A STUDY ON MALAYSIAN ROADSIDE SAFETY ADOPTING SAFETY RECOVERY ZONE CORRIDOR CONCEPT

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DOCTOR OF PHILOSOPHY

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ABSTRAK

Kemalangan kenderaan disebabkan oleh halangan-halangan di tepi jalan seperti pokok, tiang utiliti, parit konkrit dan pembentung, tebing, papan tanda dan pengadang tepi jalan merupakan penyumbang besar kepada berlakunya kematian dan kecederaan yang parah kepada individu dalam kenderaan. Keadaan menjadi lebih serius apabila kenderaan yang terbabas tidak dapat dikawal akibat rekabentuk geometri tepi jalan yang kurangnya ciri-ciri keselamatan. Rekabentuk piawai jalan yang lemah adalah antara penyumbang kepada kemalangan maut dan kecederaan parah kerana rekabentuk piawai merupakan perkara asas kepada kerja-kerja rekabentuk dan pembinaan. Setelah menyedari bahayanya objek penghalang di tepi jalan, konsep zon keselamatan perlu diwujudkan bagi membendung ancaman tersebut. Ketiadaan piawai zon keselamatan di tepi jalan telah mendorong usaha ujian kereta dijalankan di lapangan bagi menentukan saiz zon keselamatan di tepi jalan mengikut kesesuaian dengan kelajuan dan kecerunan tebing untuk kegunaan jurutera rekabentuk dan teknolojis dalam kerja-kerja merekabentuk jalan raya. Penilaian dan pengesyoran akan dibuat terhadap garis panduan semasa bagi rekabentuk kerja lanskap di rizab jalan Malaysia bagi mengenalpasti bahagian yang bercanggah dengan konsep zon keselamatan untuk pindaan pada masa akan datang. Kajian kes bahaya di tepi jalan raya di Malaysia juga dilaksanakan bagi mengenalpasti tahap masalah pembinaan sedia ada dan seterusnya mengemukakan cadangan penambahbaikan dari segi rekabentuk. Ujian sebenar di lapangan telah dijalankan bagi menentukan ukuran lebar zon keselamatan di tepi jalan yang bersesuaian dengan kecerunan tepi jalan raya di Malaysia. Sepuluh lokasi telah dipilih daripada empat buah negeri iaitu di Pahang, Johor, Selangor dan Perak yang mempunyai jalan raya dengan pelbagai kecerunan tebing jalan dan keadaan permukaan yang berbeza. Sampel lokasi ujian bagi 4 buah negeri ini adalah mewakili 30% daripada 13 buah negeri di Malaysia. Ujian yang lengkap dengan kawalan keselamatan telah dijalankan oleh 4 orang pemandu yang sihat tubuh badan dan berlesen dalam lingkungan umur 20 hingga 24 tahun. Empat buah kereta yang telah dipilih bagi ujian di lapangan dengan kapasiti enjin antara 1.3 sehingga 2.3 liter silinder adalah Proton Saga FLX 1.3, Honda City 1.5, Mazda 3 2.0 and Ford Escape XLS 2.3. Semua kereta yang diuji adalah kurang daripada 10 tahun jangka hayat dan prestasinya dalam keadaan baik. Ujian telah dijalankan dengan pemanduan pada kelajuan yang dikehendaki, dan kemudian tersasar daripada laluan perjalanan melalui garisan berwarna merah yang dicat pada jalan yang dianggap sebagai *vehicle's exit angles*, dan seterusnya pemanduan kembali semula ke laluan perjalanan asal. Ujian pemanduan diulang hanya sebanyak 5 kali sahaja untuk setiap kelajuan perjalanan yang telah dipilih kerana pengulangan ujian yang seterusnya mungkin boleh merosakkan permukaan tanah dan menjejaskan ketepatan keputusan ujian. Kajian menunjukkan bahawa lebar zon keselamatan di tepi jalan raya yang diukur selari dengan laluan perjalanan adalah meningkat apabila meningkatnya kecerunan tebing tepi jalan dan tahap kelajuan perjalanan. Bergantung kepada jenis rekabentuk jalan dan kecerunan tepi jalan, lebar zon keselamatan di tepi jalan yang minimum bagi jalan luar bandar adalah di antara 1.64 hingga 8.07 meter untuk kelajuan kenderaan antara 50 km/jam sehingga 110 km/jam. Manakala, lebar zon keselamatan di tepi jalan yang minimum bagi rekabentuk jalan di bandar pula adalah di antara 1.64 hingga 6.82 meter untuk kelajuan kenderaan antara 50 km/jam sehingga 100 km/jam. Kesimpulan daripada kajian ini jelas menunjukkan bahawa keperluan zon keselamatan di tepi jalan raya masih belum diambilkira dalam piawai rekabentuk Malaysia bagi mengurangkan kadar kemalangan maut dan kecederaan parah.

ABSTRACT

Run-off-road vehicle collisions with roadside obstructions such as trees, utility poles, concrete drains and culverts, roadside slopes and signboard pillar and roadside barriers known as hazards have contributed to a large proportion of fatalities and severe injuries to the vehicle occupants. The unforgiving design of roadside geometry had multiplied the issue when the skidding vehicles were unable to traverse to safety. The mistakes unfriendly design policy has been causing fatal accidents and severe injuries because it forms the basis for engineering design and construction works. Introducing the concept of safety recovery zone corridor will ensure the roadside is free of obstructions or hazards, an environment forgiving to skidding errant vehicles. This missing chapter has inspired this research work by carrying out live field experiments to determine the widths of roadside safety recovery zone corridors for the various vehicle travelling speeds and roadside gradients for the use of engineers in the road and highway design. The research discovered that the current Malaysian landscape design guide permits the planting of trees classified as hazard within the safety recovery zone corridor, a clause conflicting to the forgiving design concept, and has been identified for adjustment. A case study was carried out to Malaysian roadside hazards to reveal the depth of the existing construction problems, demonstrated some examples of practical design improvement. The research process included live field experiments in determining the relationship between widths of roadside safety recovery zone corridor against the various roadside slopes for a set of vehicles design speeds specified in the Malaysian design guide. The study selected ten driving test fields from four states, namely Pahang, Johor, Selangor, and Perak of Malaysia, with a variety of roadside slope gradients and ground surface conditions. The sampling of 4 states represents 30% of 13 states of Malaysia. Four fit and fully licensed drivers aged between 20 to 24 years safely executed the field driving tests. The selected four cars for field testing works ranging from 1.3 to 2.3 litres cylinder capacities were namely Saga FLX 1.3, Honda City 1.5, Mazda3 2.0 and Ford Escape XLS 2.3. All the cars were less than ten years old and in good working condition. The tests were carried out by driving the vehicle at the desired speed, and then skidding off the travel lane through the marked red line of vehicle's exit angles painted on the road, and then traversing back to the travel lane. The driving test was repeated five times for each selected travelling speed, as further repetition may damage the ground surface and impair experiment's result. The study showed that the widths of safety recovery zone corridor measured perpendicular from travel lane increase with the increase of the roadside slope gradients and the vehicle travelling speeds. Depending on the road design types and roadside gradients, the discovered minimum width of safety recovery zone corridor for rural roads is ranging between 1.64 to 8.07 meters for vehicle speeds between 50 km/h to 110 km/h. On the other hand, the discovered minimum width of safety recovery zone corridor for the urban roads is ranging between 1.64 to 6.82 meters for vehicle speeds between 50 km/h to 100 km/h. The outcome of this study proved the necessity to fill the gap in the design chapter with safety recovery zone corridor concept in Malaysian standard to reduce road traffic fatalities and severe injuries.

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θ	Vehicle exit angle from travel lane into roadside
P	Cumulative percentage of accident
S	Roadside slope gradient
V	Vehicle travelling speed
Z	Safety recovery zone corridor width
R^2	Statistical measure that's used to assess the goodness of fit of our regression model

LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
AASHTO RDG	American Association of State Highway and Transportation Officials Roadside Design Guide
CEDR	Conference of European Directors of Roads
ECMT	European Conference of Ministers of Transport
FARS	Fatality Analysis Reporting System
FRDG	Forgiving Roadside Design Guide
GSLDTB	Guide for Selecting, Locating, and Designing Traffic Barriers
IRTAD	International Road Traffic and Accident Database
JKJR	Jabatan Keselamatan Jalan Raya
JKR	Jabatan Kerja Raya
MIROS	Malaysian Institute of Road Safety Research
PJKJR	Pelan Keselamatan Jalan Raya Malaysia
PRT	Perception Reaction Time
REAM	Road Engineering Association of Malaysia
RISER	Roadside Infrastructure for Safer European Roads
ROR	Run Off Road
SBPWM	Simple Boost Pulse Width Modulation
SVA	Single Vehicle Accidents
UNGA	United Nations General Assembly

CHAPTER 1

INTRODUCTION

1.1 Overview

Road accident has been one of the highest health hazards in the world. Many parties are putting efforts to improve road design guidelines to minimise road fatalities. On 11 May 2010, the United Nations General Assembly announced that the period 2011 - 2020 as the decade of action for road safety to reduce traffic fatalities around the world through networking at national, regional and global levels (UNGA, 2011).

The United Nations registered ten reasons to act on road deaths are each year nearly 1.3 million people killed on the world's road, estimated 50 million people are injured and disabled for life, developing countries contribute 90% casualties, the forecast shows by 2020 annual road traffic death is reaching 1.9 million, leading cause of young people death worldwide is road traffic injuries, children age above five years in developing countries by 2015 is expecting to suffer health problem associated with road traffic injuries, the developing countries are expected to carry economic cost of US$100 billion a year, hospitals and health systems are facing a heavy responsibility on road traffic injuries, avoid road crashes, and implementing practical measures globally will save millions of lives.

Everyday 3,500 road users killed and 137,000 injured due to road accidents throughout the world (PJKJR, 2014). In the year of 2013, Malaysia recorded 477,204 road accidents, 6,915 people killed, giving an average of 19 people killed every day, more than 12,000 road user injuries of which 4,000 serious injuries with estimated loss close to RM 9.0 billion. Realising the importance of road safety, Department of Road Safety under

Ministry of Transportation Malaysia in collaboration with Malaysian Institute of Road Safety Research issued Malaysian Road Safety Plan 2014 - 2020. The five safety plan pillars are road safety management, safer roads and mobility, safer vehicles, safer road user, and post-crash response. The study was initiated from the first Global Ministerial Conference on Road Safety in Moscow on 19 and 20 November 2009.

Table 1.1 shows the general road accident data in Malaysia from the year 1997 to the year 2016 published by the Malaysian Institute of Road Safety Research (MIROS, 2019). In the year 2016, the Malaysian Institute of Road Safety Research reported 521,466 road crashes and 7,152 road deaths, giving a rate of about 20 people killed every day. The predicted for the year 2020 will increase to 10,716 (Rohayu et al., 2012). Run-off-road accidents involve a single vehicle for the years 2007 through 2010 showed a significant proportion (Ahmad Noor Syukri ZA et al., 2012).

Three elements in road safety concept are infrastructure design, vehicle design, and driver's education. This thesis covers only one of the above concepts i.e., on infrastructure design. Roadway infrastructure design generally involves the design of travel way and roadside. The design process involves both structural and geometric requirements. The structural design focuses on the strength and durability of the elements, while the geometric design addresses configuration and space to satisfy intended functions, of which safety is part of them.

The increasing number of run-off-road (ROR) or also known as single-vehicle-accidents (SVA) has driven institutions to study and introduce roadside geometric design guidelines to reduce the number of fatalities and severe injuries. Providing the right configuration, dimensions of a roadside slope cross-section and right environments would allow travel lane motorists who have strayed off the travel lane an opportunity to take a safe way of traversing back into driving lanes. It is a very positive measure to reduce run-off-road fatal accidents or severe injuries.

The term roadside defines an area beyond the travel lane, as illustrated in Figure 1.1 (FRDG, 2012). Its geometric design refers to establishing the configuration, dimensions, and gradient of the roadside infrastructure's cross-sections to meet design objectives. The width of safety recovery zone corridor is measured perpendicularly away toward roadside from the marginal strip (a white painted line beside a travel lane) or edge of the travel lane (where the marginal strip is not applicable).

Table 1.1 General road accident data in Malaysia from the year 1997 to the year 2016

Year	Registered Vehicles	Population	Road Crashes	Road Deaths	Serious Injury	Slight Injury	Index per 10,000 vehicles	Index per 100,000 population	Index per billion VKT
1997	8,550,469.00	21,665,600.00	215,632.00	6,302.00	14,105.00	36,167.00	7.37	29.10	33.57
1998	9,141,357.00	22,179,500.00	211,037.00	5,740.00	12,068.00	37,896.00	6.28	25.80	28.75
1999	9,929,951.00	22,711,900.00	223,166.00	5,794.00	10.366.00	36,777.00	5.83	25.50	26.79
2000	10,598,804.00	23,263,600.00	250,429.00	6,035.00	9,790.00	34,375.00	5.69	26.00	26.25
2001	11,302,545.00	23,795,300.00	265,175.00	5,849.00	8.680.00	35,944.00	5.17	25.10	23.93
2002	12,068,144.00	24,526,500.00	279,711.00	5,891.00	8,425.00	35,236.00	4.90	25.30	22.71
2003	12,819,248.00	25,048,300.00	298,653.00	6,286.00	9,040.00	37,415.00	4.90	25.10	22.77
2004	13,828,889.00	25,580,000.00	326,815.00	6,228.00	9,218.00	38,645.00	4.52	24.30	21.10
2005	15,026,660.00	26,130,000.00	328,264.00	6,200.0	9,395.00	31,417.00	4.18	23.70	19.58
2006	15,790,732.00	26,640,000.00	341,252.00	6,287.00	9,253.00	19,885.00	3.98	23.60	18.69
2007	16,813,943.00	27,170,000.00	363,319.00	6,282.00	9,273.00	18,444.00	3.74	23.10	17.60
2008	17,971,907.00	27,730,000.00	373,071.00	6,527.00	8,868.00	16,879.00	3.63	23.50	17.65
2009	19,016,782.00	28,310,000.00	397,330.00	6,745.00	8,849.00	15,823.00	3.55	23.80	17.27
2010	20,188,565.00	28,910,000.00	414,421.00	6,872.00	7,781.00	13,616.00	3.40	23.80	16.21
2011	21,401,269.00	29,000,000.00	449,040.00	6,877.00	6,328.00	12,365.00	3.21	23.70	14.68
2012	22,702,221.00	29,300,000.00	462,423.00	6,917.00	5,868.00	11,654.00	3.05	23.60	13.35
2013	23,819,256.00	29,947,600.00	477,204.00	6,915.00	4,597.00	8,388.00	2.90	23.10	12.19
2014	25,101,192.00	30,300,000.00	476,196.00	6,674.00	4,432.00	8,598.00	2.66	22.00	10.64
2015	26,301,952.00	31,190,000.00	489,606.00	6,706.00	4,120.00	7,432.00	2.55	21.50	9.60
2016	27,613,120.00	31,660,000.00	521,466.00	7,152.00	NA	NA	2.59	22.60	NA

Source: MIROS (2019)

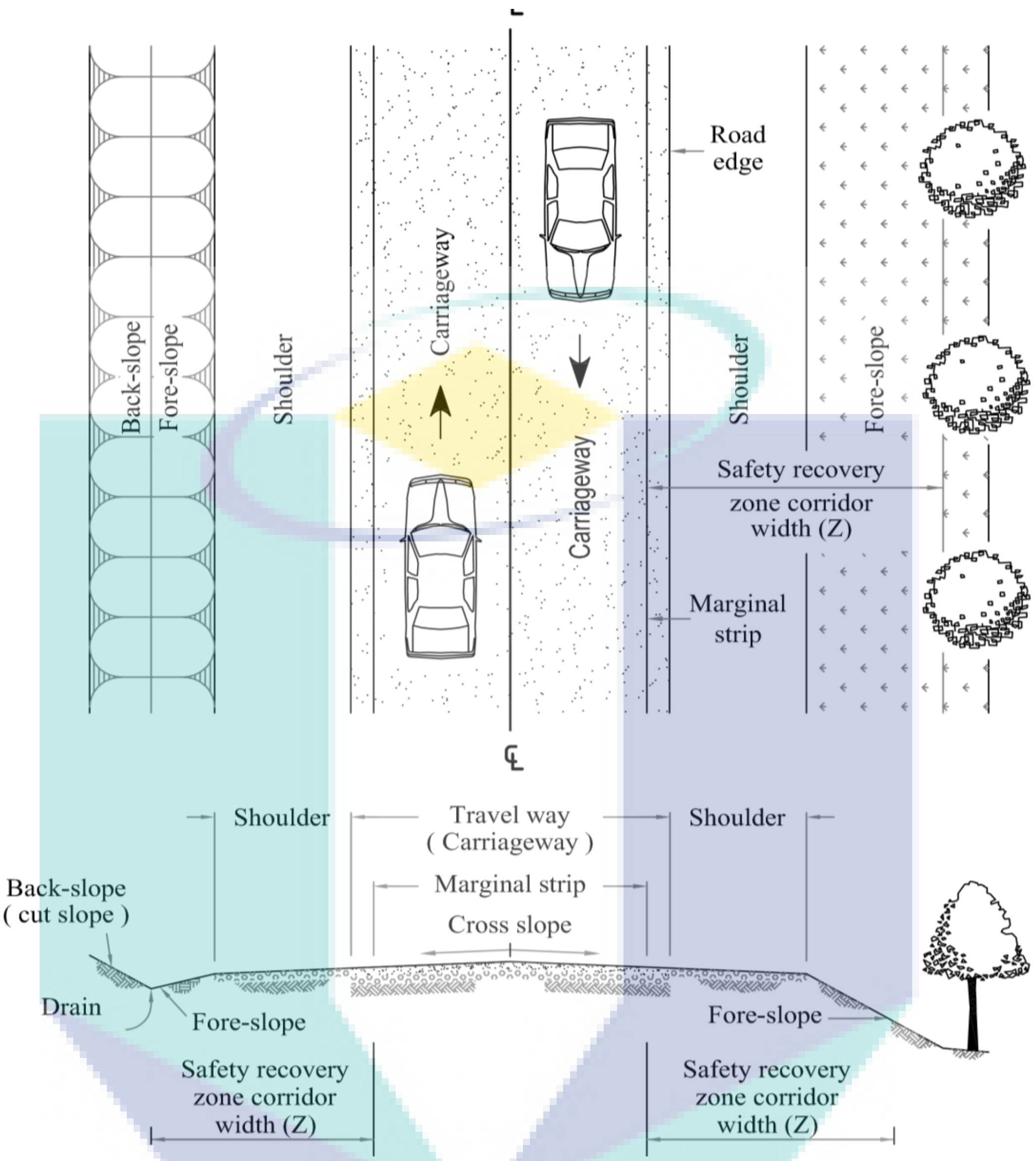


Figure 1.1 Roadway cross-section showing roadside safety recovery zone corridor

Source: FRDG (2012)

The geometric design for roadside safety recovery zone corridor is that once a vehicle encroaches the area, an errant driver could manoeuvre his vehicle to get back to the travel lane to save his life. Providing the safety recovery zone corridor to a roadside is achieving a forgiving roadside design concept. In realizing the safe get back to travel way, the roadside safety zone shall not contain any dangerous obstructions or hazards that will seriously injure or kill vehicle's passengers. The roadside geometric design for safety deals with treatments that are made to minimize the likelihood of severe injuries or death to the passengers when a vehicle runs off the road. It is hard to deduce the correlation between influencing factors and fatalities (Rohayu et al., 2012).

The sustainable roadway safety concept must be able to meet the present and future generation's requirements. Both United Nations and World Health Organisations declared injuries due to road collisions is an ongoing significant global issue demands governments, communities, businesses, and public to solve the global problems (Vicky, F.W. and Gord, L., 2012). China's run-off-road accidents account for half of the significant accidents involving three or more deaths (Fang, Y. and Guo, Z., 2013).

1.2 Problem Statements

Run-off-road vehicle collisions with roadside obstructions such as trees, utility poles, drain or culvert, hard surface slope, signboard pillar, and metal barrier contributed to a large proportion of fatalities and severe injuries to the vehicle occupants. The collisions informed that specific optimal size of corridor width of the roadside should be clear of hazards to avoid crashes. This call for a revised roadside design policy to specify the requirement of safety recovery zone corridor i.e., the clear zone roadside corridor from obstructions or hazards, and traversable by car roadside slopes. Currently, the Malaysian road design standards do not specify this requirement, which is a research gap and under the scope of this study.

An inquiry made to MIROS informed that the department did not register and kept accident statistics on the roadsides, instead the department data coverage was limited to travel lanes. Study in European Union countries reported that 42% of roadside crashes were fatal (Roque C. et al., 2015; NHTSA, 2014). Study in the United States reported that 23.1% of roadside crashes were fatal (AASHTO, 2011). Table 1.2 shows the number of deaths and their percentages caused by vehicles crashing into objects fixed on the roadside in the United States in 2013 (Insurance, 2013). Lack of the safety recovery zone corridor concept in the roadside design contributed to most of the accidents. In the absence of the safety recovery zone corridor chapter in Malaysian road design guidelines has lead local industry's practice to install structures on roadsides (herein classified as hazards) close to emergency lanes, and thereby causing crashes with skidding vehicles.

Table 1.2 Number and percentage of fixed object crash deaths by object struck, 2013 in US

Object Struck	Number	%
Tree	3,604	50
Utility pole	913	13
Traffic barrier	610	8
Embankment	397	5
Ditch	257	4
Culvert	237	3
Fence	178	2
Building	155	2
Bridge pier	140	2
Wall	136	2
Highway sign support	111	2
Other	501	7
Total	**7,239**	**100**

Source: Insurance (2013)

A study has shown that by flattening a roadside slope from 1V:2H to 1V:7H or more may reduce 27% of run-off-road crashes (Cheng, G., et al., 2019). The study suggested expediting risk analysis to improve the safety of highway roadsides. The survey projected that by the end of 2016, China's highway mileage to reach 4,696,300 km with roadside accidents reaching half of them.

Presence of trees within the safety recovery zone corridor is a significant hazard on the roadside. Lesson learned from past accident suggested road authorities place a crash cushion or metal roadside guardrail to a set of trees when their locations are near to the travel lane, as shown in Figure 1.2. The rationale behind the placement of metal guardrail because it offers less impacting force to vehicle compared to a tree. However, the use of metal guardrail itself is a hazard (MnDOT, 2011). This study aims removal of such trees or replanting them at the right place.

Figure 1.2. Roadside trees protected by guard rail at Lebuhraya Pantai Timur at Chenor Exit, Pahang

Utility poles for telephone and electrical cables, lighting, and signposts were installed at fringes of emergency lanes to ease installation and maintenance. Roadside accidents statistic has shown that their presence is a threat to skidding errant vehicles and has contributed to a high number of fatal crashes and serious injuries. The need to introduce the safety zone corridor concept in design policy to ensure correct placement of poles and posts is critical to traffic safety.

Urban areas use more kerbs than rural areas. Kerb is a concrete edging to a pavement or raised path to separate with the pedestrian pavement. Generally, kerbs are for drainage control, pavement edge support, and sidewalk separation. Poorly designed kerb is harmful to traffic and classified as a hazard. Walls are reinforced concrete or rubble pitching placed along the roadside for supporting earth embankment. Given their hard nature and producing a high impacting force on collision with vehicles, they are hazards. Chapter 4 case study discussed problems discovered on these objects.

Roadside barriers or guardrails are roadside safety system designed to prevent skidding errant vehicle straying into dangerous or off-limits areas. However, wrongly selected or installed roadside barrier can itself become a hazard. The case study carried out and discussed in Chapter 4 revealed cases where they became a hazard to traffic. Introducing safety zone as recommended in this study will eliminate or minimize the need of barrier to protect unnecessary hazards which applied in designed works.

Providing culverts and roadside drains are unavoidable for tropical countries like Malaysia due to her location in heavy rainfall areas. Roadside drains and culverts were installed to convey stormwater from road surface and roadbed to an outlet. The drainage systems were maintained by road or local authorities divided according to their locations. Malaysia being in the tropical region subject nearly half-year rain, the provision of a sound drainage system is essential. The choice of unsuitable drain type can be harmful to traffic and classified as a hazard. A case study carried out revealed that most of the constructed systems were not forgiving design to the skidding errant vehicles. Chapter 4 discussed some of the findings and proposed solutions.

Often run-off-road skidding vehicle unable to traverse back to travel lane for safety due to roadside slope gradient was steeper than 1V:4H, an inclination that is not traversable by any vehicle as quoted in American Roadside Design Guide (AASHTO, 2011). Current Malaysian roadside embankment design standard recommends roadside slope gradient ranging from 1V:2H for fill slope to 1V:1H for cut slope is not traversable by car and has caused skidding car to plunge and collide with roadside hazards. United States, Europe, and Australia are among countries practicing the forgiving roadside concept, which allows skidding vehicle to traverse the roadside slope to safety. It is time for Malaysia to adopt a similar practice to avoid roadside traffic fatal accidents and severe injuries by introducing safety recovery zone corridor policy. Therefore, this study aims to produce a safety recovery zone corridor table for various roadside slope gradients and the vehicle travelling speeds to save the life of skidding vehicles' passengers.

Currently, most of the Malaysian roadside structures have not been upgraded to the forgiving design concept and have contributed to fatal accidents and serious injuries. This study has evaluated some roadside structures in Kuantan and recommend feasible solutions. In determining the optimal widths for roadside safety recovery zone corridor, 180 live field experiments were carried out at varying travelling speeds and roadside slope gradients. The outcome of this study produced a relationship between widths of safety recovery zone corridor, the vehicle travelling speeds, and roadside slope gradients for engineers' application in future roadside design.

1.3 Research Questions

Research questions arise from the problem statements are:

1. What are the widths of safety recovery zone corridor for varying gradients of roadside slopes and vehicles travelling speeds to make roadside environment forgiving to skidding errant vehicles?

2. What is the reason behind trees has become a significant hazard on the roadside and what corrective action is required?

3. What can be done to existing roadside infrastructures design that is not forgiving to skidding errant vehicle which has led to fatal accidents and serious injuries?

1.4 Research Objectives

The modern concept of forgiving highway design is to provide a safer roadside geometry and environment for errant skidding vehicle and keeping the application of roadside barrier, which itself is a hazard only to areas where constructing a safety zone corridor is not practical. In achieving the new forgiving design concept, actions are to be taken through the following objective:

1. To determine the widths of roadside safety recovery zone corridor for the various vehicle travelling speeds and roadside slope gradients through live field experiments.

2. To evaluate the performance of current Malaysia's roadside landscape design guidelines known as "Intermediate Guidelines to Road Reserve Landscaping" based on the concept of forgiving roadside and suggest adjustment as appropriate.

3. To carry out a case study to validate research outcome on safety recovery zone corridor and demonstrate some samples of alternative designs following a forgiving roadside concept to the existing roadside problems.

1.5 Scope and Limitation of the Study

This study focussed on roadside safety for run-off-road errant skidding vehicles. In providing a roadside environment that is forgiving to the errant vehicles, research into roadside physical and geometrical hazards is essential. The physical hazards refer to objects that are installed on the roadsides while geometrical hazards are design flaws inherent in the infrastructure that can be seen by professionals familiar with the works.

The selected vehicle travelling speeds range from 50 km/h to 110 km/h in the step of 10 km/h. These are design speed limits range following the Road Engineering Association of Malaysia (REAM) standard known as A Guide on Geometric Design of Roads (REAM-GL 2, 2002). The standard covers the entire category of roads from road type R1 through R6 for rural roads and U1 through U6 for urban roads. R and U denote for rural and urban roads respectively.

