Constant parameter visco-elastic model of a normal incidence football impact

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The FIFA (Fédération Internationale de Football Association) Quality Programme was established in 1996 to standardise the quality of playing equipment used in competitions [1]. The programme assesses the physical properties of a football (e.g., mass, circumference, and sphericity) and dynamic performance (e.g., rebound height from a 2 m drop). There are over 1,000 football models approved for use in competitive play [2]. The combination of materials, joining technique and the outer-panelling design contribute to the overall mechanical properties of the football and will alter the dynamic response of the ball [3]. Quantitative knowledge of the mechanical properties of footballs is important in the development of standards to maintain football performance in match play, to ensure that developments in sports equipment do not adversely change the nature of the game.

Previous literature has analysed the effect of construction, orientation, and internal pressure of a football on impact metrics including the coefficient of restitution (COR), contact time and football deformation [4] [5] [6]. The COR is associated to the damping properties of a ball and influences the rebound speed [3]. The contact time and ball deformation are considered functions of ball stiffness and influence the rebound angle [3]. However, there has been no relationship established between the mechanical properties and dynamic response of a football. It has been shown in published literature, mathematical models can be used to explain changes in the dynamic response between ball constructions [7] [8].

A methodology was developed to allow the accurate measurement of the velocities and forces required to develop a viscoelastic model of a football impact, at normal incidence, on a rigid surface. High speed camera images were synchronised with ground reaction force data using an external trigger and Bioware data acquisition software (v5.0.3.0, Kistler Holding AG). A sampling frequency of 10 kHz was used to capture the full force-time data and minimise integration errors for a 2 m football drop with no imparted spin.

The data captured from a 2 m drop was used to calculate a first approximation. High-speed camera images provided the data necessary to estimate the model coefficients. The model coefficients were initially calculated using the equations presented by Dignall [9] and then optimised to reduce the root mean square error (RMSE) between the measured and modelled force and contact time was maintained.

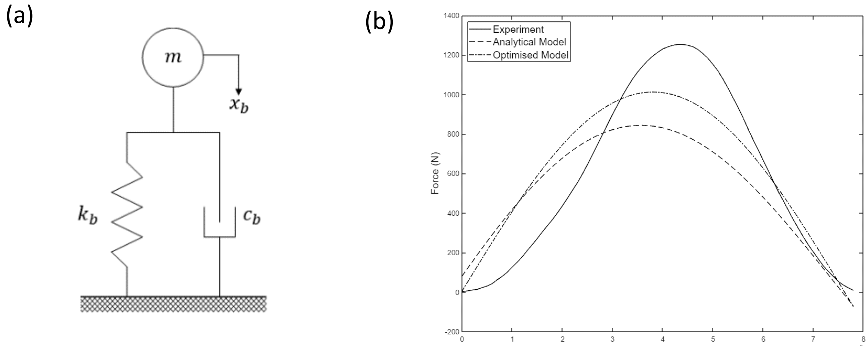

Fig 1: (a) A viscoelastic model of a football impact on a rigid surface (b) Comparison between the force calculated by the viscoelastic model and experimental data obtained using a force platform (Vb = 5.4 m/s)

A comparison between the analytical models and measured force-time data is shown in Figure 1. The loading rate between the initial analytical model and force platform during the initial phase of compression are significantly different ($p < 0.001$). The analytical model has a smaller loading rate during the initial phase of compression, compared to the force platform; this influences the occurrence time and magnitude of the peak

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force. The model estimates the peak force to occur 0.7 ms earlier and underestimates the magnitude by 30% compared to the force platform results.

The assumption that the stiffness and damping coefficients remain constant throughout impact are not suitable to model the non-linear, inelastic behaviour of the football. An initial starting force and tensile force at the end of contact are physically unrealistic. The model coefficients were optimised using standard pattern search algorithms in MATLAB (R2021b, MathWorks, USA) to minimise the RMSE between modelled and measured force, whilst maintaining the contact time. Although the correlation between the magnitude of peak force between the experimental results and optimised model improved by 11%, the damping coefficient was reduced to effectively zero. This further illustrates the limitations of a simple visco-elastic model with constant coefficients to describe the behaviour of a football. Further work will examine the quasi-static properties of a range of footballs to develop non-linear model coefficients with the aim to improve the physical similarities between the model and impact mechanisms.

A visco-elastic model with constant coefficients is presented for a normal incidence impact between a football and a surface. The results indicated the model assumptions led to unrealistic behaviours. The study limited the construction, internal pressure, and orientation of the football. A further limitation is the consideration of only one impact speed. The methodology will be extended to study impacts using different football constructions at higher inbound velocities. This work is useful to advance the understanding of football dynamics and ensure the FIFA Quality Programme remains applicable to assess the dynamic behaviour of modern-day football constructions.

References

[1] FIFA, " Testing manual FIFA quality programme for footballs ," 2018.

[2] FIFA. *Resource Hub*. Available: https://football-technology.fifa.com/en/resource-hub/certified-product-database/equipment/.

[3] R. Cross, "Dynamic properties of tennis balls," *Sports Engineering,* vol. 2, pp. 23-33, 1999.

[4] D. S. Price, R. Jones and A. R. Harland, "Advanced finite-element modelling of a 32-panel soccer ball," *Proc. Inst. Mech. Eng. Part C,* vol. 221, *(11),* pp. 1309-1319, 2007. . DOI: 10.1243/09544062JMES711.

[5] N. Wiart *et al*, "Effect of temperature on the dynamic properties of soccer balls," in 2011, . DOI: 10.1177/1754337111411644.

[6] G. Holmes and M. J. Bell, "effect of football type and inflation pressure on rebound resilience," vol. 61, pp. 132-135, 1985.

[7] S. R. Goodwill and S. J. Haake, "Modelling of tennis ball impacts on a rigid surface," *Proc. Inst. Mech. Eng. Part C,* pp. 1139-1153, 2004. . DOI: 10.1243/0954406042369080.

[8] R. J. Dignall and S. Haake, "Analytical modelling of the impact of tennis balls on court surface," in *Tennis Science and Technology*, S. J. Haake and A. O. Coe, Eds. 2000, .

[9] R. J. Dignall, "Modelling the Impact of Tennis Balls on Court Surfaces." , The University of Sheffield, 2004.

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