UNIVERSITI PUTRA MALAYSIA

FINITE ELEMENT SIMULATION AND EXPERIMENTAL EVALUATION OF MOTORCYCLE BASKET FOR CRASHWORTHINESS ANALYSIS

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By

HOW CHEE KEONG

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~ ♥ ~

To my parents, How Hock Seng and Tan Chah Boh;

my best friend and wife, Lim Tan Chin;

and my brother and sisters,

Siew Cheng, Chee Hua and Siew Hoon.

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LIST OF ABBREVIATIONS

AIS	Abbreviated Injury Scale
ASTC	Applied Safety Technologies Corporation
ATD	anthropomorphic test device
EDO	Extended Data Output
FE	finite element
FEM	finite element method
FEMB	Finite Element Model Builder
FTSS	First Technology Safety Systems Inc.
GDP	Gross Domestic Product
LLNL	Lawrence Livermore National Laboratory
MAAP	Microcomputer Accident Analysis Package
MODENAS	Motorsikal Dan Enjin Nasional Sdn. Bhd.
MPP	Massively Parallel Processor
ms	millisecond(s)
PC	personal computer
PDRM	Royal Malaysia Police
RSRC	Road Safety Research Centre
SAE	Society of Automotive Engineers
SMP	Symmetric Multi-Processor
TRL	Transport Research Laboratory
UPM	Universiti Putra Malaysia
UTM	Universiti Teknologi Malaysia

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science.

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By

HOW CHEE KEONG

July 1999

Chairman: Megat Mohamad Hamdan Megat Ahmad, Ph.D.

Faculty: Engineering

In this study, a detailed finite element model of a motorcycle basket used in Malaysia was developed. The model was developed specifically to address motorcycle safety issues, which had reached an alarming rate of casualties in road traffic crash. The finite element method was employed to investigate large deformation of basket at different impact speeds.

The study described the simulation results of a full rigid wall impacting a basket using a non-linear finite element code, LS-DYNA. Drop tests were conducted to validate and compare with the simulation results. The comparisons were made at the impact speed of 10-km/hr. Evaluation between experimental and simulation results in terms of overall impact deformation of the basket were presented. The results clearly indicate that the model correlated well with the test. Additional simulations for higher impact speeds were performed and discussed. Furthermore, simulation of a finite element model of human lower extremity striking a basket at 50-km/hr were also

addressed. The results suggest that a significant amount of energy was transformed by the leg to the basket and consequently caused the basket to deform extensively. As a result, the injury risk of the motorcyclist was minimised through absorbing most of the energy by the basket. However, further study needs to be done to improve the leg-basket model and to incorporate the model with other motorcycle structures.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains.

SIMULASI UNSUR TERHINGGA DAN PENILAIAN SECARA EKSPERIMEN TERHADAP RAGA MOTOSIKAL UNTUK ANALISIS KETAHANAN PELANGGARAN

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Dalam kajian ini, satu model unsur terhingga yang terperinci untuk raga motosikal yang biasa digunakan di Malaysia telah dibina. Model ini dibina khas bagi menangani isu keselamatan motosikal memandangkan kadar kecelakaan jalan raya yang melibatkan motosikal agak membimbangkan. Kaedah unsur terhingga telah diguna untuk mengkaji perubahan bentuk raga yang ketara pada kelajuan hentaman yang berbeza.

Kajian ini menunjukkan keputusan simulasi untuk hentaman dinding tegar penuh terhadap raga dengan menggunakan suatu kod unsur terhingga tak linar, LS-DYNA. Ujian hentaman untuk mengesahkan serta membandingkan dengan keputusan simulasi telah dilaksanakan. Perbandingan telah dilakukan pada kelajuan hentaman 10-km/j. Penilaian di antara ujikaji dan simulasi dari segi perubahan bentuk hentaman secara menyeluruh terhadap raga telah ditunjukkan. Keputusan ini jelas menunjukkan kesepadanan di antara model dan ujian. Simulasi tambahan untuk kelajuan hentaman

yang lebih tinggi telah dilakukan dan dibincangkan. Selain daripada itu, simulasi model unsur terhingga yang melibatkan hentaman bahagian kaki manusia terhadap raga pada 50-km/j juga dilakukan. Keputusan ini menunjukkan sejumlah tenaga yang jelas telah dipindah daripada bahagian kaki kepada raga dan seterusnya menyebabkan perubahan bentuk raga secara ketara. Lantaran itu, risiko kecederaan penunggang motosikal dapat dikurangkan hasil daripada lebih banyak tenaga yang diserapi raga. Walau bagaimanapun, kajian selanjutnya untuk model raga-kaki perlu diperbaiki dan disesuaikan dengan struktur motosikal yang lain.

