for the entire jib-stick, considered as a system with one degree of freedom.

Thus, to compare the practical results with theoretical calculations, the materials of the R&D report "Dynamic parameters evaluation of a pedestrian bridge span on the Station 156 +32 at the object:
Reconstruction of the road from the airport "Knevichi" to St. Sanatornaya on a hack of the highway M-60 "Ussuri" Khabarovsk-Vladivostok between 747-750 km" were used [1]. The graph of the span heaving based on the test results is shown in Fig. 1.

Figure 1. Parameters of heaving (according to one of the vibration sensors Vibran-3.0) in the middle of the pedestrian bridge span during dynamic tests [1]. A fragment of vibrodiagram.

The solution obtained in [1] is approximate, since it does not take into account the internal resistance forces of the jib-stick material, which depend difficultly on the jib-stick material and on the movement parameters.

In this paper, Voigt's hypothesis, in which the jib-stick material is considered as elastic-viscous, is used to account for the resistance force:

$$\sigma = E \cdot \varepsilon + \chi \cdot E \cdot \frac{d \varepsilon}{dt},$$

where $\varepsilon$ - the amount of deformation, $\chi$ - the coefficient of viscous friction. Here the stresses $\sigma$ depend not only on $\varepsilon$, but also on the rate of strain change in time $t$.

According to Voigt's hypothesis, the effect of internal resistance forces is replaced by a force $F = -k \cdot \frac{d \varepsilon}{dt}$ applied at the point where the mass is fixed (the jib-stick is considered as a system with one degree of freedom).

Then the equation of free oscillations with linear damping takes the following form:

$$\frac{d^2 \xi}{dt^2} + 2\beta \cdot \frac{d \xi}{dt} + \omega^2 \xi = 0,$$

where $\beta$ is the coefficient of resistance or attenuation.

The exact solution of equation (1) will be

$$\xi = C \cdot e^{-\beta t} \cdot \sin(\eta t + \phi), \ \eta = \sqrt{\omega^2 - \beta^2}.$$

Here, the arbitrary constants are the amplitude $C$ and the phase $\phi$ determined from the initial conditions. It should be noted [2] that the value of $\eta$ is little different from the frequency of natural oscillations without attenuation of $\omega$, since the value of $\beta^2$ is practically small compared to $\omega^2$ (Fig. 2).
As a basis, we took an example of an accurate calculation of the jib-stick’s own oscillations without taking into account attenuation [1], according to which \( T = 0.618 \text{ c} \). Using the numerical data of this example (\( \ell = 42 \text{ m}, m = 1599 \frac{\text{kg}}{\text{m}}, E = 2.060 \cdot 10^8 \frac{\text{kPa}}{} \), \( I_x = 2.561 \cdot 10^6 \frac{\text{cm}^4}{} \)) in our approximate case we have:

\[
\omega_1 = \sqrt{\frac{\pi^2}{T_1^2}} = 10.089; \quad T_1 = \frac{2\pi}{\omega_1} = \frac{2\pi}{10.089} = 0.623 \text{ c}.
\]

The margin of error \( \delta = \frac{0.623 - 0.618}{0.618} \cdot 100\% = 0.8\% \) is less than one percent.

Some results of numerical solution of the differential equation (1) for various parameters of motion are shown in Fig. 3 – Fig. 4.
Figure 3. Vibrations of the attached mass at $\beta = 0.2$; $\xi(0) = 0$ and different initial loading speeds $\frac{d\xi}{dt}(0)$. 
Figure 4. Vibrations of the attached mass at $\beta = 0.3$; $\xi(0) = 0$ and different initial loading speeds $\frac{d\xi}{dt}(0)$.

Similarly, graphs are constructed for other numerical values of the attenuation coefficient $\beta$ ($0.4$ – $0.6$). Comparing these graphs, we note that the time $t_*$ at which the oscillations disappear is directly proportional $\frac{d\xi}{dt}$ and inversely proportional $\beta$ (Fig. 5).
Figure 5. Dependence $t_*$ on the attenuation coefficient of $\beta$ the initial velocity $\frac{d\xi}{dt}(0)$.

