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THE FRICTION FORCE DEPENDENCE AT SIMPLE PENDULUM SLIDERS BY RELATIVE SPEED AND TEMPERATURE OF THE SURFACES IN CONTACT

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ABSTRACT

Some bridges located in areas of high seismic risk have the decks supported through simple pendulum what dissipates energy by dry friction. The friction force that occurs by motion of the two surfaces is dependent on both the relative speed and temperature of the two elements. Changing these dissipative forces can significantly influence the dynamic behavior of the bearing structure of the bridge during seismic actions, which may result in partial or total destruction. For this reason, this paper characterizes the dependence of the friction force between sliding surfaces depending on relative speed and temperature.

KEYWORDS: bridge, seismic excitation, coefficient of friction, PTFE

1. INTRODUCTION

Seismic isolation system with dry friction (Fig. 1) is similar to a pendulum. In case of this seismic insulation system, the energy transmitted from ground motion to the superstructure is damped through a spherical element that slides on a concave surface [1].

The concave surface on which glides the spherical element (articulated slider) is a completely smooth surface with a roughness factor of 0.1 or less, or less than 0.05 for a high speed sliding with a minimum of friction coefficient.

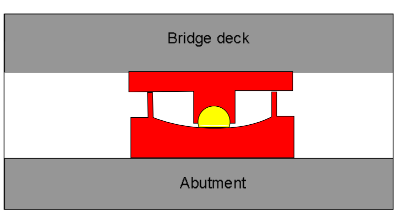


Fig. 1 Friction pendulum sliders

Dependence of the coefficient of friction with speed is a characteristic of teflon based materials [2]. The system acts as "safety" systems which enter in motion unless is taken out of steady state by the earthquake. Once set in motion the system develops lateral friction force equal to the return force as a result of movements along the concave surface.

The seismic isolation is performed by moving the natural period of the structure to higher values.

2 FRICTION FORCE

The damping effect generated by simple pendulum is due to dry friction, as it occurs in relative motion between the concave bearing pivot and support. The friction force generated at the surfaces in contact can be written [4]:

$$F = \mu \cdot N \qquad (1)$$

where
μ - friction coefficient;
F - friction force;
N - normal loading force on the surface.

Usually, mathematical characterization of the rigid solids with dry friction links is applying Coulomb's law (which continued previous studies by Amontons and Leonardo da Vinci), as follows [1]:

- Friction force is proportional to the load;
- Friction is independent of surface (apparent or nominal) contact;
- Friction is independent of sliding speed;
- Friction force depends on the type of materials in contact.

It has been shown that these laws are applying only if the dry friction occurs in elastic deformations. When occurs friction between metal surfaces, such as friction pendulum bearings, these laws contain some approximations:

- For large values of normal force loading, friction does not depend on the first power of the friction coefficient.
- Coefficient of friction generally decreases with speed having a maximum value when speed is zero. In this case the coefficient of friction μ is called the coefficient of adhesion.

In the case of dry friction dampers, friction force depends on the following parameters:

- Diameter of the bearing;
- Contact pressure;
- Speed;
- Temperature;
- Wear.

The friction force can be explained starting from the microscopic contact that occurs at the level the surfaces that come in contact. So far tribology specialists failed to develop an algorithm based on forces that can be expected of friction at the atomic level [4].

When two bodies are in contact, at the level contact surface are formed links between materials atoms, known as junctions. In fact, the area of contact between two bodies is the sum of the areas junctions (roughness) developed along the contact surface. These links are opposed to the removal of body's state of rest by a force known as the adherence force:

$$F_a = \tau \cdot A_r \tag{2}$$

where
F_a - adherence force;
A_r - real surface;
τ - shear resistance.

3. EFFECT OF SPEED ON COEFFICIENT FRICTION

After initiating the movement of two bodies, the friction force generated at the surface contact decreases in value due to the rapid decline of contact surface or due to the reduced resistance force given by asperities in contact.

On machines with friction pendulum bearings, the friction occurs between two types of materials: PTFE (polytetrafluoroethylene known under the trade name Teflon) and stainless steel. The contact between two such surfaces decreases the sliding force friction compared to the adherence force. It is explained by the transfer of very thin Teflon film on the surface of stainless steel.

For a constant value of contact pressure between the surfaces of PTFE and stainless steel, the dependence of coefficient of friction on speed is given by Eq [1]:

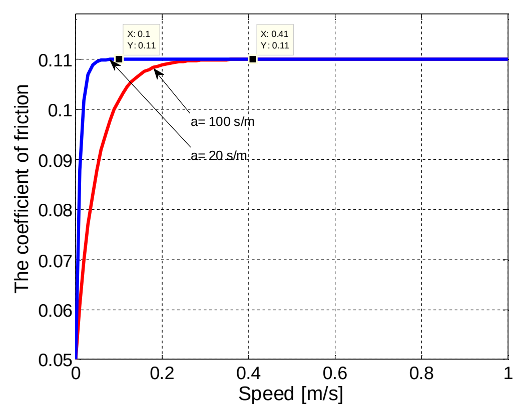
$$\mu = \mu_{\max} - (\mu_{\max} - \mu_{\min}) e^{-a|v|} \tag{3}$$

where
μ_{max}, μ_{min} - represent maximum and minimum values of the coefficient of friction, and
$\mu_{max} / \mu_{min} = 2{,}5 \div 5$ [4], [6];
a - parameter that controls the friction transition from maximum to minimum;

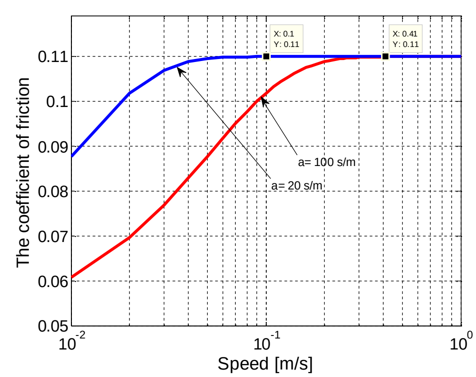
a=20-30 s/m for PTFE;

a=100 s/m for composite PTFE.

