DOI: 10.24904/footbridge2017.09755

PARTIAL SQUATS – THE DYNAMIC LOAD OF THE FOOTBRIDGES

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Summary

Load models of the ground refraction forces (*GRFs*) has a great practical importance in dynamic analyses of the structures used by pedestrians, including footbridges. One of the important type of dynamic loading of a susceptible and light-weight structures can be the *GRFs* generated during rhythmically repeated squats. In the paper the characteristic and mathematical models of the *GRFs* generated during squats have been presented. The proposed models were elaborated on the basis of laboratory tests of *GRFs* carried out by author using the force platform and were initially validated during numerical analyses and filed tests of exemplary footbridges. The results of the field tests and numerical analyses have confirmed correctness and effectiveness of the models used to estimate the values of the *GRFs* and to calculate the dynamic response of the structure.

Keywords: squat; ground reaction forces; dynamics; response; vibration; footbridge

1. Introduction

For dynamically susceptible structures vibrating in vertical direction the *GRFs* generated during rhythmical vertical body movement in a form of squats are the very probable dynamic loads. When the structure vibrate slightly in vertical direction, people staying on the structure (pedestrians or persons standing still) want to see if their feelings are true and starts perform a vertical movement of their body down-and-up in order to intentionally induce the vibrations of the structure. They start performing squats.

The squats considered within this paper are alternately performed vertical down-and-up movements of the body with maintaining constant contact of the feet with the ground and with alternate bending and straightening of the knees.

Dynamic action in form of squats can be classified as a vandal load of the structure. In dynamic analyses of the footbridges these actions can be taken into account as an exceptional load case (extreme load case) to estimate extreme dynamic response of the structure. The most important is the vertical component of the *GRF* (*VGRF*) arising during the squats.

2. Squats – general features

Squats can be performed with different depths, generally measured by the degree of knee flexion. The squats can be informally categorized into three basic groups: partial squats (0-70° – knee flexion angle (usually about 40°), 0° is for straight leg), half squats (70-100°), and deep squats (>100°) (Fig. 1). The knee flexion angle is defined here as the angle measured on the outside of the leg between inclined thigh and the straight line being an extension of shank.

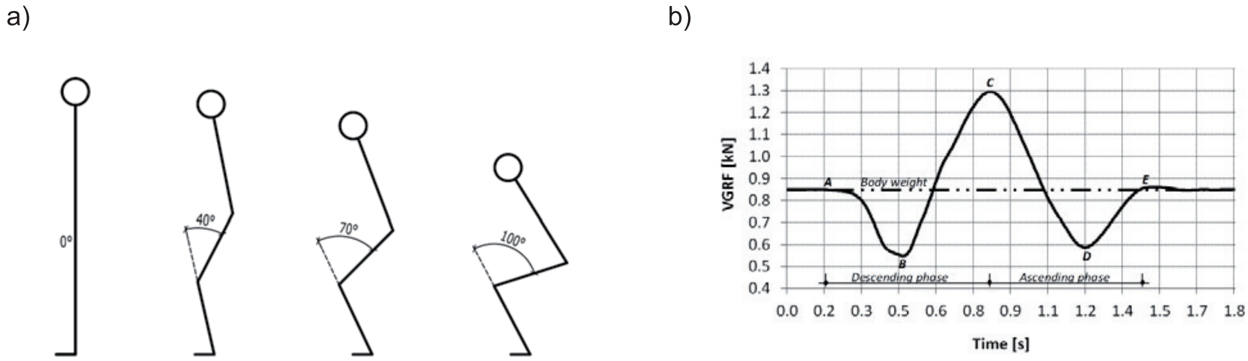

Fig. 1. Selected features of the squats a) knee flexion angle during partial, half and deep squats, b) vertical GRF (VGRF) generated during single partial squat

3. The *VGRF* load models for partial squats

Based on the results of the laboratory tests the load models of the *VGRFs* generated during partial squats were elaborated for two frequency ranges $f_{sq} \le 1.60$ Hz and $f_{sq} > 1.60$ Hz.

The equation (1) is proposed as a load model of the *VGRF* in a frequency range $f_{sq} = 1.00 \div 1.60$ Hz:

$$F_{VGRF}(\Delta t) = k_1 \cdot G \cdot \left[0.5 + k_2 \cdot \frac{\sin\left(4 \cdot \pi \cdot f_{sq} \cdot \Delta t\right)}{\Delta t} \right] \tag{1}$$

where: G – the body weight of a person performing squats, f_{sq} – frequency of the squats, k_1 – coefficient: $k_1 = 1.35$ for G < 0.7 kN, $k_1 = 1.0$ for G ≥ 0.7 kN, k_2 – coefficient: $k_2 = -0.06 \cdot f_{sq} + 0.16$ for $f_{sq} = 1.00 \div 1.50$ Hz, $k_2 = 0.07$ for $f_{sq} = 1.50 \div 1.60$ Hz, Δt – time step: $\Delta t \in (-0.5T_{sq}, 0.5T_{sq})$, T_{sq} – period of the squat $T_{sq} = 1/f_{sq}$.

For frequencies $f_{sq} > 1.60$ Hz when the *VGRF* curves are more or less a sine curves the equation (2) is proposed:

$$F_{VGRF}(\Delta t) = G \cdot \left[1.1 + \sin\left(2 \cdot \pi \cdot f_{sq} \cdot \Delta t\right) \right] \tag{2}$$

where: G, f_{sq}, as previously ($f_{sq} > 1.60$ Hz), Δt – time steep: $\Delta t \ge 0$.

4. Conclusions

The proposed load models are the idealisation of the real dynamic forces generated during partial squats which allow to correctly estimate the value of the *VGRF* and dynamic response of the structures in frequency range 1.20 – 2.8 Hz.

The results of numerical dynamic analyses of the exemplary footbridge shows that proposed load models (1), (2) allow to determine the vibration acceleration that are comparable to the values of acceleration obtained during simulations made with the use of forces acquired during laboratory tests.

It is worth noting that the very easy to use load model (2) allows for a very accurate estimation of the values of the *VGRF* generated during squats with frequency $f_{sq} > 1.6$ Hz and for accurate estimation of the vibration acceleration of the structures.

Further numerical analyses and field or laboratory tests can be performed to check the effectiveness and correctness of the proposed dynamic load models over a wide range of vibration frequencies.