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COMPUTATIONAL MODELLING OF SMALL MOTORCYCLE CRASHES AND EXPERIMENTAL VALIDATION

TAN KEAN SHENG

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COMPUTATIONAL MODELLING OF SMALL MOTORCYCLE CRASHES AND EXPERIMENTAL VALIDATION

By

TAN KEAN SHENG

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, In Fulfilment of the Requirements for the Degree of Doctor of Philosophy

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TO

My beloved parents and teachers

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

COMPUTATIONAL MODELLING OF SMALL MOTORCYCLE CRASHES AND EXPERIMENTAL VALIDATION

By

TAN KEAN SHENG

March 2016

Chairman : Wong Shaw Voon, PhD
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Researches in motorcycle crash simulations have been largely focused on the large motorcycles that are commonly found on the roads in developed nations, whereas for the small motorcycles that are used as daily transport in developing nations, the development is relatively far lacking. The present study was thus set out to create and validate a finite element model of a small motorcycle with fully deformable capability for simulating frontal crashes, and to establish guidelines for the entire development process. The Malaysian national motorcycle, Modenas Kriss 110, was selected as the reference motorcycle and the model was developed in LS-DYNA environment. The front wheel and fork which often experience severe and highly dynamic deformations in frontal crashes were modelled to be fully deformable for capturing detail deformation mechanisms and also interactions involved. The models of these crucial subassemblies were validated separately against experimental data. The overall validity and sensitivity of the models were also assessed using factorial experiment approach. The validated front subassemblies were then assembled together with other parts to form the full motorcycle model. A specially designed apparatus and the associated measuring technique were developed to determine the location of centre of gravity and mass moment of inertia of the actual motorcycle. These inertial properties were incorporated in the full motorcycle model. The full motorcycle model was validated against an actual laboratory-based full motorcycle impact test. The global behaviour of the motorcycle and the major deformations sustained particularly by the front wheel and fork were compared. Time histories of motorcycle kinematics were validated against the test data using Roadside Safety Verification and Validation Program (RSVVP). The computed values of the metrics Sprague-Geers MPC and ANOVA are all met the acceptance criteria: 17.6% (magnitude), 16.5% (phase), 24.2% (comprehensive), 0.9% (average) and 21.6% (standard deviation) for the horizontal acceleration; -11%, 22.7%, 25.2%, 0.8% and 19.8% for the corresponding metrics for the vertical acceleration. It is thus concluded that the validated motorcycle model was successfully developed. Detail modelling aspects in developing the models including major numerical instabilities encountered and proposed resolutions, and also limitations and discrepancies exhibited by the models were discussed. The robustness of the model was demonstrated by its capability in simulating severe deformations and the geometric failure of the rim. A guideline to effectively and systematically develop a high fidelity finite element model of a small motorcycle for use in simulating frontal collision of a motorcycle was established.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMODELAN BERKOMPUTER PERLANGGARAN MOTORSIKAL KECIL DAN VALIDASI SECARA EKSPERIMEN