Some characteristic graphs showing the dependence $\xi(t)$ on $\beta = 0.1 - 0.6$ at different $\frac{d\xi}{dt}(0)$ are shown in Fig. 6-Fig. 7.

Figure 6. Oscillations of the attached mass at initial constants $\frac{d\xi}{dt}(0) = 0.2$ ; $\xi(0) = 0$ and different values of the attenuation coefficient $\beta$. 
Figure 7. Oscillations of the attached mass at initial constants $\frac{d\xi}{dt}(0) = 0.6$; $\xi(0) = 0$ and different values of the attenuation coefficient $\beta$.

Analysis of the obtained graphs allows us to obtain the law of variation of the attenuation coefficient $\beta$ over time $t_*$ (Fig. 8).
Figure 8. Dependence $\beta$ on the time of disappearance of oscillations $t_*$. 

Here, fig. 8 does not show the graphs at $\frac{d\xi}{dt}(0) = 0, 1; 0, 4; 0, 8$; since they almost merge with those already shown.

Note that according to Fig. 8, a certain numerical value $\beta$ corresponds to a certain range of variation $t_*$, which allows, in the presence of appropriate devices that allow measuring $t_*$ (shown with arrows in Fig. 8), to judge in the first approximation of the value $\beta$ for the considered span.

Thus, a simple practical way to determine the attenuation coefficient is proposed $\beta$.

In conclusion, we consider equation (1) to obtain a similarity criterion. According to the Fourier rule, the dimensions of all three terms of the equation are the same, since the differentiation operator does not affect the dimension. Omitting the differentiation operators in the equation

$$\frac{d^2\xi}{dt^2} + 2\beta\frac{d\xi}{dt} + \omega^2\xi = 0,$$

and dividing all its sum by one of its components (here there are three possible variants), we get:

$$I + 2\beta\cdot\frac{\xi}{t} + \omega^2\frac{\xi}{t^2} = 0, \text{ or } I + 2\omega t + \omega^2 t^2 = 0;$$

$$I\frac{\xi}{t^2} + \frac{\xi}{2\beta} + \frac{\xi}{2\beta t^2} = 0, \text{ or } \frac{I}{2\beta} + \frac{I + \omega t}{2} = 0;$$

$$I\frac{\xi}{t^2} + 2\beta\cdot\frac{\xi}{t} + \frac{I}{\omega^2\xi} + 1 = 0, \text{ or } \frac{I}{\omega^2 t^2} + \frac{2}{\omega t} + 1 = 0.$$

In all three obtained characteristic equations, there is a dimensionless parameter $\omega t$, which, therefore, is the fundamental similarity criterion for describing free oscillations of a system with one degree of freedom, and which must be the same for both nature and model:

$$\pi = \omega t = const.$$

2. Conclusions

The correspondences obtained between the basic parameters of the span oscillations and the attenuation coefficient make it possible to evaluate the influence of viscoelastic properties of polymers on the dissipative characteristics of the system as a whole. Based on a number of field tests of polymer bearings
with different rigidness and damping properties, it will be possible to account for the dissipative properties of the system in computational solutions. Thus, at the stage of numerical modeling of pedestrian bridge spans, it will be possible to set the necessary dynamic parameters by using polymer bearings with a certain degree of viscoelasticity.

3. References

[1] Belutskiy I Y, Tomilov S N, Grishin A I, Lovtsov A D and Chzhao Tszyan 2012 Dynamic parameters evaluation of a pedestrian bridge on the Station 156 +32 at the object: Reconstruction of the road from airport "Knevichi" to St. Sanatarnaya on a hack of the highway M-60 "Ussuri" Khabarovsky-Vladivostok between 747-750 km (Khabarovsky) R&D report vol 06/12 p 40

[2] Feodosiev V I 1999 Strength of materials: Textbook for universities (Moscow: Moscow State Technical University named after N. E. Bauman Publishing House)

[3] Belutskiy I Y, Iovenko V V, Lapin A V 2017 Determination of the values of the proper oscillation period of span structures supported on rubber-metal bearings by approximate methods (Omsk: Bulletin of SibADI-Omsk) vol 6/58 pp 91-98

