NUMERICAL SIMULATION OF ROADSIDE SAFETY BARRIER FOR CRASHWORTHINESS ASSESSMENT

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2011

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by

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A thesis is submitted in fulfillment of the requirement for the degree of Master of Science (Mechanical Engineering)

School of Mechatronic Engineering
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2011

ACKNOWLEDGEMENT

I would like to express my sincere gratitude to Allah SWT for all the blessing. My supervisor Dr. Rakhmad Arief Siregar for his guidance, support and encouragement that has helped me throughout the completion of my masters in University Malaysia Perlis. Then, I would like to express my sincere gratitude to my co-supervisor En. Ahmad Yusri Ismail for his guidance, support, comments and discussion.

I would also like to thank the School of Mechatronic Dean and staff for their supports, help and cooperation throughout this research work.

Big thanks to my late parents, family, uncle and aunt for their endless love, support, advice and prayers throughout the time. Special thanks to my friends who have helped me with many supports, discussions, remove the obstacles and difficulties faced in this research. Last but not least, I would like to thank the University Malaysia Perlis for all the facilities that has helped me to finish my research.

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LIST OF ABBREVIATONS

AASHTO	American Association of State Highway and Transportation Officials
EN	European Committee
FEA	Finite Element Analysis
JKJR	Jabatan Kerja Jalan Raya
ASI	Acceleration Severity Index
CAD	Computer Aided Design
Kg	Kilogram
m	Meter
MPa	Mega Pascal
q	Load per Unit Area
q_u	Ultimate Bearing Capacity
D_f	Depth of Foundation
γ	Unit Weight of Soil
N_c	Bearing Capacity Factor
N_q	Bearing Capacity Factor
N_γ	Bearing Capacity Factor
ϕ	Soil Friction Angle
Kpy	Passive Pressure Coefficient
FS	Factor Safety
$q_{net(u)}$	Net Ultimate Bearing Capacity
Q	Total Allowable Gross Load
B	Width of The Foundation

L	Length of The Foundation
HIC	Head Injury Criteria
THIV	Theoretical Head Impact Velocity
$\bar{a}_x$	Average Acceleration in x Direction
$\bar{a}_y$	Average Acceleration in y Direction
$\bar{a}_z$	Average Acceleration in z Direction
$\hat{a}_x$	Limit of Acceleration along Body Axes x
$\hat{a}_y$	Limit of Acceleration along Body Axes y
$\hat{a}_z$	Limit of Acceleration along Body Axes z
g	Gravity = 9.81 ms^{-2}
E	Young Modulus
v	Poisson's Ratio
G	Modulus of Rigidity
ε	Strain
σ	Stress
σ_{VM}	Von Misses Stress
kN	Kilo Newton
mm	Millimeter

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ABSTRACT

Pada masa sekarang, walaupun dengan keselamatan trafik yang moden, beberapa kemalangan beresiko tinggi masih berlaku. Banyak kecederaan parah bahkan kemalangan jiwa berlaku kepada pengguna jalan raya. Kajian terhadap tahap keselamatan untuk semua pengguna jalan raya telah dibangunkan kebelakangan ini. Keselamatan penghadang tepi jalan adalah satu system yang boleh dibangunkan untuk mengurangkan jumlah kecederaan parah. Untuk penggunaan penghadang keselamatan pada lokasi yang dipilih beberapa ujian harus dilakukan. Kebanyakan ujian ini hanya tertumpu pada kesan kelajuan tinggi disebabkan oleh beranggapan bahwa kesan kelajuan tinggi boleh menyebabkan kecederaan utama pada pengguna, kemusnahan kepada struktur pengahdang keselamatan dan juga kendaraan. Disebabkan oleh keprihatinan sebilangan kecil penyelidikan dijalankan utuk kendaraan yang kelajuan rendah. Walau bagaimanapun kesan kelajuan rendah boleh juga menyebabkan kecederaan pada pengguna dan memusnahkan kendaraan dan struktur penghadang. Objektif penyelidikan ini adalah untuk mempersembahkan impak simulasi pada kendaraan berkelajuan rendah dan menganalisa risiko kepada pengguna, struktur penghadang dan kriteria kegagaan tapak konkrit. Simulasi pelanggaran adalah diantara pengahdang jenis W-beam (alang) kepada kendaraan ringan diaplikasi dengan tiga jenis kesan kelajuan (40, 60 dan 80 km/jam). Model situasi pelanggaran dirujuk kepada profil kejadian sebenar dijalan Jamin Ginting Medan, Indonesia. Model simulasi terdiri dari empat bahagian utama iaitu pengahdang keselamatan jalan, tapak konkrit, kendaraan ringan dan jalan.Spesifikasi Pertumbuhan Lebuh Raya Tempatan dan Pegawai Pengangkutan Amerika telah digunakan untuk membangunkan model penghadang keselamatan ini. Semua bahagian utama dibangunkan menggunakan perisian CAD yang kemudiannya dipindahkan kepada perisian FEA komersial. Simulasi menggunakan FEA komersial. Tapak penghadang alang W dan resiko kecederaan pengguna dianalisa. Semasa bebean impak maksima yang berlaku pada tapak diluar beban yang dibenarkan. Nilai Indeks Ketegasan Pecutan (ASI) semua kesan kelajuan masih lagi dalam lingkungan yang boleh diterima.