Oleh

TAN KEAN SHENG

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Kajian dalam simulasi perlanggaran motosikal telahpun banyak fokus kepada motosikal besar dan berat yang biasa didapati di jalan-raya di negara-negara maju, sedangkan bagi motosikal kecil dan ringan yang digunakan sebagai pengangkutan harian di negara-negara membangun, perkembangannya sangat terhad. Maka, kajian ini telah dijalankan untuk membangunkan dan mengesahkan model unsur terhingga motosikal yang berkeupayaan berubah bentuk penuh bagi simulasi perlanggaran depan, dan juga untuk mewujudkan garis panduan untuk seluruh proses pembangunan. Motosikal nasional Malaysian, Modenas Kriss 110, telah dipilih sebagai motosikal rujukan dan pembangunan model dilaksankan dalam persekitaran LS-DYNA. Struktur roda dan fork depan yang sering mengalami deformasi teruk dan sangat dinamik dalam perlanggaran depan telah dimodelkan dengan keupayaan berubah bentuk penuh bagi menangkap mekanisme deformasi terperinci dan juga interaksi terlibat. Model individu bagi struktur penting tersebut telah disahkan secara berasingan terhadap data eksperimen. Validiti dan sensitiviti keseluruhan model juga dinilai dengan menggunakan pendekatan reka bentuk faktorial. Struktur depan yang sah kemudian dipasang bersama dengan bahagian-bahagian lain untuk membentuk model motosikal penuh. Peralatan yang direka khas dan teknik pengukuran yang berkaitan telah dibangunkan untuk menentukan lokasi pusat graviti dan momen inersia jisim motosikal sebenar. Sifat-sifat inersia berkenaan dimasukkan dalam model motosikal penuh. Model penuh motosikal disahkan dengan ujikaji impak motorcycle sebenar berasaskan makmal. Kelakuan global motosikal serta deformasi utama yang dialami terutamanya oleh struktur roda dan fork depan dibandingkan. Sejarah masa data kinematik motosikal disahkan terhadap data ujikaji dengan menggunakan perisian *Roadside Safety Verification and Validation Program*. Hasil pengiraan berdasarkan metrik *Sprague-Geers MPC* dan ANOVA didapati menepati kriteria penerimaan: 17.6% (magnitud), 16.5% (fasa), 24.2% (komprehensif), 0.9% (purata) and 21.6% (sisihan piawai) bagi pecutan mendatar; -11%, 22.7%, 25.2%, 0.8% dan 19.8% untuk metrik yang berkenaan bagi pecutan menegak. Dengan itu adalah disimpulkan bahawa model motosikal yang sah telah berjaya dibangunkan. Aspek pemodelan terperinci dalam pembangunan model-model termasuk ketidakstabilan utama numerikal yang dihadapi dan resolusi yang dicadangkan serta juga had dan sisihan yang dipamerkan oleh model dibincangkan. Keteguhan model didemonstrasikan oleh keupayaannya dalam simulasi deformasi yang teruk dan kegagalan geometrik rim. Garis panduan bagi membina secara efektif dan sistematik model unsur terhingga motorsikal kecil yang berealistik tinggi untuk digunakan dalam simulasi perlanggaran depan motorsikal telah dibangunkan.

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I certify that a Thesis Examination Committee has met on 29 March 2016 to conduct the final examination of Tan Kean Sheng on his thesis entitled "Computational Modelling of Small Motorcycle Crashes and Experimental Validation" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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Signature: ______________________
Name of Member of Supervisory Committee: Dato' Ir. Radin Umar bin Radin Sohadi

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LIST OF ABBREVIATIONS

2D	two-dimensional
3D	three-dimensional
ACEM	European Association of Motorcycle Manufacturers
ASEAN	Association of Southeast Asian Nations
ATM	Automatic Target Marking
CAD	Computer aided design
CAL3D	Calspan three-dimensional
CG	centre of gravity
DEKRA	*Deutscher Kraftfahrzeug-Überwachungs-Verein* (German Motor Vehicle Inspection Association)
DOF	degree-of-freedom
ESV	Experimental Safety Vehicle
ETSC	European Transport Safety Council
EU	European Union
FE	finite element
FEMA	Federation of European Motorcyclists Associations
FHWA	Federal Highway Administration
HUMOS	HUman MOdel for Safety
I	mass moment of inertia
IMA	Inertial Measurement Apparatus
LSM	Least-Squares Matching
MADYMO	MAthematical DYnamic MOdels
MATD	Motorcycle Anthropometric Test Device
MB	multibody
MDI	Motorcycle Dynamics Impact program
MIROS	Malaysian Institute of Road Safety Research
MWD	mass weighted damping
NBS	No Binary Search
NCAC	National Crash Analysis Center
NCAP	New Car Assessment Programme
NHTSA	National Highway Traffic Safety Administration
OPAT	Occupant Protection Assessment Test
PTW	powered two-wheeler
RMP	Royal Malaysia Police
RoSPA	Royal Society for the Prevention of Accidents
SBOPT	segment-based contact options
SFM	scale factor on default master penalty stiffness in LS-DYNA
SFS	scale factor on default slave penalty stiffness in LS-DYNA
SLSFAC	scale factor for sliding interface penalties
SOFSCL	scale factor for constraint forces of soft constraint option in LS-DYNA
STM	Sub-pixel Target Marker
TRL	Transport Research Laboratory
TRRL	Transport and Road Research Laboratory
UKDS	United Kingdom Draft Specifications
WHO	World Health Organization

