INVESTIGATION OF ROLLOVER PERFORMANCE FOR MALAYSIA BUS SUPERSTRUCTURE

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A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Engineering (Mechanical)

Faculty of Mechanical Engineering
Universiti Teknologi Malaysia

APRIL 2014

Special dedicated, in thankful appreciation for support, encouragement and understanding to my beloved parents, Mak (Noraini binti Onan), Abah (Afripin bin Nong) and my siblings Afrizani, Ika, Aqila and Affiza.

ACKNOWLEDGEMENTS

First and foremost, all praise be to Allah, the most merciful to His creation and give me strength to complete this study and to see this thesis becomes a reality. Through the process of creation and completion of this thesis, many people had contributed directly and indirectly from knowledge, moral and money supports.

Therefore, I would like to express my gratitude to my supervisor, Associate Professor Mustafa bin Yusof, the members of CSM laboratory, Mohd Shauqy Amin, Mohd Aliff, Amir, the members of the Solid Mechanics laboratory, Mohd Fadli, Mohd Zakaria and all other laboratory technicians of the faculty of Mechanical Engineering, Universiti Teknologi Malaysia for assisting me in planning, brainstorming, writing, editing and correcting stages of this project and thesis.

I am indebted and would like to express my appreciation to Fundamental Research Grant Scheme (FRGS) for providing me the fund to complete this study. I also would like to extend my thankfulness to Universiti Teknologi Malaysia for providing me with the high technology facilities in completion of this research.

Lastly but not least, I am thankful because having really lovely parents, Afripin Nong, Noraini Onan and siblings, Afrizani, Zulaikha, Aqila, Affiza that understand me and always be there for me.
Thanks to all.

ABSTRACT

Accidents involving bus rollover can be classified as one of the most fatal types compared to other types of motor-vehicle accident. There are various aspects that lead to occupant injury and fatality. Two prominent aspects are superstructure strength and occupant kinematics. This study deals with the two stages of analyses which are superstructure strength having rollover and occupants kinematic analysis. In accordance to UNECE R66, the bus superstructure should be able to withstand the impact load produced by the rollover accident. The validation process using finite element model was done by comparing the strain results obtained from simple box rollover experiment with the simulation results. A total of four full-scale models of the bus superstructures had undergone rollover simulation using finite element analysis software. The predicted results suggested that the structural strength having rollover strongly depends on the bus design parameters in terms of the beam profile size and main bus dimensions. Analyses of the occupant kinematics were also included in this study. Occupant's injury of restraint occupant was compared to unrestraint occupant using the Mathematical Dynamic Model (MADYMO) software. Overall, the injury indexes for unrestraint occupant are greater than that for restraint occupant. By using a restraint system, the occupant injury and number of fatalities can significantly be reduced.

ABSTRAK

Kemalangan yang melibatkan bas berguling boleh dikategorikan sebagai kemalangan paling bahaya jika dibandingkan dengan jenis kemalangan yang lain. Terdapat pelbagai aspek yang menyebabkan kecederaan dan kematian kepada penumpang. Dua aspek yang terpenting adalah kekuatan rangka bas dan kinematik penumpang. Tesis ini merangkumi dua peringkat kajian iaitu analisis kekuatan rangka bas yang berguling dan analisis kinematik penumpang. Berdasarkan piawaian yang ditetapkan oleh UNECE R66, struktur rangka bas perlu mempunyai kekuatan yang cukup bagi menahan hentakan yang berpunca daripada kesan bas berguling. Proses pengesahan bagi kaedah unsur terhingga telah dijalankan melibatkan perbandingan keputusan terikan antara eksperimen gulingan kotak mudah dan simulasi gulingan kotak mudah. Empat buah bas terlibat dalam proses simulasi bas berguling dengan menggunakan perisian kaedah unsur terhingga. Hasil analisis mengesahkan kekuatan struktur bas yang mengalami kemalangan bas berguling bergantung kepada rekabentuk bas yang terdiri daripada saiz profil rasuk, dan ukuran utama dalam bas. Analisis kinematik penumpang juga turut dimasukkan ke dalam kajian ini. Kecederaan yang dialami oleh penumpang yang memakai tali pinggang keledar dibandingkan dengan penumpang tanpa tali pinggang keledar dengan menggunakan perisian model dinamik matematik (MADYMO). Secara umumnya, indeks kecederaan yang dicatat oleh penumpang tanpa tali pinggang keledar melebihi penumpang yang memakai tali pinggang keledar. Dengan menggunakan sistem sekatan, kecederaan penumpang dan seterusnya kematian dapat dikurangkan.