CHAPTER I
INTRODUCTION

Background of the Study

With reference to Economic Report 1998/99 (Ministry of Finance, 1998), Malaysia's population of 21.666 million[1] in 1997 has increased 27.9% over the last decade. At the same period of time, the country's average annual Gross Domestic Product (GDP) has been growing at a rapid rate of 8.7% from 1988 to 1997. As a result of the tremendous economic boom, there is a resultant growth in the number of registered vehicles in Malaysia. This number has increased from 3,674,482 in 1987 to 8,550,469 in 1997 (PDRM, 1997), which is 132.7% within 11 years (See Table 17 in Appendix A for general road crash data). This of course has put the country's road network under great stress. Consequently, there is a relatively high increase rate in national road traffic crashes (formerly known as accidents), with an annual increase in fatalities by 5.6% on average between 1987 and 1997 (PDRM, 1997). Injuries are reported to be one of the leading causes of death and disability in Malaysia. Road injuries, therefore, form a significant proportion of them (Ho, 1994).

Apart from Malaysia, other countries in the Asia Pacific region such as India, Pakistan, Bangladesh and South Korea are also undergoing uninhibited motorisation and thus are in a rapid transition process (Krishnan, 1996). Since increases in the capacity of public transportation systems have failed to match transportation needs,

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[1] Forecast result.

private ownership of vehicles, especially motorcycles in rapidly motorising country has soared. In Malaysia, the single largest group of registered vehicles on the road and consequently recorded the highest proportion for casualties in traffic crashes (62.8%) is motorcycle (PDRM, 1997). The majority of motorcyclists, especially in the rural areas today, are commuters who have adopted the motorcycle as a convenient, fast and cheap mode of personalised transport (Radin Umar, 1996a). The PDRM statistical report of road crash (1997) states that the number of registered motorcycles in Malaysia in 1997 is 4,328,997 (Table 18, in Appendix A). Due to the increasing number of motorcycle on the road, on average, there was an annual increase of 10.7% in crashes involving motorcycle between 1987 and 1997. In addition, the rate of motorcycle crashes has increased from 9.66 reported crashes per 1,000 motorcycles in 1987 to 18.50 per 1,000 motorcycles in 1997 (Table 18).

This situation has taken a disproportionately higher toll on the road in the last ten years. The average annual increase in motorcycle deaths, which includes motorcyclists and their pillions, was 8.2% between 1987 and 1997 (PDRM, 1997). Therefore, it is not surprising that motorcyclist and the pillion constituted 58.9%, an alarmingly high percentage of death in road traffic crash in 1997.

Owing to the highest fatalities in motorcycle crashes, a Cabinet Committee on Road Safety, with the Prime Minister as the Chairman was formed in 1990. The committee has set a target of reducing fatalities by 30% by the year 2000 based on a forecast linear model by Aminuddin (1991). However the forecast result is far less than the real situation because of rapid growth in traffic exposures following the economy recovery since late 1980s. In addition, gauging from the trends, Krishnan (1996) reports that the incidence of road injuries can be expected to increase further.

Due to motorisation policies of the government, private ownership of vehicles will increase until public transportation is widely available and acceptable. In line with this, the motorcycle will continue to remain the main mode of transport for lower to middle income families. Therefore, a more realistic target was justified and reviewed by the Road Safety Research Centre (RSRC), Universiti Putra Malaysia (UPM, formerly known as Universiti Pertanian Malaysia). The outcome of the research is illustrated by the following statistical model which predicted that 9,127 road users will be killed in road crashes in the year 2000 if traffic exposures continue to increase at projected rate (Figure 1). Among the total deaths, about 5,200 (57%) will be motorcyclists and their pillions. Besides, for every death case, there will be at least 3 permanent disabilities and 10 more other injuries (Radin Umar, 1996b and Radin Umar, 1997).