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ABSTRACT

Nowadays, even with modern traffic safety regulations, some high risk accidents still occur. Many fatal injuries or even death accidents occur to road users. The research of safety levels for all road users has been developed over the years. Roadside safety barrier is one of the systems that have been developed to reduce number of fatal injuries. In order to employ the suitable safety barrier at a referred location several test must be perform. Many of these tests only focused in a high velocity impact because it is considered that high speed impact can cause major injury to the occupant, damage to the safety barrier structure and also vehicle. Because of this consideration minor research has been perform for low vehicle velocity. However low velocity impact can also cause injuries to the occupants and damage to the vehicle and safety barrier structure. The objective of this study is to perform impact simulation on low vehicle velocity and analyze the occupant injury risks, safety barrier structure and concrete foundation failure criteria. The crash simulation is between W-beam type safety barrier to a light vehicle applied with three types of impact velocities (40, 60 and 80 m/hour). The situation model of the crash refers to a real road profile located at Jamin Ginting Street, Medan, Indonesia. The simulation models consist of four main parts that are roadside safety barrier, concrete foundation, light vehicle and the road. American Association of State Highway and Transportation Officials (AASHTO) specification was used to develop the safety barrier models. All the main parts were developed from CAD software then exported to Finite Element Analysis (FEA) software. The simulations are carried out using LS DYNA, commercial FEA software. The foundation of the W–Beam barrier and the occupant injury risks were analyzed. During the impact the maximum load that occurred at the foundation was below the allowable load. The Acceleration Severity Index (ASI) value of all impact velocities was still at the acceptable range.

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CHAPTER 1

INTRODUCTION

Safety in traffic is a major concern in the world. Many improvements are made to achieve a better safety levels to road users and drivers. Nowadays engineers made vehicle technologies that make drivers more comfortable and safe. Roadside safety barrier is one of the components that have been developed in order to achieve a better safety level. From wood type of safety barrier, becoming concrete, beam and cable roadside safety barrier.

1.1 Problem Definition

Accidents in traffic are one of the leading causes of mortality in modern society (Teng et al., 2008). In some countries numbers of car accidents are still high. One of the case is a vehicle crashes to a roadside safety barrier. Roadside safety barrier is part of road safety system that is used to prevent the vehicle from veering off the road and restraint it from entering dangerous area. Road side safety barrier also can reduce occupants injuries and other traffic participants (Boronvinsek et al., 2007) as can be seen in Figure 1.1.

Figure 1.1 Real Accidents Between a Vehicle to Roadside Safety Barrier

Most of published research focused only on a high speed impact cases that causes fatal injuries. High speed impact crash may cause major injuries to the occupant. However minor investigation on low speed impact has been performed. In low speed impact the occupants may also suffer injuries that can lead to permanent injury.

This thesis discuss low speed impact cases which it assumes that the occupant of the vehicle already aware of the situation and make preliminary actions by reducing the vehicle velocity and minimize the impact angle between the vehicle to the safety barrier. The road model refers to a real location at Jamin Ginting Street, Medan, Indonesia. The road was selected for the simulation because of the extreme conditions of the profile and up till now there are no available research using this type of road profile. The simulation data was analyzed to investigate the possibility of occupant injury risks utilizing the Acceleration Severity Index (ASI) method.