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LIST OF ABBREVIATIONS

USA	-	United States of America
FARS	-	Fatality Analysis Reporting System
SCI	-	Spinal Cord Injury
TBI	-	Traumatic Brain Injury
UNECE	-	United Nation Economic Commission of Europe
NHTSA	-	National Highway and Traffic Safety Administration
Km	-	Kilometers
Plus	-	Projek Lebuhraya Usahasama Berhad
a.m.	-	ante meridiem
FEM	-	Finite Element Method
MADYMO	-	Mathematical Dynamic Model
NASS	-	National Automotive Sampling System
CDS	-	Crashworthiness Data System
FEA	-	Finite Element Analysis
ASME	-	American Society of Mechanical Engineer
ECBOS	-	Enhanced Coach and Bus Occupant Safety
CAE	-	Complete Abaqus Environment
TASS	-	TNO Automotive Safety Solutions
MADPost	-	MADYMO post-processing program
GSI	-	Gadd Severity Index
HIC	-	Head Injury Criterion
TTI	-	Thoracic Trauma Index
EuroSID	-	Side Impact Dummy
HybRID	-	Rear Impact Dummy

AIS	-	Abbreviated Injury Scale
NIC	-	Neck Injury Criterion
VC	-	Viscous Injury Response
Mm	-	Millimeter

LIST OF SYMBOLS

S_R	-	Seat Reference Point
$\propto$	-	Alpha (angle)
h_o	-	Vertical Height
t	-	Transverse distance
L1	-	Longitudinal distance

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Bus can be described as prevalent transport worldwide. Progressively more individuals are choosing bus due to the convenience offer over other public transport services. Usually bus can accommodate up to 40 passengers. If accident occurred, it will jeopardize many occupants. Besides, rollover accident itself is one of the main accidents that can lead to severe injury and sometimes death to bus occupants. This is showed by bus rollover accident happened in Genting Highlands involved 37 fatalities. Furthermore, this type of accident can lead to severe injury and subsequently, affect the daily life of rollover victim. Besides, most of the factory used bus to transporting workers. If accident occurred, it will effect on company productivity. Thus, national productivity can decrease due to workers health problem. Burns et al. [1], found that rollover incidence frequently becomes a major factor of Spinal Cord Injury (SCI). In the United States, 30 percent of SCI cases came from rollover accidents. Furthermore, rollover victims also exposed to Traumatic Brain Injury (TBI). In that case, the occupant's impact with roof can lead to head injury and TBI [2].

Present knowledge on bus rollover accident's study related on occupant kinematics and strength of various bus superstructure designs is inadequate. Most researchers only focus on the effect of bus roof strength towards severity of rollover accidents without considering occupant kinematic. According to United Nation Economic Commission of Europe (UNECE) Regulation 66 [3] which is uniform technical prescription concerning the approval of large passenger vehicles with regard to the strength of their superstructure, bus can operate on the road if superstructure not infringes into residual space during impact and post-impact. The ultimate goal of rollover test as mentioned in the regulation is to minimize the intrusion of superstructure into the occupant compartment. However, it might be possible that occupant's life still in danger although that superstructure passes the test due to the failure of occupant kinematic consideration.

Most of previous study used a simulation method according to Annex 9, UNECE R66 [3]. Annex 9 allows bus manufacturers to evaluate its new bus superstructure design crashworthiness in rollover events using computer simulation while following real test condition (Annex 1).

Most of the rollover accident involving roof crushes will result higher rate of spine injury, brain injury and mortality [4]. Apart from weak bus superstructure, another factor that leads to occupant injury is rapid movement of occupant during rollover. This kinematic movement also known as diving hypothesis as introduced by Moffat [4]. Moffat [4] discovers that, in a rollover crash, the roof of the vehicle is stationary against the ground and occupants will speed subsequently impact the roof due to inertia. Consequently, high load acted on the occupant's body resulting spine injury.

Another cause of occupant injury is occupant ejection outside bus superstructure [5]. It can be prevented by maintaining structural integrity of bus superstructure. By strengthening the joint and other critical parts, the structure has a higher possibility of preserving its shape after having rollover accident. Other ways to avoid this incident is seat belt usage especially for front seat occupant and using laminated windows. Therefore, if these features are implemented in bus coach, there is a possibility that occupants will not eject outside bus frame.

