UNIVERSITI PUTRA MALAYSIA

BUS SUPERSTRUCTURE ROLLOVER ANALYSIS USING FINITE ELEMENT METHOD

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By

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Bus rollover accidents cause severe damage to its superstructure which results in severe injury and death to the passengers. The bus superstructure must be strong enough to absorb energy of impact at a time the superstructure touches the ground. In this work, a bus superstructure with a capacity of forty four passengers was analysed to identify the capability of the superstructure to absorb crash energy using two different materials and varying structure thicknesses during a bus rollover crash. The superstructure was modelled and simulated according to the United Nation Economic Commission of Europe Regulation Number 66 (UN-ECE, R66) using the finite element analysis software, LS - DYNA. The simulation was conducted to determine the permanent deformation of the superstructure of the bus un-laden and laden kerb weight on the passenger residual space during the rollover crash, and the effect of 3.0 mm, 2.3 mm, and 1.6 mm thicknesses of Ultra-galvanise (Ultragal) C350 and 2.3 mm thickness of material made with ASTM A500 grade B on the deformation. The validation process was completed using the quasi-static three-point bending simulation on the waist rail knot of the bus superstructure. The simulation results clearly indicate that appropriate material selection is critical to design and build a strong and lightweight bus superstructure. The simulation of both laden and un-laden kerb weight scenario significantly shows that a heavy frame design will affect the overall bus superstructure, especially the standard hoop structure. The thickness and the type of material assigned to the standard hoop structure also need to be considered to prevent the structure from collapsing and intruding the passenger residual space during a rollover crash. In this study, for bus standard hoop structure with Ultragal C350 material, the intrusion reducing linearly with increasing thickness over the thickness range of 1.6 mm to 3 mm. From the results obtained, the value of thickness for zero intrusion is found to be 2.75 mm. For laden bus structure simulation zero intrusion obtained is 3.1 mm by extrapolation method. The simulation result for the un-laden kerb weight scenario shows that the standard hoop structures does not intrude the passenger residual space where there is a distance of 53 mm between the standard hoop structure and passenger residual space. The un-laden kerb weight scenario shows that the structure absorbed a

maximum internal energy of 95 MJ while the laden kerb weight scenario shows that with the same standard hoop structures thickness had intrude 99 mm into the passenger residual space with higher energy absorbed (internal energy) by the structure at 137 MJ.

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

ANALISIS GULING LAMPAU STRUKTUR RANGKA BAS DENGAN MENGGUNAKAN KAEDAH UNSUR TERHINGGA

Oleh

MAHATHIR BIN RAHMAN

Januari 2017

Pengerusi: **Nuraini Binti Abdul Aziz, PhD**
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Kemalangan guling lampau bas menyebabkan kerosakan yang besar kepada struktur utama bas yang mana ianya boleh mengakibatkan kecederaan parah dan juga kematian kepada penumpang. Struktur utama bas ini hendaklah dibina dengan cukup kuat dan teguh bagi menyerap tenaga impak pada masa struktur utama bas tersebut menyentuh lantai. Dalam penyelidikan ini, Struktur utama bas dengan kapasiti tempat duduk empat puluh empat orang penumpang dianalisis bagi mengenalpasti keupayaan struktur utama bas di dalam menyerap tenaga impak dengan menggunakan pelbagai jenis bahan dan juga ketebalan bahan struktur tonggak bas apabila kemalangan guling lampau berlaku. Struktur utama bas ini telah dimodel dan disimulasi dengan menggunakan perisian analisis unsur terhingga LS - DYNA dengan merujuk kepada kaedah yang ditetapkan oleh Suruhanjaya Kesatuan Ekonomi Negara Eropah, Peraturan nombor 66. Simulasi ini telah dijalankan bagi menganalisis kesan remukan pada struktur utama bas yang merangkumi berat kenderaan tanpa muatan dan berat kenderaan dengan muatan ke atas ruang selamat penumpang apabila kemalangan disebabkan guling lampau berlaku dan juga kesan ketebalan bahan iaitu 3.0 mm, 2.3 mm dan 1.6 mm bagi bahan jenis Ultragal C350 dan ketebalan bahan 2.3 mm bagi bahan gred ASTM A500 B ke atas struktur utama bas. Proses pengesahan simulasi telah dibuat dengan menggunakan separa tiga mata statik membengkok pada bahagian pendakap - simpul struktur utama bas. Hasil simulasi mendapati pemilihan bahan yang sesuai adalah perlu dibuat sebelum struktur utama bas dapat dibina dengan kuat dan ringan. Simulasi bagi kedua - dua keadaan iaitu berat kenderaan tanpa muatan dan berat kenderaan dengan muatan menunjukkan berat keseluruhan bas memberi kesan ketara kepada struktur utama bas terutama sekali pada struktur tonggak bas. ketebalan dan jenis bahan yang digunakan ke atas struktur tonggak bas juga perlu dipertimbangkan bagi memastikan struktur utama bas tidak remuk dan memasuki ke dalam ruang selamat penumpang. Dalam kajian ini, untuk struktur tonggak bas dengan bahan Ultragal C350, kemasukan struktur tonggak bas ke dalam ruang selamat penumpang adalah berkurangan secara linear dengan peningkatan ketebalan struktur tonggak bas di dalam julat 1.6 mm hingga 3 mm. keputusan yang diperolehi, menunjukkan nilai ketebalan struktur tonggak bas bagi tidak memasuki ke dalam ruang selamat penumpang adalah 2.75 mm. Keadaan Bas dengan muatan sarat,