Three main parts of the geometric design are alignment (route), profile (vertical contour), and cross-section. The scope in this study was limited to the roadway with straight alignment, horizontal profile, and skidding car traversable slope cross-section, i.e., 1V:4H or gentler. The current industry practice on curved roads is to apply roadside metal barrier due to difficulty of handling by errant skidding vehicles as observed from past accidents. Experimenting driving on the curved road is dangerous and not practicable due to difficulty in handling the car. Hence, only the straight road and horizontal profile is the basis of this study. However, the application of this study to a slightly curved road is permissible by applying the factor of safety to the research outcome on safety recovery zone corridor width. The magnitude of the safety factor shall vary depending on history rate of accidents to each location to the discretion by design engineers.

The typical roadway cross-section shows carriageways, emergency lanes, roadside slopes gradients, drainage and other structures complete with materials for surface formation. In line with roadside safety, area of study coverage was on roadside slopes gradients, drainage, and other structures, in particular, those classified as hazards. Roadside slope classified into two categories, namely fore-slope and back-slope. Roadside with fore-slope is having slope declining down from the outer edge of the emergency lane, which represents the majority of roadways. The back-slope roadsides formed from cut slope are rare and non-critical cases as they do not permit vehicles to skid over. Thus, the study was centred on fore-slope as it represents the majority of slopes, and execution of the field test is practicable.

The current industry practice on mountainous roads is to apply roadside barriers due to the construction of gentle traversable slopes are not practical and economy considering their high elevation. Thus, the study was limited to non-mountainous roads. However, one may apply the outcome of fore-slope roadside results in the back-slope application for buffer zone consideration.

The core of this study focussed on national road geometrical design policy which employs bituminous mixture coated road. Hence, only bituminous mixture coated road was covered in this study to keep in line with the current industry practice for roadway and highway. The village and agricultural roads with top coatings made of laterite and crusher run were not in the study.

This study excluded road median because of industry's practice applies metal barriers on both sides of the median to ensure non-crossing of traffic to the opposing lane.

Testing works executed with cars because Malaysian statistic from the year 2007 to 2010 reported that for passenger vehicles having fatalities with three and above and commercial vehicles with one fatality and above are dominated by cars with fatal accidents (Ahmad Noor Syukri ZA et al., 2012). Lorries, trailers, and motorcycles are not covered in the study because they are not dominant vehicles. Besides, these vehicles are not safe for field testing works because they are not stable in traversing on roadsides slopes. Hence, all field-testing works were carried out with cars.

A total of four states selected for the field experiments. Two states each from the west and east coasts of peninsular Malaysia. Field tests sampling rate of ten locations selected from four states, namely Pahang, Johor, Selangor, and Perak of Malaysia having various roadside slope gradients. The Malaysian road authority has never published on rural versus urban casualty crashes accounting percentage of run-off-road cases. Study in Australia and New Zealand reveals that rural versus urban casualty crashes are 57% and

18% respectively (Jurewics, C. et al., 2014). The statistic informed that casualty crashes in rural roads were more than three times in urban roads. Thus, testing on rural roads outcome representing the majority of accident cases. All field tests were carried out in rural roads due to density of traffics in urban roads are heavy, and the situation is not permissible. However, having the same design of roads will yield the same results. Besides, most areas in town centre roads were built with roadside kerbs to raise sidewalk pavement elevation for a safe pedestrian walk and made it impossible for driving test execution.

Four fit male drivers aged between 20 to 24 years with valid full driving lessons carried out the field tests. No female volunteer to be drivers because of the risk involved during testing work has discouraged them. Young drivers were chosen because a study has shown that they are the main contributor to road accidents. Collected data from 30 countries reveals that young drivers aged between 18 to 25 years represent the majority in road trauma statistics (Scagnolari, S. et al., 2015: IRTAD, 2012). Organization for Economic Co-operation and Development consisting of 34 countries, reported that about 8,500 young drivers (15-24 years old) killed each year is about double the older drivers.

The selected four cars for field testing works were ranging from 1.3 to 2.3 litres cylinder capacities were namely Saga FLX 1.3, Honda City 1.5, Mazda3 2.0 and Ford Escape XLS 2.3. All the cars were less than ten years made and in good working condition.

1.6 Significance of the Study

This study aimed to solve existing roadside problems causing skidding errant vehicles unable to recover to driving lanes due to an unforgiving environment. The unforgiving environment was due to obstructions along vehicles' travelled paths and unfriendly state of roadside engineering geometry and poor ground surface conditions causing drivers' poor handling ability. The identified problems discussed in the problem statement and research objectives were set out as countermeasures in solving the problems which will ultimately yield benefits discussed in the following sections.

The introduction of roadside safety recovery zone corridor in design policy will prohibit the future presence of hazards such as trees, utility poles, drain or culvert, hard surface slope, signboards pillar, metal barrier and the like in the safety zone. Once the safety zone corridor policy is adopted, a routine safety audit crew will identify these hazards and register them for removal. Thus, the study will prevent run-off-road vehicles from collisions with the hazards to save human life and avoid severe injuries to vehicle occupants. The adoption of this design policy is in line with the new roadside design concept of providing a forgiving roadside environment to forgive human error in driving.

The study will contribute to avoiding unnecessary losses of damaged properties such as trees, utility poles, drain or culvert, hard surface slope, signboards pillar, metal barrier and vehicles due to crashes between vehicles and the structures.

The elimination of roadside hazards and providing traversable roadside slope under the safety recovery zone corridor concept will enable skidding errant vehicles to manoeuvre back to travel lane. Under the forgiving environment, the driver is said to be having a second chance to correct his mistake by traversing his car to safety.

Every road design has to meet requirements in design standards before road authority approval for construction. Unforgiving design standard is the one causing a fatal accident and severe injuries. In correcting the problem at its source, an amendment to the existing design policy has to take place. Thus, this study fills the gap. Among critical issues were planting trees and installation of lighting and utility poles within the safety zone and existence of non-traversable roadside slope by skidding vehicles. Amendment to the design guidelines will avoid the recurrence of problems.

1.7 Thesis Organisation

Chapter 1, under the title "Introduction", the thesis started with an overview covering the development relating to study in other countries and followed by a recent study in Malaysia. The chapter outlined the 3-pillar concepts of road safety and informed the concept selected for this study i.e., infrastructure design. The chapter defines the roadside safety recovery zone corridor assisted with the diagram to ensure clarity of the terminology. Then, the chapter addresses a problem statement that briefly summarises issues that give rise to the study initiative. In the absence of Malaysian roadside accident statistics, statistics from other countries shared as the issue is global. The section states the problem of Malaysia's lacking design guides on the safety recovery zone corridor. Some typical cases were discussed to provide a better understanding of the issues. Based on the problem statements, the research questions outlined. In line with three research questions, three research objectives established. The section continued with the study and highlight the scope and study limitations, the significance of the study and finally on the thesis organisation.

Chapter 2 under the title "Literature Review", the section begins with an overview of the mode of discussion and highlight institutions referenced for the study. It starts with findings on the causes of run-off-road accidents. Subsequently, the section discusses various types of roadside hazards such as trees, poles and posts, kerbs and walls, roadside barriers, drains and culverts, and roadside safety recovery zone corridor. The section continues briefly discusses Malaysian landscape standard and road classification and design standards. Then, the chapter reports findings on the vehicle's exit angle based on past accident records, roadside shoulder, the status of Malaysian standard on roadside slope geometric design guide and breakaway features for sign supports, utility poles and other roadside features. The chapter continues with road safety auditing, roadside strip, and chapter summary. Finally, the literature review of chapter summarised and discussed.

Chapter 3, titled "Research Methodology", discusses the choice of research methods i.e. three methods adopted by the road research industry on roadside safety, and why the live experimental method was adopted. The chapter explains on field experimental study works from developing the concept, then followed by designing the method of experiment. The section discusses procedures in the selection of test sites, speeds, drivers, vehicles, and the vehicle's exit angle. Then, the chapter proceeds with test site preparation and result measurement. Finally, the chapter informs on selected sites for field experiments, data collection, regression analysis, the factor of safety, and summary.

Chapter 4 titles as "Result and Analysis". The chapter started by discussing the data collection and analysis of field results for all sites. The chapter reviews the safety of existing roadside structures against sound engineering practice and compliance with current Malaysia's guidelines where applicable. The section continues with case studies on existing roadside hazards, namely trees, poles and posts, drains and culverts, kerbs and walls and roadside barriers. Then, the section discussed the various types of solutions applicable to the cases.

Chapter 5 titles as "Conclusion and Recommendation". This chapter concludes on the outcome of the research on the safety recovery zone corridor and recommends the application to Malaysian roads. The chapter compares this study outcome with another study from the United States. It reported model equations for the relationship between the safety recovery zone corridor widths and roadside slopes for a various car travelling speeds. The section continues with a suggestion to the authority to make changes to the landscape design guide to improve the road safety environment. The study informs that the existing structures can be improved to a forgiving concept to minimise the rate of fatal accidents and serious injuries. Finally, it recommends an improvement for future study.

CHAPTER 2

LITERATURE REVIEW

The presentation of the following literature review begins with a discussion on the causes of run-off-road accidents and continues reporting findings of institutions and private studies on selected subjects. The four leading institutions referenced for this study are the American Association of State Highway and Transportation Officials (AASHTO), European Research Area Network, Austroads Limited (Australian standard) and Road Engineering Association of Malaysia (REAM). The design practice in Australia and New Zealand is a design guide published by Austroads an association of Australasian road transport and traffic agencies. All the institutions aim to provide expert technical input to national road and transport policy development, improving the practices and capability of road agencies, and promoting their operational consistency. Given the core area of this study is on design policy, frequent reference to the said design guidelines are inevitable. The American, European, and Australian standards are referenced in this study because they are authentic and in the English language.

A quote from Australia's guide to road design states "Adopting a safe system approach to road safety recognises that humans as road users are fallible and will continue to make mistakes, and that community should not penalise people with death or serious injury when they do make mistakes. In a safe system, therefore, roads (and vehicles) should be designed to reduce the incidence and severity of crashes when they inevitably occur" (AGRD, 2010).

The objective of the literature review is to find information related to this study on roadside safety. The kinds of literature sought are causes of run-off road accidents, objects categorised as roadside hazards, roadside barriers, forgiving drainage design, roadside safety recovery zone corridor, Malaysia design guideline related to trees as a significant hazard, Malaysian road classification and design standards parameters related to field testing requirement, road safety auditing, vehicle's exit angle required for field testing, roadside slope geometric design requirement affecting roadside safety, and road accessories features to improve roadside safety.

2.1 Causes of Run-Off-Road Accidents

Four factors that contribute to road accidents are human, road infrastructure, vehicle and weather condition. Some studies reported that 30% of the crashes were contributed by infrastructure factor (Camacho-Torregrosa, F.J. et al., 2013). Infrastructure factor is a factor contributed by the condition of the road and its roadside environment. Its critical contribution shown by the repeating crashes at the same segment of roadway. The highway infrastructure design involves geometrical and structural engineering for a roadway and roadside. This study focuses on improving geometrical and structural engineering of roadside in reducing fatal crashes and severe injury.

Lack of concentration while driving is critical for safety (Qu, W. et al., 2015). Distraction has a significant impact on driving safety (Chen, Z. et al., 2015). Distraction due to multitasking, such as the use of mobile phone while driving, is among the prevalent causes of accidents (Saifuzzaman, M. et al., 2015). The recent experiments on 241 drivers driving for 43,000 hours while using mobile phones showed an increased number of crashes as compared to other distractions. The quality of sleep governs biological-related alertness (Darwent, D. et al., 2015).

Fatigue leads to lack of concentration during driving and partly contributed by insufficient sleep (Darwent, D. et al., 2015). Several studies have reported that fatigue could lead to either short-term risk as in the case of safety or long-term risk as in physical and psychological health (Dawson, D. et al., 2011). It is estimated that fatigue contributed to 20% of road vehicle crashes (Noya, Y.I. et al., 2011).

Ageing increases the level of crash risk because of decreasing in cognitive, visual and physical ability (Jessica, B. C., 2015). Senior drivers are more likely to suffer from severe injuries and fatal accidents than younger drivers (Jessica, B. C., 2015; Kahane, C.J., 2013). Older drivers i.e. aged 65 years and above, generally encounter driving difficulty mainly because of weak physical condition, especially in unsecured urban roads (Yeung, J.S. et al., 2015).

Driver's experience influences the probability of an accident, daily travelled distance and driving patterns (Ayuso, M. et al., 2014). Reacting timely and correctly when confronting hazards is crucial, particularly in an urban area (Yeung, J.S. et al., 2015).

Conclusion

Studies reflected from the section informs that infrastructure factor contributed 30% of crashes. Therefore, providing right roadside infrastructural design through implementing safety recovery zone corridor concept will reduce part of the percentage. Providing roadside rest area for drivers may minimise crash factors such as lack of concentration, fatigue and ageing.

2.2 Roadside Hazards

It has been a continuous effort in collecting facts on accidents, evaluating them and recommending measures to prevent road accidents or minimise damages (Dupont, E. et al., 2010). The United States recorded in 2008, 23.1% of the fatal crashes were single-vehicle run-off-road crashes, a considerable margin that cannot be ignored (AASHTO, 2011). Run-off-road crashes in the United States were more than 95% due to errant drivers, a combination of factors of inattention, fatigue, and rushing (Liu, C. and Ye, T.J., 2011).

Figure 2.1 shows the number of deaths and their percentages caused by vehicles crashing into objects fixed on the roadside in the United States in 2013 (Insurance, 2013). A forgiving roadside design may not reduce the number of accidents considerably, but it will minimise the crash severity and fatality substantially (Francesca La Torre et al., 2012).

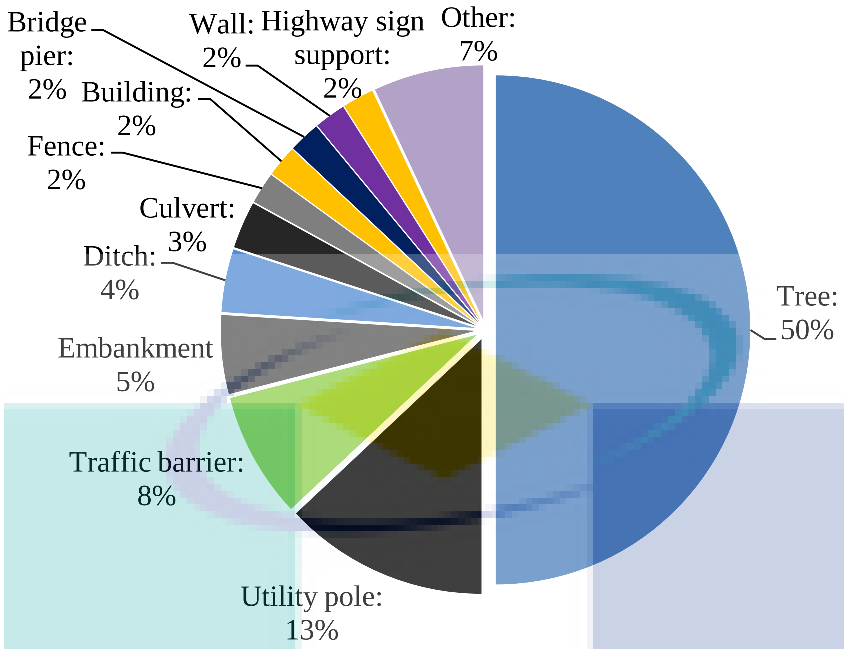


Figure 2.1 Percentage of fixed object crash deaths by object struck, 2013 in US

Source: Insurance (2013)

Europe, each year, about 43,000 victims fatally injured (FRDG, 2012). From 2001 to 2010, European Union recorded that 32% of crashes were single-vehicles (Roque C. et al., 2015), and 42% of single-vehicle off-road were fatal crashes (Roque C. et al., 2015; NHTSA, 2014). Managing roadside hazards to provide a forgiving environment to the vehicle's occupants is a safe system (Jurewics, C. et al., 2014).

Based on Conference of European Directors of Roads report titled as "Forgiving Roadsides Design Guide" issued in November 2012 (CEDR, 2012), initiatives have been carried out by the European Union countries to provide some design guidelines to improve roadside safety. In the executive summary section "Analysis of fatal road accidents in the European Union shows that 45% are single-vehicle accidents. These accidents are primarily run-off-road accidents. A roadside is unforgiving if hazardous objects such as trees are placed at an inappropriate distance from the road so that the risk of severe accidents increased. The purpose of the forgiving roadside concept is to avoid crashes of errant vehicles with potential hazards or to minimise crash consequences". The quoted section shows that the European Union has embarked on the practice of "forgiving roadside" concept.

The Australian design guide classifies embankments and cuttings, roadside objects such as trees and poles, culvert ends, non-traversable open drains, bodies of water, road safety barriers and oncoming traffic as hazards. Fixed objects on the roadside and gradient of roadsides influence crash rates and severity of accidents (Donald, C.W. et al., 2014). The study showed that roadside without fixed objects exhibited lower crash rates compared to sites with fixed objects. Higher crash frequencies were at horizontal curves despite at flat ground. The study suggested that curved roads shall be with slower speed compared to straight roads. Among the main contributors to the accident are roadside unpaved and undersized road shoulders.

Conclusion

The classification of hazards between the United States, Europe, Australia and Malaysia are about the same. The Australian guidelines have added bodies of water and oncoming traffic as additional hazards for consideration in design works. The hazards remain the area of concern addressed in all the design guidelines of the countries. Managing hazards is managing road safety, minimising their presence in safety recovery zone corridor is increasing road safety.

2.3 Trees

Trees can either manually or naturally grow on roadsides in most countries. Trees are planted to beautify the roadside area, minimise erosion, reduce dust particle and noise pollution. Trees are the most prevalent hazards on roadways in the world, as evidenced through many studies. However, trees, when located beyond the roadside safety recovery zone corridor, are not regarded as hazards. Certain species of trees with plenty of leaves are planted outside the safety zone to serve for noise and other environmental purposes.

Run-off-road crashes into trees represents more than 50% of fixed object crash deaths by object struct in the United States in 2013 (Insurance, 2013). In the United States, each state highway agencies develops own guideline for design, landscaping, construction, and personnel training for maintaining their properties. In general, an existing tree with a projected mature size of 100 mm or more at stub height (stub height is the bottom portion of tree stem height) is classified as hazardous fixed object and should be removed for new construction and reconstruction (AASHTO, 2011). For the purpose of reducing the number and level of severity for run-off-road crashes, America's standard recommends the application of Table 2.1.

Table 2.1 Objective and strategies for reducing crashes with trees

	Objective		Strategies
A.	Prevent trees from growing in hazardous locations.	A1	Develop, revise, and implement planting guidelines to prevent placing trees in hazardous location.
		A2	Develop mowing and vegetation control guidelines.
B.	Eliminate the hazardous condition and/or reduce the severity of the crash.	B1	Remove trees in hazardous locations.
		B2	Shield motorist from striking trees.
		B3	Modify roadside clear zone in the vicinity of tress.
		B4	Delineate trees in hazardous locations

Source: American Standard, AASHTO (2011)

Two methods in approaching roadside trees problem are firstly keeping the motorist on the road and secondly mitigate the danger inherent on crash impact with the tree (AASHTO, 2011). The first method of keeping motorist on the roadway is by pavement markings on the centreline, and edge line is an effective and least costly, particularly for night time and lack of vision driving. The rumble strip is a series of raised strips along road edges which changes the noise of tyres intended to awaken vehicle driver. The shoulder rumble strips may warn the skidding motorist that they are leaving the roadway.

The delineators are light-reflecting devices placed alongside a road to inform traffic on changing alignment. Installing warning signs and roadway delineators may alert motorists for extra caution on the incoming high-risk area in particular sharp turning curves (AASHTO, 2011). The design guide recommends roadway improvements such as increasing super elevation, shoulder widening, and paving may reduce crashes though not cost-effective in all cases.

The second method of approaching roadside trees is by either tree removal or shielding (AASHTO, 2011). The removal option is when a particular tree is an obstruction and located at likely to be hit. Such trees often recognised from past histories and scars on the stem indicating previous crashes. An isolated tree located close to the roadway shall be removed. Provide a well-designed barrier when a tree or a group of trees located in a vulnerable location if severity striking the tree is greater than striking the barrier.

A study based on 265,000 run-off-road cases from seven European countries namely Austria, Finland, France, the Netherlands, Spain, Sweden and the United Kingdom revealed that 67% were hitting objects cases (CEDR, 2012). Crashes on drains were 11.1% of which 17 fatal, 39 serious injured and 44 with slight injuries. The study reported that trees are the most dangerous roadside objects, and 17% of trees associated accidents were fatal and mostly involved with impact speeds of 70 km/h and above (CEDR, 2012). The text quoted that the U.S. Department of Transportation's Fatality Analysis Reporting System (FARS) study on the fixed object crash deaths in 2008 shows that trees represent the highest percentage of 48%. Old and established trees which are not permitted to be removed or relocated to be treated to ensure safety to crashing motorists and vehicles on.

Austroads publish the design guidelines for practice in Australia and New Zealand. The guideline considers trees having diameter bigger than 70 to 100 mm (depending on the species) and located close to travel lanes are classified as hazards, unless if they are beyond the deflection area of a safety barrier (AGRD, 2010). It includes tree stumps projecting over 100 mm above ground level. The design guide does not allow planting of trees, instead, if naturally grown tree bigger than 70 to 100 mm diameter (depending on the species) nearby to travel lane is a hazard and to be removed.

Conclusion

The statistic in the United States, Europe, Australia and New Zealand above are evidence that trees are significant roadside hazards and focal areas in their design guidelines. Despite no statistic currently published for Malaysia, these four countries statistics are indirectly supporting the problem statement claimed in this study.

The American roadside design guideline issued standing instruction for state transportation agencies to "develop, revise, and implement planting guidelines to prevent placing trees in hazardous location" (named in this study as to safety recovery zone corridor). In an existing situation where removal of trees is possible, the policy allows eliminating hazardous condition by shielding to reduce the severity of the crash. Hence, the American roadside design guide is in support of the aim of this study. Trees as a hazard were in the case study discussed in Chapter 4. The American roadside design guide proposed additional preventive measures from vehicles encroaching into roadside by providing pavement marking, rumble strips, signs, delineators, and roadway improvements. These preventive measures partly adopted in some places in Malaysia. In the case study exercise in Chapter 4, assessment on the application of preventive measures evaluated.

2.4 Poles and Posts

Generally, poles and posts are structures in round, hexagon or square forms made of steel, concrete or timber for carrying electricity cable with or without lamp, and telephone wires. They include gantry poles; high mast lighting columns and sign supports. Poles are long and slender structures, whilst posts are short structure.

The poles are designed with sufficient strength to withstand lateral wind and cable forces. The pole high structural strength and the small collision contact are causing severe crash (Esawey, M.E., and Sayed, T., 2012). In the year of 2009, USA reported 738 fatal collisions were associated with utility poles representing 5% of run-off-road fatalities.

Run-off-road crashes with utility pole represents about 13% of fixed object crash deaths by object struct in the year of 2013 (Insurance, 2013). The rate of crashes is associated with the number of poles and posts in use, their proximity to the travelling lane, and their impact on non-absorbing nature. The American's practice recommends sign and luminaire supports to be relocated away from possible crash areas. In addition, power and telephone cables are to be buried where possible to overcome from being obstacles to the traffics (AASHTO, 2011).

A European study reported that due to structural strength of utility and other support structures and small contact areas between the structures and vehicles have contributed 40% to fatal crashes or serious injuries (CEDR, 2012). The study reported that road designers' approach to protecting roadside obstacles is not necessarily the most forgiving solution. The investment could be very costly compared to the benefit returned. The moment a hazard is identified, its distance from travel lane to be measured and check against the clearance width recommended by the safety zone schedule specific to the roadside slope and design speed. If the obstruction is outside the range of safety zone, it does not hazard.

Australian new National Road Safety Action Plan 2015-17 was developed jointly by federal, state and territory transport agencies intended to improve road safety. Among actions is to mandate standard on pole side-impact to occupant protection for new vehicles (DIRD, 2015). Generally, poles and posts are hazardous objects, unless if their placement is beyond the deflection area of a safety barrier (AGRD03, 2016). The poles with slip-base (pole break away upon vehicle impact) type and frangible (pole deform upon vehicle impact) posts are non-hazardous objects in the design guide (AGRD, 2010). Traffic signal posts at urban intersections having thin wall are non-hazardous. Even though these objects may not be hazardous to vehicle occupants, but they are hazardous to motorcyclists, they are to be minimised and designed to unconditional forgiveness.

The Malaysian practice requirement on lighting and signage for roadwork is in the guide for the geometric design of roads (REAM-GL 2, 2002). For the safety of the road, the guide requires the provision of lighting to interchanges, intersections, railroad grade crossings, narrow or long bridges, tunnels and at roadsides having interferences. The requirement on exact offset distance of lighting and signage from carriageway is not in the guideline.

In keeping to a minimum cost of construction standpoint, the Malaysian industry's practice is to install lighting pole about one metre or less outside the road shoulder or emergency lane (REAM-GL 2, 2002). Hence, the pole is located about 2.5 to 4 metres from the carriageway depending on the width of the road shoulder. The shoulder widths for both rural and urban roads recommended by design standard depend on design type of the roads and ranging between 1.5 to 3 metres. There is no specific instruction to design engineer on keeping a clear distant for the pole from the travel lane has resulted in frequent crashes with skidding vehicle.

The Malaysian design guideline recommends placement for fixed objects such as lighting, and ground-mounted sign supports that cannot be away from the clear zone area should be made of a breakaway pole. Except where pedestrians and nearby traffics are of danger, all light and signs poles that can be struck by a vehicle should be of the type with slip-base to prevent injury to the vehicle passengers. Shielding by application of longitudinal barrier to the obstacle is the last step when eliminate, relocate and make the pole to be breakaway are not possible.

Conclusion

Statistic and studies in the United States, Europe, Australia and New Zealand, and Malaysia above are evidence that poles and posts are among significant roadside hazards, and addressed as part of their design guidelines. Keeping them outside roadside safety recovery zone corridor is a necessary action to improve roadside safety. All design guidelines are in a collective agreement that under the situation when relocation of the poles and posts are not possible, depending on the type of structures and site situation, they can be either fitted with a breakaway or slip-base system or shielding with a longitudinal barrier. In some industrial applications, barriers are of sandboxes. The above discussion confirmed that having poles and posts in safety recovery zone corridor are hazardous as claimed under this study problem statement. The above facts considered in the case study discussed in Chapter 4.

2.5 Kerbs and Walls

Roadside kerb and wall are raised edge of pavement to separate them from the road and typically made of concrete. American design guide recommends controlling roadway drainage, supporting pavement edge to prevent structural failure, delineation of traffic, aesthetic to the environment, separating the roadway from the sidewalk path and reducing maintenance works (AASHTO, 2011).

Two types of kerbs specified in the design guide are a vertical and sloping wall (AASHTO, 2011). The vertical kerbs design is with the traffic face nearly vertical with projection above the pavement of 150 mm, or more to prevent motorists from leaving the travel lane. The sloping kerbs with the traffic face height of 100 mm or less are traversable by the skidding motorists. Generally, traffic face higher than 100 mm irrespective of vertical or sloping kerbs may crash with the underside of specific vehicles. Kerbs installed on the roadway in the city beside the sidewalk intended to protect pedestrian from traffic is classified as not hazard, and no mitigation is necessary. Provision of obstructions (structures obstructing the free passage of skidding vehicle) at intersections and driveway openings, the design guide recommends a minimum lateral offset of 0.9 m beyond the face of kerbs. For other areas, a minimum offset of 0.5 m beyond the face of kerbs is recommended (AASHTO, 2011).

