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**Autor:** Kazakevych, Mykhailo L. / Kulyabko, Volodymyr V.
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# Stabilization of a Cable-Stayed Footbridge

## Stabilisation d'une passerelle haubanée

## Stabilisierung einer Schrägseil-Fussgängerbrücke

**Mykhailo L. KAZAKEVYCH**
Professor
Univ. of Railway Transport Eng.
Dnipropetrovsk, Ukraine

Mykhailo Kazakevych, born 1939, was involved for 25 years in problems of dynamics, aerodynamics and theory of vibration damping of structures. Author of many books and papers, he is currently Head of Structural Engineering Department at the University.

**Volodymyr V. KULYABKO**
Associate Professor
Institute of Civil Engineering
Dnipropetrovsk, Ukraine

Volodymyr Kulyabko, born 1938, has been engaged in research of dynamic problems of buildings, structures and machines. He presently works in the Department of Structural Mechanics of the Institute.

**SUMMARY**

Methods of determining dynamic characteristics and natural frequencies of bridges are discussed, with the example of a cable-stayed pedestrian bridge in Vilnius, Lithuania. Vibration resonance in the horizontal plane was effectively eliminated by stiffening the bridge girders with added inclined cables.

**RÉSUMÉ**

Les méthodes de calcul des vibrations naturelles de ponts sont présentées dans le cas d'une passerelle piétonnière haubanée à Vilnius, Lithuanie. Une stabilisation efficace, permettant d'éviter une résonance horizontale est obtenue au moyen de haubans additionnels.

**ZUSAMMENFASSUNG**

Ein Verfahren zur Bestimmung der Eigenschwingungen der Brücken werden am Beispiel einer Schrägseil-Fussgängerbrücke in Vilnius, Lithauen, diskutiert. Durch Anordnung zusätzlicher Stabilisationskabel wurden Resonanzschwingungen der Brücke in der horizontalen Ebene vermieden.

## 1. INTRODUCTION

The cable-stayed footbridge across the river Neris in Vilnius, Lithuania, was built in 1984. The bridge was designed by the Transmost Institute in St. Petersburg (then Leningrad), Russia.

Structures of this type are rather sensitive to dynamic effects, especially moving pedestrian loading, which is characterized by periodic load pulses with a frequency of about 2 ± 0.2 Hz in the vertical direction and 1 ± 0.1 Hz in the horizontal plane [1]. Resonance oscillations occur when natural frequencies of the structure in the vertical or the horizontal plane coincide with the frequency of loading impulses.

In this case users complained about feelings of discomfort when crossing the footbridge. Review of the design calculations revealed that no dynamic analysis had been performed. Tests on the structure proved the existence within its natural frequency spectrum of a horizontal frequency of about 1 Hz. This indicated the need for stabilization of the bridge in the horizontal plane, which could be best achieved by modifying the horizontal rigidity and the associated horizontal natural frequency of the bridge to preclude resonance.

## 2. DESCRIPTION OF THE STRUCTURE

The footbridge is a three-span structure with span lengths of 118.5 + 51.0 + 34.5m (Fig. 1). Its cable stays, supported by the 47m high reinforced concrete pylon, are located in the central vertical plane of the bridge. Each of the four stays consists of six wire ropes made of 91 parallel galvanized wires of 5mm diameter.