simulasi menunjukkan ketebalan struktur tonggak bas 3.1 mm dikira dengan menggunakan kaedah extrapolasi bagi memastikan struktur tonggak bas tidak memasuki ke dalam ruang selamat penumpang. Keputusan simulasi bagi keadaan berat tanpa muatan menunjukkan struktur tonggak bas tidak memasuki ke dalam ruang selamat penumpang. Jarak 53 mm diukur diantara struktur tonggak bas dengan ruang selamat penumpang. Penyerapan tenaga maksimum oleh struktur adalah 95 MJ sementara bagi kenderaan berat dengan muatan struktur tonggak bas memasuki 99 mm ke dalam ruang selamat penumpang dengan penyerapan tenaga tertinggi oleh struktur adalah 137 MJ.

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I certify that a Thesis Examination Committee has met on 19 January 2017 to conduct the final examination of Mahathir bin Rahman on his thesis entitled "Bus Superstructure Rollover Analysis using Finite Element Method" 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 Master of Science.

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LIST OF ABBREVIATIONS

a	Acceleration
a (t)	Resultant acceleration
ASTM	American Society for Testing and Materials
CFE	Crush Force Efficiency
CE	Carbon Equivalent
CNC	Computational Numerical Control
$\dot{\varepsilon}$	Straining Rate
(ε_{xx})	True Strain
E	Material Modulus of Elasticity
EPS	Effective Plastic Strain
ES	Effective Stress
ECE	Economic Commission for Europe
ETA	Engineering Technology Associates
FE	Finite Element
FEA	Finite Element Analysis
FEM	Finite Element Method
FS	Friction Factor
g	Gravitational Acceleration
L_c	Parallel Length
L_1	Overall length of the sample
MOT	Ministry of Transportation
NHTSA	National Highway Traffic Safety Administration
P	Force
RTD	Road Transport Department
UN	United Nation
W	Work
SEA	Specific Energy Absorption
S_O	Cross sectional area
v	Crosshead Separation Velocity
σ_{XX}	True Stress
φ	Standard hoop structure intrusion into passenger residual space

CHAPTER 1

INTRODUCTION

1.1 Background

Buses are one of the most popular public transports for short and long-distance travels in Malaysia. Recently, many reported road accidents involve the public transport sector, especially buses. The statistics of road accidents show that the total number of commercial bus accidents increased from 106 in 2003 to 182 in 2012 [1]. One of the most tragic accidents that occurred in Malaysia was in 2007 at Bukit Gantang, Perak, where an express bus had rolled-over into a canyon, killing 23 people on-board. The weaknesses of the bus superstructure caused the roof to collapse from the main frame structure [2]. Since the incident, bus manufacturers are enforced by governing bodies such as the Ministry of Transport (MOT) and the Road Transport Department (RTD) to provide bus superstructures with sufficient strength to use on the road as well as to protect the passengers, simultaneously enforcing the bus construction law.

The United Nation - Commission for Europe, Regulation Number 66 (UN-ECE, R66) of Uniform Technical Prescription Concerning the Approval of Large Passenger Vehicle with Regards to The Strength of Their Superstructure was adapted into the Road Transport Department of Malaysia rules. The regulation essentially focuses on the body frame's integrity and their durability. The main frame itself must be built with continuous transversal structure to sustain it in the event of a rollover. The structure of a bus is composed of standard hoop structures, roof structure frame assembly, floor structure frame assembly and side wall assembly. The standard hoop structure is a hoop structure with vertical pillars running between the floor beam and the roof bows, which in conjunction with the floor beam forms a complete closed hoop structure. The side wall assembly is a fabrication consisting of hoop pillars, stub pillars, waist rail, sill rails and diagonal bracing that is prefabricated and then welded to the floor beam.