LIST OF SYMBOLS

$\boldsymbol{C}$	system damping coefficient matrix
$\boldsymbol{C}$	system source vector
$\mathbf{C}^e$	source vector from an element
c	speed of the sound
D	minimum diameter of the target for PhotoModeler
$\mathbf{D}$	system degree of freedom vector
$\mathbf{D}^e$	element degree of freedom vector
D_p	minimum target diameter in pixels for PhotoModeler
d_{max}	maximum distance of a target from the camera
$\Delta dist_i^s$	incremental distance the *i*th slave node has moved during the current time step
$\Delta dist_i^m$	incremental distance the *i*th master node has moved during the current time step
E	Young's modulus
$E_{contact}$	contact energy in LS-DYNA
E_{damp}	damping energy in LS-DYNA
E_{hg}	hourglass energy in LS-DYNA
E_{int}	internal energy in LS-DYNA
E_{kin}	kinetic energy in LS-DYNA
E_{ratio}	ratio of the total energy to the sum of initial energy and external work
E_{rw}	rigid wall energy in LS-DYNA
E_{sli}	sliding or contact energy in LS-DYNA
E_{total}	total energy of a system in LS-DYNA
E_{kin}^0	initial kinetic energy in LS-DYNA
E_{int}^0	initial internal energy in LS-DYNA
F_L	focal length of the lens
F_S	horizontal size of the image format
ΔF_i^s	interface force between the *i*th slave node and the contact segment
ΔF_i^m	interface force between the *i*th master node and the contact segment
I_S	width of the image in number of pixels
$\mathbf{K}$	system stiffness matrix
$\mathbf{K_{eff}}$	system effective stiffness matrix
l_c	shortest element edge length
$\mathbf{M}$	system mass matrix
m_T	total mass of a complete motorcycle
n_m	number of master nodes
n_s	number of slave nodes
$\boldsymbol{S}$	square matrix of the system
$\boldsymbol{S}^e$	square matrix from an element
Δt	time step size
Δt_{cr}	critical time step size
$\mathbf{u_0}$	displacement vector
$\dot{\mathbf{u}}_0$	velocity vector
$\ddot{\mathbf{u}}_0$	acceleration vector
W_{ext}	external work in LS-DYNA
ρ	density
ω	circular frequency

ω_{max}	maximum circular frequency
ζ	damping ratio at maximum natural frequency
γ	numerical parameters in Newmark's integration scheme
β	numerical parameters in Newmark's integration scheme

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

The motorcycling mode of transportation is generally characterised by convenient mobility, energy savings, economy of use and unique personal experience (Carey-Clinch & Stevenson, 2014) and it has been gaining popularity with these favourable features. There are differences in the main use of motorcycles between the developed and developing countries. In large cities of European countries, motorcycles are more commonly used for commuting whilst in other developed countries such as Japan and United States, touring is more common than commuting (Howorth, 2012). Though the purposes are different in these countries, the main reasons for riding are the same, i.e. pleasure and enjoyment (Broughton & Walker, 2009). On the other hand, motorcycling is a main practical mode of daily transport in developing countries.