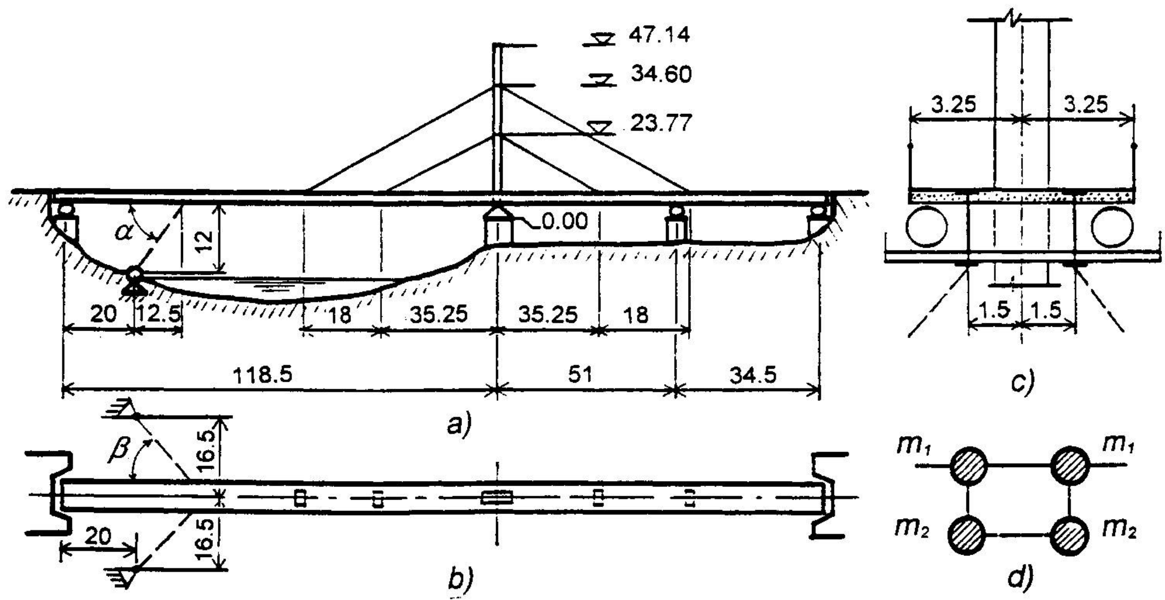


*Fig. 1. Cable-stayed pedestrian bridge in Vilnius, Lithuania. a) Elevation; b) Plan; c) Cross Section; d) Calculation model of the cross section.*

The 2.5m deep main girders are spaced at 3.0m. The girders have fixed bearings at the tower pier and expansion bearings at all other supports. The roadway width is 6.5m between the railings.

The bridge was designed for a pedestrian load of 400 kg/m and the weight of two hot water pipelines at 1700 kg/m.

## 3. DYNAMIC INVESTIGATIONS

### 3. 1. Determination of natural frequencies

The purpose of dynamic analysis is to obtain the lowest natural frequencies for the various vibration modes of the structure. Then the effect of pedestrian loading intensity on the values of natural frequencies and the various methods of modifying the vibration characteristics of the structure can be studied.

A discrete-continuous model with 46 degrees of freedom was used for the dynamic analysis by the finite element method. Longitudinal deformations of the elements and the asymmetry of the mass and the rigidity distribution along the depth of the bridge cross section were considered. The mass was assumed localized at four points of the cross section (Fig. 1 d).

The five characteristic vibration modes and the values of corresponding frequencies are shown in Fig. 2, arranged in order of increasing frequencies.

