DETERMINATION OF A GROUND REACTION FORCE AFFECTING HUMAN BODY DURING JUMP

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ABSTRACT
The article presents a study on calculating the ground reaction force, which affects the human body during landing after the jump. A basic, one mass model of human body and an equation of movement are presented in the paper. The model for the studies was created in Adams software and the study on a change of the ground reaction force was performed by using different values of height and mass.
KEYWORDS: ground reaction force, jump, body model

WYZNACZANIE SIŁY REAKCJI PODŁOŻA DZIAŁAJĄCEJ NA ORGANIZM CZŁOWIEKA PODCZAS ZESKOKU

STRESZCZENIE
Artykuł opisuje metodę wyznaczania siły reakcji podłoża oddziałującej na ciało człowieka podczas zeskoku. W pracy przedstawiono prosty, jednomasowy model ciała człowieka wraz z opisującym go równaniem ruchu. Zbudowano model ciała w środowisku Adams, a następnie przeprowadzono obliczenia siły reakcji podłoża dla różnych wysokości i mas.
SŁOWA KLUCZOWE: siła reakcji podłoża, zeskok, model ciał

1. Introduction

The ground reaction force (GRF) in biomechanics is an external force acting upon the human body in motion. It's based on the second and the third Newton law stating, that for every action there is an equal and opposite reaction. During landing after the jump this force is responsible for the stress in human locomotive system, possibly causing damage, especially in the neck of the femur bone. The stress distribution in the neck is shown in Karpiński et al. [1, 2].

The GRF can be simulated using numerical methods, based on differential equations or with a use of specialized software like Matlab or Adams. Calculations result in obtaining a graph of function representing changes of the GRF in time, and ultimately in computing the maximum GRF, which for example can be used in studies regarding the stress distribution in a lower human limb.

2.   The methodology of the study

2.1. A mathematical model of the GRF during jump

In order to analyse properties of biomechanical systems, scientists developed multiple mathematical models of the human body. The mathematical model describes the function of biomechanical structures (i.e. bones, muscles, ligaments) with a use of springs and dampers.

To simulate the GRF during jump, a simple, one mass model of the human body can be used [3]. The graphic interpretation of given model is presented in Fig. 1.
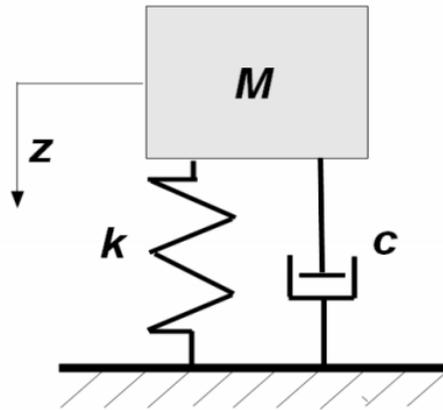

Fig. 1. One mass model of the biomechanical system [4]

Based on the graphic model a differential equation of the movement can be described as

$$M\ddot{z} + kz + c\dot{z} - Mg = 0 \tag{1}$$

where:
$\ddot{z}$ – acceleration
M - human weight,
$\dot{z}$ – velocity of human weight M,
z – positionof human weight M,
k – spring constant factor
c – viscous damping coefficient
g – gravitational acceleration

2.2. Simulating the GRF during jump in MSC Adams

MSC Adams is the software for multibody dynamics and motion analysis. For the purpose of the study, Adams used the physical model of simulated system. Adams incorporates real physics by simultaneously solving equations for kinematics, statics, quasi-statics and dynamics [5].

A model used in the study consists of a ball-shaped body of mass *M*, falling from a height *H* on a system of a spring and a damper simulating human lower limbs (Fig. 2), with a constant factor *k* (equals 9600 N/m) and viscous damping coefficient *c* (equals 600 Ns/m) describing properties of the spring and the damper. The software calculates changes of the force affecting the body in time, resulting in creation of force-time graphs for each body mass falling from height altitudes (Fig. 3-5).
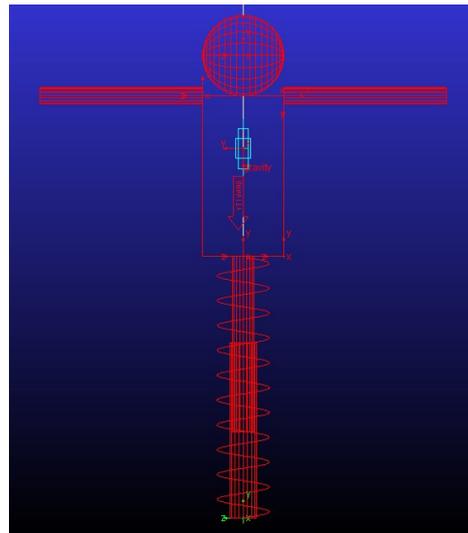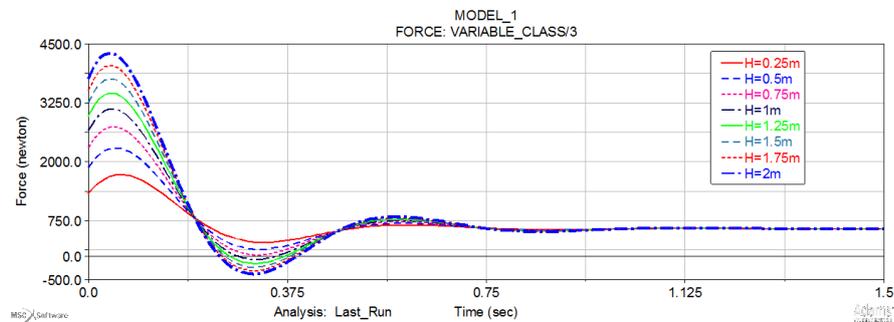
Fig. 2. Representation of the one mass model in MSC Adams