[4] Belutskiy I Y, Lapin A V 2017 Adaptation of the finite element model of a pedestrian overpass span to the actual conditions of the construction (Moscow: RDE “Stroitel’stvo” Construction mechanics and calculation of structures vol 5 pp 28-31

[5] Belutskiy I Y, Lapin A V 2015 Features of dynamic operation of pedestrian bridges spans, Far East: Problems of development of the architectural and construction complex (Khabarovsky: Pacific National University Publishing House) vol pp 263-270

[6] Belutskiy I Y, Lapin A V, Chzhao Tszyan 2015 Box spans of pedestrian bridges with enclosed spaces, Far East: Problems of development of the architectural and construction complex (Khabarovsky: Pacific National University Publishing House) vol 1 pp 320-325

[7] Belutskiy I Y, Tomilov S N, Grishin A I, Lovtsov A D and Chzhao Tszyan 2012 Dynamic parameters evaluation of a pedestrian bridge on the Station 156 +32 at the object: Reconstruction of the road from airport "Knevichi" to St. Sanatarnaya on a hack of the highway M-60 "Ussuri" Khabarovsky-Vladivostok between 747-750 km. (Khabarovsky) R&D report vol 06/12 p 40

[8] Belutskiy I Y, Lapin A V, Sim A D, Tomilov S N and Chzhao Tszyan 2014 Scientific-and-technical report on the topic "Study of the work of the construction of pedestrian bridge on 60 years of October Avenue of the bus stop Yubileynaya in Khabarovsky and the evaluation of its dynamic and weight lifting parameters" (Khabarovsky: Pacific National University Publishing House) p 45

[9] Belutskiy I Y, Lapin A V, Sim A D and Chzhao Tszyan 2014 The research report on "The study of the stress-strain state and estimation of possible introduction into service of pedestrian overpass span on PC 103+90 the hack between 733.5-747 KM of highway M-60 "Ussuri" Khabarovsky-Vladivostok) (Khabarovsky: Pacific National University Publishing House) p 73

[10] Belutskiy I Y, Chzhao Tszyan 2012 Accounting for real conditions of span support in creating their finite element model (Ulan-Ude: Bulletin of VSGUTU) vol 2(37) pp 192-197

[11] Sanitary rules 2011 35.13330.2011 Bridges and pipes Updated version (Moscow: Min.Region JSC "TsNIIS" p 340

[12] Iovenko V V 2016 Selected lectures on the Strength of materials (Khabarovsky: Pacific National University Publishing House) p 223

[13] Yelovskiy R E, Lyuzovik S S and Kozyrev S V 2010 Calculation of span Pedestrian overpass Span (L) = 42 m "Reconstruction of the road from airport "Knevichi" to Sanatarnaya st. on a hack of the highway M-60 "Ussuri" Khabarovsky-Vladivostok between 747-750 km (SPA Mostovik) p 21

[14] Timoshenko S P 1967 Oscillations in Engineering (Moscow: Publishing House "Nauka") p 444

[15] Lapin A V 2015 Topical issues of cross-section layout of spans of pedestrian bridges (Khabarovsky : Electronic scientific publication "Scientific notes of Pacific National University ") vol 6(2) pp 6-18 http://pnu.edu.ru/media/ejournal/articles-2015/TGU_6_66.pdf
[16] Birger I A and Panovko Y G 1968 Strength, stability, oscillations Handbook in three volumes (3) (Engineering) p 567
[17] Belutskiy I Y, Chzhao Tszyan and Yatsura V G 2012 Study of the influence of pier tables of steel reinforced concrete bridges in the system of continuous temperature spans on their free oscillations (Khabarovsk: Journal of Pacific State University) 4(27) pp 79-86
[18] Smirnov A F 1958 Stability and oscillation of constructions (Transzheldorizdat) p 571
[19] Guidelines for vibration-based diagnostics of road bridges 2001 (Ministry of transport of the Russian Federation The State Road service Rosavtodor) p 25
[20] Sanitary rules 2012 79.13330.2012 Bridges and pipes Rules for surveys and tests Updated version of SNiP 3.06.07-86 (Min. Region OJSC CNIIS) p 33