However, these previous findings are not includes the effect of various designs on bus superstructure. Apart from that, occupant injuries only take by statistical data without proper occupant simulation in rollover case. More in-depth studies are needed to confirm these findings.

Aside from the studies conducted on the factors that affected the strength of bus superstructure having rollover, there is an important need to determine the best bus superstructure design that can withstand rollover impact. This is because many factors can affect bus superstructure deformation after rollover such as total weight, material used, size of window and floor. These factors need to be determined to provide better survival space for occupants. Therefore, both factors those cause kinematic injuries which introduced by Moffat [4] need to be covered in this study.

1.1.1 Bus Definition and Classification

A bus can be defined as a large motor vehicle carrying passengers by road, especially that serving the public for a fare and has a schedule. Its classification is commonly done by referring to its seating capacity, capable of load carriers, body style, service provided, stopping pattern and other physical or usage based feature.

In Malaysia, bus can be classified into two main types which are single storey and double storey bus [6]. The single storey bus represents a single deck for passengers and the height range is from 3 to 3.5 meters. Usually the length for this type of bus is basically range from 5 to 12 meters but for some countries, up to 15 meters is permissible due to its operation road which needs to be wide and straight. There are 2 types of single deck bus which are low and high floor. It is important to recognize that the addition of a wheelchair ramp at the entrance and barrier-free facilities for low floor are 2 main features that can be seen clearly in order to distinct between low and high floor single deck. Usually, low floor bus is used for transit and it help wheelchair users and senior citizens to access the bus easily due to the smallest gap between the road surface and bus floor. High floor bus normally designed for coach usage or long journey travel. Furthermore, extra space under the passenger seat is use for luggage storage.

Double storey buses can be divided into two types according to their usage which are double deck and high deck [6]. Double deck commonly used for double storey transit bus. It has a low floor for better accessibility and better headroom for the lower deck. Maximum of 100 passengers can board on this bus at one time. 55 seats passengers are located on the upper deck while estimated of 28 seats located on the lower deck. Standing position is allowed for lower deck passengers while upper deck passengers need to seat properly due to space constraint and wheelchair bay is also provided as a facility for wheelchair users. High deck is the term used for double storey bus that operates for a long journey travel. Most of the passenger seats are located on upper deck. Passengers for this type of bus are not more than 50.

Buses are also known with others unique terms such as Omnibus, Motor coach and Autobus [7]. Until now, there were no single universal legal definition for the bus and it changes widely by nations. Therefore, it is very difficult to identify the crashworthiness aspects of different types of buses originate from lack of a shared definition and the missing harmonized classification for buses. Generally, most of the country use length, weight and vehicle’s passenger as their criteria for bus classification [7]. Legal definition for bus according to respective country is in Appendix A.

1.1.2 Rollover Classification

Compared to the other type of accidents, rollover is the most critical accident based on number of fatalities and severe injuries. Figure 1.1 shows the type of accident percentages (Source from Fatality Analysis Reporting System (FARS) for the USA market):

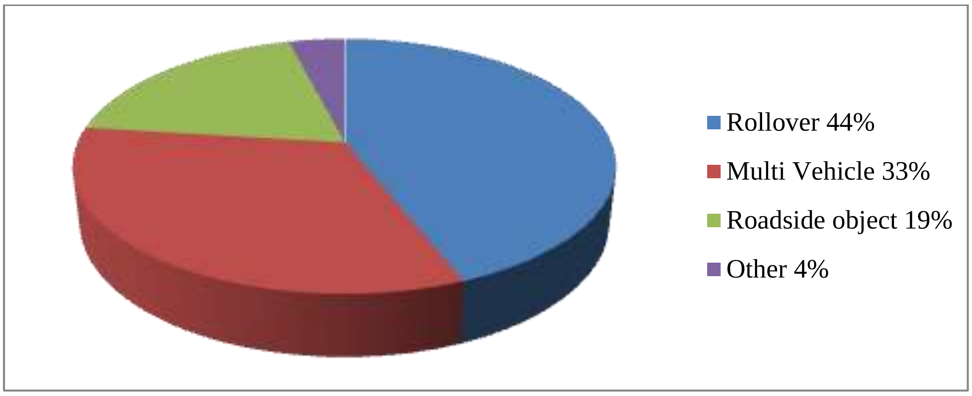

Figure 1.1 : Motor coach Fatal Events (FARS 1999-2008)

Surrounding and road surface condition of the accident scene has strongly influenced the type of rollover accident. Therefore, rollover accident can be categorized into two main types which are:

1. **Tripped**: this occurs when the vehicle's tire comes in contact with an object that sudden stop the lateral motion of the vehicle and initiates the vehicle into roll condition around that object. Tripping objects usually are curbs, rock, soils and ramp.