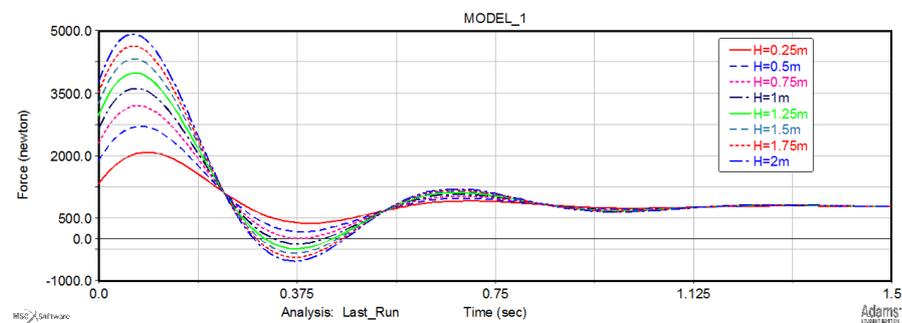*Fig. 3. Graph force-time for various jump heights for M = 60kg*

Fig. 4. Graph force-time for various jump heights for M = 80kg

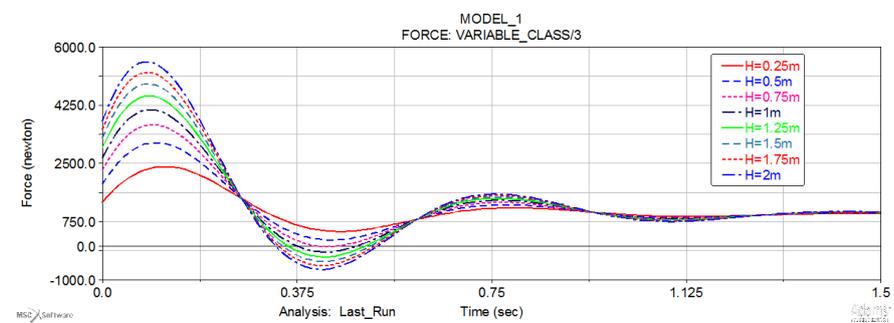*Fig.5. Graph force-time for various jump heights for M = 100kg*

Based on procured data it was possible to extract maximum values of the ground reaction force, which are presented in Table 1 and on Fig. 6.

Table 1. Results of extraction of maximum values of the ground reaction force

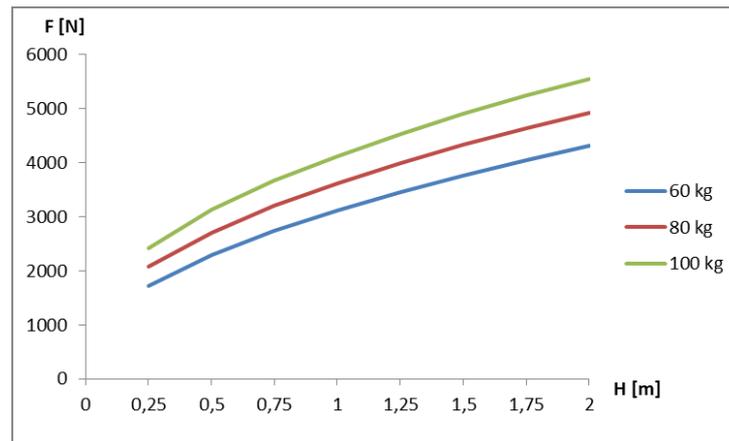| H [m]	F_{max60} [N]	$F_{max\ 80}$ [N]	$F_{max\ 100}$ [N]
0,25	1727,5	2080,1	2409,7
0,50	2297,0	2706,4	3126,5
0,75	2742,7	3196,7	3664,1
1,00	3118,5	3617,4	4119,5
1,25	3456,9	3988,2	4527,8
1,50	3762,9	4323,4	4897,0
1,75	4044,3	4631,6	5236,4
2,00	4306,2	4920,8	5552,4

Fig. 6. Graph maximum ground reaction force-height for various values of mass

3. Summary

MSC Adams presents an interesting way for calculating the ground reaction force affecting human body. Results of the study show that the maximum GRF seems to be directly proportional to the height (*H*) of the initial position, but to validate this trend it is crucial to perform further analyses in order to obtain more information. The values of maximum GRFs affecting the body for given variables are between c. 560 and 730 percent of body weight, and it would seem, that they should not have a pathological impact on the neck of the femur bone.

Moreover, it is essential to remember, that the outcome may vary depending on initial values of *k* and *c* factors, which result from different properties of each human body. For achieving more personalized results, it may be necessary to perform practical tests, using force plates measuring forces during jump to calculate *k* and *c* factors, and then implementing given values to further theoretical studies, which thereafter should predict the GRF for other variables.

4. References

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