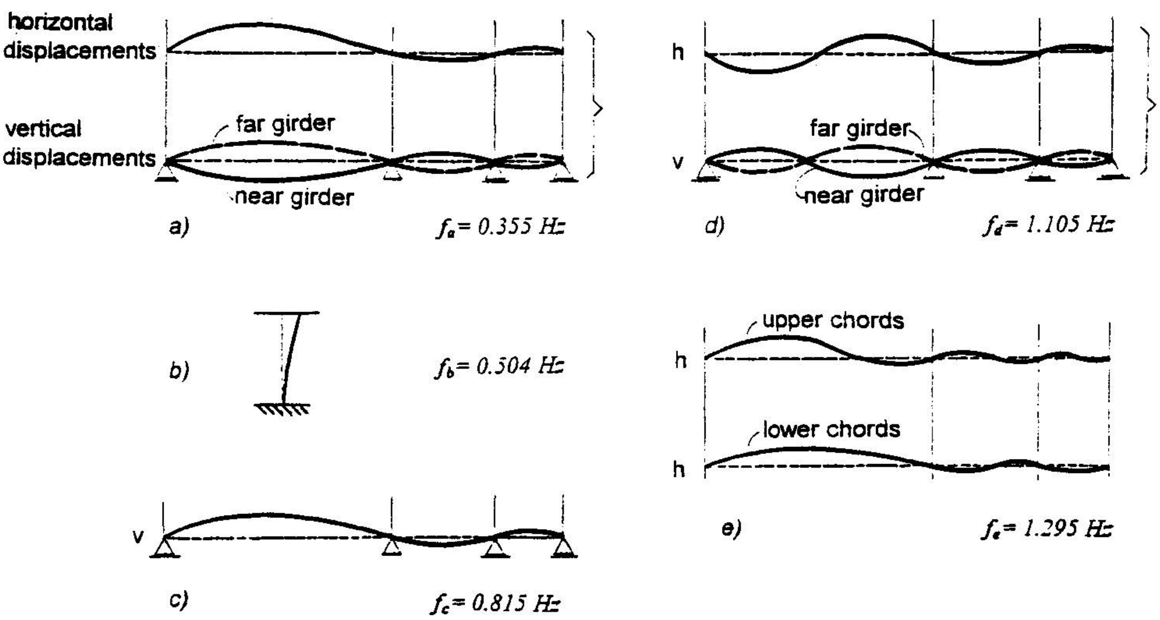


*Fig. 2. Vibration modes and natural frequencies of the bridge without pedestrian loading. a) flexural-torsional horizontal vibrations, first mode; b) lateral vibrations of the bridge pylon; c) vertical vibrations of the span; d) and e) second and third modes of the flexural-torsional horizontal vibrations.*

The lowest frequency was obtained for the first mode of the flexural-torsional horizontal vibrations (a). The lateral vibration out of the bridge plane is second lowest (b). Next is the vertical vibration of the span structure together with the pylon vibration in the longitudinal plane (c). Coupled flexural-torsional horizontal vibrations in the second and the third modes (d), (e) have the highest frequencies. The characteristic relationships between the torsional and the flexural horizontal vibrations of the structure are governed by the existence of only one (vertical) symmetry axis of the bridge cross section.

### 3. 2. Effect of pedestrian loading on dynamic characteristics

Dynamic effects on the bridge are governed by two characteristic properties of moving pedestrian loading:

a) the frequency $f$ the load impulses depends on the intensity $q$ of the pedestrian loading;

b) the velocity $V$ of pedestrian movement along the bridge also depends on the load intensity $q$.

These relationships were determined by numerous investigations by I. I. Kazej, S. I. Kazej, A. L. Zakora and M. I. Kazakevych and can be expressed by the following formulas:

$$q = \frac{400}{1 + 1.4f}, \quad kg/m^2$$

$$V = 0.036\,(25f^2 + 30f), \quad km/h$$

The relationships between the pedestrian load intensity, the velocity of the pedestrians' movement and the frequency of the load impulses are shown graphically in Fig. 3.

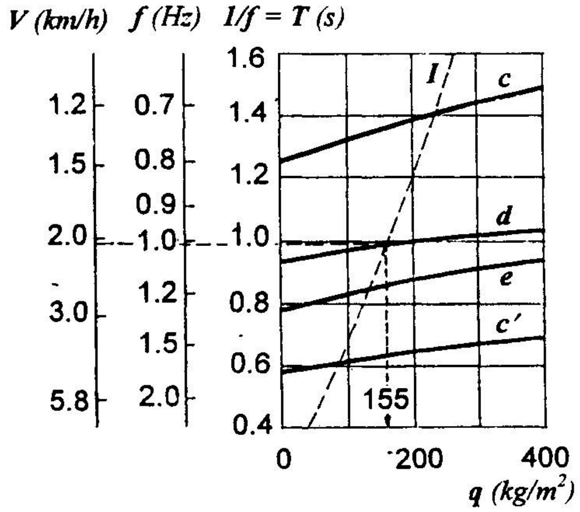


*Fig 3. Graphic representation of relationships between the footbridge frequencies f, velocity of pedestrian movement V, and pedestrian loading intensity q for relevant vibration modes shown in Fig. 2.*
*c) vertical vibrations, 1st mode;*
*c) vertical vibrations, 2nd mode;*
*d) flex.tors. horiz. vibr. 2nd mode;*
*e) flex.tors. horiz. vibr., 3rd mode;*
*I) interaction curve.*

