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ORIGINAL ARTICLE

Crash Simulation of Lower Limb with Motorcycle Basket

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Summary

Lower limb injuries are the main cause of temporary and permanent disability among motorcyclists in Malaysia. They cause non-fatal but serious injuries requiring hospitalisation. Detailed studies on factors influencing lower limb injuries are justified in an attempt to reduce the occurrence of these injuries. This study presents a computer simulation of the crash behaviour of the basket of a small-engined motorcycle with the lower limb using finite element (FE) methods. The results suggest that the extensive deformation of the motorcycle basket may reduce the risk of injury to the lower limb. The behaviour of the basket during collision is analogous to the crumple zone of automobiles.

Key Words: Lower extremity injuries, Motorcycles, Finite element method

Introduction

Small-engined motorcycles are the main mode of transport for middle and low income groups in Malaysia, both for the rural and urban populations. While these motorcycles are a convenient, fast, and cheap mode of personalised transport, their riders form a significant proportion of deaths and disabilities on Malaysian roads, accounting for 59.7% of all road fatalities and 67.2% of all serious road injuries[1]. Protection of these motorcyclists is still not adequate. The main cause of fatalities are head injuries[2], but lower limb injuries are the main cause of non-fatal but serious injuries requiring hospitalisation. Fifty-five percent of all casualties are between 15 to 24 years of age.

The lower limbs provide the primary means of locomotion for the human body and are frequently injured during motorcycle crashes. Injuries to the lower limbs are rarely fatal, but they cause permanent and temporary disablement which affects the productivity of individuals and the nation. These injuries usually involve the younger members of the national workforce. Measures to reduce this injury level is being addressed at many levels, one of which is the design of the small-engined motorcycle.

The basket that is fitted on most of these motorcycles has become a necessary utility. Since it is located right in front of the seat, it is also the first object to be struck by the lower limb in a frontal collision. The objective of this study was to investigate the crash behaviour of this basket when a lower limb was colliding with it.

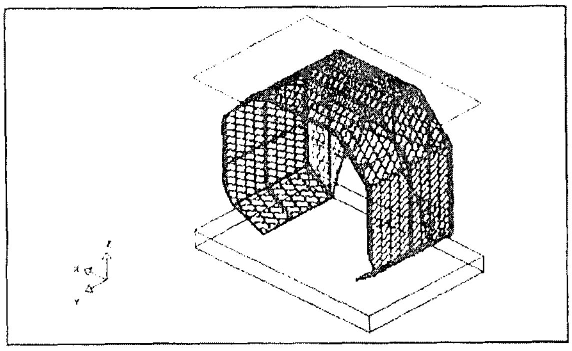

Fig 1 : Isometric View of the FE Model of a Motorcycle Basket.

Table I
Material and Mass Properties of Lower Extremity Model

Property	Type/Value
Material type	Isotropic and linearly elastic
Element type	Thin shell element
Young's modulus (Mg/mm^2)	15,000
Poisson's ratio	0.33
Surface Area (mm^2)	134000 (400 x 335)
Density (Mg/mm^3)	7.5 x 10^{-8}
Mass (Mg)	0.01005

Materials and Methods

The basket of a Honda C70 motorcycle, 1997 model was used for this study (Fig. 1). The basket was appropriately modelled using *finite element (FE) method* with shell and beam elements where applicable. The basket model had a deformable structure and was created with an accurate three-dimension geometry. The basket model was validated against a drop hammer test at the impact speed of 10 km/h. The test involved a 50kg hammer impacting a Honda C70 motorcycle basket[4]. The FE model of this basket was built using HyperMesh pre-processor, version 2.1b. The PC version of LS-DYNA version 9.40, a non-linear, explicit, large deformation FE package was used for simulating and analysing the basket response. Post-processing, which was used to interpret the results was done using Finite Element Model Builder (FEMB) for Microsoft Windows, version 26.5d.

After the validation of the basket model, an elementary *finite element* leg model with suitable material and mass properties (Table I) was developed. The limb consisted of a thin shell element with uniform unity thickness. The geometry of limb for the FE mesh was linearly elastic. The mass of the leg model was 10kg[5], which represents about 11.2% of the estimated mass of a leg of a 60kg male Malaysian adult. The simulations were carried out at the Road Safety Research Centre (RSRC), Faculty of Engineering, Universiti Putra Malaysia. The pre- and post-processing, and all simulations were done on an Intel based personal computer (PC) consisting of 166-MHz Pentium processor with MMX technology.