1.2 Objective and Scope of Research

The objectives of this research are:

i. To develop a 3D model of W-Beam barrier and the road model based on the standard design to perform impact simulation.

ii. To developed the W-Beam barrier and road model using LS-DYNA codes.

iii. To perform impact simulation with a straight road profile and curved road profile.

iv. To investigate the effect of Acceleration Severity Index with different type of road and impact velocity.

1.3 Thesis Outline

This thesis is organized into five chapters. Chapter 1 presents brief introduction of this research. It describes the background of this research, the problem definition, the objective and scope of this study. At the same time, the thesis outline is provided.

Chapter 2 illustrates the literature review of this research. It briefs some previous research by other researcher, commonly used safety barrier models, models material, formulas used to analyze the occupant injury risks and concrete foundation failure criteria and also review about Finite Element Method.

The models development and the procedure of utilizing FEA software LS-DYNA described in chapter 3. This chapter also presents the steps in developing all the models (road and safety barrier) and codes that was utilized in the impact simulation in order to obtain the expected results.

In chapter 4, results from the simulation are explained. This presents the analysis and the presentation of data during impact. Giving details about how the impact affect to the sustainability of the foundation and also the performance of the parts and the analysis of the occupant injury risks utilizing the Acceleration Severity Index (ASI) method.

Chapter 5 concludes all of the conducted works. This chapter also gives discussion that can be applied in future work

1.4 Conclusion

In some countries numbers of car accidents are still high. One of the case is a vehicle crashes to a roadside safety barrier. Roadside safety barrier is used to prevent the vehicle from veering off the road and restraint it from entering dangerous area. Road side safety barrier can also reduce occupant injuries and other traffic participants. In high speed accidents vehicle occupants can suffer major injuries. From this condition many research focused on high speed impact crash. However in low speed impact the occupants may also suffer injuries that can lead to permanent injury.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The present chapter discussed research and investigation utilizing numerical simulation that has been carried out. Most of this research focused high speed impact that cause major injuries to the occupants and also vehicle structure. Several methods used to achieve better safety levels for road users. Commonly used safety barrier, Acceleration Severity Index, finite element and concrete foundation also presented in this chapter.

2.2 Area of Research

Nowadays numerical simulation are widely use for many research and investigation on crashworthiness. Numerical simulation offers less expensive alternatives and lesser time to perform (Bojanowski, 2009).

(Ren and Vasenjak, 2005) perform crash test utilizing real crash test and computational test. The computational test performs using FEA software LS DYNA. The purpose of the research was to develop the road safety barrier models and evaluate using a full-scale computational test for use in crash simulations and to further compare the computational results with real crash test data. Result from the simulation shows some differences between the computational and experimental. The differences can be attributed to parameters used to describe material dynamic behavior in computations, which were obviously underestimating the stiffness increase of the material under dynamic impact loading. The ASI value for computational test is 0.66 and experimental test is 0.63.

(Andrea Costanzo et al., 1998) perform real crash test using a small type of vehicle to a Steel Barrier. The objective is to analyze the type and entity of injuries caused to the occupants of the vehicles involved in accidental impacts against guardrails with the high containment level. The vehicle velocity applied is 100 km/hour with an impact angle 20^0. The occupant injury risks measured using the ASI method. It was found that the ASI value is 1.34.

(Borovinsek et al., 2006) perform computer simulations of road safety barrier behavior under vehicle crash conditions for high containment levels as mandated by the European standard EN 1317. With several types of vehicles (small, truck and bus) the crash simulation utilize four type of steel barrier that applied different reinforcements. The reinforcements are tension belt, wheel guidance, lower wire rope and upper wire rope. The maximum ASI value for truck using tension belt reinforcement is 1.02 wheel guidance 0.96, upper wire rope 1.21 and lower wire rope 1.14.

Several investigations also perform crash test between motorcycle to roadside safety barrier. (Berg et al., 2005) investigated full scale test between motorcycle to roadside safety barrier. The motorcycle drove by Hybrid III Dummy (50^{th} percentile male) crashed the safety barrier (concrete and steel) with two impact scenarios. In the first impact scenario the motorcycle was driven in an upright position prior to impact. In the other scenario the motorcycle struck the barrier while skidding on its side. The motorcycle velocity is 60 km/hour for both tests. Injury to the passenger was analyzed.