Australia's design guide classifies kerbs as hazardous objects if their shape and height do not suit vehicle travelling speed and affecting adjacent infrastructures (AGRD, 2010). Retaining walls are among non-frangible objects, and their classification by the guide as hazard depends on their type, height and lateral location from traffic. The wall surface and end condition have an impact on the degree of damage to errant vehicle occupants.

Incorrect use of kerbs can become hazards to roadside safety in particular to high-speed roads (CAREC, 2018). Use of kerbs are for low-speed roads, and low-profile kerbs are preferred. Applying kerbs close to barrier may result in the errant vehicle to jump and hit the barrier at an undesired level resulting in the non-performing system.

Conclusion

All the above studies reported that kerbs and walls are useful and yet are hazards if not placed correctly. Choice of the kerb's type and location for placement are significant factors for safety. This study included them as hazards in the problem statement and case study.

2.6 Roadside Barriers

Roadside barriers or guardrails is a roadside safety system designed to prevent vehicle straying into dangerous or off-limits areas. A properly designed and installed roadside barrier should reduce the impact and severity of injury (Road, 2010). Application of longitudinal barrier has been the main features for existing roadways, despite being hazard itself (Johnson, N.S. et al., 2015). The state of the art practice is to use modern hardware complying with stringent standard with proper end treatment to form a forgiving structure in reducing the severity of collision (MnDOT, 2011).

The Minnesota best practice and policies for safety strategies on the highway and local roads quotes "Guardrail is an obstacle and should be only considered when engineering judgement suggests that hitting the obstacle it protects would be worse" (MnDOT, 2011). Before installing a guardrail, analysing priorities in the order of object removal, object redesign, object relocation and object remain without shielding shall have taken place first.

Generally, the placement of roadside barriers is essential for a steep embankment or harmful roadside object (AASHTO, 2011). It is quite common that the roadside barrier is used to shield motorists from natural and human-made hazards. The manual recommends a further application to protect bystanders, pedestrians, and cyclists from vehicular traffic. The manual sets the barriers to performance standards and recommends selection and system design. The manual specifies guidelines that provide the methodology for assessing the existing barriers system for upgrading in enhancing their safety performance (AASHTO, 2017). Traffic barrier reduces the severity of potential crashes.

America's three categories of roadside barriers specified in the design guide are flexible, semi-rigid and or rigid (AASHTO, 2011). The guideline classifies them according to their deflection characteristics upon vehicle impact. It specifies a proprietary crash cushion system known as Cushion Wall II System, as shown in Figure 2.2 made of high molecular weight, high density polyethylene. The plastic cylinders are generally used for frequent lateral impacts location as in the case of sharp horizontal curves. The system consists of interconnected plastic cylinders that can be easily customised to requirements. The picture shows the system is protecting from high impact to the concrete wall placed at the back. The cylinders will absorb energy and redirecting impacting vehicle at a shallow angle, allowing the driver to avoid secondary accidents. The system capable of self-restoring upon impact is a unique feature compared to conventional metal barrier system. It offers low maintenance cost, and easy installation made the barrier an attractive option. The level of success of this type of high density polyethylene system has not been reported as the system is still new on the road. The system is yet to on Malaysia road. Some of the present unforgiving design of barriers ends often punctured into passengers' compartments contributed to many fatal accidents and severe injuries.

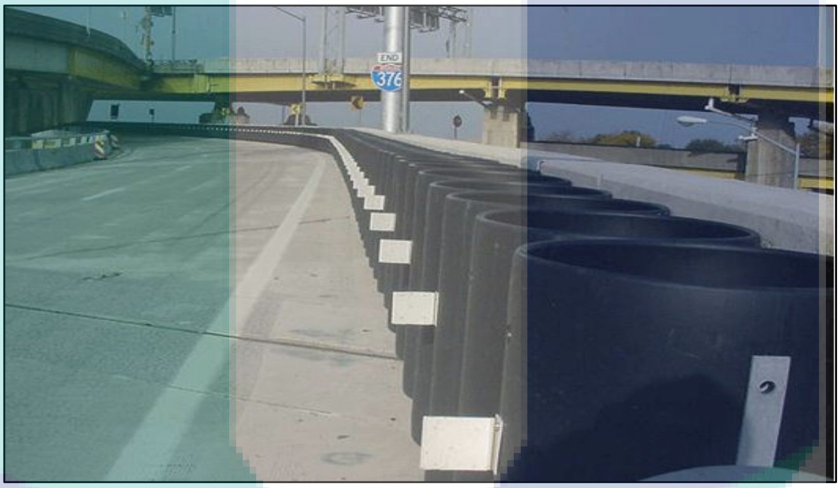


Figure 2.2 Crash cushion wall known as cushion wall II system

Source: AASHTO (2011)

European design guide has accepted that safety barriers are forgiving roadside treatments if able to shield hazardous objects or prevent vehicles from skidding away from travel lanes (CEDR, 2012). The design of the safety barrier in Europe has to meet the requirement of EN 1317. Examples of acceptable safety barrier terminations are the blunt end, ramped instead of the flared end, as shown in Figure 2.3. The blunt end terminal is a crash cushion that is fully re-directive and energy-absorbing designed to protect motorists from impacting the end of concrete barriers, toll plazas, bridge piers and other hazards. The barriers are hazardous if their ends are not properly anchored or ramped down into the ground, or when they did not flare away from travel lanes.

Figure 2.3 Safety barrier with blunt end with crash cushion

Source : www.ontimeguardrail.com.uk

Australian and New Zealand code of practice has introduced clear roadside zone, i.e. within which should be clear of hazards (AGRD, 2010). However, the guide states that for some reason, the situation could be unavoidable, then cushioning hazard or reducing hazard impact through design consideration is essential. Conceptually, installation of a safety barrier to protect hazard is a choice if it offers a safer situation than without having it. The guide alerts that striking force on the barrier should be less than directly to the object as it has a larger contact area. When working on an existing road, the standard recommends improvement to the road, including alignment, pavement surface, delineation and /or removing the hazards as an initial step before applying the barrier.

The Malaysian most recent practice on roadside barriers is governed by design guide known as Guidelines on Design and Selection of Longitudinal Traffic Safety Barrier published by Road Engineering Association of Malaysia REAM in collaboration with Jabatan Kerja Raya Malaysia (REAM-GL 9, 2006). It is the revision of the previous manual known as Manual on Design Guidelines of Longitudinal Traffic Barrier issued by Cawangan Jalan JKR (Arahan, 1/85).

The Malaysian design guide informs that highway traffic barrier placed on road shoulder is to prevent skidding vehicle's encroachment into steep embankments or to crash harmful objects, and placed on medians to prevent collision with opposing traffic (REAM-GL 9, 2006). Traffic barriers are hazards in nature, and hence their application must be well justified, and the number reduced. The prescribed function of guardrails is to protect vehicle occupants from potential severe injuries on crash impact instead of protecting roadside objects. The engineer has to weigh and satisfy himself that placing the guardrails next to roadside object offer better protection to vehicle occupants than without them.

Two Malaysian types of traffic barriers named in the design guide are longitudinal barriers and crash cushions (REAM-GL 9, 2006). The longitudinal traffic barrier works by diverting errant vehicles away from the protected hazards while crash cushion barriers decelerate errant vehicles to stop, resulting in a minimised degree of head-on impact. Disadvantages of metal beam roadside barriers seen on road accidents scene as discussed in the case study in Chapter 4 need to be improved in term of their design and application with refinement to better forgiving design features. In managing hazard safety, the guideline recommends engineers to give two primary considerations before shielding the obstacle, firstly by removing or relocating the obstacle and secondly to make the obstacle breakaway when possible. The design guideline recommends for fixed objects such as light, and ground-mounted sign supports that cannot be relocated away from the clear zone area should be made of a breakaway pole. Except where pedestrians and nearby traffics are of danger, all light and signs poles that can be struck by a vehicle should be of the type with slip-base to prevent injury to the vehicle passengers. Objects with slip-bases or breakaway features do not require shielding.

The types of objects that warrant shielding are rough rock cuts, large boulders, permanent bodies of water with depth of greater than 600 mm, line of large trees (matured diameter greater than 200 mm), bridge piers and abutment at underpasses, retaining walls and culvert headwalls, culvert end or wing walls forming abrupt drops greater than about 1.0 m in height, gap between twin bridges, narrowing of roadway (loss of shoulder) over structure, street lighting poles, traffic sign poles in particular gantry signs, and railway tracks if running about parallel and nearby.

The traffic sign poles employed in Figure 2.4 shielded differently on each side. One pole shielded with metal barrier and the other with sandbox. The metal barrier was used due to the high elevation of the pole on steep roadside slope considered secondary hazard. The sandbox barrier surrounding the pole was chosen to benefit gentle roadside slope and no secondary hazard beyond the pole. In this scenario, the first hazard was the pole.

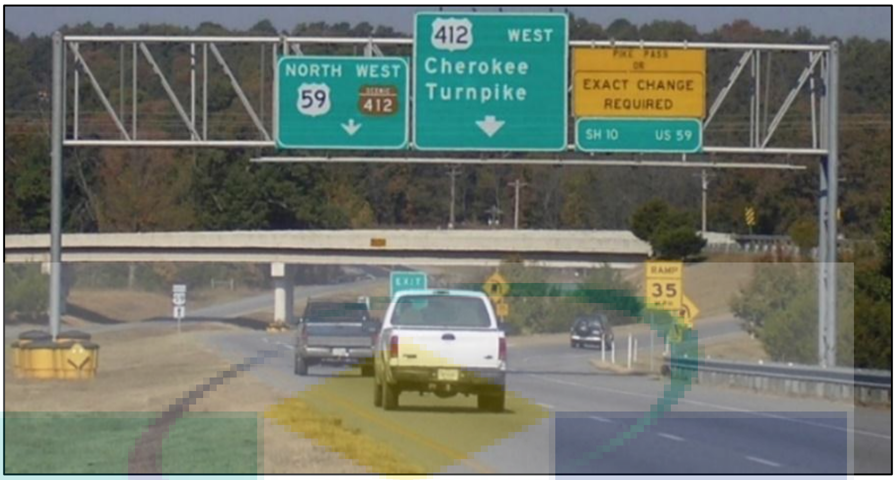


Figure 2.4 Gantry sign poles applying different types of shielding on each sides

Source: Wikipedia (2018)

In the issued Pelan Keselamatan Jalan Raya Malaysia 2014-2020 (PJKJR, 2014) by Jabatan Keselamatan Jalan Raya (JKJR) and Institut Penyelidikan Keselamatan Jalan Raya Malaysia (MIROS) in its one of the seven programmes focus on roadside barriers. It states that roadside trees and poles/posts objects are to be shielded. The safety plan programme has identified signage and roadside furniture as hazards, and it plans to review their related standards or regulations. In summary, the named hazards are trees, poles/posts, signage and roadside furniture.

Conclusion

The American, European, Australian and Malaysian design guidelines have a collective agreement that roadside safety barriers are forgiving roadside treatments provided that their design meet required safety standards of the respective countries. Their design guides shared a standard view that safety barriers are to be applied when the roadside hazard is not removable, and the application of barriers are less harmful than without them. The Malaysian design guide requires shielding of hazards with crash cushion barriers. The barriers included in the problem statement and case study. The case study will refer to some of the above works of literature where relevant.

2.7 Drains and Culverts

Drainage systems are an integral feature of highway safety (FHWA-SA-09-024, 2009). The drainage system is mostly run along the road and occasionally across the road. Most drainage system becomes harmful when they are not concealed, and known as a surface drain. Developing a new drainage system that can cope with the high discharge with forgiving features is a difficult task, but is an important compromise (Camacho-Torregrosa, F.J. et al., 2013). Culverts crossing roads having their ends uncovered with gratings and not flushed with roadside slopes are typical in Malaysia and classified as hazards because of harmful nature to traffic.

The channel covered in the American roadside design guide is an open channel placed along the roadway to collect surface runoff from the roadway and the surrounding area of right-of-way and conveying to acceptable outlet points (AASHTO, 2011). The guide specifies that the channel should be designed to service the design runoff with minimal highway flood and damage. The design guide recommends traversable cross-section of vee-shaped and rounded bottom drains.

In America, culverts of varying sizes from 457 mm to 3 m diameter made of concrete, metal and plastic used as cross-drainage structures underneath the roadway and its embankments. Their typical concrete made inlets and outlets headwalls and wing walls for large structures and bevel-end (structure end flushed with roadside slope) sections for smaller culverts. The bevel-end for small culvert inlet and outlet is to reduce projection that is hazardous to traffic. In maintaining a traversable slope, crossing culvert ends can be shortened or lengthen to suit a particular need. An example of shortening a culvert end and built up with steel grating to flush up to maintain a traversable slope is shown in Figure 2.5 (FHWA-SA-09-024, 2009).

Figure 2.5 Roadside culvert concrete headwall is replaced by metal grating for safety

Source: Maintenance of Drainage Features for Safety, FHWA-SA-09-024 (2009)

The European Union design guide titled a Forgiving roadsides design guide does not include roadside drainage as a hazard and has no specific design requirement (CEDR, 2012). Indirectly the design engineer may design to what he deems fit for the work.

Australia and New Zealand design guide classify drain as hazardous objects when they have fore slope with gradients at 1V:3H or steeper, in V shape form with fore slope and backslope of 1V:2H in view to possible crash at the back slope, positioned at the bottom of fill slope or fore-slope, and internally fixed with harmful object such as concrete (AGRD, 2010). The design guide classifies that culverts that do not have their inlet and outlet matched to a traversable fore-slope are a hazard. Untreated single size culverts having a width larger than 1.0 m are a hazard to passenger size vehicles. Besides, the guide requires culvert head design matching the fore-slope, and grating shall be provided to culverts end for single pipe larger than 900 mm diameter, for multiple pipes larger than 750 mm diameter. Despite the need to have culvert headwall to refrain ingress of eroded earth into the culvert opening, the design guide considers they are hazardous when located near the travel lane, the projection shape does not match the fore-slope, the culvert headwall projection is more than 100 mm high, and placed on the drain next to the travel lane.

The Malaysian standard known as A Guide on Geometric Design of Roads issued by the institution known as The Road Engineering Association of Malaysia (REAM) requires drainage design to be an integral part of road geometric design (REAM-GL 2, 2002). The toe, shoulder and roadside drains serve to collect and transfer stormwater runoff on the carriageway and the batter of cuttings or embankments to the edge of the formation (REAM-GL 3, 2004). It states that adequate drainage to be provided to ensure highway is free of flood with minimum construction and maintenance costs. The guideline requires no treatment to roadside drainage system as it does not classify it as a hazard.

The Malaysian design guidelines for a road drainage system is known as Surface Drainage addresses on the requirements and recommendation of the surface drainage system for roads (REAM-GL 3 V4, 2002). It states that concealed roadside drains are preferred compared to exposed drains. The guide provides three typical design for surface drains where the drain walls for all the designs for embankment toe drain with earth drain, concrete drain and stoned-lined are with a maximum slope of 1V:1.5H. The maximum drain wall slope is 1V:1H for interceptor drain placed on the embankment wall. The guide recommends the use of swale for roadside drainage for environmental consideration, as shown in Figure 2.6 and Figure 2.7. The swale section having low gradient wall and made of soft material sand and soil is an ideal replacement to concrete or rubble lined drain wall.

The guide recommends the use of swale for roadside drainage for environmental preservation so as not to discharge debris and oil to stream and river, as shown in Figure 2.6 and Figure 2.7. The swale section having low gradient wall and made of soft material sand and soil is an ideal replacement to concrete or rubble lined drain wall. The swale slope gradient on the travel lane side must not be steeper than 1V:4H to facilitate errant skidding vehicle to traverse down and up the slope to travel lane for safety.

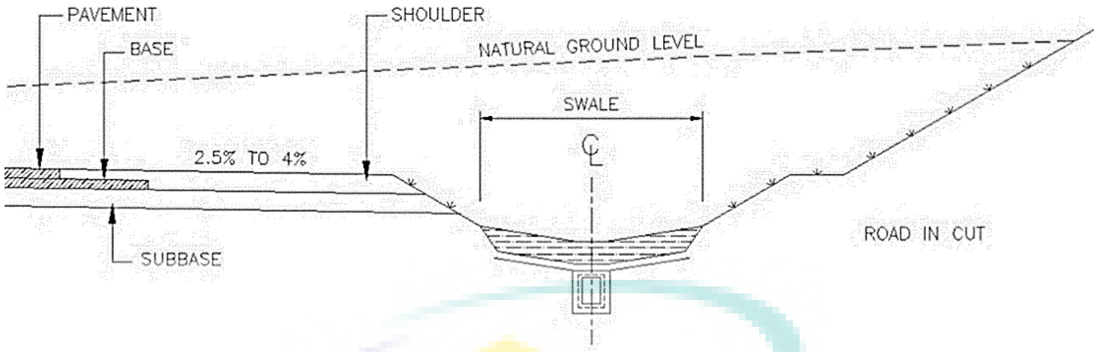


Figure 2.6 Cross-section of swale located at roadside

Source: Guidelines for Road Drainage Design titled as Surface Drainage, REAM-GL 3 V4 (2002)

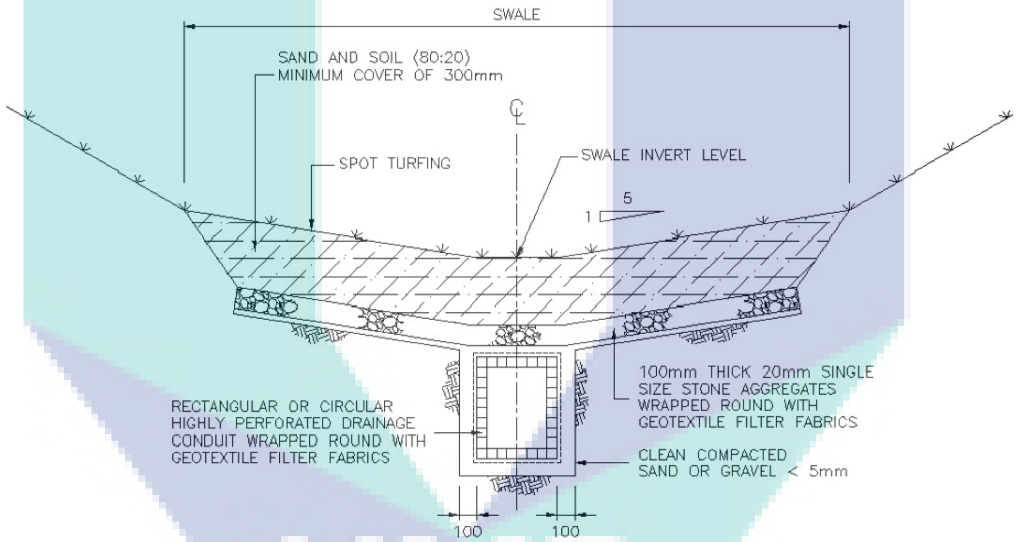


Figure 2.7 Details of swale located at the roadside with close-up view

Source: Guidelines for Road Drainage Design titled as Surface Drainage, REAM-GL 3 V4 (2002)

The volume 5 of Guidelines for Road Drainage Design titled as Subsoil Drainage has some essential tools applicable to existing drainage system where for some reasons if the drain cannot be relocated outside the safety recovery zone corridor (REAM-GL 3 V5, 2002). The guide permits use of subsoil drainage at the roadside for intercepting seepage water from surrounding it and removal of stationary water and be used to drain the subgrade and pavement surface runoff. Figure 2.8 and Figure 2.9 shows a typical design of roadside subsoil drain for multiple lanes road. In combination with the swale system, the subsurface drainage provides an excellent tool for the roadside drainage system.

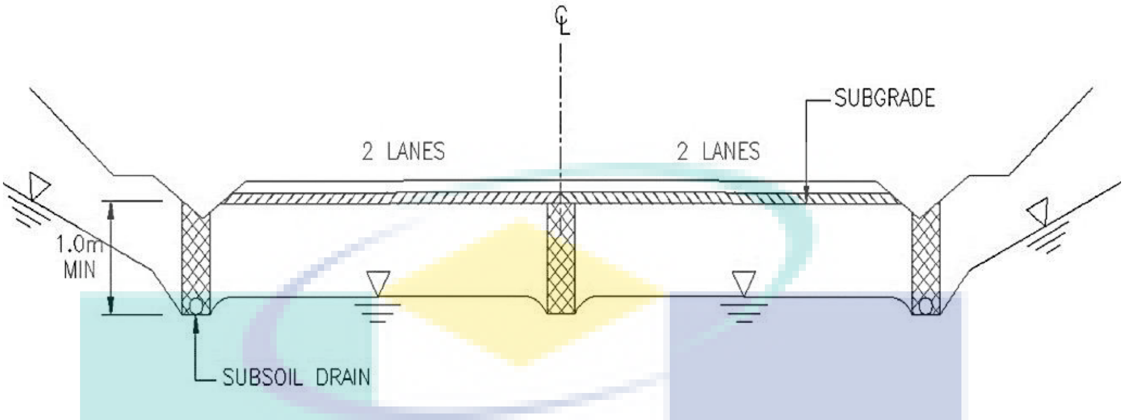


Figure 2.8 Cross-section of roadside subsoil drain

Source: Guidelines for Road Drainage Design titled as Subsoil Drainage, REAM-GL 3 V5 (2002)

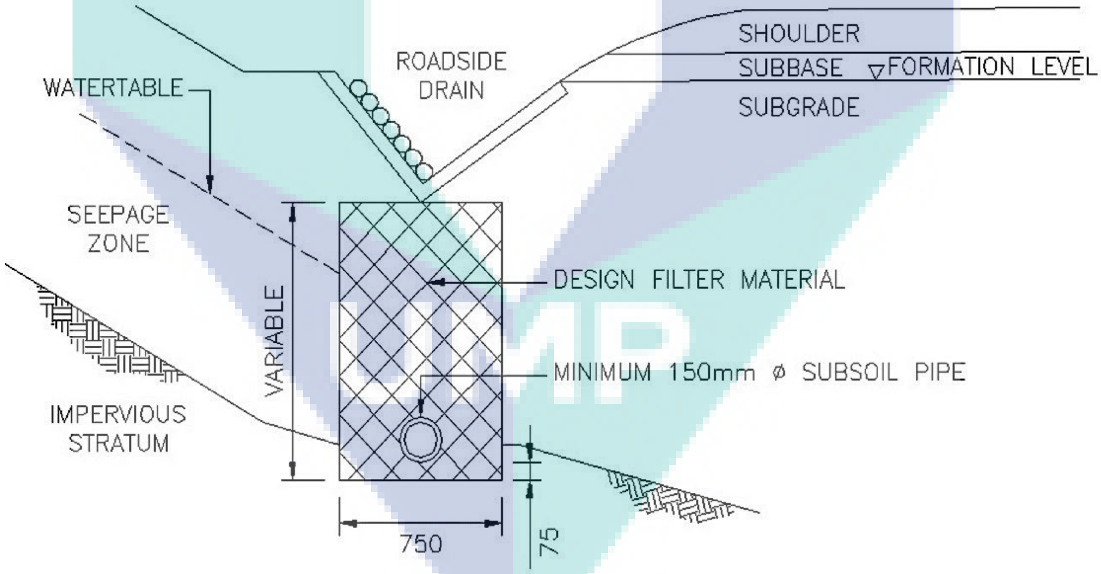


Figure 2.9 Detail of roadside subsoil drainage

Source: Guidelines for Road Drainage Design titled as Subsoil Drainage, REAM-GL 3 V5 (2002)

Conclusion

American, Australian, New Zealand and Malaysian practices with one standard view that open or surface roadside drains are hazards when placed within roadside safety recovery zone corridor. European Union countries have not placed forgiving roadside drainage in their design guidelines (CEDR, 2012). Compared to American, Australian and New Zealand practices, Malaysia design guide offers best forgiving roadside drainage concept because it states the preference of concealing roadside drains against exposing drains. Besides, the Malaysian design guide gives examples of forgiving sub-surface drainage typical design that can be transformed to suit desired discharged capacity. The excellent feature of sub-surface or sub-soil drainage is that it can allow seepage of groundwater, thereby strengthen road base. Despite the introduction of subsurface drainage in the design guide has been for about 17 years, but its application is quite limited. Drains within roadside safety zone have been identified as hazards in this study and included in the case study.

2.8 Roadside Safety Recovery Zone Corridor

Safety recovery zone corridor width is the width adjacent to travel way or carriageway measured perpendicularly from the edge of carriageway that is clear of fixed objects and having a proper gradient to allow for uninterrupted and passage of errant vehicle upon encroaching into roadside as illustrated in Figure. 2.10. The free of obstructions corridor is to permit the errant vehicle to recover his journey back to carriageway to save his life.

The forgiving roadside geometric design comprises of two elements, namely the sufficient width of roadside safety recovery zone corridor and gentle gradient of a roadside slope to facilitate skidding vehicle to traverse. For a given rating of the vehicle travelling speeds, the width of the safety recovery zone corridor has to suit the gradient of the roadside slopes. The risk of run-off-road casualty crashes for safety recovery zone corridor widths exceed 8 metres is 21% lower than those in the 4 to 8 metres range widths (Jurewicz, C., Pyta, V. 2010).

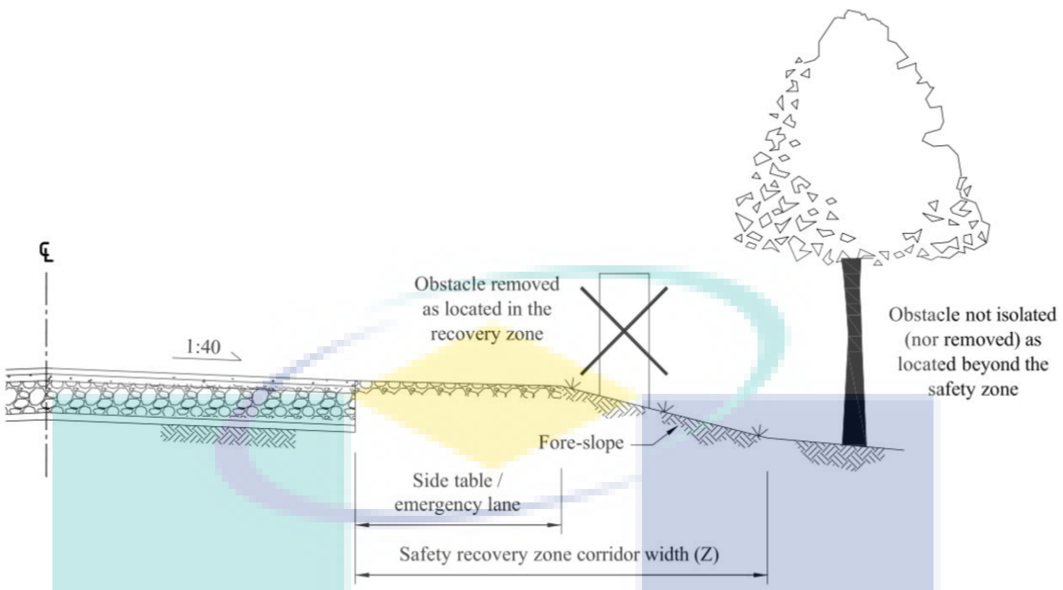


Figure 2.10 Typical road cross-section shows safety recovery zone corridor width

The American highway design guideline has produced safety recovery zone corridor chapter, therein named as "clear recovery zones" (AASHTO, 2011). National Cooperative Highway Research Programme prepared based on Report 247 in May 1982. The report states that the study was on field survey on limited actual accident data due to short of fund. The report prepared in May 1982 by Jerry L. Graham and Douglas W. Hardwood from Midwest Research Institute, Kansas City, Missouri was a field survey of existing data randomly selected sample from accident data from three states namely Illinois, Minnesota and Missouri. The roadside slopes taken for the study were 1V:6H clear zone, 1V:4H clear zone and non-clear zone. The design guide recommends safety recovery zone corridor width range of 2 to 13.5 and 2 to 14 metres for vehicle's travelling speeds of 60 km/h (or below) to 100 km/h and 60 km/h (or below) to 110 km/h for roadside slope between 1V:4H to 1V:6H or flatter. No provision made for roadside slope steeper than 1V:4H due to unsafe for an errant skidding vehicle to traverse. The design guide states that a design engineer needs to bear in mind that the given values are only guidelines computed based on limited empirical data that were further extrapolated to cover a broader range of condition. The guide recommends adjustment with a multiplier from 1.1 to 1.5 to the safety corridor width where accident histories or site investigation prove a need. Before the introduction of this design guide, most American highway agencies practised nine metres.