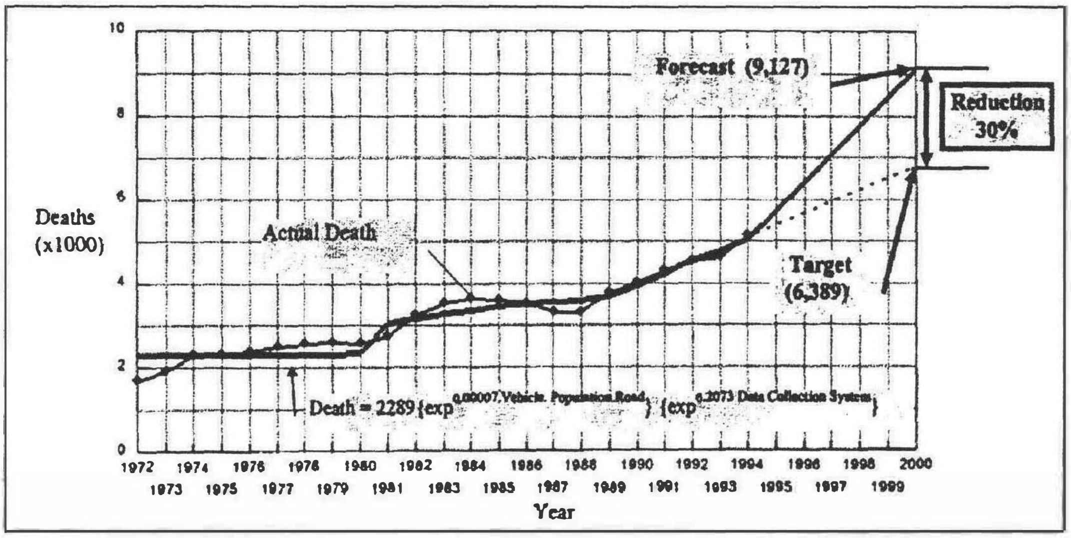

Figure 1: Fatality Model and Safety Target in Malaysia (Radin Umar, 1997)

Furthermore, motorcycle casualties disproportionately affect the young and the economically disadvantaged. In Malaysia, it is estimated that one in about three thousand males between the ages of 13 and 45 or one in about two thousand male motorcyclist dies of motorcycle injuries each year. This does not include those with severe, minor and unreported injuries (Krishnan, 1993). A significant proportion of those injured on the road suffers from injuries to the lower extremities. They become permanently and temporary disabled. In 1997, it is reported that leg injuries constituted the highest proportion for serious injuries. There were 43.1% (3,511 out of 8,144) of the motorcycle riders and 53.8% (733 out of 1,363) of their pillions involved in serious leg injuries (PDRM, 1997). Apparently, injuries to the lower extremities are an important cause of loss of productivity years of life.

Prevention is always better than cure. Since road crashes are unfortunately inevitable, prevention is of course the ideal way of reducing casualties. Owing to this, research to protect the motorcyclists and their pillions ought to be directed at investigating the most frequent serious injuries, which are leg injuries. Likewise, most of the local light-powered motorcycles are attached with a basket as shown in Plates 1(a) and 1(b). The location of the basket has a very close and immediate contact with the lower extremities of the rider. Thus, injuries to the lower extremities caused by secondary impact with the basket is very much possible. To have a better understanding on this problem, research on basket is carried out to investigate its crash behaviour under different impact speeds.

Local light-powered motorcycles, with engine displacement not more than 120 cm^3 (cc), dominate more than 80% of the motorcycles in Malaysia. In view of this, it is important either to keep the motorcyclists and their pillions out of trouble in the first place, or to minimise injury should a crash occur. Apart from anti-lock braking system (Cart and Pickenhahn, 1991; Hikichi *et al.*, 1991; Präckel *et al.*, 1996),

Plate 1(a): Side View of a Typical Basket of Honda Motorcycle

Plate 1(b): Back View of Motorcycle Basket motorcycle airbags (Hirsch and Bothwell, 1973; Danner *et al.*, 1985; Happian-Smith and Chinn, 1990) and leg protectors (Chinn *et al.*, 1989; Chinn, 1991; Yettram *et al.*, 1994), research on other motorcycle structures or components is still very few. Hence, the possible effects and crash behaviour of basket should be evaluated and discussed. By understanding the problem better, it is hoped that the chances of reducing the injury risk are the greatest in case of frontal collisions.

Numerical Crashworthiness Analysis

Engineering structures are designed to withstand loads below a certain level. If excessive loads are applied to it, the structure is likely to fail. During crashes, a structure may be exposed to excessive loads, which are far beyond the capacity of the structure. It experiences non-linear geometric and material deformations. Consequently, the structure may be destroyed within a fraction of a second.

As occasional road crashes such as car and motorcycle crashes cannot be avoided, it is highly desirable that a structure under crash loads should behave in such a way that harm to occupants, riders and economic loss is minimised. The term 'crashworthiness' is used to denote the ability of a structure to sustain a crash in such a way that the part of the structure holding occupants or payloads does not suffer excessive distortion or deceleration (Zhong, 1993).

In earlier stages, experimental approaches and/or analytical approaches were exclusively used due to the lack of other available choices. However, with the parallel development of the finite element method (FEM) and computational mechanics, and modern computer techniques; it is possible to perform crashworthiness analyses numerically. The computer system used to perform these analyses must have enough