INTRODUCTION

The International Gymnastics Federation (FIG) has specific guidelines for tolerance levels of landing mats. However the criteria are based on threshold values obtained from vertical drops of a 20 kg mass with a contact area of 10 cm$^2$ and a landing velocity of 3.96 m/s. If the mat properties are to be included in future inverse or forward dynamics analyses of gymnastics landings then the mechanical properties and responses to the requisite horizontal and vertical loading regimes needs to be quantified.

Spring-damper models have been used to represent the foot-ground interface (Lui & Nigg, 2000) and have included a variety of structures within a single lumped model (heel pad, mid sole, snow, tumbling track). Little experimental evidence is available to support the justification of a single ‘lumped’ model in all cases. In gymnastics the type of landing mat can vary and this has a distinct effect on gymnast landing perception. The modelling of the mat separately from the gymnast’s foot would appear to be justified in these landings.

Landing mats are bulky, have a number of component layers and undergo large area visco-elastic deformations. To produce an accurate model of them would require an array of masses interconnected by spring-dampers. (Peikenkamp, Fritz & Nicol, 2002). This could prove computationally time consuming.

The purpose of this paper was to develop a simple model of a sample gymnastic landing mat that can be incorporated into future research involving injuries during landing.

METHODS

The force F measured by a force plate beneath the mat may be expressed as:

\[ F = -kx - rvx - ma \]

The additional ‘ma’ term represents the mass of the mat accelerated during the impact. In this study an attempt was made to model the measured force F without including an effective mat mass m. using a linear spring damper model developed using Matlab MathWorks Inc. An impactor of mass 24 kg, contact area (25 cm by 25 cm) was used to represent a gymnast landing. The 24 kg mass of the impactor was determined via subject testing. The landing mat was a custom made Continental mat weighing 6.1 kg measuring 0.9 m by 0.6 m by 0.2 m. It was partially constrained to the force plate (Kistler 9281B) and two accelerometers (PCB Piezotronics) were securely attached to the impactor. Two Phantom high-speed cameras (1000 Hz) were used to record the vertical deformation and the area deformation of the landing mat, based upon the methodology of Yeadon and Nigg (1988).

Five different drop heights were used to
produce vertical impact velocities between 4.5 and 6.5 m/s. Additional oblique tests were carried out at five different angles (45°, 50°, 55°, 60° and 65°) on a custom built rig. Angles and landing velocities covered the range of those seen in competition landings (Takei 1998).

A static loading test was used to determine the approximate vertical stiffness coefficient of the landing mat. A series of weights were placed on the mat’s surface and the amount of vertical deformation recorded. Simulated Annealing used the static stiffness as an initial guess of the spring stiffness parameter. Two points on the impactor were manually digitised using the Phantom software. DLT and reconstruction was performed in Matlab using the KineMat toolbox.

Markers on the impactor were used to calculate impact velocity and landing surface deformation. The damping coefficient was adjusted using Simulated Annealing to minimise the difference between the force time characteristics recorded via the force plate and the corresponding characteristics from the spring damper model and the high-speed video data.

RESULTS AND DISCUSSION

With an impact velocity of 5.5 m/s (Takei, 1998) the maximum vertical mat deformation was 0.083 m with a vertical peak force on the force plate of 7054 N at 0.20 s. Firstly a 3 spring damper model was used to simulate the impact. The three spring damper simulation produced a peak force of 7045 N at 0.20 s (Figure 1) with a vertical deformation of 0.086 m.

Secondly a single spring damper system was used to simulate the impact. The resulting force-time trace was virtually identical to that in Figure 1.

![Figure 1: Force time trace. Raw data (continuous) plotted over simulation (dashed) three spring dampers.](image)

The single spring damper model produced a peak force of 7060 N at 0.20 s with a vertical deformation of 0.086 m.

SUMMARY

A single spring damper has been used successfully to simulate the loading characteristics for an impact at 5.5 m/s. At an impact velocity of 4.5 m/s the model overestimated the peak force by 3.4%. At 6.5 m/s the model underestimated the peak force by 13.0%. This is probably due to the increase in the mass of the mat being accelerated at the higher velocities.

REFERENCES