The Australian and New Zealand design standard Austroads recommends safety recovery zone corridor width range of 3 to 13.5 and 3 to 14 metres for vehicle's travelling speeds of 60 km/h (or below) to 100 km/h and 60 km/h (or below) to 110 km/h for roadside slope between 1V:4H to 1V:6H or flatter (AGRD, 2010). No provision made for roadside slope steeper than 1V:4H due to unsafe for an errant skidding vehicle to traverse. In the same way as the American standard, it treats slope steeper than 4:1 (the Australian practice that the first digit is for horizontal and the second is for vertical values) or 1V:4H as non-traversable and the amount of clear zone is not specified. The standard said their design table is for low angle departure but does not specify the angular limit. The design table applies to a light vehicle such as a car and not applicable to a heavy vehicle such as trucks and motorcycles. The Austroads states that according to AASHTO (2006), the table is a general approximation and not absolute as they prepared from limited empirical data extrapolated to cover a wide range of conditions. The designer may increase or decrease as deem appropriate to suit site condition.

The present Malaysian road design guide publications are by a joint committee of Jabatan Kerja Raya of Malaysia JKR and Road Engineering Association of Malaysia REAM. The related publication to road geometry is known as A Guide on Geometric Design of Road (REAM-GL 2, 2002) covering on carriageway and roadside table or emergency lanes widths. It is hoped that future revised version will include on roadside safety recovery zone corridor. The efficiency of highway safety is strongly related to highway geometry and traffic speed (Semeida, A.M., 2012).

Conclusion

The American highway design guideline has introduced safety recovery zone corridor width against a vehicle travelling speed and roadside slope gradient through the issuance of roadside design guide in the year of 2011. The current Australian standard on safety recovery issued in the year of 2010 refers to the American standard 2006. Therefore, there is a slight difference between the American and British standards. The Malaysian standard future revision will likely include a chapter in safety recovery zone corridor as its importance recognised worldwide. The safety recovery zone corridor discussed in the problem statement. The outcome of this study applied to the case study presented in Chapter 4 to reveal the potential benefits of safety recovery zone corridor application in design work to save human lives and avoid serious injuries.

Generally, application of clear-zone concept can easily be applied for rural areas in view to lack of constraints or roadside structures and having a bigger size of right-of-way. However, application of clear zone in urban environments is often limited by the size of right-of-way and characterised by roadside structures, enclosed drainage, numerous fixed objects such as signs, utility poles, luminaire supports, fire hydrants, sidewalk furniture and traffic-stops. In the urban environment that has lower operating vehicle travelling speeds and sometimes with on-street parking, travel lane requires lateral offset to vehicle obstructions namely signs, utility poles, luminaire supports, fire hydrants and breakaway devices. On-street parking is usual in Malaysia during the Friday prayer.

2.9 Malaysian Landscape Standard (JKR Nota Teknik (Jalan) 19/97)

A call was made by Malaysia's prime minister to make the country a ‘Garden State" by the year 2005 (JKR, 1997). Two cabinet meetings on the 9th. and 24th. of May 1995 had discussed on the call and approved a programme to landscape the nation. In 1997, the Malaysian government through its agency Cawangan Jalan of Jabatan Kerja Raya, Malaysia introduced a design standard known as Intermediate Guidelines to Road Reserve Landscaping. On the 3rd. March 1997, the Prime Minister made a nationwide launching known as ‘Landscaping the Nation' at the given target of one million trees a year. Since then, trees are among the Malaysian most popular roadside hard objects, and some are being planted too close to the roadway and has become injurious to the road users. In the context of highway and roadways design, trees are green belts to reduce noise pollution (Onder, S. and Kocbeker, Z., 2012).

The landscape design guide requires planting of trees outside the "Clear Zone" (JKR, 1997). The text reads as "Clear zones is defined as the area adjacent to the road pavement to the first tree (of diameter greater than 100 mm) planted. It must be wide enough for stray vehicles to recover and go back into the road without hitting the trees". The intention of the clause is clear that clear zone is meant to be a skidding vehicle safety recovery zone corridor. The Malaysian landscaping design guide recommends clear zone for rural and urban to be 9 and 4 metres respectively, and within this space planting of trees smaller than 100 mm are permissible.

Conclusion

The Malaysian design guide requires provision of roadside clear zone of 9 and 6 metres for rural and urban respectively. However, it permits planting of trees of less than smaller than 100 mm diameters, which has grown bigger and finally become hazards to traffic. Chapter 4 under case study evaluate the consequential problems and recommend solution.

2.10 The Malaysian Road Classification and Design Standards

The Malaysian road classification and design standard is governed by REAM-GL 2/2002 (REAM-GL 2, 2002). Thus, the following contents referenced to this design guide. The outcome of this study presented on safety recovery zone corridor widths in the template of the Malaysian standard template. The following discussion on Malaysian road classification and design standard information will facilitate a better understanding of outcome presentation in Chapter 4. The Malaysian road design guideline categorizes roads classification into urban and rural roads. Urban roads are roads located in urban areas defined by area gazette under municipal limits or township with population 10,000 or more where buildings and houses are in the same area and having business activity. Any roads outside the area and connecting municipalities beyond 5 kilometres apart are rural roads.

Malaysia's National Speed Limit is a set of speed limits set out for Malaysian expressways, federal roads, state roads and municipal roads. On 1 February 1989 under the National Speed Limit Orders 1989, the speed limits were enforced, and failure to comply is an offence subject to Malaysian Road Safety Act 1987 (Road Act, 1987). The variety of national speed limits for different types of roads is to satisfy safety requirement. Expressways for rural area speed limit is 110 km/h by default, but depending on constraints such as mountainous, crosswind and urban areas the speed may reduce to 80 or 90 km/h. Federal roads speed limit is 90 km/h by default and reduced to 60 km/h in the town area. State roads speed limit is 90 km/h by default and reduced to 60 km/h in the town area.

Fundamentally, the design of urban and rural roads is the same. The urban road has more vehicles stopping areas, pedestrian paths, intersections and congested buildings. Thus, its design applies lower speed and different geometrical design to accommodate the more massive traffic and adjoining property. Table 2.2 and Table 2.3 is the design speeds for rural and urban roads, respectively.

Table 2.2 Design speed for rural roads

Design Standard	**Category of Road**	**Design Speed (km/h)**		
		Terrain		
		Flat	Rolling	Mountainous
R6	Expressway	110	100	80
R5	Highway Primary Roads	100	90	70
R4	Primary Roads Secondary Roads	90	80	60
R3	Secondary Roads	80	60	50
R2	Minor Roads	60	50	40
R1		50	50	30

Table 2.3 Design speed for urban roads

Design Standard	**Category of Road**	**Design Speed (km/h)**		
		Area Type		
		I	II	III
U6	Expressway	100	90	80
U5	Arterials Collectors	90 80	70	60
U4	Arterials Collectors Local Streets	80 70 70	60	50
U3	Collectors Local Streets	60	50	40
U2	Local Streets	50	40	30
U1		40	30	30

Note:

Type 1	Relatively free in road location with very little problems as regards land acquisition, affected buildings or other socially sensitive areas.
Type II	Intermediate between I and III.
Type III	Very restrictive in road location with problems as regards land acquisition, affected buildings and other sensitive areas.

Conclusion

Even though the above Malaysian road classification and design standard publication has been for about 17 years, it remains the current version of design guideline. Design speed is for engineer's design purpose but may change according to the guideline revision, but road speed limit change according to authority instruction. Presentation of this study outcome into the Malaysian standard template will assist the engineer in the quick application of in his design work.

2.11 Analysis of Vehicle's Exit Angle Based on Past Accidents Record

Vehicle's exit angle is an angle of the direction taken by a vehicle when leaving the road and encroaching into the roadside safety recovery zone corridor at the time of the accident. The exit angle value is a necessary parameter for application in carrying out field driving experiments. Determination of vehicle's exit angle based on accidents record is real-time information. It remains the most reliable fact as it was generated from the real accident situation which has accounted for a combination of vehicle's natural exit angle with the human factor contributed by the driver's intervention and producing modified vehicle's path.

The relationship between the vehicle's exit angle versus the cumulative percentage of accidents is shown in Table 2.4 (TRL, 2005). The values given in the table will be analysed for selection of vehicle's exit angle to be carried out for the vehicle's field testing.

Table 2.4 Vehicle's exit angle versus cumulative percentage of accidents

Vehicle's Exit Angle (degrees)	**5**	**15**	**25**	**35**	**45**	**90**
Cumulative Percentage (%)	10	55	83	94	98	100

Source: TRL (2005)

Conclusion

The field testing works for this study applied the vehicle's exit angle drawn from the above literature. The study worked on 70% road accidents, employed an exit angle of 20 degrees for all field testing experiments as discussed in methodology. Even though this finding has been almost 14 years, it was employed because no newer finding discovered.

2.12 Roadside Shoulder

Malaysian standard titled A Guide on Geometric Design of Roads (REAM-GL 2, 2002) defines road shoulder as an area placed at the side of carriageway serving as an emergency lane. It is spaced away from the travelling lane to avoid accidents or reduce its severity. It provides an area for occasional motorist stoppage and acts as lateral support to carriageway structure. A shoulder has proven to be very important as sometimes it allows the errant skidding driver to manoeuvre back to the travel lane without going deep into the roadside and involve with an accident (Torre, F.L. et al., 2012).

Malaysia's current requirement on shoulder width design for roads is between 1.5 to 3.0 metres depending on the road types and condition of the terrain (REAM-GL 2, 2002). The standard demands paved shoulder for road type R3 to R6 for the minimum width of 1.5 to 2.5 metres. Likewise, for urban roads, the paved shoulder width shall be from 1.5 to 3 metres depending on the road type and their respective location classification.

Conclusion

Road shoulders are a requirement in the Malaysian design guide. The shoulders are the first contact area for the errant skidding vehicle to traverse back to travel lane to safety. Malaysia is in a tropical zone subject to heavy rainfall has been causing continuing erosion to the unpaved road shoulder. In view that road shoulder constitutes part of safety recovery zone corridor, its condition evaluated in the case study carried out.

2.13 Roadside Slope Geometric Design Based on Malaysian's Standard

Slope Engineering Branch, Jabatan Kerja Raya (JKR), Malaysia issued design guide known as Guidelines for Slope Design first published in January 2010 (JKR, 2010). The preface section of the guidelines informed that it was formulated to assist the design engineer in the assessment of slope stability, safety and mitigation. The recommended roadside slope gradient for cut slope is 1V:1H to 1V:1.5H and for fill slope is 1V:2H (steeper than the traversable limit of 1V:4H).

The slope guideline requires all untreated slopes constructed with minimum 2 metres berm wide and a maximum of six metres wall height with a minimum safety factor of 1.3 (JKR, 2010). The minimum global safety factor for treated slope is 1.5. A maximum of six berms is permissible for cut and fill slopes or else designer to identify alternative solutions. The current guideline provision of the roadside slope gradient is practically for the slope stability point of view without due consideration for motorist safety for the errant skidding vehicle.

The term recoverable slope refers to a slope that is traversable by a skidding vehicle to return to the travel lane to save his life (JKR, 2010). Based on AASHTO's design guide, a slope of 1V:4H or flatter is recoverable fore slope, while steeper than 1V:4H is not recoverable. In a situation where recoverable traversing is desirable, the Malaysian roadside maximum slope for a cut or fill shall reduce to 1V:4H or flatter. In a situation where the recoverable traversing is not practicable, an alternative solution such as guard rail to be provided. The scope of practice in designing roadside slope shall be extended to cover motorist safety consideration in addition to slope structural stability for the non-mountainous road.

Conclusion

A design engineer will refer to road geometrical design guideline when performing his design on a roadside slope. Introducing a section on the requirement of slope design for non-mountainous road design in the Guidelines for Slope Design discussed above will streamline the two design guidelines. The steep roadside slope as a hazard highlighted in the problem statement and case study.

2.14 Breakaway Features for Sign Supports, Utility Poles and other Roadside Features

Breakaway devices are safety structures designed and tested, and once installed to roadside features; they could break and absorb impact force when struck by a vehicle in order to minimise the severity of the accident to a motorist. Roadway breakaway sign (or the like) is an element of a forgiving design concept, and it should fail predictably (Xu. L. et al., 2016). The design shall account for impacting force contributed by a vehicle travelling speed, initial crash contact area and the vehicle approaching angle. In a situation when the preference of having roadside safety recovery zone corridor free of hard obstructing objects is not practicable, the potential crash impact could be mitigated by introducing breakaway features, shielding or crash cushions if within a safety recovery zone corridor.

Light sign structures may employ U-channel Post, Sleeve Assemblies as The Base (left) or Slip Couplings (right) used in the United States as in Figure 2.11. These devices will increase the safety of a vehicle's passengers as impact pressure is to the signpost.

Figure 2.11 U-channel post, sleeve assemblies as the base (left) or slip couplings (right)
Source: FHWA (2010)

Large sign structure installation is by using a slip base connecting post to the foundation, as shown in Figure 2.12. Once struck, the base slipped off from the foundation and rotated around the hinge plate below the sign panel which allows the vehicle to pass through safely. The technician assigned for installation work must fully understand the procedure and ensure correct compliance with its requirements.

Figure 2.12 Large sign structure using a slip base connecting post to the foundation
Source: FHWA (2010)

The main objective of the study in reducing collision impact is to minimise the degree of crash impact to vehicle's passengers (Ispas, N., and Nastasoiu, M., 2017). The impacting collision force to passengers reduced by increasing the vehicle safety and utility pole ability to absorb crash energy. Among countermeasures recommended include placing utility lines underground, increasing pole offset and spacing, shielding pole with a roadside safety device and delineating pole.

Conclusion

Breakaway devices are not that popular in Malaysian practises. The devices are expensive, usually stolen unless anti-theft devices introduced. Road authorities have begun to carry out studies on roadside hazards, and may in future direct responsible authorities to replace the existing devices to safe industry practice. The case study had included the report of examination into currently installed devices on their usage of breakaway features.

2.15 Road Safety Auditing

Road safety auditing is a procedure to examine the safety performance of in-service and future roads, preferably by an independent team (Wang, Y.G, et al., 2011). Road safety shall investigate and gather information on potential hazards and assess whether the road is in forgiving state. The state at which impact of crashes is not fatal or with severe injuries to vehicle passengers (Strong, H., 2017). The study shall include evaluation of visibility of hazards, adequacy of design guidelines and updated to current industry's practise.

Conclusion

In case studies to selected areas, auditing was carried out against the application of some of the above concept and outcome of safety recovery zone corridor widths proposed in this research works.

2.16 Summary

The summary in Table 2.5 is covering selected issues directly related to roadside safety. Studies in the 20th century have shown that vehicles run-off-road accidents for European Union countries, Australia and the United States is between 30% to 40%, of which fatal crashes are between 23% to 42%. The figure indicates that roadside safety shall not be ignored. Despite there is no statistic on Malaysian roadside accidents issued by MIROS, lessons learned from other countries shall initiate our road stake holders to observe on the similar issue of skidding vehicles crashed with roadside hazards. Their studies have shown that placing structures at inappropriate locations are not consistent with the concept of forgiving roadside, an environment where skidding errant vehicles may not traverse to safety due to steep roadside slope and obstructing objects.

Table 2.5 Summary of studies on roadside hazards and safety recovery zone corridor from Chapter 2

Reference	Findings/comments	Safety zone width vs slope and vehicle's speed	Research method
Jurewics, C. et al., 2014	Placing any dangerous structures at inappropriate locations are not consistent with the concept of forgiving roadside.	No coverage	Not applicable
CEDR, 2012	Severity of run-off-road accident depends on the nature and layout of roadside objects.	No coverage	Not applicable
MnDOT, 2011	Modern hardware complying with stringent standard shall be used for treatment to unforgiving roadside structure.	No coverage	Not applicable
Roque C. et al., 2015; ERSO, 2012	From 2001 to 2010, European Union recorded that 32% of crashes were single-vehicles, and of which 42% were fatal crashes.	No coverage	Not applicable
Torre, F.L. et al., 2012	A forgiving roadside design may not reduce the number of accidents considerably, but it will minimize the crash severity and fatality substantially.	No coverage	Not applicable
AGRD, 2010	Hazards to be placed outside roadside safety zone unless with treatments.	No coverage	Not applicable

Table 2.5 Continued

Reference	Findings/comments	Safety zone width vs slope and vehicle's speed	Research method
REAM-GL 2, 2002	The Malaysian design guide specify geometry for rural and urban roads carriageway and roadside table or emergency whilst other related standards are on road furniture design.	No coverage A research gap for Malaysia	Not applicable
JKR Nota Teknik (Jalan) 19/97	Malaysian landscaping design guide recommends clear zone for rural and urban to be 9 and 4 metres respectively within which planting of trees smaller than 100 mm are permissible, and today has turned them into hazards.	No coverage	Not applicable
Torre, F.L. et al., 2012	A forgiving roadside design may not reduce the number of accidents considerably, but it will minimize the crash severity and fatality substantially.	No coverage	Not applicable
Wang, Y.G. et al., 2011	Safety performance audit for roadside and median barriers using freeway crash records: Case study in Jiangxi, China.	No coverage	Not applicable
REAM-GL 2, 2002	The Malaysian design guide specify geometry for rural and urban roads carriageway and roadside table or emergency whilst other related standards are on road furniture design.	No coverage A research gap for Malaysia	Not applicable
REAM-GL 2, 2002	The Malaysian design guide specify geometry for rural and urban roads carriageway and roadside table or emergency whilst other related standards are on road furniture design.	No coverage A research gap for Malaysia	Not applicable
Strong, H., 2017	Is your road forgiving.	No coverage	Not applicable
TRL, 2005	As the vehicle's exit angle increases from 5 to 90 degrees, the cumulative accident percentage increases from 10 to 100%.	No coverage	Not applicable
Semeida, A.M., 2012	The efficiency of highway safety is strongly related to highway geometry and traffic speed	No coverage	Not applicable
JKR, 2010	The guideline to serve roadside slope structural stability. The recommended roadside slope gradients 1V:1H to 1V:2H steeper than traversable gradient of 1V:4H. It is against the concept of forgiving design to save human life and shall be revised.	No coverage	Not applicable

Table 2.5 Continued

Reference	Findings/comments	Safety zone width vs slope and vehicle's speed	Research method
Ispas, N., and Nastasoiu, M., 2017	Analysis of car's frontal collision against pole. Automotive and Transportation Department, Transilvania University of Brasov, Romania.	No coverage	Not applicable
AASHTO, 2011	The United States recorded in 2008, 23.1% of the fatal crashes were single-vehicle run-off-road crashes, a considerable margin that cannot be ignored. It recommends safety recovery zone corridor width based on roadside slope vs vehicle travelling speeds based on past accident records of three districts.	Has coverage	Not applicable
This study	Roadside safety recovery zone corridor width based on roadside slope vs vehicle travelling speed.	Has coverage	Live field experiments

European Union countries, Australia and New Zealand have adopted a similar approach to the American practice of providing safety corridor where roadside objects are kept out of the designated area or in unavoidable situation apply safety treatment to the objects. The United State is the only country found to introduce roadside safety recovery zone corridor width against slope and vehicle travelling speed for both keeping area free of hazards and providing roadside slope at a gradient traversable by skidding vehicle to safety. The method employed by the American study in determining the width of safety corridor against slope and vehicle travelling speed is based on limited past accident records from three districts and interpolating them to cover up for missing data. The American approach differs from this study, where data obtained is from live experiments carried out in the fields.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Choice of Research Methods

A research methodology is a process employed in collecting information and data for analysis and making an outcome of a study. The methodology for this study had included the presentation of two conference papers, the publication of two international journals to get feedbacks and collecting information from other studies, both local and international. The choice of research methods available for this study was between computer simulation study, analysis of past accident records and by the observational study through live experiment.

The computer simulation method is a study applying a computer program that simulates an abstract model of a particular system. The computer simulation study does not account for a human reaction which varies from one person to another person. Typically, the simulation system uses the same model of car in comparison to the many types of cars on the road. The influence of different model of cars, the reaction from different drivers and the varying ground conditions contributed to accident outcomes are not accounted in the computer simulation method to yield accurate results. In real life situation, there are no two similar site conditions in term of the density of grass, soil compositions, surface hardness and profile of the surface. Based on the above grounds, the observational study through live experiments in the fields took preference over the computer simulation research method.

In a research, the most scientific of all methods is an experimental method (Holah, 2018). It states that the experimental method eliminates the problem in lack of control over the situation, as often encounter in the non-experimental method. It is a study of cause and effect, which overcome the deliberate manipulation of one variable while trying to keep all other variables constant as in the case of non-experimental method. The search for a sample of a method for obtaining the width safety recovery zone corridor by live field experiment from other studies was not available. The method employed in this study was the first of its kind at the research time. The flow of activities for the study as shown in Figure 3.1.

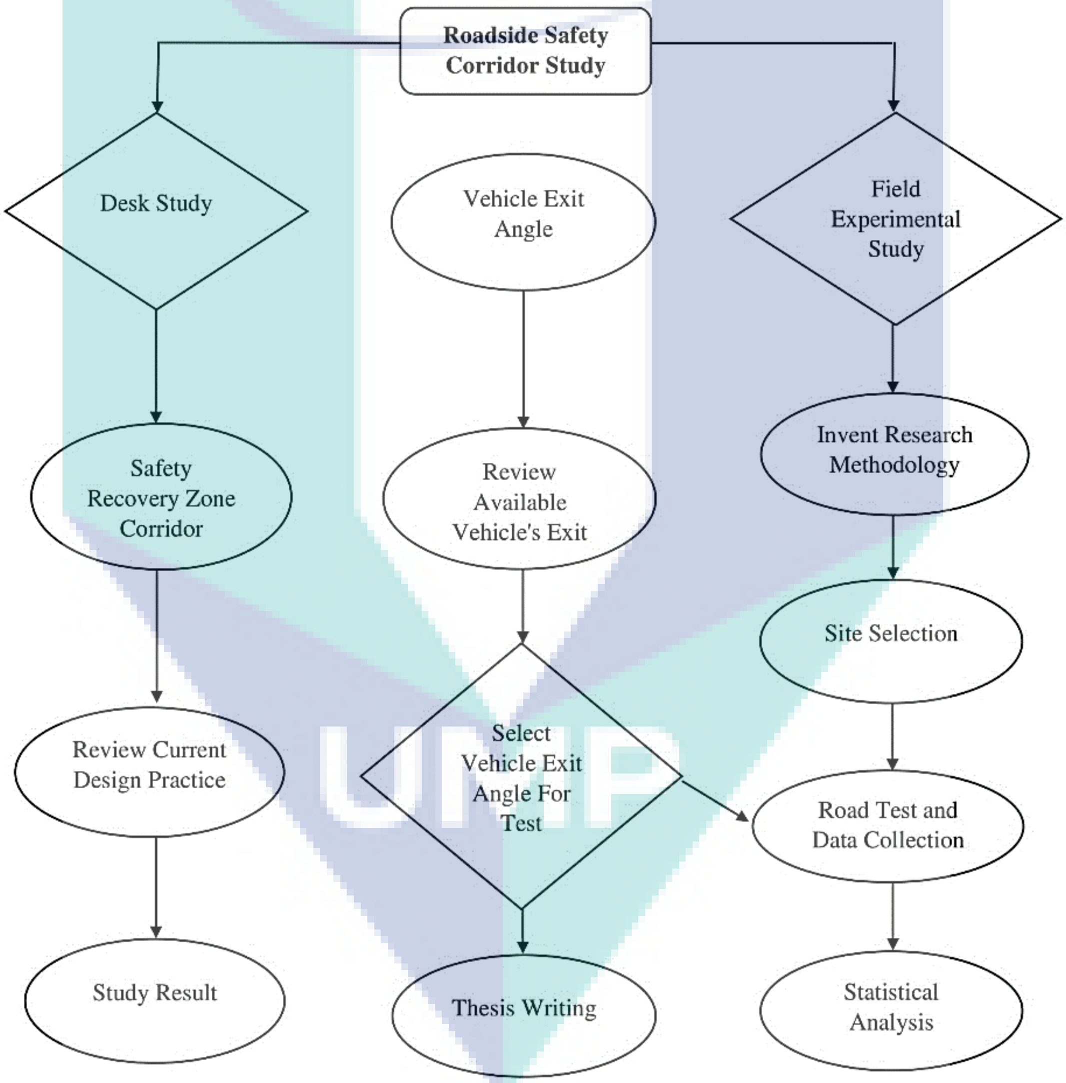


Figure 3.1 Flowchart for research methodology

3.1.1 Selection of Experiment Sites Based on Traffic Density and Ground Surface Condition

The study began with a set of field trial tests before an actual test was carried out. The field trial tests revealed that the travelling time from skidding to recovery back to the travel lane took less than 10 seconds. Based on the 10 seconds time frame, test locations selected were from areas of low traffic volume having the density of not more than a car in about 20 seconds, i.e. twice the actual time frame to ensure the safe distance of oncoming car when a live experiment is taking place. Generally, roads that can meet these criteria are rural roads at remote locations.

In addition to the time frame criteria of not more than one car passing in 20 seconds at the test spot, the selected field for driving tests were from areas having reasonably good ground-surface conditions, such as free of potholes, minimal gravels and covered with good density of grass to ensure the running car will not be sliding on slippery sand surface. The field test crew inspected all sites to ensure no ground projection such as rock or the like that may cause the testing car to be airborne. If any, the roadside drain shall not be too close to the projected test car trajectory unless the drain is small enough to be traversable during a situation of emergency.

Ten locations selected were from four states, namely Pahang, Johor, Selangor, and Perak of Malaysia having various roadside slope gradients and ground-surface conditions, as shown in Figure 3.2. The sampling of four states represents 30% of 13 states of Malaysia. A percentage deem reasonable to represent Malaysia's scenario.