While motorcycling offers the aforementioned favorable features, it also comes with disadvantages that mainly associated with the vulnerability of the motorcyclists. Motorcycle riders are categorised as vulnerable road users, alongside with bicyclists and pedestrians, due to the absence of the protective cage and with almost the only protection afforded to a rider and pillion is the helmet. The unique hazards of this transportation mode and the potential protective value of helmets have already long been documented, dating back to as early as 1941 (as cited in Waller, 1985). The riding of a motorcycle involves a complex operation that requires well-honed motor coordination and balancing skills (Mannering & Grodsky, 1995). This, coupled with the agile maneuvers the motorcycle can perform due to its single-track design and its stability being more sensitive to environmental conditions, and also the lack of protection to the motorcyclists (Royal Society for the Prevention of Accidents [RoSPA], 2001), had associated the motorcyclists with more safety issue compared to four-wheelers. It was estimated that the factors associated with the inherent characteristics of the motorcycling had contributed to 85% of fatal powered two-wheeler crashes (Preusser, Williams, & Ulmer, 1995). Indeed, the risk of having a crash is not higher for motorcyclists compared to motorists (European Association of Motorcycle Manufacturers [ACEM], 2004); Federation of European Motorcyclists Associations [FEMA], 2004), but it is the risk of serious or fatal injury that matters. In Malaysia, it is reported that an overall relative risk of death or injury is about 20 times higher for motorcycle compared with the passenger-car users (Radin Umar, Mackay, & Hills, 1995). Some motorcycle crash studies conducted in other countries also found such consistent results. For example, in Great Britain, motorcycle riders are 18 times as likely to be killed or seriously injured in a road accident as car drivers (Chinn, 1991) whilst it is 20 times in Australia (Johnston, 1992). The fatality and injury rates of motorcyclists in Singapore are respectively about 19 and 7 times higher than other motor vehicle occupants (Haque, 2011).

Despite the fact of such exceptionally high risk of serious and fatal injuries, the motorcycle is still a preferable mode of transport to many road users. The world's total registered motorcycles had increased tremendously from about 200 millions in 2002, to 313 millions in 2006, and further to 455 millions in 2010, which constituted about 30% of all registered vehicles and equivalent to 69 motorcycles per 1000 people worldwide (Nguyen, 2013). The corresponding growth rate is about 57% from 2002 to 2006, and 45% from 2006 to 2010, respectively, which has surpassed that of the car which are 20% and 8% respectively, in the same period. The worldwide market demand for motorcycles is forecasted to expand 7.2% annually to 134.5 million units in 2016 (Freedonia Group, 2013), with the Asia/Pacific region, which predominantly utilises small and inexpensive motorcycles, will continue to dominate worldwide demand, representing 84% of all units sold in 2016.

Asia, being the continent with the highest number of registered motorcycles, comprises about 79% of world's motorcycles (World Health Organization [WHO], 2013). This is expected as Asia has the largest proportion of world's population and most developing countries in the region have been experiencing rapid economic growth that brought about the rapid trend of urbanisation and motorisation over the past decade. The high level of congestion in major cities has caused the motorcycle to become the dominating transport mode. Among the Asian countries, some of the nations in Association of Southeast Asian Nations (ASEAN) such as Thailand, Cambodia, Laos, and Indonesia, motorcycles comprise even more than 70% of the total vehicles.

The trend of the increase in motorcyclist fatalities has been seen to be accompanied by the growing ownership of the vehicles due to the increase of possibility of conflict on the road. Motorcyclist fatalities were reported to comprise of 23% of half of the world's road traffic deaths occur among vulnerable road users, besides pedestrians (22%) and cyclists (5%) (WHO, 2013). In European Union (EU), while the motorcyclist fatalities among the countries varies, the overall fatality rate for EU stands consistently at about 13-18% in the ten years time of 2001-2010, with the rate had only increased slightly at 1% per year (Broughton et al., 2012). The situation is, however, totally in contrast for most developing countries as the rate is alarmingly far higher.

