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A SIMPLE METHOD FOR MONITORING SPRINGBOARD REACTION FORCE IN GYMNASTIC VAULTING

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This work was to found a new method for measuring the reaction force of springboard (BRF), which provides scientific supports to the diagnosis of take-off technique. The elastic moduli of GYMNOVA soft and hard springboards were derived by method of mechanics of material, then the springboards were tested in static, dynamic experiments and computer simulations. An equation with different coefficients for soft and hard spring boards, which describe force-displacement of the springboard, *F=kx+cx* was obtained and validated. This equation can be used with convenience by employing a high speed camera shooting to the springboard for rapidly monitoring the take-off BRF, and provide scientific supports in the enhancement of vaulting techniques, and in injury preventions as well.

KEY WORDS: Vault; Springboard; Mechanical properties

INTRODUCTION

The technique of take-off is essential for successful performance in gymnastic vaulting[1]. The gymnasts accumulate kinetic energy and horizontal momentum in run-up. During the take-off phase, parts of the horizontal momentum were transformed into vertical and angular momentums, and a portion of kinematic energy was transformed into potential energy. Springboard reaction force (BRF) plays a very important role in take-off technique. The objective of this work was to develop a simple method for monitoring BRF that may be applied in actual daily trainings and competitions.

METHODS

1. Constitution Equation of the Springboard. A soft and a hard GYMNOVA springboards (France), which models have been designated by the Federation International de Gymnastique (FIG) for vaulting in formal competitions, were used in our study. The mechanical characteristics of the springboards are determined by their construction and mechanics of their components. In mechanics of material, calculation of elastic modulus for a spring is as follows:

$$\mathrm{k} = \frac{F}{\lambda} = \frac{Gd^4}{8D_2^3 n} \qquad (1)$$

where k is the spring elastic modulus, F is load upon the spring, λ is deflection of the spring, G is shear modulus of material of spring (60Si2Mn steel, 8000kg/mm), d is diameter of the wire, D is diameter of the spring, and n is number of the wire circles.

As shown in Fig 1, a springboard has 5 springs (2 at A, and 3 at B). The dimensions of soft and hard boards are same except for the diameters of the spring wires. In general, the total modulus of paralleled springs is the sum of the springs. However, because of the construction of the springboard, contribution of each spring, equivalent modulus, to the total modulus of springboard should be re-calculated. Assume the modulus of spring at B is k_B=k, which is set as baseline, then equivalent modulus at A should be:

$$k_A = k\frac{\tan a * OA}{\tan b * OB} \qquad (2)$$

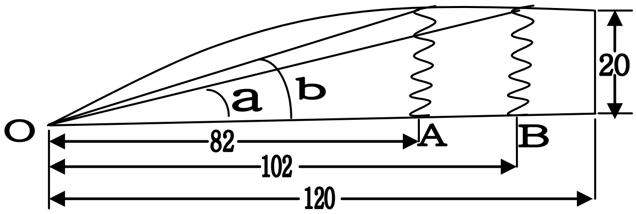


Fig 1 The configuration of the springboard. Note: The lengths unit is cm.

The difference between angle a and angle b is very small. It can be computed based on the dimension of the board, 1≤tana/tanb≤1.078. The more the springboard be depressed, the more this value is close to 1. Thus, the equation (2) can be simplified as:

$$k_A = k\frac{\tan a * OA}{\tan b * OB} \approx k\frac{OA}{OB} = 0.8k \qquad (3)$$

As there are 2 springs at A and 3 at B (Fig. 1), the total modulus of the springboard is:

$$k_{total} = 2k_A + 3k_B = 4.6k \qquad (4)$$

During the depressing of the springboard, there are not only spring elastic forces, but also damping forces of the structure. Commonly, the damping force is assumed to be,

$$F_d = c\dot{x} \qquad (5)$$

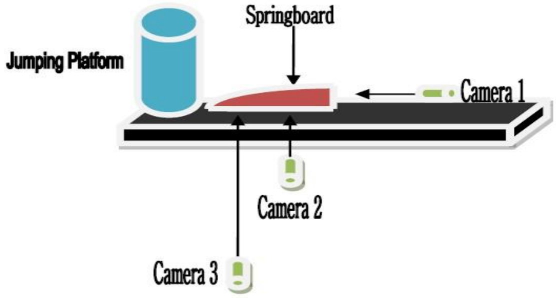
where c is coefficient of damping, and $\dot{x}$ is velocity of the depression. And thus the BRF is:

$$F = F_e + F_d = kx + c\dot{x} \qquad (6)$$

2. Test of the Springboard. The test of the springboard included static and dynamic experiments (Fig 2).

In static test, weights of 160, 180, 210, and 230 kg were put on the springboard respectively, while cameras 1 and 2 (600 Hz) were employed for capturing the deflection of the board. Four markers were pasted at the edges of the board. In dynamic test, a subject (male, 165cm, 60kg) performed drop jumping (DJ) from the jumping platform (1.25 m) to the board, while camera 3 (300 Hz) was used to capture the motion of the subject. Camera 1 and 2 were also used to record the deflection of the board. All videos were digitized using SIMI MOTION (Germany).

3. Computer Simulation. Based on MSC ADAMS/LifeMod, a model of human multibody was developed for simulating the DJ movement. The model includes 19 segments and 50 freedoms. In the computer simulation, the damping coefficients of springboards were obtained.