Inspection of this diagram shows the unfavorable coincidence of the horizontal frequency of the pedestrians' effect with the natural frequency of 1.02 Hz of the flexural-torsional horizontal vibrations of the second mode, which occurs when the average velocity of the pedestrians' walk $V$ is about 2.05 km/h. This case corresponds to the pedestrian load $q = 155\ kg/m^2$, or an average of 2.21 pedestrians per one square meter of the bridge deck. This explains the pedestrians' discomfort described as "the ground slipping from under the feet".

### 3.3. Comparison of analytical and experimental results

Ground rules for analytical diagnostic investigations of dynamic behavior of bridge structures under service conditions as well as during the erection have been outlined in [2]. Dynamic characteristics can also be obtained directly, by tests on the completed structure. The methods for dynamic testing of bridges are described in detail in [3]. The relevant factors in such investigations are: the wind effects, vibrations induced by vehicular traffic which may magnify the natural vibrations of the structure, dynamic characteristics of pedestrian loading. Experimental methods, which can provide verification of analytical results, are generally more reliable.

Comparison of dynamic characteristics obtained by the two methods for the Vilnius bridge is given in Table 1.

| Case (refer to Fig. 2) | Analysis | Tests |
|---|---|---|
| a) flexural-torsional horizontal vibrations, 1st mode | 0.355 | 0.37 |
| b) pylon vibrations out of the bridge plane | 0.504 | - |
| c) vertical vibrations, 1st mode | 0.815 | 0.83 |
| d) flexural-torsional horizontal vibrations, 2nd mode | 1.105 | 1.20 |

***Table 1.*** *Calculated and experimental values of vibration frequencies (Hz)*

The comparison shows good qualitative agreement between the analytical and the experimental results, however, the values of frequencies obtained by testing are consistently higher by about 3 - 5%.

Dynamic testing also provided data for determination of the damping characteristics of the structure. For vertical oscillations the logarithmic decrement value of damping $\delta$ was found to be 0.033; for the flexural-torsional horizontal oscillations the value of $\delta$ was 0.017 to 0.04.

## 4. STABILIZATION OF THE BRIDGE

The bridge is one of the access routes to the well frequented Vinginis Park in Vilnius; therefore pedestrian comfort, in addition to fatigue strength of the structure, were important considerations.

Investigations established the need to increase the flexural-torsional horizontal vibration frequency of the second mode (case (d) in Fig. 2) in order to preclude resonance. Two methods of achieving this aim were considered:

1. Increase of the horizontal rigidity of the bridge by means of two additional girders to be placed outside of the existing ones;

2. Increase of the horizontal rigidity by means of added cable stays.

Based on considerations of structural effectiveness, economy, construction problems and maintainability the second alternative was chosen.

Added cable stays with Angles of inclination $\alpha = 44°$ and $\beta = 53°$ are attached to the bottom flanges of the girders at a point 32.5m from the end support (Fig. 1). The lower ends of the cables are anchored in special foundation blocks in the flood plane of the river.

The lower cable ends are provided with spring absorbers having longitudinal natural frequency of 10 Hz, with the purpose of stabilizing the vertical displacement of the span under the effects of temperature and pedestrian loading.

By these means the frequency of the second mode flexural-torsional horizontal vibrations of the structure, which was causing resonant vibrations under the effects of pedestrian loading, was increased by 20% and the problem was eliminated.

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