2. **Untripped**: the main cause for this accident is severe steering maneuvers such as J-hooks, fast turns and instant lane changes. This accidents different with tripped because rollover happens without trip object and more focus on change of center of gravity location rapidly.

According to National Highway and Traffic Safety Administration (NHTSA), Rollover can be classified by referring to its commencing reasons. The definitions include the following factors:

1. **Trip-over**: When vehicle wheels dig into a curb, pavement or pothole, the lateral motion of the vehicle will suddenly slow or stopped inducing rollover. Figure 1.2 shows the vehicle trip-over diagram.

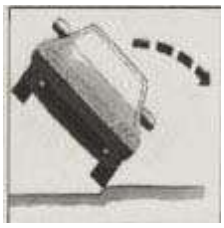

Figure 1.2 : Vehicle trip-over

2. **Fall-over**: When the vehicle center of gravity becomes outboard of its wheels. The movement of center of gravity caused by vehicle travelling slopes downward in the direction of its movement. The difference between this type of rollover and turn-over is negative slope. Figure 1.3 displays vehicle fall-over out of the road.

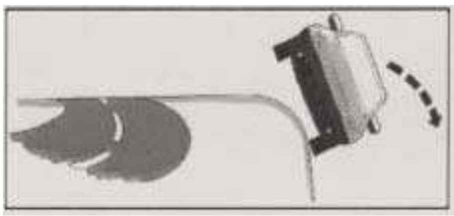

Figure 1.3 : Vehicle fall-over out of the road

3. **Flip-over**: When a vehicle hit ramp like object such as back slope of a ditch or a turned down guardrail, it will rotate around its longitudinal axis. The illustrations for vehicle flips-over show in Figure 1.4.

Figure 1.4 : Vehicle flips-over

4. **Bounce-over**: When a vehicle overturns after rebounds off a fixed object. The rollover needs to occur close to the fixed object as shown in Figure 1.5.

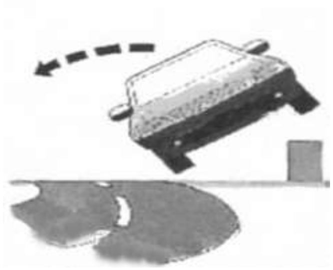

Figure 1.5 : Vehicle bounce-over after rebound with a fixed object

5. **Turn-over**: When a vehicle taking sharp turns and centrifugal forces produced resisted by normal surface friction caused the vehicle to roll as shown in Figure 1.6.

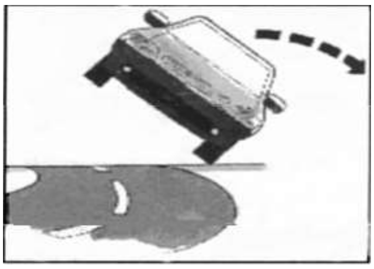

Figure 1.6 : Vehicle turn-over due to centrifugal force resisted by normal surface friction

6. **Collision with another vehicle**: When a vehicle roll immediately after hit or hit by another vehicle

7. **Climb-over**: When a vehicle pass over a high fixed object such as barrier or guardrails and that object is high enough to lift the vehicle off the ground as shown in Figure 1.7.

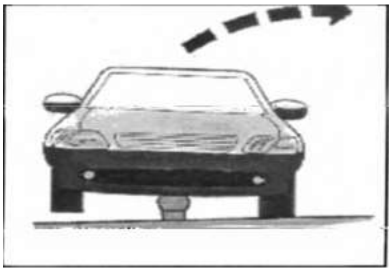

Figure 1.7 : Vehicle climbs over a fixed object

8. **End-over-end**: When a vehicle rolls about its lateral axis. Sometimes happen when vehicle apply sudden break and load transfer to the front. Figure 1.8 illustrates the vehicle rolls on its axis.

Figure 1.8 : Vehicle rolls on its lateral axis

1.1.3 Main Occupants Injury Mechanism due to rollover.

Four main injuries during rollover that may endanger the occupants are listed as follows [5]:

1. Intrusion: Happen if bus superstructure cannot withstand impact from rollover accident and then having large deformation. Consequently, structures infringe into residual space and contact with the occupant's body.