Results

The simulation of the deformation of the basket as the leg strikes it during impact at 50 km/h is shown in Fig.2. The time sequence of the deformed geometry plots show: (i) undeformed geometry at 0 ms, (ii) initial deformation at 5 ms and (iii) large motions at impact area at 10 ms. Plots (iv) and (v) show the propagation of these disturbances to the impact area and then to the entire basket at 15 and 17.5 ms while (vi) shows more developed deformations of the basket with self contact in the basket and multiple points of contact between leg and basket at 20 ms. Finally, plot (vii) shows the upper region of the modelled leg about to strike the solid block with the collapse of the basket almost complete at 22.5 ms. In this simulation model, the rectangular plane that represents the leg is virtually intact throughout the sequence.

Discussion

Fig. 3 shows the *Energies Time History* of the leg striking a basket at 50 km/h. The total energy of a system during a collision is the sum of all the different forms of energy in all components of the system and is conserved. In vehicle-barrier or occupant-vehicle collisions, almost all the energy in the system will be kinetic and strain (internal) energy. Kinetic energy is the energy of motion of the particles while strain energy produces distortion and displacement[6-8]. The energy change at the impact simulation displays several important characteristics. First, the kinetic energy of the leg-basket model at 0 ms is 969.329 Joules (Equation $T_o = 1/2mv_o$ with m

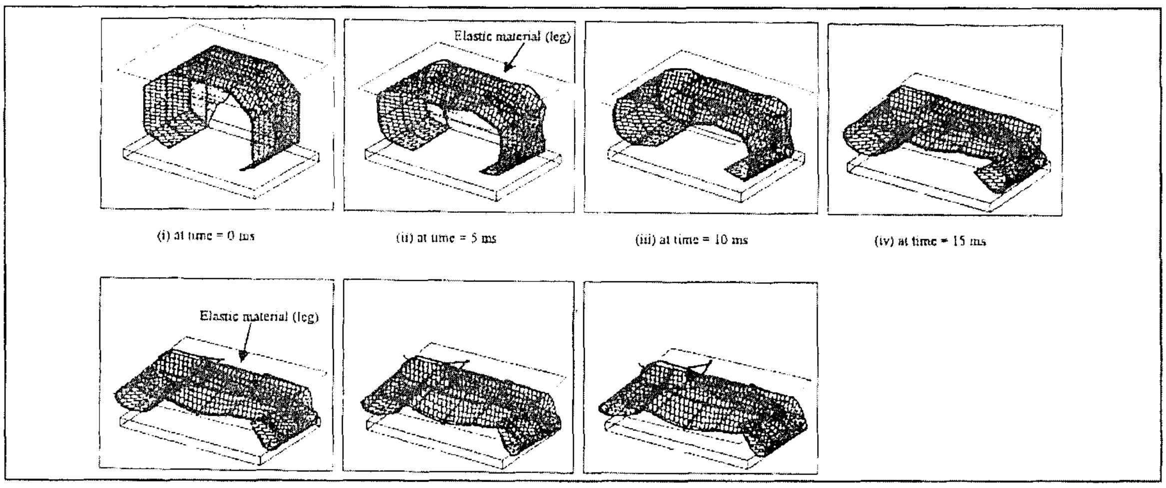

Fig 2 : Isometric View of Simulation for Elastic Material into Basket at Impact Speed 50-km/hr.