3.2 Selection of Test Sites based on Roadside Geometric Requirements

Selection of roadside slopes having gradients and ground surfaces with tractions traversable by cars was the basic requirement to perform driving field tests. The roadside slope gradient to be gentler than 1V:4H as any slope steeper than this will not permit most skidding vehicles to traverse back to travel lane as quoted under Clause 3.2.1 of American Roadside Design Guide (AASHTO, 2011) and TRL Report PPR298 (2005). The favourable slopes were between 1V:4H, 1V:5H, 1V:6H, 1V:7H, 1V:8H, 1V:9H and 1V:10H. However, none of the all ten sites selected for testing had exactly these roadside slope gradients though they were set perfectly by land surveying instruments before construction. Malaysia is located just above the equator; the climate is equatorial characterise by rainy throughout the year will subject the roadside slope under continuous weathering. The roadside slope constitutes of grass and soil under continuous erosion process throughout the year. Despite the slopes surface were not in perfect conditions, but in the light of the research perspective, the experiments were carried out in the variety of actual conditions.

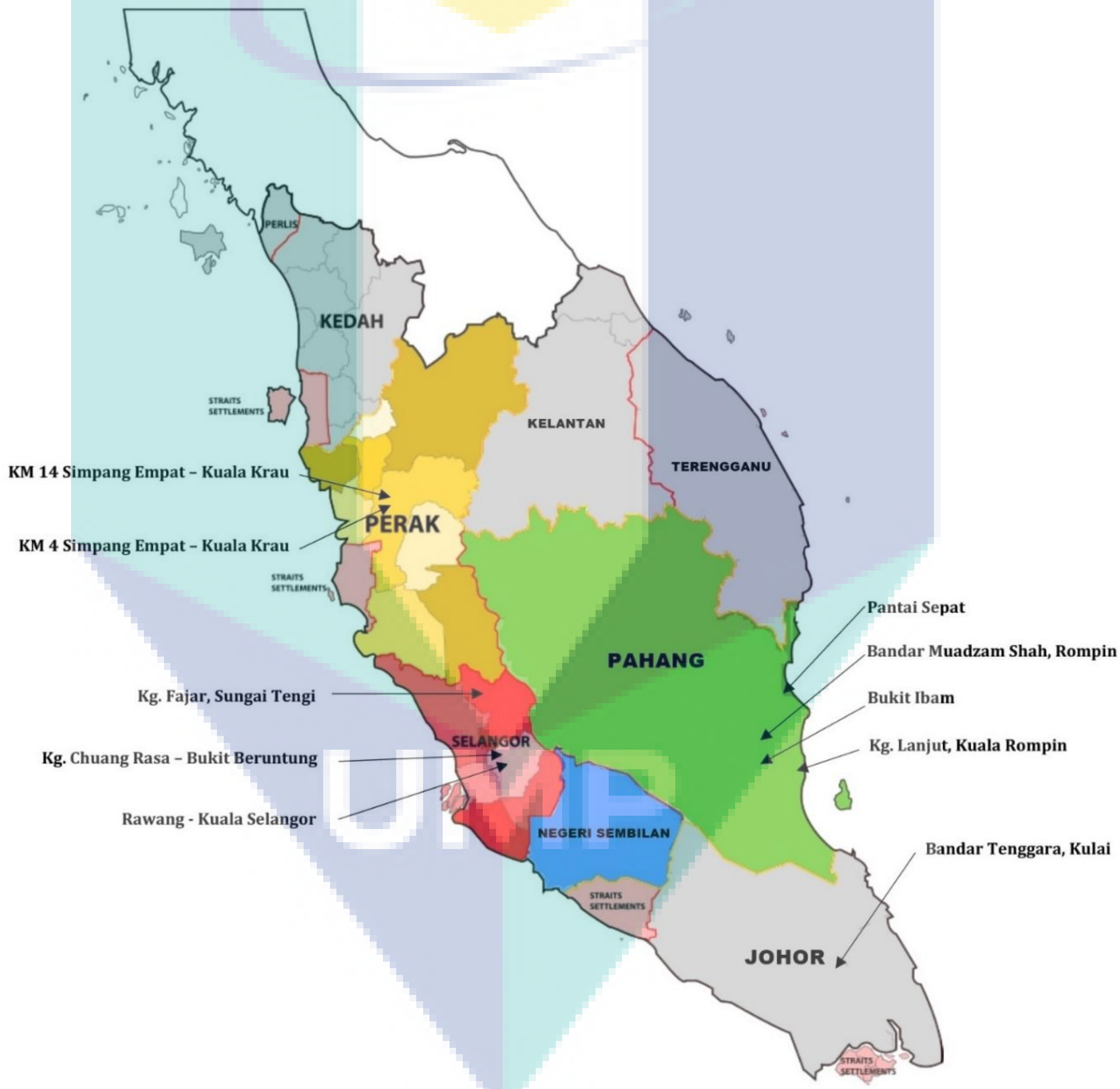


Figure 3.2 Ten test locations selected in Peninsular Malaysia

Roadside corridors with a specific working area of clear open width and span were essential to ensure practicability and safety for the car trajectory on skidding. The field tests selected were roadside open space corridors width between 6 to 10 metres measured horizontally and perpendicular to the carriageway, and 50 metres stretch along the road to permit adequate space for the vehicle trajectory running track. Several cars driving trial run before an actual 5 round tests at selected speeds were carried out to ensure safe performance on testing.

In ensuring good safety practice, the selected non-hazardous area extended beyond the required working areas. Depending on roadside slope gradients, an extension surrounding of about a few metres to test area were without obstructions and fully traversable. The fixed objects were trees, lamppost, signboard post or the like. The ground surface shall be even ground without potholes and bumps as they were considered hazards. Any bump will cause the vehicle to be airborne.

All selected roadside slopes complied with Jabatan Kerja Raya JKR landscaping and turfing works specification. The sites slopes surface finishes were made up of soil planted with cow grass (Axon Opus Compresses) fully turfed to JKR specification (JKR, 2014). Slight erosion of the slope's surfaces was considered acceptable due to years of the natural weathering process.

3.3 Selection of Test Speeds

Selection of vehicle travelling speeds for testing works was on a range of speeds listed in Road Engineering Association Malaysia REAM standard (REAM-GL-2, 2002). The standard specifies two separate sets of speeds for rural roads ranging from 50 km/h to 110 km/h and urban roads between 40 km/h to 100 km/h. For the test purpose, the vehicle speed of 40 km/h excluded because the executed trial tests showed no significant difference trajectory path with that of 50 km/h due to the low-speed phenomenon. However, the 40 km/h could apply the same safety recovery corridor width for 50 km/h if the need arises.

For the drivers' safety, the vehicle test speed adopted was 50 km/h to 90 km/h in the interval of 10 km/h for very safe areas. The maximum speeds reduced to 70 and 80 km/h for higher risk areas categorised by car handling difficulty during traversing.

Given poor vehicle's stability experienced when car traversing beyond 90 km/h, the potential widths of safety recovery zone corridors at the speed of 100 and 110 km/h projected from statistical equations. The same applied to non-executable speeds of 80 and 90 km/h due to restrictions by trajectory space, steep slope gradient and other constraints.

3.3.1 Limitation

Despite accidents took place beyond vehicle travelling speed of 110 km/h, this study is limited to maximum of 110 km/h. The study justified by the Malaysia national speed is limited to the maximum of 110 km/h as specified in the design guideline.

3.4 Selection of Drivers and Test Vehicles

Collected data from 30 countries reveals that young drivers aged between 18 to 25 years represent the majority in road trauma statistics (Scagnolari, S. et al., 2015: IRTAD, 2012). Organization for Economic Co-operation and Development consisting of 34 countries, reported that about 8,500 young drivers (15 to 24 years old) killed each year is about double the older drivers. Based on this statistic, young drivers were sought to carry out field testing tasks.

Recruiting voluntary drivers to participate in the field testing works was among the most challenging task because it involved human risks. Having convinced on the importance of the study in promoting new road safety standard for reducing fatalities and serious road injuries to the public, four fit and fully licensed male volunteers age between 20 to 24 years accepted the tasks to be drivers for the testing works. However, no female driver participated because of no volunteer. Within three months period, the team comprised of four members found ten suitable test sites for experiments. God blessing, all the drivers employed performed the test safely, diligently and successfully.

Four non-four wheels driven cars were used to execute the live fields tests. Four wheels driven car was not employed because it will give smaller safety recovery zone corridor value as it has super slope climbing capability, will result in lower safety margin. The selected four cars for field testing works were ranging from 1.3 to 2.3 litres cylinder capacities, namely Saga FLX 1.3, Honda City 1.5, Mazda3 2.0 and Ford Escape XLS 2.3. All the cars were less than ten years of operation and in right working conditions. During driving trial tests, at the same travelling speed showed no noticeable difference in safety zone widths by varying engine capacity of cars.

3.5 Selection of Vehicle's Exit Angle (Encroachment angle)

The vehicle's exit angle or also known as encroachment angle is the angle at which the errant vehicle strays off from travel lane and get into the roadside. Generally, angle of exit for errant vehicle straying off from travel lane will depend on many factors such as road-tire friction, condition of car tire alignment and camber, travelling speed, the lateral position of the vehicle against the edge of road, road geometric design, vehicle type, road cross-slope, driver's skill etc. However, this study will focus on the vehicle's exit angle in combination with roadside slope gradient influence to the final vehicle speed forming trajectory path in generating the width for roadside safety recovery zone corridor.

The relationship between the vehicle's exit angle versus the cumulative percentage of accidents is in Table 3.1 (TRL, 2005). Referenced to Figure 3.3 generated from Table 3.1, suggests the vehicle's exit angle that is most probable based on 70% of run-off-road cases is about 20 degrees. The 20 degrees vehicle's angle applied throughout the field road tests, and the outcome represents up to 70% of the cases. It was impossible to skid off from travel lane each time at 20 degrees, but the repetitions of 5 times to each test speeds will compensate the varied results. The 20 degrees lines were painted red and bold to assist drivers' sight.

Table 3.1 Vehicle's exit angle versus cumulative percentage of accidents

Vehicle's Exit Angle θ (degree)	**5**	**15**	**25**	**35**	**45**	**90**
Cumulative percentage P (%)	10	55	83	94	98	100

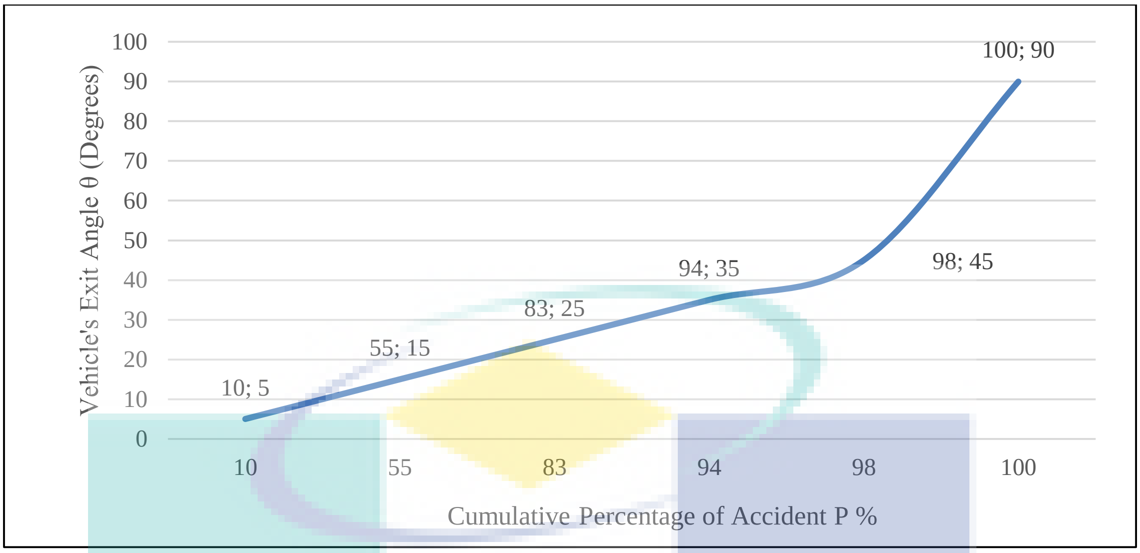


Figure 3.3 Vehicle’s exit angle versus cumulative percent of accident

Source: TRL (2005)

3.6 Test Site Preparation and Result Measurement

Preparation of live driving experiment test sites demands thorough works to ensure the safety of drivers, trajectory-produced reliable data and accurate measurement of results. A few trial driving tests were carried out to each site to ensure sliding was not excessive to the extent of endangering the drivers. Each site ground surface conditions examined to ensure no potholes or humps that could be causing bumpy rides producing unreliable data.

Marking 20 degrees vehicle's exit angle lines measured anti-clockwise from the direction of travelling were carried out by painting edge of the road pavement triangular template as shown in Figure 3.4. A metre length of 100 mm width red painted lines road marking provided excellent visibility to the drivers. Offset to the red line in the roadside corridor; the ground pegged with 300 mm long red-painted wooden sticks laid at 0.5-metre intervals for a total width of 6 metres measured horizontally and perpendicularly to the travel lanes to enable measuring of car trajectory widths as shown in Figure 3.5 and Figure 3.6.

The tests were carried out by driving the cars skidding off the travel lanes through the red marked vehicle's exit angles lines and traversed back to the travel lane. The driving tests were repeated five times for each selected travelling speeds. Trial driving tests showed that repetitions more than five times had damaged the ground surface and impaired experiment's result. All successful field tests demonstrated that the influence of vehicle speeds on safety recovery zone corridor widths, as shown in Figure 3.7. The skidding car trajectory widths of safety recovery zone corridor were videoed, photographed, and offsets measured to nearest 0.1 metres. The videos and photographs were to ensure that correct track lines were measured. The weather conditions and the lapsed times in carrying out each test were recorded.

Figure 3.4 Vehicle exit angle of 20 degrees marked with redline on the road

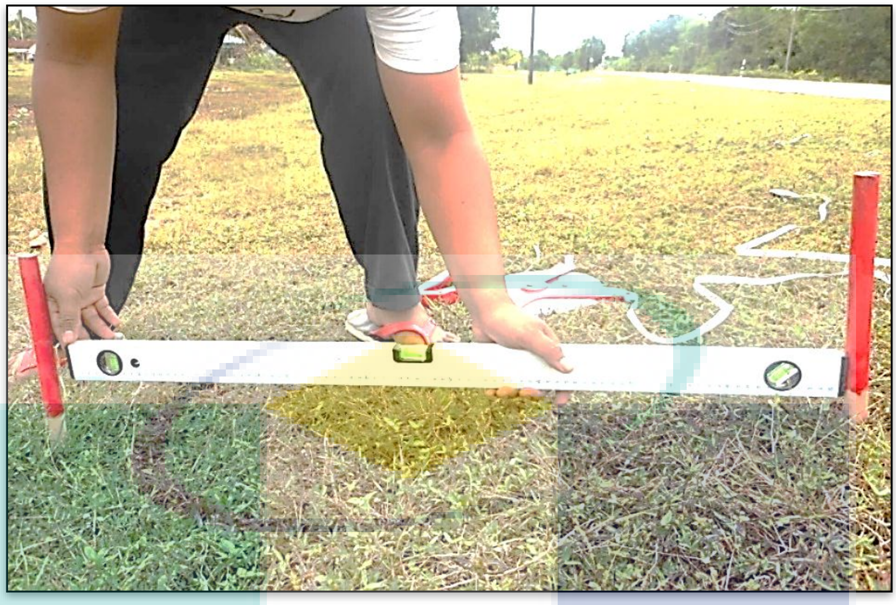


Figure 3.5 Setting offset distances to the marked vehicle exit angle to measure safe zone distances

Figure 3.6 Pegging red wooden sticks marking offsets to the vehicle exit angle

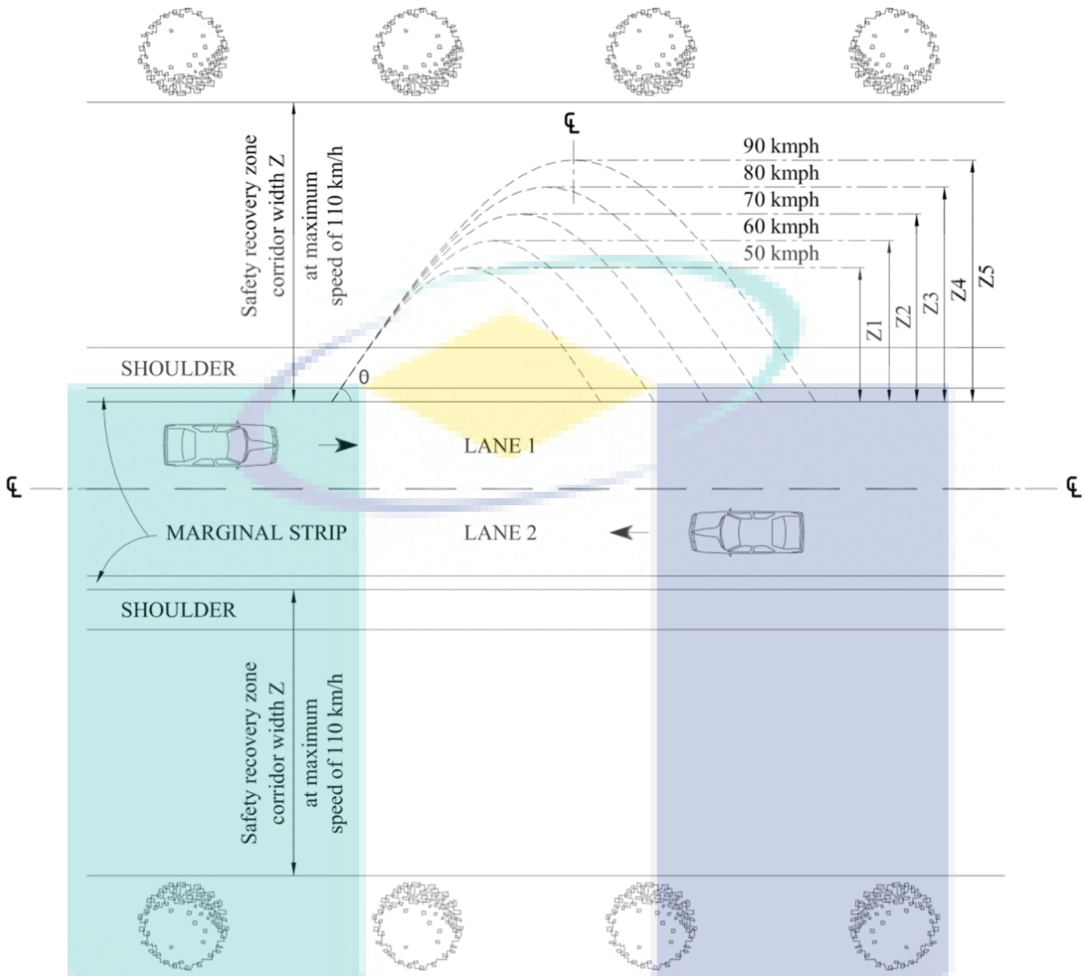


Figure 3.7 Influence of vehicle speeds on safety recovery zone corridor widths

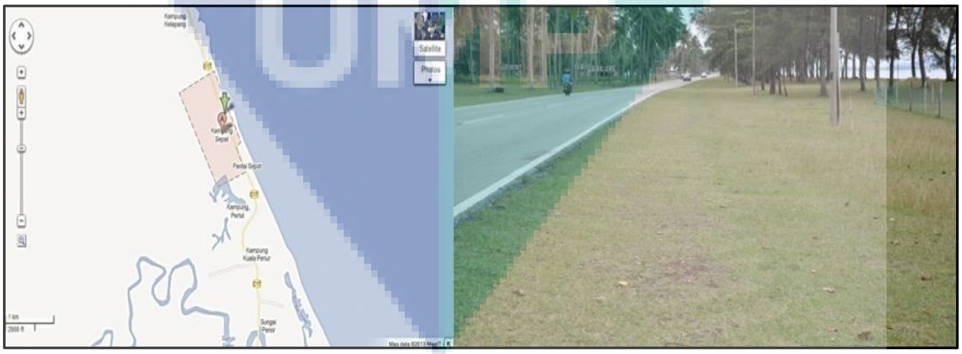
3.7 Selected Sites for Field Experiments

Based on the criteria outlined above, ten test sites selected from four states, namely Pahang, Johor, Selangor and Perak. The ten locations selected from had a set of variables in term of roadside slope gradients, a variety of soil type and ground surfaces conditions. All test fields selected were from rural roads at remote locations because they complied with the set criteria.

3.7.1 Pantai Sepat, Kuantan, Pahang

The Jalan Pantai Sepat, Kuantan in the state of Pahang was once a bustling road, but ever since the completion of Kuantan-Muadzam Highway, its traffic volume reduced substantially. The test location is shown in Figure 3.8. The broad roadside slope with clear open space, excellent ground and non-undulating surface, and having a very low traffic volume made it a chosen ground for the road testing work. Running along the roadside were telephone poles offset at about five metres from the travel lane and spaced at 30 metres centres did not obstruct the testing work. The roadside slope gradient of 1V:7.1H was in the range of selection criteria because gentler than 1V:4H roadside slope gradient for the safe driving test.

The surface of the test area consisted of short to medium-length grass surface on fine sandy clay soil. Some laterites and sands filled the interstices of the grass. The available testing trajectory space was 10 metres wide by 120 metres long. The utility poles offset were about 5 metres away from road edge and distributed at every 30 metres interval. Despite the ground surface has a very gentle slope and generous space, testing at 100 km/h and higher was not possible because of slippery laterite surface due to long weathering process removed the fine particles between coarse laterites made them in loose form. The slippery laterite has caused the driven car to slide sideways at 90 km/h at turning trajectory path. The road elevation against surrounding was shallow compared to other sites because of the non-flooding area contributed by good natural drainage adjacent to the sea. There were no drains beside the road contributed to fewer roadside hazards. The long and straight alignment of the road made the traffic observation during the testing process easy.



(a) Satellite map (b) Test site photo

Figure 3.8 Pantai Sepat at KM 35 Kuantan-Pekan, Pahang: (a) Satellite map and (b) Test site photo

3.7.2 Bukit Ibam, Pahang

The site is located at KM 9 to Bukit Ibam from Muadzam Shah in the state of Pahang, as shown in Figure 3.9. The roadside has adequate obstruction-free open space measuring approximately 8 metres width was suitable for test car traversability. The road with low traffic volume ensures a sufficient time frame for vehicle skidding and recovery test period for both driver and road user's safety. Generally, the ground surface was suitable for the road testing work, with the exception that some gravel may affect the test reading slightly. The roadside slope gradient of 1V: 5.6H fulfil the criteria limit of gentler than 1V:4H roadside slope gradient for a safe driving test.

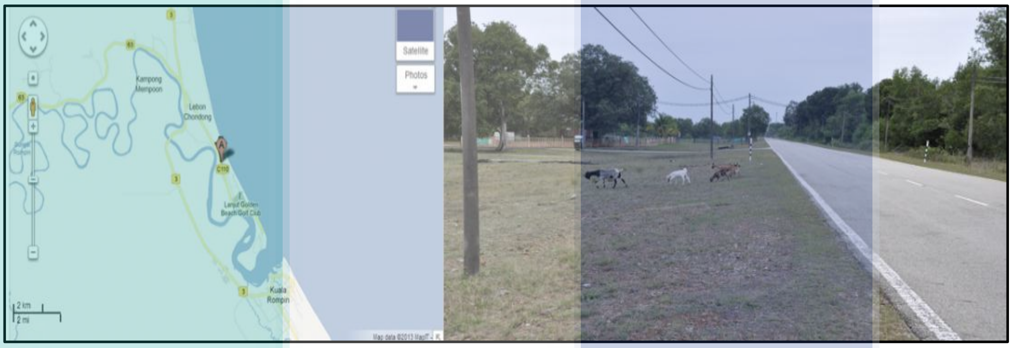
The surface conditions of the test area were low-density medium-length grass surface and topped with a mixture of laterite and crusher run on sandy clay ground. The available roadside testing trajectory space was 8 metres width by 150 metres long. The rough and undulating surface has slightly affected vehicle manoeuvring efficiency. The removable reflector sticks were located at 8 metres away from road edge and spaced at 30 metres intervals. On car skidding test at travelling speed of 70km/h, the driver experienced car sliding on making the turn and poor control due to bumpy and slippery ground surface. The driver requested not to proceed with the driving test at 80 km/h and above because he feared the situation would be unsafe.

(a) Satellite map (b) Test site photo

Figure 3.9 KM 9 Muadzam-Bukit Ibam Highway, Pahang: (a) Satellite map and (b) Test site photo

3.7.3 Pantai Lanjut, Kuala Rompin, Pahang

The test site is located 50 metres away from the golf resort at Pantai Lanjut, Kuala Rompin, Pahang, as shown in Figure 3.10. The roadside has adequate width of open space free of obstruction for approximately 20 metres from the edge of travel lane for skidding car to traverse back to travel lane on testing. The low traffic volume road is a suitable ground for safe road testing work because it permits enough traversing time for the car driving test. The utility poles situated at about 5 metres offset from the road edge and spaced at 33 metres centres were not obstructing for skidding vehicle trajectory path during testing activities. The roadside slope gradient of 1V:5.8H met the selection criteria gentler than 1V:4H roadside slope gradient for a safe driving test.



(a) Satellite map (b) Test site photo

Figure 3.10 Location at 50 m from Golf Club, Pantai Lanjut, Rompin, Pahang: (a) Satellite map and (b) Test site photo

The surface of the test area had more laterite than turf. The available testing trajectory space was 20 metres wide by 110 metres long. On driving test at 70 km/h, the driver experienced difficulty in handling the car sliding on laterite gravels and sand. The driver abandoned the driving test at 80 km/h and above on safety ground

3.7.4 Bandar Muadzam Shah, Rompin, Pahang

The site is located at KM 71 to Kuantan from Muadzam Shah in the state of Pahang, as shown in Figure 3.11. It has 10 metres wide by 140 metres long obstruction-free roadside space with low traffic volume at more than 20 seconds per vehicle passing. The well-turfed roadside slope surface with the gradient of 1V: 4.8H met the selection criteria limit of good surface condition and gentler than 1V: 4H for safe testing activities.

The roadside reflector stick was temporarily removed during the road test to allow for more car passage area. The test area is a lay by for vehicle stoppage.

(a) Satellite map (b) Test site photo

Figure 3.11 KM 71 Muadzam-Kuantan Highway, Pahang: (a) Satellite map and (b) Test site photo

The surface conditions of the test area were moderate lush medium-length grass surface grown on sandy clay soil. The available driving test trajectory space is 10 metres wide by 140 metres long. The reflector sticks were located 8 metres away from the road edge and spaced at 30 metres interval. The slippery, damp turf surface caused the vehicle to slide further than usual. The field condition was not suitable for test speed at 90 km/h and higher due to steep roadside slope gradient, close utility poles spacing and slippery damp turf conditions.

3.7.5 Bandar Tenggara, Kulai, Johor

Bandar Tenggara is located in the centre of the Kulai, Kota Tinggi and Kluang in the state of Johor, as shown in Figure 3.12. The roadside open space of about 6 metres wide by 90 metres long was a sufficient car trajectory's path. The ground surface with thick grass has increased the trajectory width due to slippage. The roadside slope gradient of 1V:6.7H gentler than 1V:4H and low traffic volume satisfied both the geometrical and safety requirements.