2. Projection: It is due to the rapid kinematic movement of the occupants inside the bus that hit structural parts inside bus compartment.

3. Partial Ejection: This type of mechanism happens when an occupant's body part such as leg, arms or head is partially eject outside bus superstructure frame.

4. Complete Ejection: It is almost the same with partial ejection but the difference is instead of the occupant's body partially ejected, from this mechanism, occupant's body fully ejected from the bus superstructure through the opening like window and door.

1.1.4 Bus Accident Cases in Malaysia

Recently, numbers of bus accident case occurred in Malaysia keep increasing from time to time. The worst bus accident case was recorded until now occurred on 21st August 2013 at 2.15 P.M. The accident which took place near Chin Swee Temple, Genting Highlands Pahang involving fatality of 37 passengers and 16 others were injured. The bus carrying 53 passengers lost control as it was going down an incline and it plunged into a deep ravine at about 60 meters at the kilometer 3.5 of the Genting Sempah – Genting Highlands Highway. The bus driver died on the spot. Figure 1.9 illustrates the bus superstructure after rollover happened.

Figure 1.9 : Bus Superstructure after having a rollover accident in Genting Highlands

On the other events, on 20th December 2010, one of the worst accident cases happen involving 27 dead, mostly Thai tourists. This tragedy occurred at Cameron Highland when the bus was lost control as going down the road and hit the middle divider subsequently landed on the other side of the road. Then, the bus was rollover and roof of the bus was ripped off as shown in Figure 1.10.

Figure 1.10 : Bus Superstructure after having a rollover accident in Cameron

The other accident that involving a high number of fatalities was happened on 14th August 2007 involving 22 passenger fatality and injury of 7 passengers. It takes place at km 229, North-South Plus Highway near Bukit Gantang around 4.45 a.m. The bus superstructure was plunge into a ravine and its roof was ripped off as shown in Figure 1.11.

Figure 1.11 : Bus Superstructure Having Rollover Accident at Bukit Gantang

Based on rollover scenario, the strength of roof and superstructure play an important role to protect occupant from any harm. Therefore, the bus manufacturers need to ensure their bus provide high level of safety before operating on the road and the authority need to enforce the law to elude weak bus superstructure from operating on the road.

1.2 Statement of Problem

Malaysia has experienced a dramatic growth in the number of fatalities in bus rollover accident case. In 2007, one dramatic bus rollover crash involving fatality of 22 passengers that took place near Bukit Berapit, Bukit Gantang. Since then, most of Malaysian much more concern for bus superstructure safety. This accident shows that bus superstructure needs to be strong enough to withstand rollover impact and provide better survival space for occupants. Adequate design and sufficient strength of bus superstructure can reduce the number of injuries and fatalities.

Given the situation, it is time to takes serious effort in studying factors that can give extra strength to bus superstructure related to bus design and the needs of safety belts as passive safety feature to avoid occupant's projection movement and ejection from bus superstructure.

In order to fully lessen occupant injury, diving hypothesis need to be investigated. Thus, in this research, the relationship between belt and unbelted passenger was studied to observe the injury on human dummy model.

1.3 Objective of the Study

The objectives of this study are:

1. To investigate the performance of various designs of bus superstructure during a rollover accident.
2. To study a numerical simulation of occupant kinematics and interaction with the interior bus features during rollover.
3. To make recommendation on the safe superstructure design.

1.4 Scope of the Study

On the issue of bus superstructure rollover and its effect on occupant kinematics, the following activities have to be carried out in order to achieve the objectives of the research:

1. Simulation of simple box: It includes the simulation of simple frame using finite element analysis software to check the reliability and acceptability of results from simulation. The results were compared with simple box experiment.
2. Simulation of full-scale bus frame: It includes the simulation of bus frame using finite element analysis software to observe the effects of impact due to the rollover.
3. Simulation of occupants inside bus interior: Simulation of human dummy model using Mathematical Dynamic Model software to observe the effect of restraint system on occupant injury.
4. To give recommendations on the possible and relevant improvement in the design of Malaysia bus frame to enhance the strength of superstructure.

1.5 Research Question

1. What are the effects of different design of the bus superstructure on bus rollover?
2. What are the interactions between occupant and bus interior when rollover happened?
3. What are factors that can improve superstructure strength and reduce injury to occupants?

1.6 Significance of the Study

From this research, the design specification of bus superstructure was identified which has the potential to improve current bus superstructure strength. In addition, the utilization of restraint system has significantly reduced the injury on occupants having rollover accident.

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