Under consideration that numbers of motorcycles and fatalities increase in some ASEAN countries, (Ibitoye et al., 2007) utilizing numerical simulation perform a crash simulation between a motorcycle to a W-Beam barrier. W-Beam safety barrier designed to reduce severity of a crash when cars and trucks involved in accidents but not specifically protect motorcyclists during accident. The study examines crash study when motorcyclist crash to W-Beam barrier. A simulation using Hybrid III 50^{th} percentile Male Dummy mounted on a motorcycle and colliding with W-Beam barrier was carried out. The simulation was set up with 110 kg motorcycle with 15^0, 30^0 and 45^0 with impact speed at 32, 48 and 60 km/hour and the post spacing 2m and 4m. The obtained data shows that the existing W-Beam guardrail is not safe to motorcyclist, especially for the head injury at impact speed 48 km/hour and at impact angle 45^0.

(Ray et al., 2001) perform a real crash test and simulation to investigate the performance of weak post W-Beam guardrail. Recent crash test of standard weak post W-Beam guardrail involving the 2000 kg pickup truck resulted in a series of unacceptable test result including over-riding and penetrating the guardrail. Design modifications to the weak post W-Beam safety barrier were explored. The improved version of weak post W-Beam safety barrier was tested. The resulting system appears to satisfy the recommendation of NCHRP Report 350 for test level three.

(Gabuer and Gabler, 2005) utilized Event Data Recorders (EDRs) technologies to investigate the correlation between the ASI threshold limits and the potential for occupant injury in crash events. EDRs installed on vehicle model. EDRs are similar to "black boxes" in airplanes as they record information in the event of a highway collision that gives different perspective on the assessment of validity of occupant injury risk based on the Acceleration Severity Index. EDRs are capable of electronically recording data such as vehicle speed, brake status and throttle position just prior to and during an accident.

(Shojaati, 2003) attempted to correlate the ASI to risk of occupant injury via the Head Injury Criterion (HIC), a metric used by the National Highway Traffic Safety Administration (NHTSA) to assess head injury potential. For nine lateral sled tests, the HIC determined from a Hybrid III dummy was plotted against the ASI as determined from the measured vehicle acceleration. The available data suggested an exponential relation between HIC and the ASI but did not provide a direct correlation to occupant injury.

(Teng et al., 2008) perform a side impact simulation to analyze the performance of beams in side crashes include displacement and intrusion measurement of door and injury analysis of dummy. The crash simulation utilized the LS-DYNA finite element code. The test numerical models are based on the FMVSS-214. The simulation test consists of the vehicle model, moving deformable barrier and the side impact dummy. Vehicle velocity applied 54 km/hour with impact angle 27^0.

In order to ensure the Formula 1 drivers safety in case of high speed crashes, special impact structures are designed to absorbs the race car's energy and limit decelerations acting on human body. These energy absorbing structures are made of laminated composite sandwich materials, like the whole monocoque chassis and have to meet defined crash test requirements specified by the FIA. Heimbs et al., (2009) studied the crash behavior of the nose cone as the F1 racing car front impact structure.

Finite element models for dynamic simulations with the explicit solver LS-DYNA are developed with the emphasis on the composite material modeling. Numerical results are compared to crash test data in terms of deceleration levels, absorbs energy and crushing mechanism. The validation led satisfying results and the overall conclusion that dynamic simulations with LS-DYNA can be helpful tool in the design phase of an F1 racing car front impact structure.

2.3 Roadside Safety Barrier

Roadside safety barrier is located outside of the roadway design and is an important component of total highway design. According to State Montana Department of Transportation (2009) from the safety perspective, the ideal roadway has roadsides and median areas that are flat and should be free of obstructions or other hazardous conditions within the entire highway right-of-way. This is usually not practical because of economic, environmental or drainage factors.

In developing the roadside safety barrier some guidelines and requirements must be fulfilled. Europe has EN 1317 guideline from European Committee and America has the National Cooperative Highway Research Program report 350 (NCHRP report 350) from the American Committee (Gabuer and Gabler, 2005).