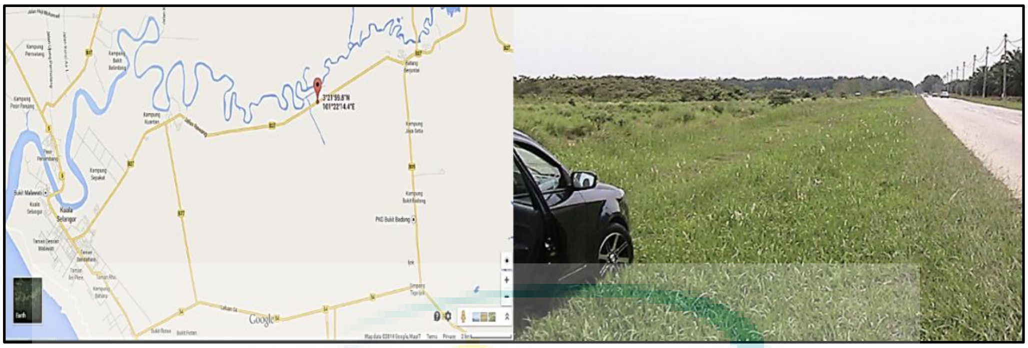
(a) Satellite map (b) Test site photo

Figure 3.12 KM 3 Bandar Tenggara from Kota Tinggi at Kampung Lukut, Johor: (a) Satellite map and (b) Test site photo

The surface conditions of the test area were lush medium - length grass surface. The damp grass surface in the morning has caused vehicle sliding when leaving the roadside and encroaching into the carriageway. The thick grass caused drying of morning dew took more extended time than short grass. The available car driving trajectory space was 6 metres wide by 90 metres long. The trees barrier located 6 metres offset from the road and sliding effect of long grass caused driving test at 80 km/h and above was not safe for execution. However, the site was selected to account for a more extensive sampling range

3.7.6 Rawang-Kuala Selangor Road, Selangor

The site is located at KM 32.4 from Rawang to Kuala Selangor through Jalan Rawang in the state of Selangor, as shown in Figure 3.13. It was a major road connecting Rawang in the east to Bestari Jaya (formerly known as Batang Berjuntai) in the west. Its tight roadside open space of 6 metres wide by 160 metres long corridor limited car skidding driving test to lower speeds only. The additional factors of low traffic volume and the gentle roadside slope gradient of 1V:5H, which is gentler than 1V:4H satisfied both safety and geometrical criteria to qualify the site for testing work. The thick uncut grass observed to be causing a slight sway when the car trajectory change direction. However, the site was selected to account for the impact of varying field conditions.



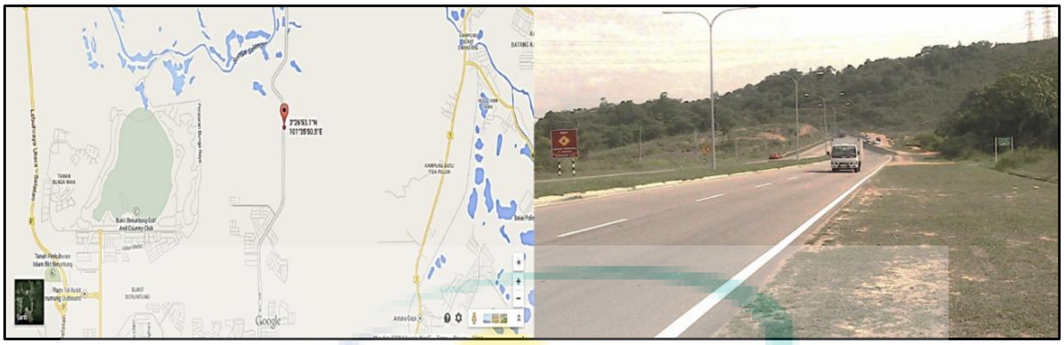
(a) Satellite map (b) Test site photo

Figure 3.13 KM 32.4 Rawang-Kuala Selangor Road: (a) Selangor Satellite map and (b) Test site photo

The surface conditions of the test area were medium to long, lush grass surface on sandy clay soil. Adjacent to carriageway was with laterite top. The available testing trajectory space was 6 metres wide by 160 metres long. Long grass caused car sliding when tyres turned direction in getting back to travel lane. The roadside drain was about 8 metres away from the road edge. The site condition did not permit for driving test speed at 80 km/h or higher due to vehicle sway on turning and risk of potential skidding into a nearby drain. Despite the car sliding factor, the site was chosen to account for a broader sampling range. The straight alignment road with wide-open space on one side of the road without utility poles was added advantage to observe oncoming traffic.

3.7.7 Kampung Chuang Rasa-Bukit Beruntung Road, Selangor

The site is located at KM 8.2 from Kampung Chuang Rasa to Bukit Beruntung route in the state of Selangor, as shown in Figure 3.14. It has right roadside corridor width of 8.5 metres free of obstruction with a concrete drain at the end of the turf. The roadside slope of 1V: 8.5H was gentler than 1V:4H and satisfied traversability requirement. The road low traffic volume was safe for vehicle skidding trajectory testing works. The ground surface little patches of loose turf but was acceptable for testing due to its gentle gradient did not affect safety for driving test. Despite the road's standard specified closed turfing, but the weathering process caused surface erosion resulted in the spot turfing condition. However, for the study outcome to represent new and old roads scenarios, the field was selected for the test works.



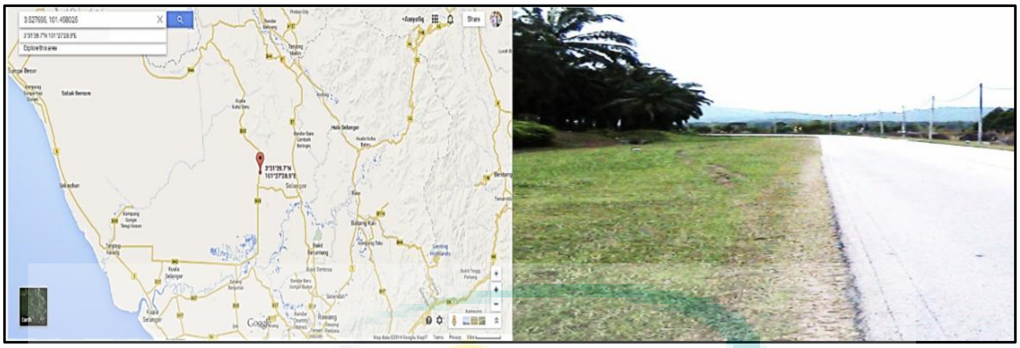
(a) Satellite map (b) Test site photo

Figure 3.14 KM 8.2 Kampung Chuang Rasa-Bukit Beruntung Road, Selangor: (a) Satellite map and (b) Photo of test site

The surface conditions of the test area have short grass and laterite on sandy clay soil. Adjacent to carriageway top surface was made of laterite soil. The available car driving test trajectory space was 8.5 metres wide by 130 metres long. The ground finish was rough and bumpy surface was not critical for low car travelling speeds. Roadside drain was located at about 14 metres from road edge. The field was not suitable for car driving test speed at 90 km/h or higher due to bumpy ground caused vehicle to become unstable for proper handling.

3.7.8 Kampung Fajar, Sungai Tengi, Selangor

The selected site is connecting Sungai Tengi to Kuala Selangor in the state of Selangor, as shown in Figure 3.15. The site is stretching along Oil Palm Plantation. The roadside corridor has functional open space and free of obstruction for 9 metres width by 120 metres long. The field tests accomplished for vehicle test speeds up to 80 km/h due to higher speed limited by track undulation. The long straight stretch alignment and well-turfed ground surface at the gradient of 1V:10H was ideal for safe driving test works because of less gravity pull.



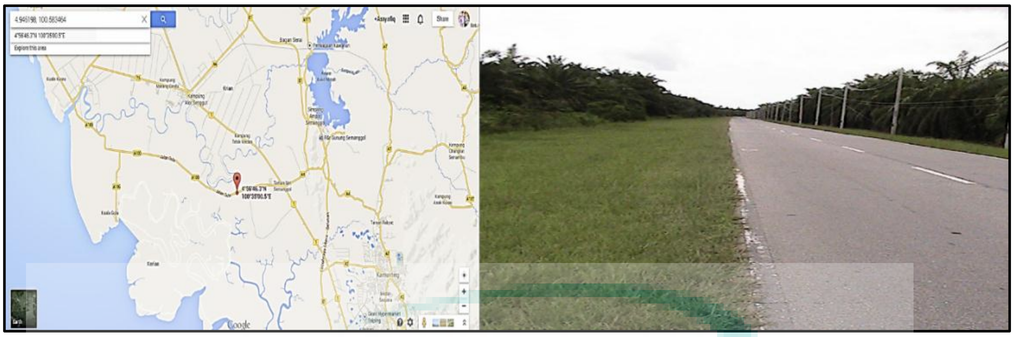
(a) Satellite map (b) Test site photo

Figure 3.15 KM 3 Kampung Fajar, Sungai Tengi, Selangor: (a) Satellite map and (b) Test site photo

The site condition of the test area was a medium density of short length grass surface on sandy clay soil. A small percentage of laterite and crusher run top was seen at the site table. The gentle roadside gradient made traversing easy. A drain was located at about 11 metres away from the road. The site was not suitable for test speed at 90 km/h or higher due to the bumpy ground had caused the vehicle to become unstable for proper handling.

3.7.9 Site A at KM 4 Simpang Empat to Kuala Kurau, Perak

Simpang Empat is a small town located at Kerian district in the state of Perak, as shown in Figure 3.16. Along the same road, two sites selected complied with the selection criteria for driving test works. Site A was located approximately at km 5 from the Simpang Empat heading to Kuala Kurau. The 10 metres width open space and free of obstruction roadside corridor gave functional space for car trajectory formation. The roadside gradient was 1H:5.3V gentler slope than 1V:4H required by site selection criteria for safe car traversing works.



(a) Satellite map (b) Test site photo

Figure 3.16 KM 4 from Simpang Empat to Kuala Kurau, Perak: (a) Satellite map and (b) Test site photo

The site conditions of the test area were medium to long, lush grass surface on sandy clay soil. Traces of laterite and crusher run was on the ground surface. Open car driving test trajectory was 10 metres wide by 150 metres long. The damp surface turf caused car sliding when vehicle changed direction and drain was at about 11 metres from the road edge.

3.7.10 Site B at KM 14 Simpang Empat to Kuala Kurau, Perak

Site B is located approximately at KM 14 from Simpang Empat to Kuala Kurau in the state of Perak, as shown in Figure 3.17. Situated 9 kilometres away from Site A, it has a significant roadside corridor of 9.5 metres width open space without obstruction. It was suitable for high travelling speed testing works. The gradient of 1V:4.6H is gentler than 1V:4H qualified for safe car traversing works.

(a) Satellite map (b) Test site photo

Figure 3.17 KM 14 from Simpang Empat to Kuala Kurau, Perak (Site B): (a) Satellite map and (b) Test site photo

The test area built with medium to long, lush grass surface on sandy clay soil. Traces of laterite and crusher run scattered on-site table. The available car driving test trajectory space was 9.5 metres wide by 150 metres long. The damp turf surface caused slight sliding when vehicle changed direction when making the required trajectory. A drain was at about 11 metres from the road edge. Utility poles were at about 10 metres from the road edge.

3.8 Data Collection

Data collection is the process of measuring and gathering field test information on variables of interest, i.e. gradient of the roadside *S*, the test car travelling speed *V* in km/h, width of safety zone corridor trajected in metres *Z* in an established systematic fashion that enables answering the research questions, test hypotheses, and evaluate outcomes. The width of errant vehicle skidding trajectory path herein named as safety recovery zone corridor *Z* is influenced by the roadside slope gradient *S* and the car travelling speed *V*. The data successfully collected from all fields with a variation on maximum travelling test speeds depending on the individual field ground conditions. The two main factors that restricted the driving tests at high speeds were firstly due to limited size of corridor space for car traversability in making the trajectory, and secondly, the uneven ground surface that caused vehicles instability in traversing suggesting motorists were in an unsafe environment. The recorded values of safety zone corridor widths Z that correspond to untested higher travelling speeds were determined by statistical computation.

3.9 Regression Analysis

Regression analysis is a statistical process for estimating the relationships between dependent variables with that of independent variables (or predictors). In this context, the dependent variable is safety recovery zone corridor width *Z*, and the independent variables are roadside gradient S and a vehicle travelling speed *V*. Microsoft Excel for Mac version 16.28 has the in-built statistical facility to perform regression analysis and able to generate trendline and regression function. The software used to produce in building a line graph and column graph. The use of linear regression analysis describes the model that best fit for the relationship between dependent and independent or predictor variables (Kumari, K. et al., 2018). The line graphs were for each site by entering data on vehicles' travelling speeds *V* on the x-axis by placing them on the spreadsheet left column and mean values of safety recovery zone corridor widths *Z* on the right column of the sheet. Then, the process continued by highlighting the range of figures to be placed in graph, under the insert tab select line chart from the ribbon list, and the graph was produced complete with the model equation. The same spreadsheet with the addition of standard deviations and standard errors values filled proceeded to the selection of column graph under the insert tab. Thus, produced the column graph. Applying the equation with the input of speeds, the unmanaged field values of *Z* for high travelling speeds were obtained. Having gathered all the data from the ten test sites, summary tables of all vehicle speeds *V*, safety recovery zone corridor widths *Z* and respective roadside slope gradients *S* were tabulated and evaluated.

For each test travelling speeds *V*, a graph of safety recovery zone corridor width *Z* versus various roadside slope gradients *S* were plotted. Based on the trendline equation, lists of *Z* values for roadside slope series of 1V:4H, 1V:5H, 1V:6H, 1V:7H, 1V:8H, 1V:9H and 1V:10H obtained for each travelling speed of 50 through 110 km/h. Roadside slope gentler than 1V:10H will adopt the same values of *Z* as for 1V:10H. Based on the tabulated values of *Z* and *S* for various values of *V*, graphs plotted, and trendlines generated. Based on the trendlines, new redefine values of *Z* obtained and compiled in a final table of *Z*, *S* and *V* values which can be referenced for road engineering design works.

3.10 Factor of Safety

If necessary, one may apply a factor of safety in the form of a multiplier to modify the safety recover zone widths *Z* values to compensate for the degree of uncertainties contributed by the undervalue of *Z* contributed by several factors. Among the factors were conscious of the panic condition of driving, different level of driving skills of drivers, different level of car performance of the test car and the actual, error contributed by the statistical software used and the varying site conditions.

The factor of safety applied to the final values of safety recovery zone corridor widths discussed in Chapter 4. The widths given were from averages of the field tests, and processed by statistical software analysis accounted with data from all the sites. Given a tremendous number of sampling with a total of 180 tests carried out obtained from ten locations with four drivers and four cars, increasing the outcome with a factor of safety deem unnecessary. Increasing the size of Z with a factor of safety is increasing the cost of construction works such as the volume of material, machinery and workforce. Design engineers may increase the Z values with the factor of safety base on the risk level of site conditions such as apply higher factor up to 1.5 for road bends.

3.11 Summary

The observational study through live experiment chosen was because it gives a real-life situation, and considering the absence of data of past accident records for roadside crashes. In ensuring safe live field testing, selection of experiment test sites was based on the frequency of traffic in relation to the safe car skidding trajectory time, i.e. 20 seconds or twice the actual skidding car recovery time to get back to travel lane. The skidding cars were able to traverse back to travel lane because the geometry of the roadside slope gradients was not steeper than 1V:4H and having adequate corridor space to suit a particular car travelling speed. The vehicle's exit angle adopted for the field driving test was based on the fact that 70% of run-off-road accidents took place at the vehicle's exit angle at 20 degrees and less, and thus 20 degrees exit angle adopted. The significance of live field test method employed yields integral outcome of safety recovery zone corridor widths between the reaction of the drivers, the roadsides geometries and conditions. The data obtained represents the majority of roadside accident cases.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Data Collection and Analysis

Field experiments data were collected from ten sites as selected and discussed in Chapter 3 Research Methodology. The whole process of finding suitable sites and testing took six months for completion. Despite constraints on safety, weather condition, drivers and working crew fitness and vehicles' condition, all test were successfully carried out with reliable data outcome. All data output was closely associated with fields conditions. Discussions on the result of each site were tied-up with fields conditions as detailed in research methodology. Thus, analysis of the results was read in conjunction with the methodology. Variation of results was expected due to a set of variables introduced into the live fields experiments, namely ten test sites with different ground conditions, four cars and four drivers

4.1.1 Field Experiments at Pantai Sepat, Kuantan, Pahang

The field experiments executed in accordance with the prescribed Research Methodology in Chapter 3. The selected site was among the most convenient and safest for the car driving test works due to its roadside corridor has wide open space and free of obstruction with the road served a low volume of traffic. Prior to the actual car driving test, several trial run activities were carried out at the adjacent site to instil comfort and confidence to the driver for producing realistic results. Concurrently, the video recording and traffic monitoring crew made their trial recording works.

The test ground was marked with the 20 degrees exit angle using the triangular angle plate, and red-painted wooden sticks pegged at every 500 mm interval perpendicularly offset to travel lane as prescribed in the methodology. The tests were carried out for the speeds from 50 km/h through 90 km/h at the interval of 10 km/h. The driving tests could not be carried out at 100 km/h and 110 km/h due to the close spacing between the electrical cable poles running along the road did not allow the driver to perform trajectory required. The experiments were carried out in the morning in fine weather, and the whole works took 6 hours to complete.

The collected experiment data with computed standard deviation and standard error are shown in Table 4.1. Plotting the measured values of safety recovery zone corridor width *Z* versus the vehicle's travelling speeds *V*, produced a graph is shown in Figure 4.1. The software generated statistical trendline equation shows the relationship between *Z* and *V* as $Z = 0.066V - 1.1098$. The linear model generated from this data provides the percentage of response variable at the variation of 91%. Deprivation of model fitness appears to be caused by the variation of testing ground condition, which affected the friction and sliding course of the tested car. The model percentage indicates a very confident prediction of *Z* values for a car travelling speed between 50 to 90 km/h. Based on the model equation, the predicted values of *Z* for the tested vehicle speeds between 50 km/h through 90 km/h and the predicted values of *Z* for the untested vehicle speed of 100 km/h and 110 km/h are shown in Table 4.2.

Table 4.1 Field experiments results for the roadside fore-slope gradient of 1V:7.1H at KM 35 Kuantan-Pekan Highway in the District of Pekan, Pahang

Speed *V* (km/h)	**Safety Recovery Zone Corridor Width *Z* (m)**						**Standard Deviation**	**Standard Error**
	Test 1	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Mean**		
50	2.53	2.48	2.56	2.51	2.11	2.438	0.186	0.083
60	2.84	2.79	3.16	2.83	2.78	2.880	0.159	0.071
70	2.91	3.22	3.38	2.99	2.82	3.064	0.231	0.103
80	4.51	3.04	4.12	4.53	3.65	3.970	0.631	0.282
90	4.99	5.04	5.33	5.29	5.31	5.192	0.163	0.073

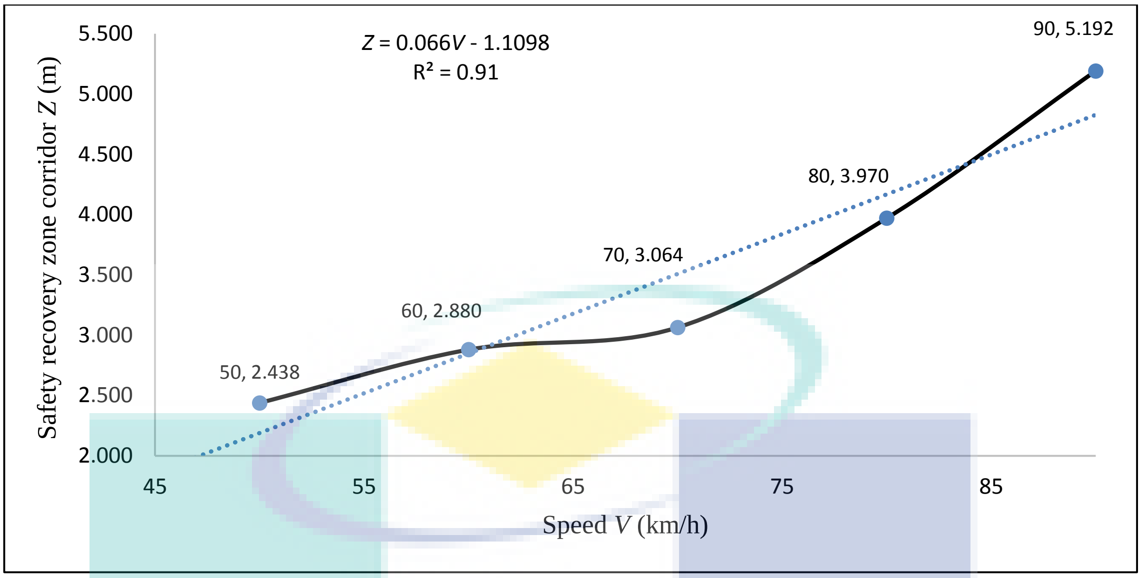


Figure 4.1 Safety recovery zone corridor widths *Z* versus vehicle travelling speeds *V* for roadside fore-slope gradient 1V:7.1H at Pantai Sepat, Kuantan translated from Table 4.1.

Plotting the mean values of *Z* against travelling speeds *V* with standard errors from Table 4.2, a column chart as shown in Figure 4.2 is produced. The figure shows the largest error bar at the car travelling speed of 80 km/h (indicated by depth of error reflector on top of the column) instead of at the highest speed of 90 km/h reporting that the longer turfgrass ground condition at earlier track is slightly more slippery as compared to the later track causing the tyres to slide more on turning on changing direction. In contrast, it can be seen the lowest error of margin is at the speed of 60 km/h instead of at 50 km/h, revealing the longer turf grass on the 60 km/h trajectory path giving more sliding effect on tyres. Based on the horizontal position of error bar caps, at the car travelling speed between 60 to 70 km/h, the variation of *Z* does not differ significantly because the condition of the ground at their trajectory paths are quite similar. Other pairs of the error bar at different car travelling speeds can be confidently stated to possess significant difference as the error bar caps are quite separated vertically. The standard errors were not arithmetic in nature, but they were qualitative, reflecting the varying grounds surface conditions producing changing frictional reactions with car tyres.

Table 4.2 Z values based on statistical trendline equation for test results at Pantai Sepat, Daerah Kuantan, Pahang

Z values based on Z = 0.066V – 1.1098 for slope 1V:7.1H							
***V* (km/h)**	50	60	70	80	90	100	110
***Z* (m)**	2.190	2.850	3.510	4.170	4.830	5.490	6.150

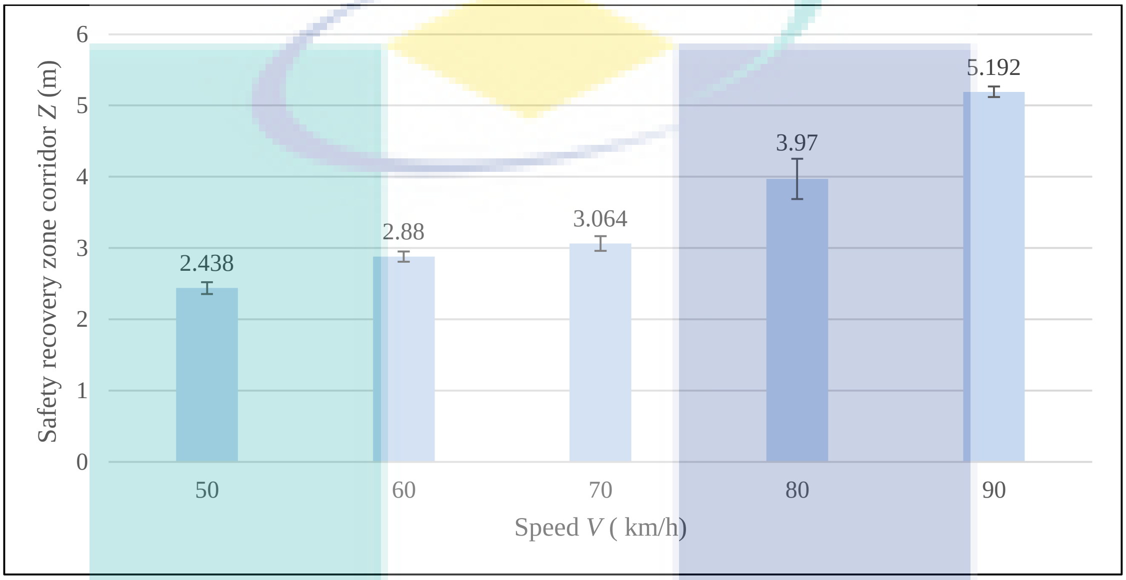


Figure 4.2 Mean of Z versus vehicle travelling speeds V for roadside fore-slope gradient 1V:7.1H at Pantai Sepat, Kuantan translated from Table 4.1.

4.1.2 Field Experiments at Bukit Ibam, Pahang

The field experiments were executed in accordance with the prescribed Research Methodology in Chapter 3. The tests were carried out for the vehicle travelling speeds of 50 km/h, 60 km/h and 70 km/h. The driving tests at the speed of 80 km/h and above were not carried out due to car handling problem when the car was travelling at higher than 70 km/h. The steep roadside slope of 1V:5.6H contributed to the main handling problem. Moreover, the ground surface partly made up of laterite and crusher run. The collected experiment data with computed standard deviation and standard error are shown in Table 4.3. The experiment was carried out in the morning in fine weather, and the whole process took 5 hours. The roadside slope gradient was quite steep compared to other sites, and tend to produce more tyre slide when tested in the morning due to moisty grass condition. Producing higher slide will increase the safety zone corridor widths were favourable because resulting in more conservative values.

Table 4.3 Field experiments results for the roadside fore-slope gradient of 1V:5.6H KM 9 to Muadzam-Bukit Ibam Highway, Rompin, Pahang

Speed *V* (km/h)	**Safety Recovery Zone Corridor Width *Z* (m)**						**Standard Deviation**	**Standard Error**
	Test 1	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Mean**		
50	3.10	3.02	3.26	3.17	3.44	3.198	0.162	0.072
60	3.81	3.94	3.72	3.46	4.04	3.794	0.223	0.100
70	4.76	4.64	4.37	4.23	4.88	4.576	0.270	0.121
80	Site condition does not permit safe testing					-	-	-

Plotting the values for the vehicle travelling speeds V versus average safety recovery zone corridor widths Z, a linear graph, as shown in Figure 4.3 is produced. Generally, the graph shows the safety recovery zone corridor widths Z increase as the vehicle speeds increase indicates the tests were in good order. The collected data generated statistical trendline equation shows the relationship between Z and V as $Z = 0.0689V - 0.278$. The linear model generated from this data provides the percentage of response variable variation at 99%. Deprivation of model fitness appears to be caused by the variation of testing ground condition, which affected the friction and sliding course of the tested car. The model percentage indicates a very confident prediction of Z values for a car travelling speed between 50 to 70 km/h. Based on the linear model, the predicted values of Z for the tested vehicle speeds between 50 km/h through 70 km/h and the values of Z for the untested vehicle speed of 80 km/h, 90 km/h, 100 km/h and 110 km/h are shown in Table 4.4.