The overall picture of the motorcycle safety status of the countries that represent the ten largest markets of motorcycles in Asia is summarised in Table 1.1. It can be seen that the fatality rates for a few members of ASEAN are distinctively higher than the others and such scenario indeed has long been existed (Sigua & Palmiano, 2005). In Myanmar, 23% of those killed in 2010 were riding motorcycles, whereas in Thailand and Laos the reported motorcyclist fatalities over total road traffic accident fatalities are both about 74% and the worst situation is in Vietnam, accounted for about 75% (WHO, 2013). Malaysia, being one of the ASEAN members is also no exception of having worrying high motorcyclist fatalities, though it is not among the worst in the region. The overall picture of the motorcycle safety status in particular to Malaysia scenario based on the statistics reported by Royal Malaysia Police (RMP, 2012) for the period 2002-2011 is depicted in Figure 1.1.

Table 1.1: Top ten largest markets of motorcycles in Asia for 2010 (WHO, 2013).

Country	Registered Cars & 4-wheeled Light Vehicles	Registered Motorcycles	Percentage Motorcycle of Total Vehicles (%)	Motorcyclists Fatalities (%)
China*	**116,632,500	95,805,176	60.7	35
India	15,313,000	82,402,000	71.7	32
Indonesia	8,148,330	60,152,752	82.7	36
Vietnam	556,945	31,452,503	94.8	75
Thailand	9,887,706	17,322,538	60.8	74
Taiwan	6,686,401	14,844,932	68.3	48
Malaysia	9,114,920	9,441,907	46.8	59
Pakistan	1,849,229	4,506,948	57.4	39
Philippines	2,770,591	3,482,149	52.5	-
Sri Lanka	619,500	2,630,375	66.5	-

*Based on statistics 2009 by International Road Federation (IRF, 2010).
**Civilian passenger cars, SUV, MPV, minivans, vans, mini and light trucks (National Bureau of Statistics of China, 2015).

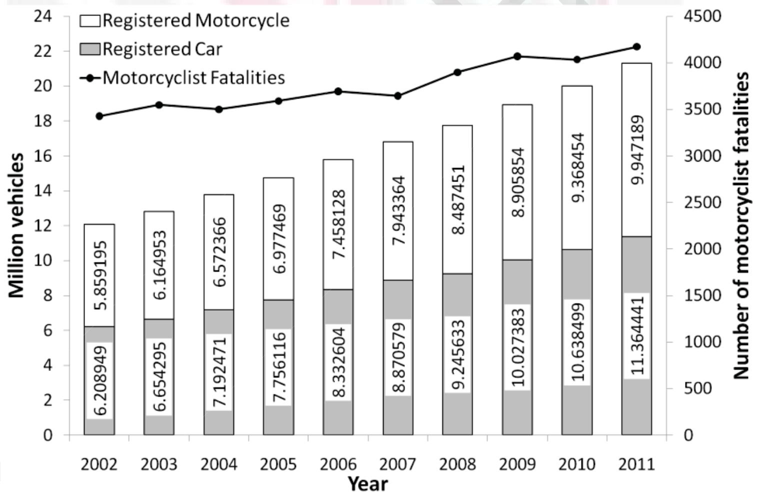

Figure 1.1: Overall picture of the motorcyclist fatalities in Malaysia.

The number of registered motorcycles has been increased consistently at an average rate of 6% per year, from 5,859,195 in 2002 to 9,947,189 in 2011, which comprised about 47%-50% of the annual total registered vehicles throughout that ten years period. In the corresponding period, the number of casualties and fatalities of motorcyclists in road crashes has also found to maintain at an alarmingly high rates, approximately 50%-67% of all traffic injuries, with constitution of nearly 58%-61% of all fatalities.

Clearly seen, with its increased popularity and the associated high risk of serious and fatal injuries, the road crashes involving motorcycles would continue to be a global issue. As such, various measures, both the primary and secondary, have long been devised from time to time attempted to minimise the numbers of casualty, the injury severity level and also the fatality rate (Bly, 1994; Tanna, et al., 2007; European Transport Safety Council [ETSC], 2008). Primary safety measures are those attempted to reduce crash risk, for example the braking system, head-light on, speed limiters and improved handling of motorcycle. The secondary safety measures comprise the interventions that can be taken to reduce the number and severity of injuries if the collision has not successfully been avoided. These included the wearing of helmet, protective clothing, leg protectors, and airbags. However, in spite of various primary safety measures being implemented continuously, the number of accidents involving motorcycle is still continues to soar. The secondary approach of minimising the injury and the risk of fatality is thus becoming relatively important.