The floor structure frame assembly is composed of floor beam and longitudinal structure members, connected by steelwork to the bus chassis frame and supporting hoops or stub pillar beam. The floor beam is a transverse of the floor structure. The roof structure assembly is a transverse and longitudinal member that is connected along the roof bow. All these frame assembly structures are made of columns welded to form an integral structure called the bus superstructure. The structural frame is then joined with the main chassis frame. These superstructures absorb the largest amount of energy during rollover impact. The structural frame is then covered on the side wall truss assembly with thin sheets of aluminium. The rear, front and roof structure assemblies are covered with fibreglass. The doors and external small door (luggage doors and engine compartment door) are also composed of structures and aluminium shell.

In this work, the existing bus superstructure will be analysed which focuses on the standard hoop structure. The analyses of the rollover impact was simulated using LS - DYNA finite element programme to determine the deformation and intrusion of the standard structure into the passenger residual space with different standard hoop structure thickness and materials types.

1.2 Problem Statement

Malaysian Government through Ministry of Transport joined World Forum for Harmonization of Vehicle Regulations (WP.29) since 4 April 2006. Through the forum, Malaysian Government have ratified an agreement called Agreement 1958 (Agreement concerning Adoption of Uniform Technical Prescriptions) that compel certification process to every technical approval standards on products or automotive system [3]. According to Road Transport Department (RTD), the technical approval standard is under Motor Vehicles (Construction and Use) (Amendment) Rules 2014 [4] implemented through vehicle type approval (VTA) process [5]. In order to pass VTA process, bus or coach superstructure must meet the general safety guideline under UNECE R66 - UNIFORM TECHNICAL PRESCRIPTIONS CONCERNING THE APPROVAL OF LARGE PASSENGER VEHICLES WITH REGARD TO THE STRENGTH OF THEIR SUPERSTRUCTURE [6]. The main basic requirements in UN-ECE R66 standards is to have sufficient strength in the structure so that the residual space during and after the rollover test on complete bus is maintained. This simply means that no bus components, such as pillars, rings and luggage racks outside the residual space, shall intrude into the residual space during test.

There are many tests according to the R66 standard and one of them is in ANNEX 9 - Computer simulation of rollover test on complete vehicle as an equivalent approval method. Researchers such as [7],[8],[9],[10],[11],[12]. Most of the study and research works were made to show the computational models provided comparable results to experimental measurements and can be used for other type of bus to avoid expensive full-scale crash tests. Furthermore, some of the study shows a successful modification on a beam element to save the analysis cost with little loss of its accuracy in comparison with a shell element model.

While in this study, the work is focusing on a superstructure size of 50 mm X 50 mm, Square Hollow Section (SHS) in determining the superstructure capability of using different types of material such as Ultragal C350 and ASTM A500 Grade B steel material with thickness of 3.0 mm, 2.3 mm and 1.6 mm. The study will provide the information on the superstructure integrity during rollover impact and capable to absorb rollover impact energy without injuring passengers and drivers according to two different bus weight condition which is laden and un-laden kerb weight situation. The results of studies that have been made can help the authorities, especially the Road Transport Department of Malaysia in setting the thickness of the structure and the type of materials to be used in standard hoop structure bus taking into account the laden weight of a bus for each analysis frame of the bus to be created and applied by each bus body makers throughout Malaysia.

1.3 Research Objective

In this study, the aim is to analyse the effect of different material types and structural thickness of the superstructure standard hoop on intrusion.
The specific objectives are:

1. To determine the deformation and intrusion of the superstructure upon rollover impact, laden and un-laden kerb weight.

2. To determine the effect of thickness and material of the superstructure laden and un-laden kerb weight on the passenger residual space intrusion during rollover.

3. To validate simulation of waist rail knot structure with experimental results.

1.4 Scope and limitation of Study

This study focuses on the effect of different material and thickness of standard hoop structure on intrusion of the passenger residual space during rollover. Therefore, the scopes of the study were set as follows:

1. The rollover simulation refers to the United Nation Economic Commission for Europe, Regulation number 66 (UN-ECE, R66).

2. The material characteristics used is according to the manufacturer's current practice which is Ultragal C350 and ASTM A500 grade B.

3. There are no changes in the superstructure design but only to the standard hoop structure thickness which is of 3.0 mm, 2.3 mm and 1.6 mm for Ultragal C350 and 2.3 mm for ASTM A500 grade B.

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