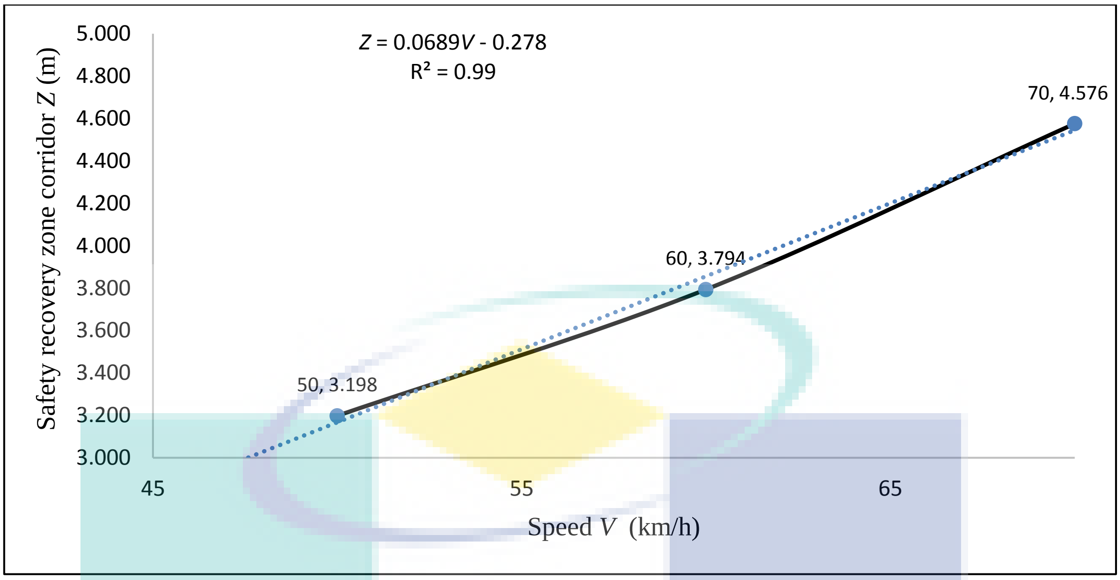


Figure 4.3 Roadside safety recovery zone corridor width *Z* versus vehicle speeds *V* for roadside fore-slope gradient 1V:5.6H at KM 9 to Bukit Ibam from Muadzam Shah, Pahang

Plotting the mean values of *Z* against travelling speeds *V* with standard errors from Table 4.4, a column chart as shown in Figure 4.4 is produced. The figure shows the largest error bar at the car travelling speed of 70 km/h indicating that at the uniform ground condition the error bar margin increases with the increase of car travelling speed giving rise to sliding force as the tyres changed in direction. In contrast, it can be seen that the error of margin is minimum at the lowest speed of 50 km/h, revealing that the driver has better control of the car when driving at low speed. Noticeably, at all the car travelling speed between 50 to 70 km/h, the variation in the safety recovery zone corridor width *Z* differed significantly due to the steep slope gradient influenced the car movement trajectory paths with higher downward force.

Table 4.4 *Z* values based on statistical trendline formula for test results at KM 9 to Bukit Ibam from Muadzam Shah, Pahang

***Z* values based on *Z* = 0.0689*V* - 0.278 for slope 1V:5.6H**							
***V* (km/h)**	50	60	70	80	90	100	110
Z	3.167	3.856	4.545	5.234	5.923	6.612	7.301

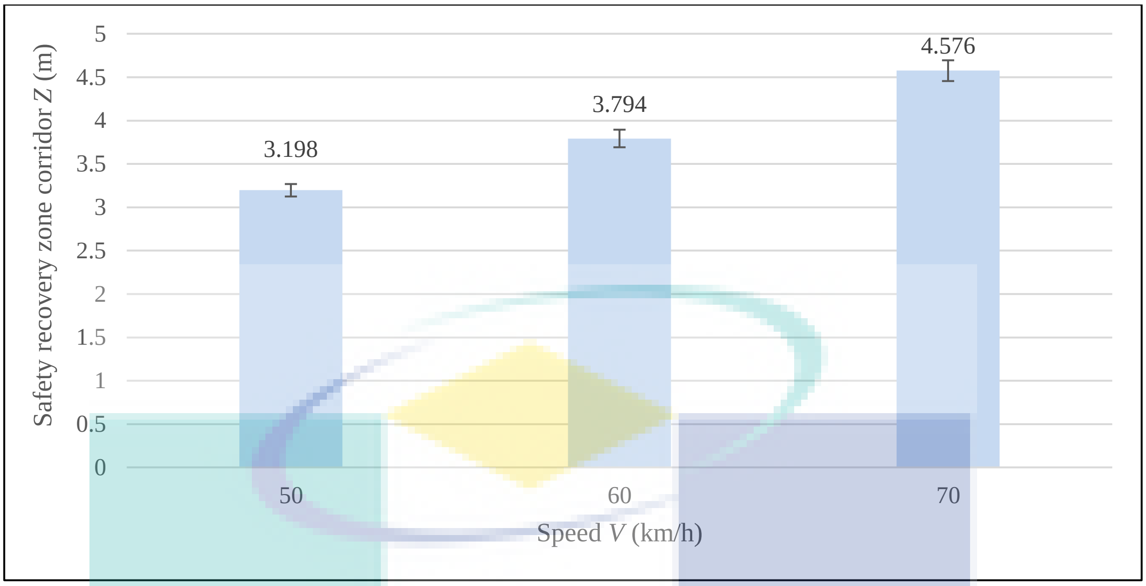


Figure 4.4 Mean of Z versus vehicle speeds V for roadside fore-slope gradient 1V:5.6H at KM 9 to Bukit Ibam from Muadzam Shah, Pahang

4.1.3 Field Experiment at Pantai Lanjut, Kuala Rompin, Pahang

The field experiments were executed in accordance with the prescribed Research Methodology in Chapter 3. The tests were carried out for the travelling speeds of 50 km/h, 60 km/h and 70 km/h. Test at a higher car travelling speed was not safe due to car handling difficulty on the steep roadside slope of 1V:5.8H. In addition, the presence of laterite on ground surface caused a slippery condition. The experiment was carried out in the morning in fine weather, and the whole process took 5 hours.

The collected experiment data with computed standard deviation and standard error are shown in Table 4.5. Plotting the values for the vehicle travelling speeds V versus average safety recovery zone corridor widths Z, a linear graph as shown in Figure 4.5 is produced. The steady inclined graph shows the safety recovery zone corridor widths Z increase as the vehicle speeds increase indicates the tests were in order. The generated statistical trendline equation shows a relationship between Z and V as $Z = 0.0788V - 1.1813$. The linear model generated from this data provides the percentage of response variable variation at nearly 100%. Less deviation of model fitness appears to be caused by the uniform testing ground condition, which did not affect the friction and sliding course of the tested car. The model percentage indicates a very confident prediction of Z values for a car travelling speed between 50 to 70 km/h. Based on the model equation, the predicted values of Z for the tested vehicle speeds between 50 km/h through 70 km/h and the values of *Z* for the untested vehicle speed of 80 km/h, 90 km/h, 100 km/h and 110 km/h are shown in Table 4.6.

Table 4.5 Field experiments results for the roadside fore-slope gradient of 1V:5.8H at 50 metres away from Lanjut Golf Resort, Kuala Rompin, Pahang

Speed (km/h)	**Safety Recovery Zone Corridor Width *Z* (m)**						**Standard Deviation**	**Standard Error**
	Test 1	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Mean**		
50	2.84	2.87	2.67	2.63	2.82	2.766	0.108	0.048
60	3.49	3.04	2.79	4.23	4.11	3.532	0.636	0.284
70	4.44	4.05	4.34	4.17	4.71	4.342	0.255	0.114
80	Site condition does not permit safe testing					-	-	-

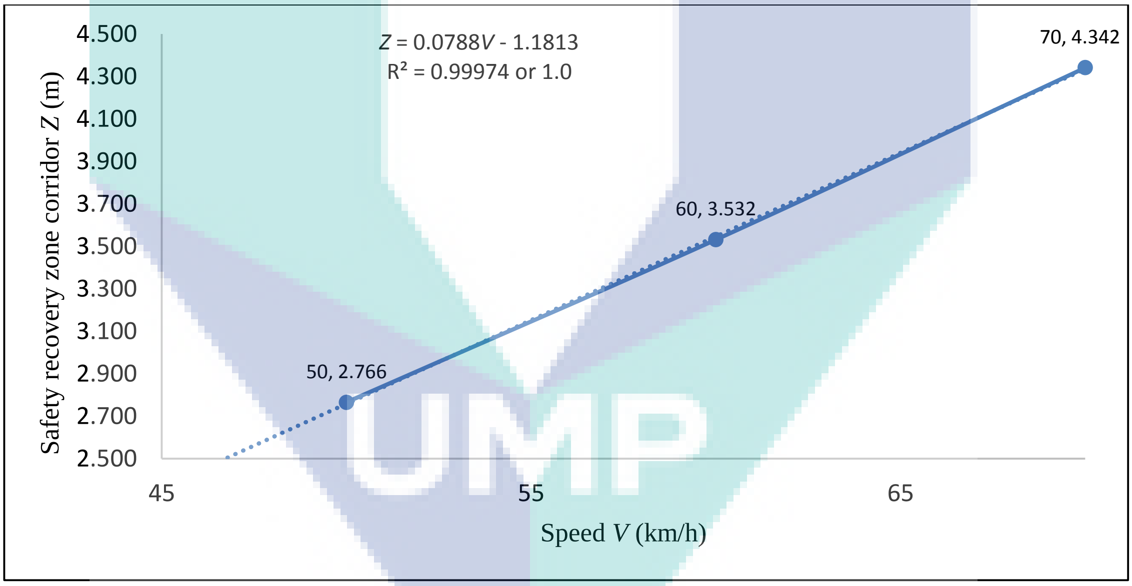


Figure 4.5 Roadside safety recovery zone corridor widths *Z* versus vehicle speeds *V* for roadside fore-slope gradient 1V:5.8H at 50 Metres away from Golden Beach Resort at Pantai Lanjut, Rompin, Pahang

Plotting the mean values of *Z* against travelling speeds *V* with standard errors, a column chart as shown in Figure 4.6 is produced. The figure shows that at the car travelling speed of 60 km/h has a larger error bar than the higher travelling speed of 70 km/h. It indicates that the higher density of laterite particles on the ground surface at 60 km/h trajectory path caused tyres sliding, giving a higher variation of *Z* values. Interestingly, it shows that under a specific environment, the condition of the ground surface may have a stronger influence than the travelling speed on the amount of *Z*. In contrast, it can be seen the margin of errors is minimum at lowest speed of 50 km/h, revealing that the driver has better control of the car when driving at low speed. Noticeably, at all the vehicle travelling speeds between 50 to 70 km/h, the variation in the safety recovery zone corridor width *Z* differ significantly because of the steep slope gradient skidding force making a bigger trajectory loop.

Table 4.6 *Z* values based on trendline equation for test results at Lanjut Golf Resort, Lanjut, Rompin, Pahang

***Z* values based on $Z = 0.0788V - 1.1813$ for slope 1V:5.8H**							
***V* (km/h)**	50	60	70	80	90	100	110
***Z* (m)**	2.759	3.547	4.335	5.123	5.911	6.699	7.487

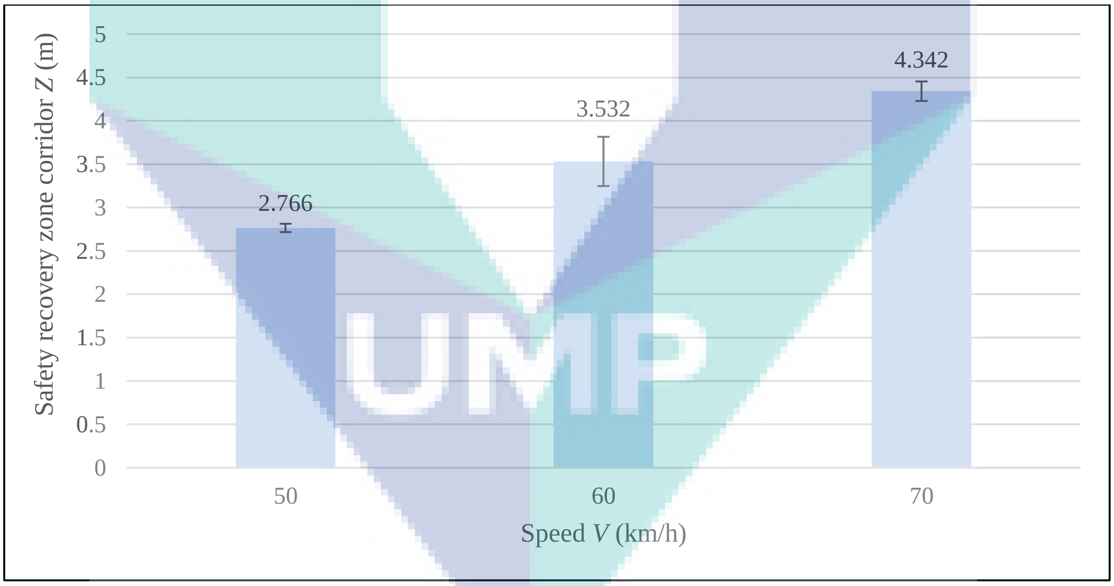


Figure 4.6 Mean of *Z* versus vehicle speeds *V* for roadside fore-slope gradient 1V:5.8H at 50 metres away from Golden Beach Resort at Pantai Lanjut, Rompin, Pahang

4.1.4 Field Experiment at Bandar Muadzam Shah, Rompin, Pahang

The field experiments were executed in accordance with the Research Methodology in Chapter 3. The tests were carried out for the vehicle travelling speeds of 50 km/h, 60 km/h, 70 km/h and 80 km/h. The driving test at the speed of above 80 km/h showed a sign of car handling problem resulting in the higher travelling speed was not carried out for safety reason. The car handling limitation was contributed by the steep roadside slope of 1V:4.8H and damp turf surface condition. The experiment was carried out in the morning in fine weather, and the whole process took 5.5 hours.

The collected experiment data with computed standard deviation and standard error is shown in Table 4.7. Plotting the values for vehicle travelling speeds *V* versus the average safety recovery zone corridor widths *Z*, it produces Figure 4.7. Generally, the graph shows the safety recovery zone corridor widths Z increase as the speeds V increase. The uniformly inclined graph indicates that the data collected is consistent and tests were successfully carried out. The software generated statistical trendline equation shows the relationship between *Z* and *V* as $Z = 0.0652V + 0.3018$. The linear model generated from this data provides the percentage of response variable variation at nearly 90%. The model percentage indicates a confident prediction of *Z* values for a car travelling speed between 50 to 80 km/h. Based on the discovered equation, the refined values of *Z* for the tested vehicle speeds of 50 km/h, 60 km/h, 70 km/h and 80 km/h, and the values of *Z* for the untested vehicle speed of 90 km/h, 100 km/h and 110 km/h are shown in Table 4.8.

Table 4.7 Field experiments results for the roadside fore-slope gradient of 1V:4.8H at Muadzam, Daerah Pekan, Pahang

Speed *V* (km/h)	**Safety Recovery Zone Corridor Width *Z* (m)**						**Standard Deviation**	**Standard Error**
	Test 1	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Mean**		
50	3.45	3.95	3.80	3.95	3.52	3.734	0.237	0.106
60	4.21	4.04	3.95	4.20	4.29	4.138	0.139	0.062
70	4.22	4.24	4.53	4.52	4.96	4.494	0.299	0.134
80	5.53	5.67	5.74	6.04	5.96	5.788	0.210	0.094
90	Site does not permit safe testing					-	-	-

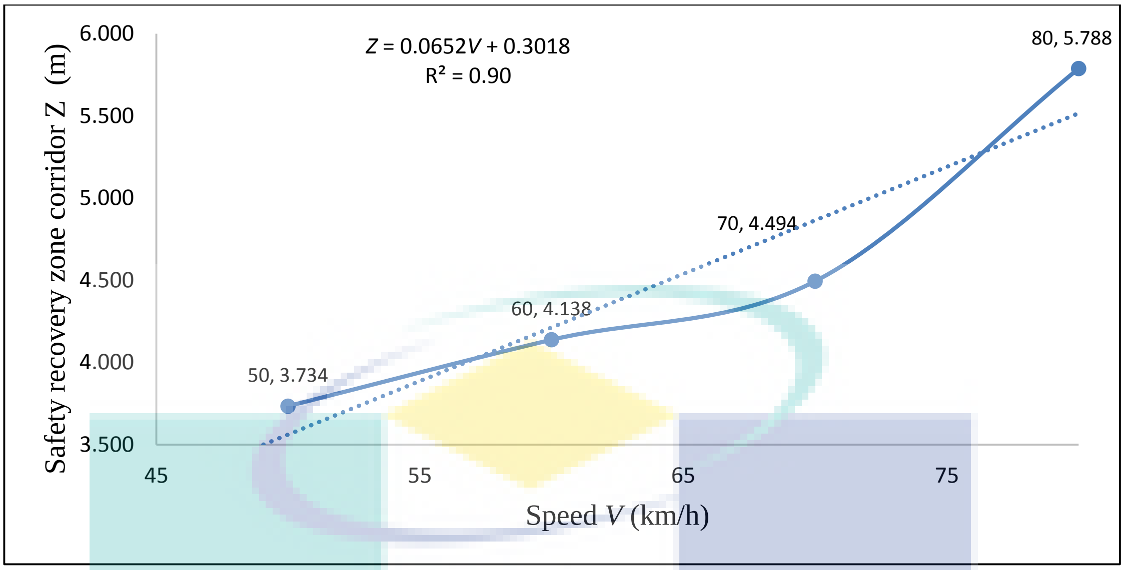


Figure 4.7 Roadside safety recovery zone corridor widths *Z* versus vehicle speeds *V* for roadside fore-slope gradient of 1V:4.8H At KM 71 Muadzam-Kuantan, Pahang

Plotting the mean values of *Z* against travelling speeds *V* with standard errors, a column chart as shown in Figure 4.8 is produced. The figure shows that at the car travelling speed of 70 km/h, the error bar is at the highest indicating that the trajectory path ground condition contributed to car handling difficulty. It is interesting to note that the 70 km/h turning trajectory path had wet and long grass turf caused the extended tyres sliding, giving a higher variation of *Z* values. The high error bar margin can be concluded due to the car handling limitation on the wet and long grass surface. It can be seen from the figure that the margin or errors are lowest at the speed of 60 km/h instead of at the lowest speed of 50 km/h. This phenomenon reveals that the variation of *Z* value is lesser on the shorter grass surface. Noticeably, at all the car travelling speeds between 50 to 70 km/h, the variation in the safety recovery zone corridor width *Z* differ moderately but significantly from the speed of 70 km/h to 80 km/h based on the column chart difference in elevation.

Table 4.8 *Z* values based on trendline formula for test results at KM 71 to Muadzam Shah-Kuantan Highway, Pahang

***Z* values based on *Z* = 0.0652*V* + 0.3018 for slope 1V:4.8H**							
***V* (km/h)**	50	60	70	80	90	100	110
Z	3.562	4.214	4.866	5.518	6.170	6.822	7.474

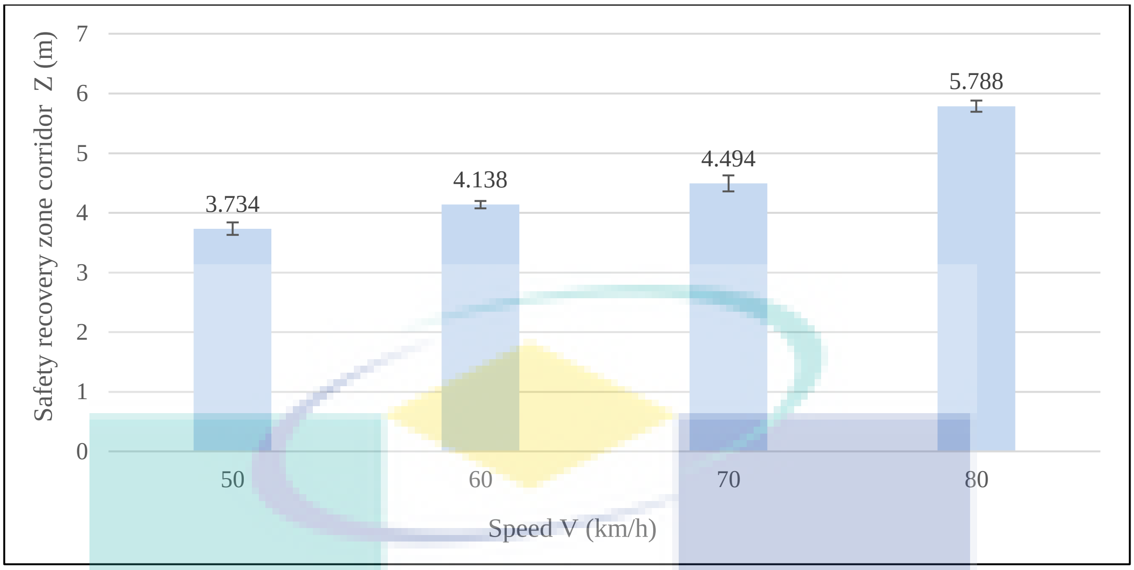


Figure 4.8 Mean of Z versus vehicle speeds V for roadside fore-slope gradient of 1V:4.8H at KM 71 Muadzam-Kuantan, Pahang

4.1.5 Field Experiment at Bandar Tenggara, Kulai, Johor

The field experiments were executed in accordance with the prescribed Research Methodology in Chapter 3. The tests were carried out for the travelling speeds at 50 km/h, 60 km/h and 70 km/h. The car driver experienced handling difficulty when traversing on long grassed turf at the speed higher than 70 km/h resulting test at 80 km/h and above was skipped for safety reason. The experiment was carried out in the morning in fine weather, and the whole process took 5 hours.

The collected experiment data with computed standard deviation and standard error are shown in Table 4.9. Plotting the values for speeds V versus average safety recovery zone corridor widths Z, Figure 4.9 is produced. In all cases, the graph shows the safety recovery zone corridor widths Z increase as the speeds V increase. The steady inclined graph indicates that the tests were successfully carried out. The generated statistical trendline equation gives a linear model relationship between Z and V as $Z = 0.0701V – 0.7793$. The linear model generated from this data provides the percentage of response variable variation (or R2) at nearly 100%. The model percentage indicates a very reliable prediction of Z values for a car travelling speed between 50 to 70 km/h. Based on the model of the equation, the predicted values of Z for the vehicle speeds V of 50 km/h to 110 km/h are shown in Table 4.10.

Table 4.9 Field experiments results for the roadside fore-slope gradient of 1V:6.7H at KM 3 Kota Tinggi-Bandar Tenggara, Kota Tinggi, Johor

Speed *V* km/h	**Safety Recovery Zone Corridor Width *Z* (m)**						**Standard Deviation**	**Standard Error**
	Test 1	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Mean**		
50	2.52	2.67	2.73	2.78	3.02	2.744	0.183	0.082
60	3.31	3.29	3.53	3.38	3.44	3.390	0.098	0.044
70	4.32	3.38	4.23	4.81	3.99	4.146	0.522	0.233
80	Site condition does not permit safe testing					-	-	-

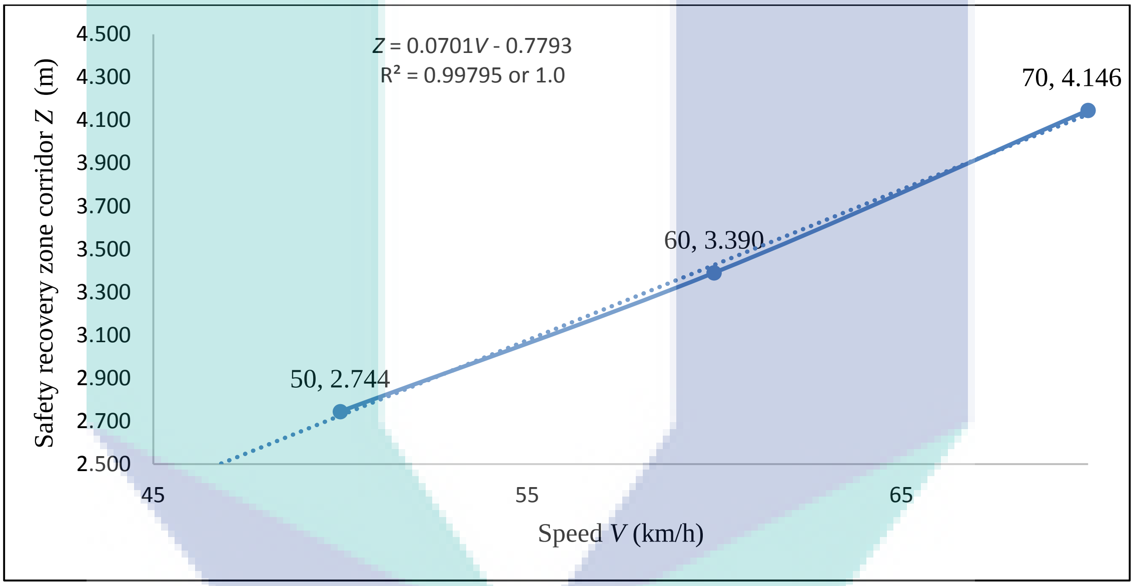


Figure 4.9 Safety recovery corridor width *Z* versus vehicle speeds *V* for roadside fore-slope 1V:6.7H at Bandar Tenggara, Daerah Kota Tinggi, Johor

Plotting the mean values of *Z* against travelling speeds *V* with standard errors, a column chart as shown in Figure 4.10 is produced. The chart shows the largest error bar in the car travelling speed of 70 km/h than other travelling speeds. It indicates that the variation in the value of *Z* for this speed was greatly influenced by the combined effect of higher sliding momentum contributed by higher speed and lack of friction in wet long grassed turf causing the aggressive slide when the car was turning direction. The smallest error bar is found at the car travelling speed of 60 km/h instead at a lower speed of 50 km/h. As the experiment was carried out in the morning, the surface condition is slightly wet due to overnight dew, the trajectory path at 60 km/h is wetter than 50 km/h as it is away from drying effect of passing by cars causing it to gain higher error margin for *Z*.

This phenomenon reveals that the drifting of *Z* value is also greatly controlled by the climatic and locality influence to ground condition. Noticeably, at all the car travelling speeds between 50 to 70 km/h, the variation in the safety recovery zone corridor width *Z* differ significantly because of the overnight dew, travelling speeds, locality and roadside slope gradients.