Fig. 1 shows us the velocity dependence of the friction coefficient.



a. linear scale representation



b. logarithmic scale representation

Fig. 1 The coefficient of friction versus speed

Experimental measurements have shown that for a higher speed of 150 mm/s, the maximum value of the coefficient of friction for any type of coating based on PTFE is reached.

4. THE DEPENDENCE OF FRICTION FORCE WITH SURFACES TEMPERATURE

By the adhesion theory of friction, the expression of the c of friction between two surfaces in contact is as follows [7]:

$$\mu = \frac{\tau_f}{\sigma_c} \tag{4}$$

where τ_f, σ_c [kg/mm^2] are shear strength and compression strength, for plastic flow, which occurs at the contact between materials. The experimental tests on plastic materials proved that the coefficient of friction is not properly characterized by the report.

Thus, the relation (4) has been corrected as follows [7]:

$$\mu = 0.3\frac{\tau_f}{\sigma_c} \tag{5}$$

where σ_c represents hardness [kg/m^2].

In order to determine the temperature dependence of the friction coefficient it is necessary to know the temperature dependence on of metal hardness and shear strength of PTFE. It has been shown that for pure or intermetallic metals there is exponential temperature dependence on hardness, according to the relation [7]:

$$\sigma_c = A \cdot e^{(-BT)} \tag{6}$$

where k is the Brinell hardness of stainless steel, B is the coefficient of softening hardness of stainless steel with temperature, T is the temperature [K].

According to [8] Brinell hardness of stainless steel at T=293K is k=1250 HB, which determines the coefficient A. A=1543.6. Softening coefficient B = $7.2\cdot10^{-4}$ K^{-1} in [9]. The last relation becomes:

$$\sigma_c = 1543.6 \cdot e^{(-7.2\cdot10^{-4}\cdot T)} \tag{7}$$

The graphic representation of hardness depending on the temperature was performed in Fig. 2.

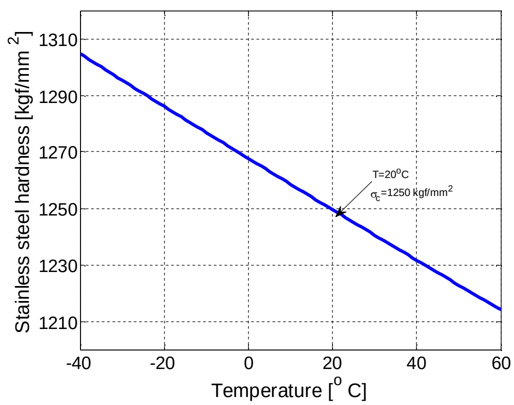


Fig. 2 The allure of hardness steel versus temperature

To take into account the metal surface roughness, the previous relation must be corrected by a multiplicative constant α> 1.

$$\sigma_c = \frac{1}{\alpha}\cdot 1543.6 \cdot e^{(-7.2\cdot10^{-4}\cdot T)} \tag{8}$$

The shear of PTFE is also an exponential dependence with temperature, fig. 1.6:

$$\tau_f = 52.09 \cdot e^{(-115.5\cdot10^{-4}\cdot T)} \tag{9}$$

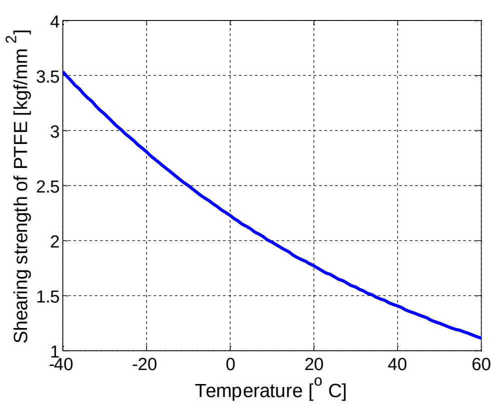


Fig. 3 Dependence of the shearing strength on temperatures

Based on the relations (8) and (9), has been determined the expression of the friction coefficient versus temperature for contact type stainless steel - Teflon (PTFE).

$$\mu = \alpha \cdot 0.0337 \cdot e^{(-108.3\cdot10^{-4}\cdot T)} \tag{10}$$

The value of α coefficient was determined knowing that the temperature of 20°C (293 K) friction coefficient has a value of $\mu_{T=293K}$= 0.04. In this case α = 28.3484.

Thus, the expression of the friction coefficient becomes

$$\mu = 0.9553 \cdot e^{(-108.3 \cdot 10^{-4} T)} \qquad (11)$$

Equations (3) and (11) are very important relations in the dynamic behavior characterization stage of the bearing structure of the bridges loaded by seismic actions.

5. CONCLUSION

This study highlights the theoretical dependence of friction coefficient on contact type stainless steel - PTFE, depending on the speed and the temperature of surfaces in contact. Between these two dependents of the coefficient of friction, with the speed respectively temperature, one of them may lead to the uncontrolled movements of the system. Thus, the increased temperature of surfaces in contact leads to a significant decrease of the friction force, and consequently to the seismic energy dissipation ability. In this way, seismic energy remains in the system for a longer period of time, the amortization movements being made slowly.

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