1.2 Importance and Justification of the Study

Identification of distribution of injuries and root mechanisms to injuries and fatalities in relation to specific crash configuration are crucial in establishing effective engineering countermeasures to improve motorcycle crash safety. In real world road crashes, there is a great variety of configurations in which a motorcycle can crash onto an opponent passenger car. Together with interactions among the three moving objects, especially between the motorcycle and rider, the motorcycle crashes thus become a rather complex event in that there are enormous possibilities of behaviours of both the motorcycle and rider following a crash. The complexity is even heightened by the fact that the improvements of one type of accident could increase hazards in another type (Berg, Rücker, & König, 2005).

In investigating such complex event of the motorcycle crash, a typical approach is by performing full scale crash tests instead of component tests, whereas in order to further obtain the generalised overview of behaviours of the motorcycle-rider system in the crashes, parametric studies are always highly needed. This would require a series of full scale crash tests to be conducted, with vast number of motorcycles, possibly with various designs, subjecting to a wide range of crash conditions. Nevertheless, it has been well known that full scale crash tests approach always consumes huge resources. For example, a complete motorcycle, an opponent vehicle, crash barriers, manpower, large space such as hundred meter-long runway, and instrumentation system for capturing experimental data, etc.

The recent Malaysian first motorcycle full scale crash test conducted by Malaysian Institute of Road Safety Research (MIROS) which includes Motorcyclist Anthropometric Test Device (MATD) was estimated to cost about RM 1.5 million (Khairil Anwar Abu Kassim, Head of ASEAN NCAP Operation Unit, MIROS, pers. comm. 08 November, 2014). These, however, have not yet take account of the cost of man power, and also efforts and resources spent for preparation works. Moreover, the actual full crash test has high difficulty of reproducibility. With such a huge cost incurred and relatively high complexity of the event, it is impractical at all to perform series of the full crash tests especially for parametric studies. Thus, there is a great need of bringing the actual full scale crash experimentation into computer simulations. Such alternative approach is substantiated by the convincing capability demonstrated by various software packages in handling complex large scale crash events (Liu, Chu, & Viera, 2011). With advancements in computer hardware and simultaneous development in coding, development of more realistic and comprehensive full scale models, and also simulations of sophisticated crash phenomena with promising results are becoming ever more possible.

1.3 Problem Statement

Various researches of motorcycle crash simulation for studying crash safety that exist in literatures have been largely focused on large and heavy size motorcycles which are commonly found on the road in developed nations. These included various sport bikes with engine capacity of 500 cc and above such as Kawasaki GPZ 500 (Nakatani, Sakurai, Chawla, & Mukherjee, 2001), of which usually having a wet mass of above 180 kg and a wheelbase of greater than 1400 mm, and even reaching 407 kg and 1692 mm for large touring bike such as Honda Gold Wing GL1800 (Namiki, Nakamura, & Iijima, 2005). On the contrary, the equivalent progress is relatively far lacking for small motorcycles which typically have an engine capacity of 125±25 cc, a wet mass of about 100±10 kg and a wheelbase of about 1250±30 mm, such as Modenas Kriss, Honda EX5, Yamaha Lagenda and Suzuki Axelo, etc. that are commonly used as a daily transport in developing nations. The simulation models of such small motorcycle is greatly needed as a computational tool for researching the associated crash safety, considering that the models of large motorcycles for crash simulations are incompatible with the small one due to a few underlying differences. The first main difference is in terms of the design characteristics of the machines, such as the weight distribution, location of the fuel tank, type of the rim used for front wheel, and front fork design. Secondly is the seating posture of the human rider, in which it is clearly noticeable in the normal riding condition that the rider on the large motorcycle tended to incline forward as opposed to the upright posture for the small motorcycle. On the large motorcycle, the rider's inner tighs and groin are in close contact with the fuel tank and the resulted interaction during the frontal collision would cause rider's initial dynamics, and so the subsequent behaviour, that is different from the one on the small motorcycle. Furthermore, the small motorcycle is generally more tended to pitch in frontal crashes compared to the large motorcycle.