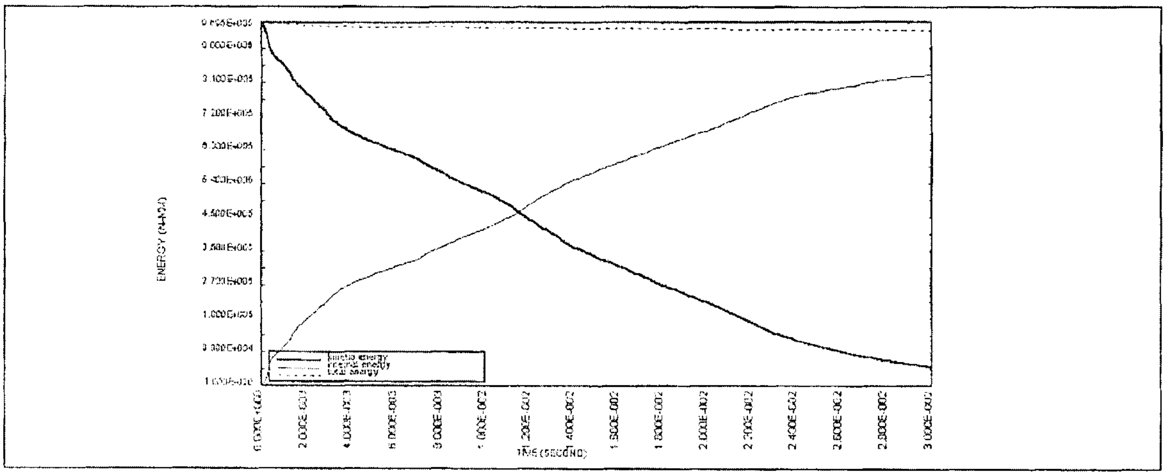

Fig 3 : Energies Time History of the Leg Striking a Basket at 50-km/hr.

10.05 kg and v = 13.8889 m/s). The initial kinetic energy obtained from the simulation is 969.484 Joules. When comparing the initial kinetic energy at 0 ms and strain energy at 24 ms in the model, a difference of 198 Joules is observed. This is mostly due to kinetic energy left in the system at 24 ms; that is when the leg impacts the basket and proceeds backward with a smaller velocity. Furthermore, the time when maximum strain energy occurred coincides with the minimum kinetic energy. At all instants the sum of kinetic and strain energy is close to the total energy in the system. This also demonstrates that the losses in energy by thermal and friction events are minor for these impact situations. Since the leg material was assigned as linearly elastic, the results suggest that most of the initial kinetic energy of the leg has been transformed into strain energy of basket and leg. The simulation also shows the leg to be virtually intact during the collision (Fig 2).

Injuries to the unrestrained occupants are usually caused in secondary collisions[9,10]. In the Malaysian context, it is usually sustained when the motorcyclists hit the

Fig 4 : Position of Motorcycle Basket in front of seat.

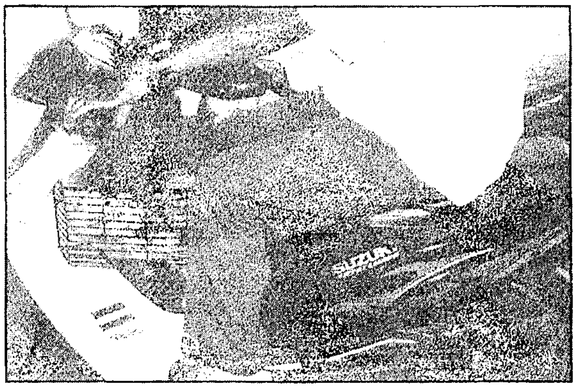

Fig 5 : Simulated position of Lower Limb against Motorcycle Basket at moment of collision.

immediate contact object. Therefore, by locating the basket in front of the seat, most of the impact (kinetic) energy is absorbed by the basket in a collision with the lower limb. As a result, extensive deformations of basket imply that the risk or severity of injury to the lower limb may be reduced.

It is appropriate to describe some of the engineering assumptions made in the evaluation of the biological lower limb in this simulation. The structural components of the body are living organisms and thus respond to stress and strain not only mechanically but also biologically. Biological tissues, particularly soft tissues, exhibit non-linear, inhomogeneous, anisotropic, viscoelastic and rate dependent behaviour. Furthermore, soft tissues are subject to great variability not only between various tissues but also within same tissue types. Therefore, the representation of material characteristics and mechanical behaviour is probably the most difficult and unascertained area of human modelling. Hard tissue, primarily bone, is one of the easier biological tissues to study. Soft tissue mechanics is more difficult to address for reasons mentioned above. It is for this reason that hard tissue alone was considered in this study. In a mechanical sense, bone is a composite material with several distinct solid and fluid phases, and has a strain rate dependent stress-strain relationship[illegible]. However, for strain rates comparable to that seen in automobile impact situations, the plastic region is eliminated and thus bone may be modelled as linearly elastic[illegible]. In the absence of accepted material characterisation tests on living subjects, FE methods are acceptable, appropriate and have been validated in numerous computations and simulations[illegible].

Conclusion

From the numerical simulations in the *finite element* analysis of a modelled leg-motorcycle basket collision, the use of a deformable motorcycle basket may reduce the risk of injury to lower limb of motorcyclists. The behaviour of the basket during collision is analogous to the crumple zone of the automobile, which can be further improved in many ways. The finite element basket model can be used as a basis for the development of different basket geometry, different basket fitting location and material type.

Acknowledgements

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