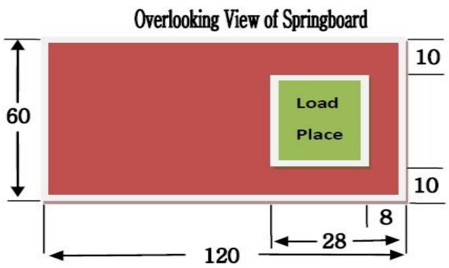


Fig 2 Illustration of dynamic test upon springboard (left) and the loading position of static test (right) (cm).

RESULTS

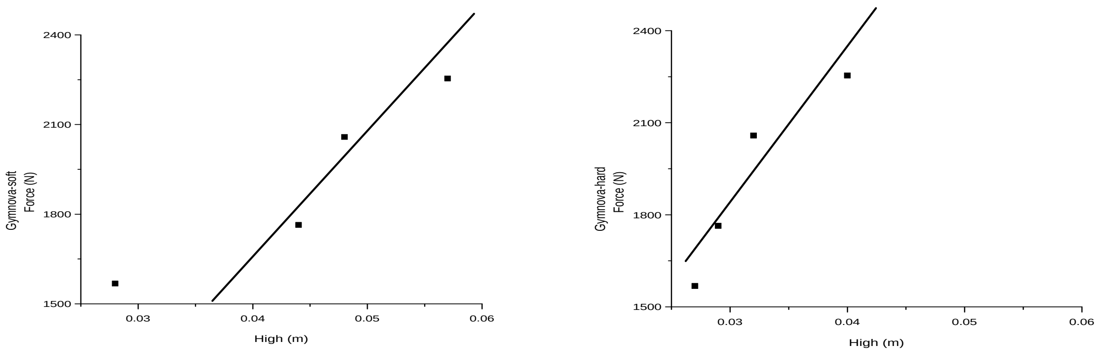


Fig.3 Comparison between experimental results and the theory results for the GYMNOVA soft (left) and hard (right) springboards. Note: The dots are corresponding to static experiment results, while the lines to the linear equations F=kx.

According to the measurements of springs, the modulus of a single spring k was calculated and the total elastic moduli of soft and hard springboard were obtained: 42200N/m, 55200N/m. The comparison between experimental and theory results fits well (Fig 3), which show that the moduli calculated from theory are valid. The BRF curves of the dynamic test were obtained by equation (6) based on the board depressing heights and velocities during the DJ experiment (Fig 4). Comparison between BRF gotten from two different ways [calculated by equation (6) and by accelerations of center of mass from 2D motion analysis of human body] in DJ experiments, and indicates that the differences are acceptable.

DISCUSSION

As shown in Fig 5, BRFs of DJ were obtained by equation (6). It is notable that the springboard began to deform after the BRFs were up to 500 N. This is because there are two side canvas bands on the springboard that make springs depressed initially. The curves of the BRF were with single peaks. The average peak force was 3959 N (6.7 BW) for the soft and 4062 N (6.8 BW) for the hard, and average time to reach the peak was 0.067 s and 0.05 s correspondingly. These values were close to those of vaulting by two elite gymnasts (6.5 BW, 0.056s)[2]. This result suggests that the forces of DJ in this study are in the same range with that of actual vaulting.

Sano et al. (2007) measured BRF by using high speed cameras (500 Hz)[3]. Their results seemed accurate enough, whereas their method was with very complex algorithm and thus might be difficult to put into use in daily trainings and competitions. The method developed in this work is much simpler. We can capture the deflections of the board during take-off using a high speed camera. After digitization of the video, we can get board displacements and velocities, and then we can simply assess the BRFs using equation (6). Our method is much more simple and convenient, without contacting the springboard, and without any interference to vaulting trainings and competitions, and thus is suitable to put into vaulting practice.

In conclusion, this work developed a new method for monitoring springboard reaction force in gymnastic vaulting.

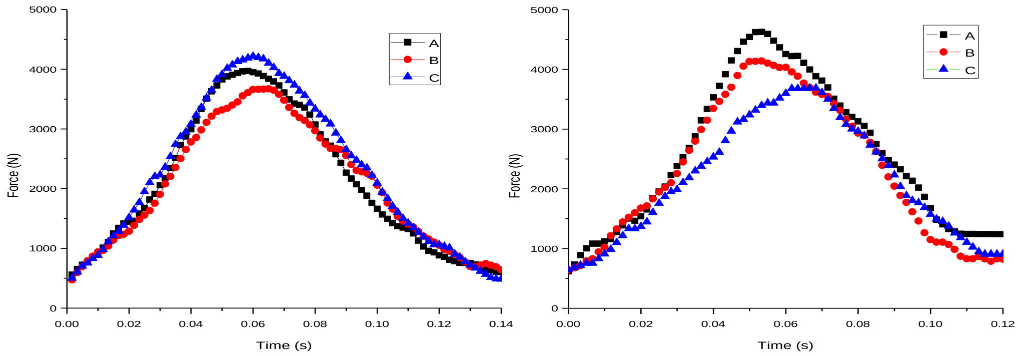


Fig.4 The springboard reaction force of the soft (left) and hard (right) springboards based on the depressing heights and velocities during the DJ experiment (A, B, and C: the first, second, and third DJ).

REFERENCE

[1] Prassas S, Kwon YH, Sands WA. (2006). Biomechanical research in artistic gymnastics: a review. *Sports Biomechanics*, 5(2): 261-291

[2] Wu CL, Hao WY. (2011). Research on kinetics relationship between man and apparatus in vault. *China Sport Science and Technology*, 47(6): 25-29.

[3] Sano S, Ikegami Y, Nunome H, et al. (2007). The continuous measurement of the springboard reaction force in gymnastic vaulting. *J Sports Sciences*, 25(4): 381-391

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