Besides, there is none of the dedicated modelling works that had incorporated the detail models of frontal critical structures, particularly the front wheel and the front fork, in motorcycle crash simulation studies. The influential effects of the behaviours of these structures on the motorcycle behaviours in frontal crashes are highlighted in some studies, such as the one conducted by Yettram, Happian-Smith, Mo, Macauly, and Chinn (1994) and Nieboer, Wismans, Versmissen, van Slagmaat, Kurawaki, and Ohara (1993), respectively for front wheel and front fork. In addition to severe deformations sustained by both structures, the fork, due to its responsive suspension characteristics, would also contract inwards immediately upon impact, causes sigfinicant diving of the motorcycle and thus significantly altered the geometry of the front end of a motorcycle (Hamzah et al., 2014). This affects the initial pitching dynamics, and so the subsequent behaviour of the motorcycle and rider in frontal collisions. Subsequently, this also implies that explicit deformations of these models are influential to the ultimate quality of the motorcycle crash simulations and thus must be precisely captured rather than just represented with a simple force-deflection model. The lacking of model details in these aspects would limit the effectiveness of utilising the models in practical design improvements of crash safety for small motorcycles.

1.4 Aim and Objectives of the Study

The main aim of the present study is to establish a method for effectively developing a full finite element model in simulating frontal collision of a small motorcycle. To achieve the aforementioned aim, the following objectives have been set:

i. To build a comprehensive finite element model of a full motorcycle with high fidelity of frontal structures based on Modenas Kriss 110.

ii. To design and develop a tool and the associated measuring methodology for determining the inertial properties of an actual full motorcycle.

iii. To design a method for validating the developed full motorcycle model.

1.5 Scope of the Study

The scope of the present study includes the development of a full finite element model for simulating the frontal collision of a small motorcycle and the relevant experimental validations by designed physical tests, with the level of details of the model includes fully deformable and functional front wheel and front fork structure. The crash scenario is limited only to the impact in perpendicular direction, between the motorcycle alone and a rigid barrier, instead of a deformable structure or other vehicle. The main reason to focus on the frontal collision was that it is generally the most frequent and severest type of crash reported in the real world accident statistics. Besides, compared to the side impact whereby an opponent vehicle crashes onto the side of a motorcycle, the frontal collision is far more complicated to be modelled as it involves severe and highly dynamic deformations of the complex front structures. The same consideration also applied to the impact with the rigid type barrier, which is the impact type that would occur in the real world when the motorcycle crashes perpendicularly onto the rim of a car. Also, by isolating the deformation from external disturbance, the mechanism can be studied in detail explicitly. Validity of the developed model in other crash configurations and interaction with deformable structures are not considered in the present study.

1.6 Thesis Layout

This thesis is divided into five chapters. Following this introductory chapter, Chapter Two gives a review of the relevant literatures, covering motorcycle road crash dynamics, motorcycle full scale crash tests, advancements in computational simulations of motorcycle crashes and some fundamental theories of finite element method. Chapter Three presents the details of the method of approach adopted in carrying out the study, includes key ideas, conceptual framework, strategies and procedures that were designed for achieving the aim and objectives, and also to overcome challenges and potential complications throughout the study. Chapter Four presents the detailed finite element modelling aspects in developing the full motorcycle model. Also in the same chapter, the implementation of experimental validations and the corresponding results and analysis were presented and discussed. The methods and precodures involved throughout the model developing process were then reviewed and synthesised, and the established guidelines to effectively develop a full finite element model in simulating the frontal collision of a small motorcycle is then presented in Chapter Five. Finally in Chapter Six, conclusions are drawn and recommendations for improvements and future works are suggested.

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