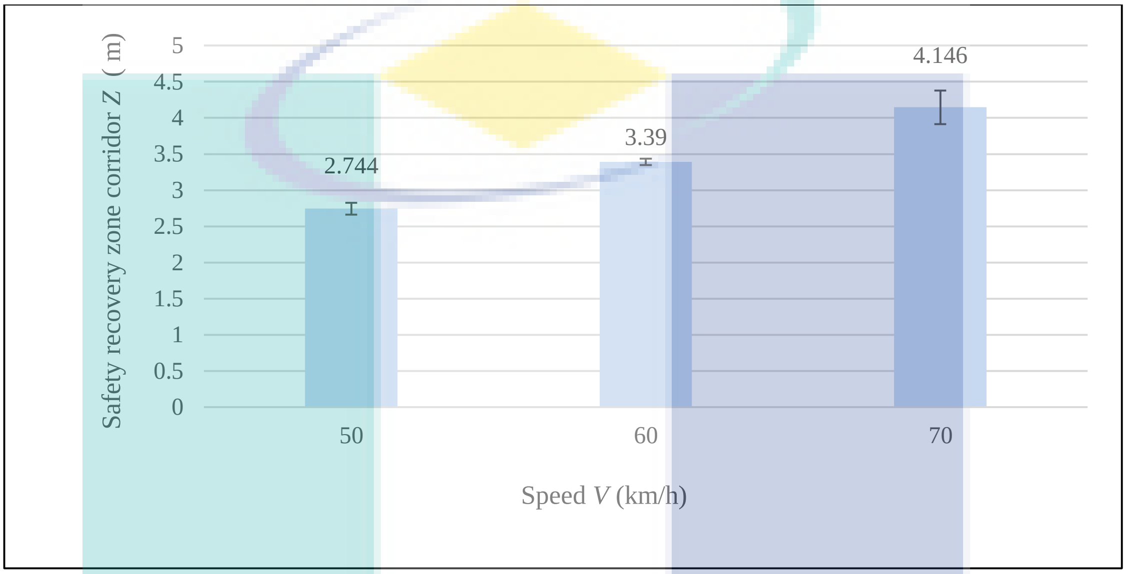


Figure 4.10 Mean of *Z* versus vehicle speeds *V* for roadside fore-slope 1V:6.7H at Bandar Tenggara, Daerah Kota Tinggi, Johor

Table 4.10 *Z* values based on trendline formula for test results at Bandar Tenggara, Daerah Kota Tinggi, Johor

***Z* values based on $Z = 0.0701V - 0.7793$ for slope 1V:6.7H**							
***V* (km/h)**	50	60	70	80	90	100	110
Z	2.726	3.427	4.128	4.829	5.530	6.231	6.932

4.1.6 Field Experiment at Road Between Rawang to Kuala Selangor

The field experiments were executed in accordance with the prescribed Research Methodology in Chapter 3. The tests were carried out for the speeds of 50 km/h, 60 km/h and 70 km/h. The test speed of 80 km/h and above were not executed due to car handling difficulty experienced by the driver when travelling speed exceeding 70 km/h. The experiment was carried out in the morning in fine weather, and the whole process took 5 hours.

The collected experiment data with computed standard deviation and standard error is shown in Table 4.11. Plotting the values for vehicle *V* speeds versus average safety recovery zone corridor widths *Z*, it gives Figure 4.11. It has been shown that for all travelling speeds, the graph shows the safety recovery zone corridor widths *Z* increase as the travelling speeds V increase. The steady inclined graph indicates that the tests were successfully carried out. The software generated statistical trend line equation gives $Z = 0.0577V + 0.59$ with R2 value of 0.99. The model 99% value informs that *Z* values can safely be predicted from the model equation. Based on the model equation, the predicted values of *Z* for the tested vehicle speeds of 50 km/h, 60 km/h and 70 km/h, and the values of *Z* for the untested vehicle speed of 80 km/h, 90 km/h, 100 km/h and 110 km/h are shown in Table 4.12.

Table 4.11 Field experiments results for the roadside fore-slope gradient of 1V:5H at road from Rawang to Kuala Selangor

Speed *V* km/h	**Safety Recovery Zone Corridor Width *Z* (m)**						**Standard Deviation**	**Standard Error**
	Test 1	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Mean**		
50	3.53	3.97	3.22	3.35	3.12	3.438	0.335	0.150
60	4.04	3.82	3.91	4.52	4.34	4.126	0.295	0.132
70	4.33	4.48	4.82	4.64	4.69	4.592	0.190	0.085
80	Site condition does not permit safe testing					-	-	-

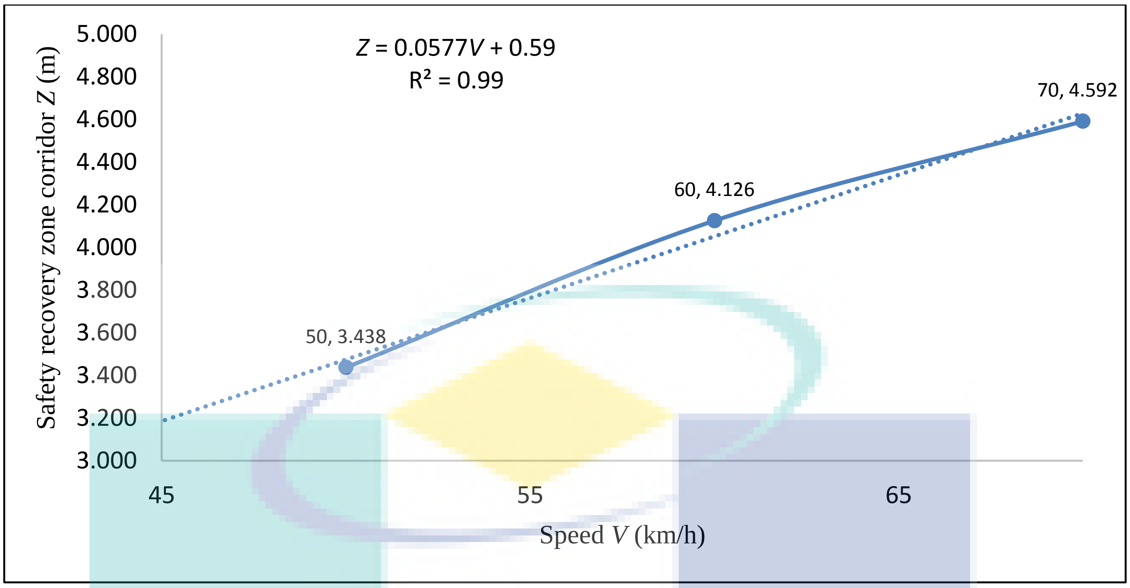


Figure 4.11 Safety recovery zone corridor width *Z* versus vehicle speed *V* for roadside fore-slope 1V:5H at road from Rawang to Kuala Selangor

Plotting the mean values of *Z* against travelling speeds *V* with standard errors, a column chart as shown in Figure 4.12 is produced. The chart shows the largest error margin took place in the car travelling speed of 50 km/h. It has a trajectory path with long grass causing the aggressive car tyres to slide when the car was turning direction in getting back to the travel lane giving a higher range of variation. The smallest error bar is found at the car travelling speed of 70 km/h instead of at the lower speeds due to the short grass on the traversing path provides good tyres traction to the ground. Noticeably, at all the car travelling speeds between 50 to 70 km/h, the variation in the safety recovery zone corridor width *Z* differ significantly due to the steep roadside slope at 1V:5H.

Table 4.12 *Z* values based on trendline formula for test results at road from Rawang to Kuala Selangor

***Z* values based on *Z* = 0.0577*V* + 0.590 for slope 1V:5H**							
***V* (km/h)**	50	60	70	80	90	100	110
Z	3.475	4.052	4.629	5.206	5.783	6.360	6.937

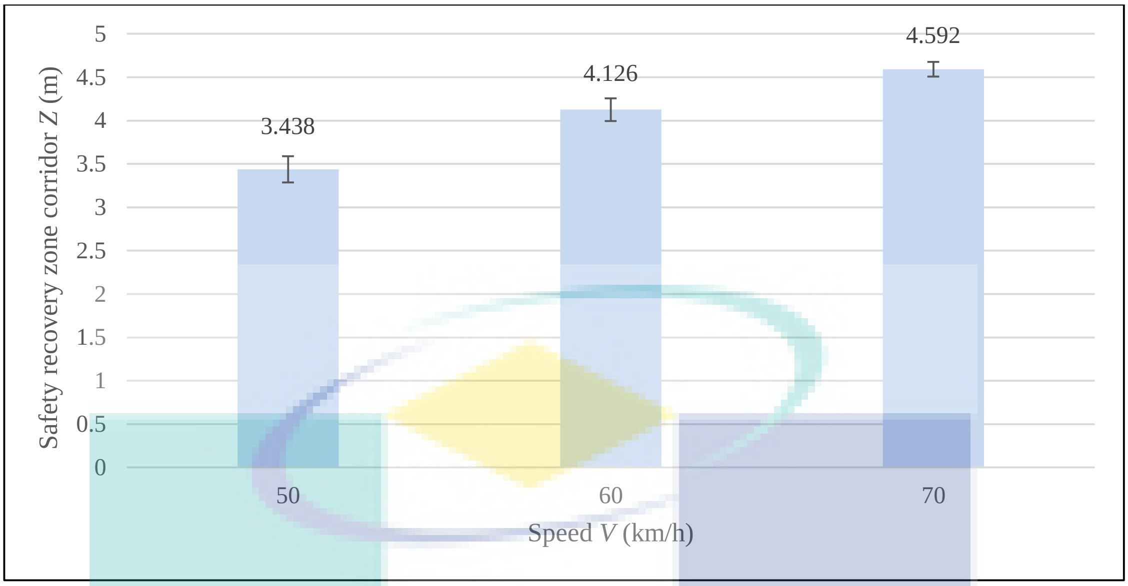


Figure 4.12 Mean of *Z* versus vehicle speed *V* for roadside fore-slope 1V:5H at road from Rawang to Kuala Selangor

4.1.7 Field Experiments at Kg. Chuang, KM 8.2 Rasa-Bukit Beruntung Road, Selangor

The driving tests were executed in accordance with the prescribed Research Methodology in Chapter 3. The tests were carried out for the speeds of 50 km/h, 60 km/h, 70 km/h and 80 km/h. The test speed of 90 km/h and above were not executed due to car handling difficulty experienced by the driver when the travelling speed exceeding higher than 80 km/h due to poor traction between tyres and ground surface condition. The experiment was carried out in the morning in fine weather and the whole process took 5.5 hours.

The collected experiment data with computed standard deviation and standard error is shown in Table 4.13. Plotting the values for vehicle speeds *V* versus average safety recovery zone corridor widths *Z*, it gives Figure 4.13. The graph shows the safety recovery zone corridor widths *Z* increase as the speeds *V* increase. The uniformly inclined graph indicates that the tests were successfully carried out. The software generated statistical trendline equation is given by $Z = 0.0709V - 1.4238$ with R^2 reads as 0.96. The model 96% value informs that *Z* values can be safely predicted from the model equation. Based on the model equation, the predicted values of *Z* for the tested vehicle speeds of 50 km/h, 60 km/h, 70 km/h and 80 km/h, and the values of *Z* for the untested vehicle speed of 90 km/h, 100 km/h, and 110 km/h are shown in Table 4.14.

Table 4.13 Field experiments results for the roadside fore-slope gradient of 1V:8.5H road from Serendah to Bukit Beruntung, Selangor

Speed *V* km/h	**Safety Recovery Zone Corridor Width *Z* (m)**						**Standard Deviation**	**Standard Error**
	Test 1	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Mean**		
50	2.23	1.97	2.54	1.76	2.14	2.128	0.292	0.131
60	2.84	2.56	2.92	2.45	2.70	2.694	0.194	0.087
70	3.53	3.92	3.61	3.84	4.09	3.798	0.229	0.102
80	4.21	3.93	3.82	4.28	4.38	4.124	0.238	0.107
90	Site condition does not permit safe testing					-	-	-

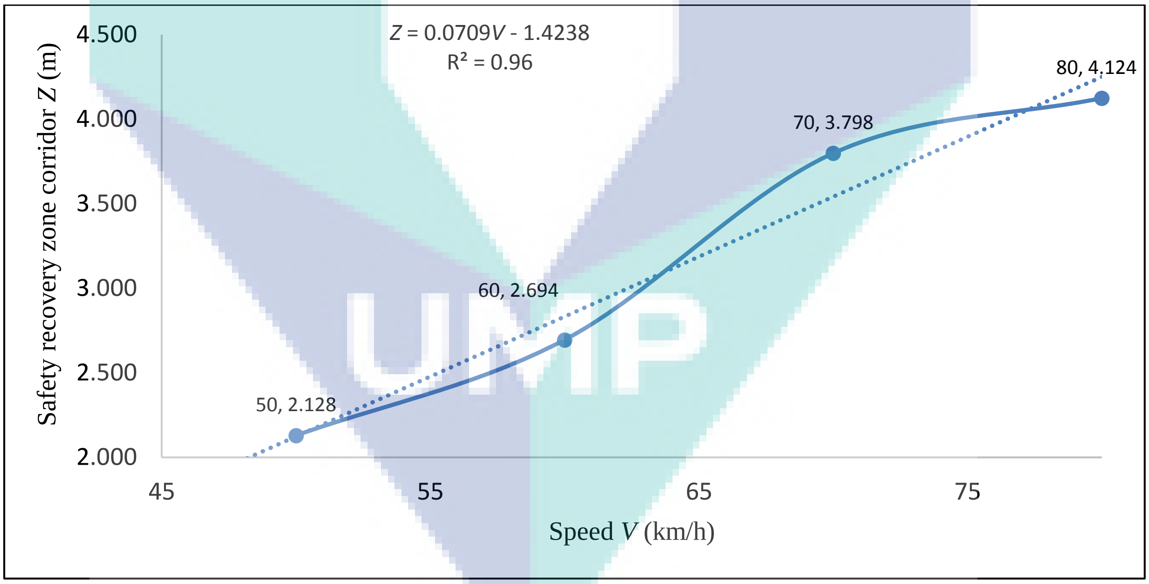


Figure 4.13 Safety recovery zone corridor widths *Z* versus vehicle speeds *V* with trendline for roadside fore-slope gradient of 1V:8.5H at Kg. Chuang, KM 8.2 Rasa-Bukit Beruntung Road, Selangor

Plotting the mean values of Z against travelling speeds V with standard errors, a column chart as shown in Figure 4.14 is produced. The chart shows the largest error margin took place at the car travelling speed of 50 km/h which. The trajectory path for this speed was made up of eroded turf with exposed bare soil due to frequent vehicles parking at the roadside had caused the aggressive car tyres to slide when the car was turning direction in getting back to the travel lane giving a higher range of variation. The smallest error bar is found at the car travelling speed of 60 km/h which has a trajectory path with good turf condition providing good traction to the car tyres. Noticeably, at all the car travelling speeds between 50 to 80 km/h, the variation in Z values differ significantly because of the changing ground surface condition.

Table 4.14 Z values based on trendline formula for test results at road from Serendah to Bukit Beruntung

***Z* values based on *Z* = 0.0709*V* – 1.4238 for slope 1V:8.5H**							
***V* (km/h)**	50	60	70	80	90	100	110
Z	2.121	2.830	3.539	4.248	4.957	5.666	6.375

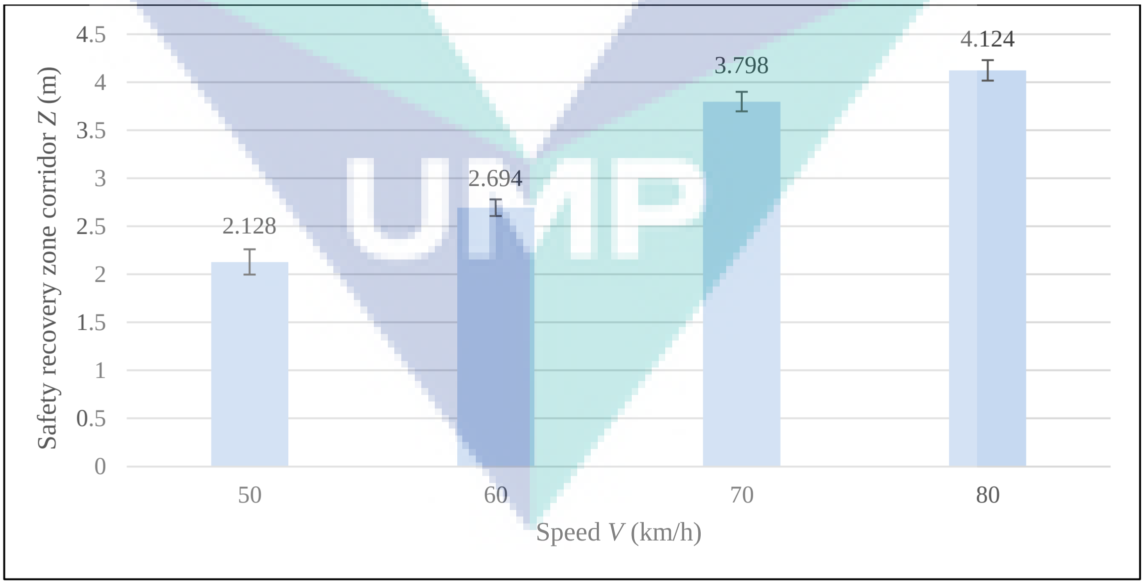


Figure 4.14 Mean of Z versus vehicle speeds V with error bars for roadside fore-slope gradient of 1V:8.5H at Kg. Chuang, KM 8.2 Rasa-Bukit Beruntung Road, Selangor

4.1.8 Field Experiment at Kg. Fajar, Sungai Tengi, Selangor

The field experiments were executed in accordance with the prescribed Research Methodology in Chapter 3. The executed tests were at vehicle speeds of 50 km/h, 60 km/h, 70 km/h and 80 km/h. The test speed of 90 km/h and above were not executed due to car handling difficulty experienced by the driver when the travelling speed was exceeding higher than 80 km/h. The experiment was carried out in the morning in fine weather and the whole process took 5 hours.

The collected experiment data with computed standard deviation and standard error is shown in Table 4.15. Plotting the values for vehicle speeds *V* versus average safety recovery zone corridor widths *Z*, it produces Figure 4.15. The accomplishment of the experiments is proven by the ascending inclined graph. The linear model curve shows the relationship between *V* and *Z* as $Z = 0.0681V – 1.762$ with R^2 reads as 0.98. The model 98% value informs that *Z* values can safely be predicted from the model equation. Based on the model equation, the predicted values of *Z* for the tested vehicle speeds of 50 km/h, 60 km/h, 70 km/h and 80 km/h, and the values of *Z* for the untested vehicle speed of 90 km/h, 100 km/h, and 110 km/h are shown in Table 4.16.

Table 4.15 Field experiments results for the roadside fore-slope gradient of 1V:10H Kg. Fajar, Sungai Tengi, Selangor

Speed *V* km/h	**Safety Recovery Zone Corridor Width *Z* (m)**						**Standard Deviation**	**Standard Error**
	Test 1	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Mean**		
50	1.53	1.84	1.59	1.42	1.30	1.536	0.203	0.091
60	2.81	2.53	2.67	2.44	2.01	2.492	0.304	0.136
70	2.92	3.33	2.71	3.22	2.77	2.990	0.274	0.123
80	4.11	3.44	3.82	3.53	3.30	3.640	0.324	0.145
90	Site condition does not permit safe testing					-	-	-

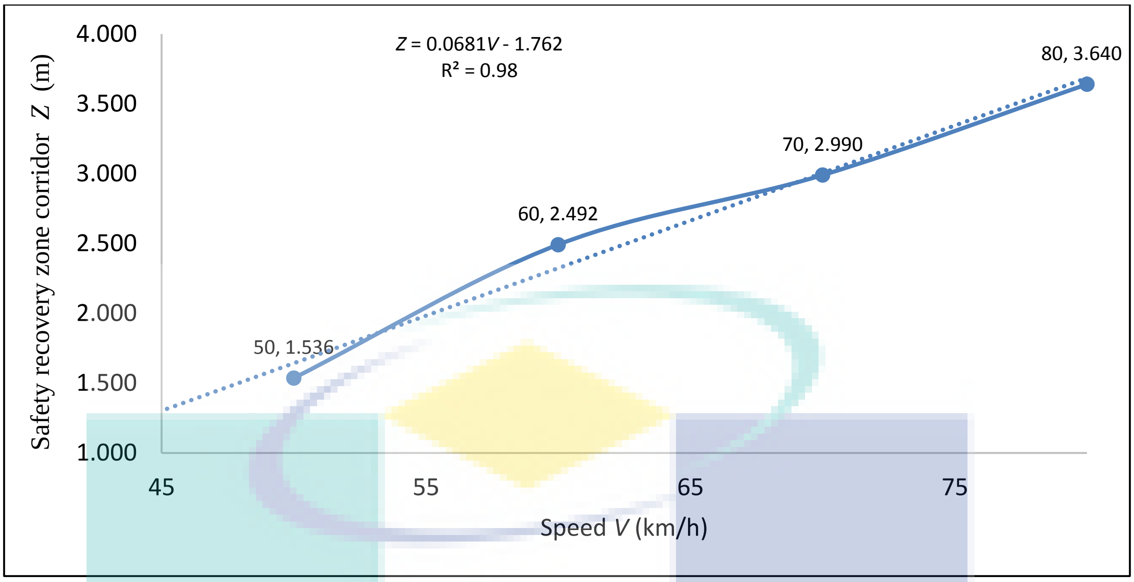


Figure 4.15 Safety recovery zone corridor widths *Z* versus vehicle speeds *V* for roadside fore-slope gradient of 1V:10H at Kg. Fajar, Sungai Tengi, Selangor

Plotting the mean values of *Z* against travelling speeds *V* with standard errors, a column chart as shown in Figure 4.16 was produced. The chart shows largest error margin took place at the car travelling speed of 80 km/h which was influenced by trajectory path long grass and high vehicle speed. The lowest error bar took place at the car travelling speed of 50 km/h contributed by which by the trajectory path with good turf condition and low travel speed providing good traction to the car tyres. It can be noticed from the error bar caps horizontal positions that for all the car travelling speeds between 50 to 80 km/h, the variation in *Z* values differ significantly due to thick grass surface condition causing the car to slide when tyres changed direction.

Table 4.16 *Z* values based on trendline formula for test results at Kg. Fajar, Sungai Tengi, Selangor

***Z* values based on *Z* = 0.0681*V* – 1.762 for slope 1V:10H**							
***V* (km/h)**	50	60	70	80	90	100	110
Z	1.643	2.324	3.005	3.686	4.367	5.048	5.729

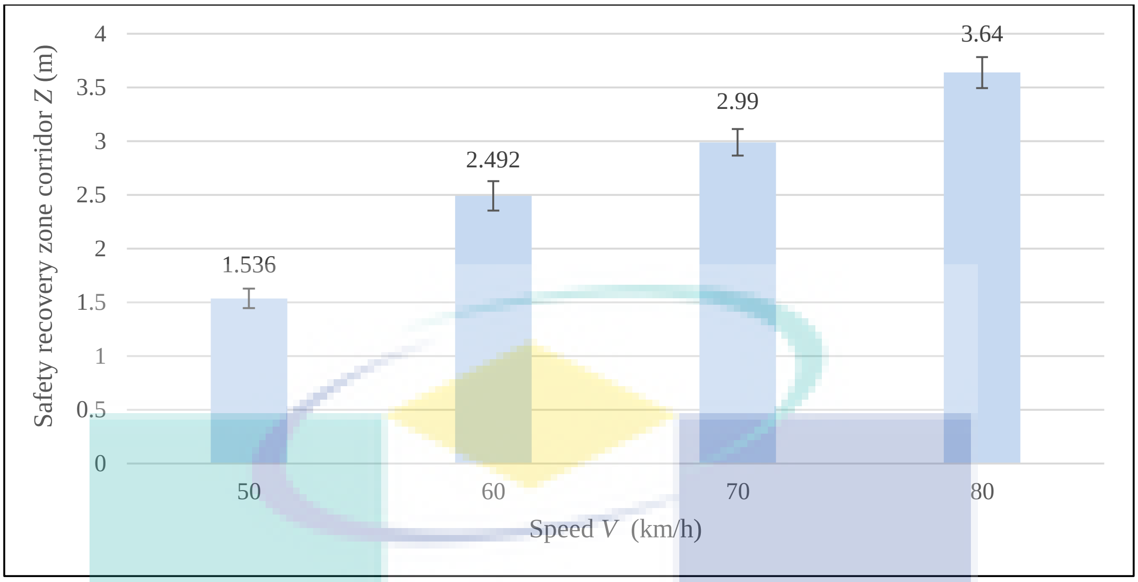


Figure 4.16 Mean of Z versus vehicle speeds V for roadside fore-slope gradient of 1V:10H at Kg. Fajar, Sungai Tengi, Selangor

4.1.9 Field Experiment at KM 5 Simpang Empat to Kuala Kurau, Perak

The field experiments were executed in accordance with the prescribed research methodology in Chapter 3. The tests were carried out for the vehicle speeds of 50 km/h, 60 km/h and 70 km/h. The test speed of 80 km/h and above were not executed due to car handling difficulty experienced by the driver when the travelling speed was exceeding higher than 70 km/h. The experiment was carried out in the morning in fine weather and the whole process took 5 hours.

The collected experiment data with computed standard deviation and standard error is shown in Table 4.17. Plotting the values for vehicle speeds V versus average safety recovery zone corridor widths Z, it produces Figure 4.17. The graph shows the safety recovery zone corridor widths Z increase as the vehicle speeds V increase. The regularly inclined graph indicates that the tests were accomplished. The linear model shows the relationship between V and Z as $Z = 0.0593V + 0.446$ with R^2 value of 0.96**.** The model 96% value informs that Z values can safely be predicted from the model equation. Based on the equation, the predicted values of Z for the tested vehicle speeds of 50 km/h, 60 km/h, and 70 km/h, and the values of Z for the untested vehicle speed of 80 km/h, 90 km/h, 100 km/h, and 110 km/h are shown in Table 4.18.

Table 4.17 Field experiments results for the roadside fore-slope gradient of 1V:5.3H at KM 5 Simpang Empat to Kuala Kurau, Perak

Speed *V* km/h	**Safety Recovery Zone Corridor Width *Z* (m)**						**Standard Deviation**	**Standard Error**
	Test 1	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Mean**		
50	3.03	3.21	3.49	2.99	3.99	3.342	0.412	0.184
60	4.81	3.93	3.22	4.55	4.20	4.142	0.615	0.275
70	4.42	3.99	4.81	3.76	5.66	4.528	0.750	0.336
80	Site condition does not permit safe testing					-	-	-

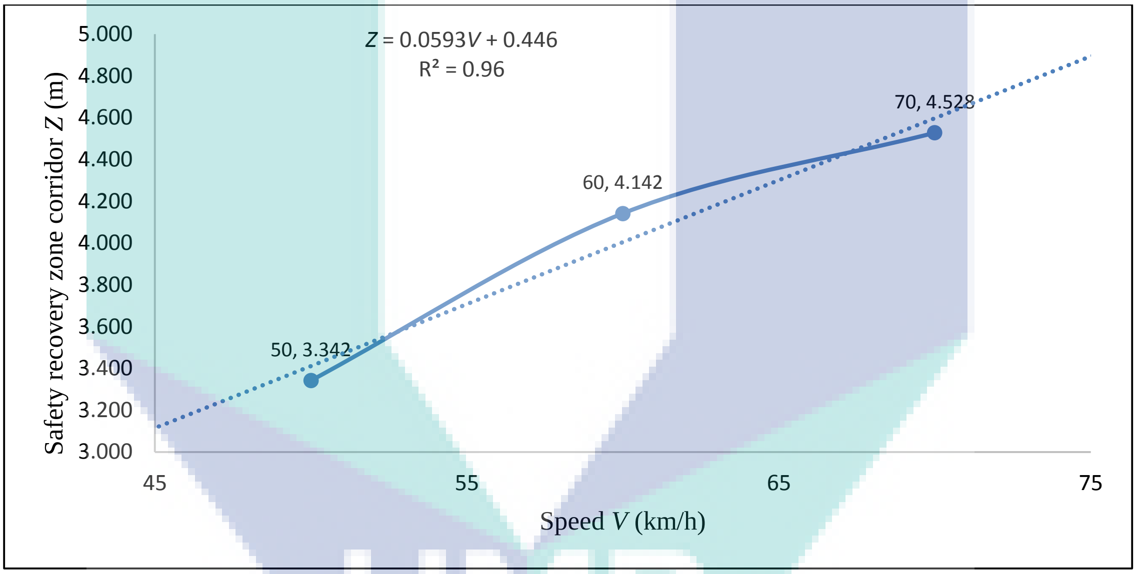


Figure 4.17 Roadside safety recovery zone corridor width *Z* versus vehicle speed *V* for roadside fore-slope 1V:5.3H at KM 5 Simpang Empat to Kuala Kurau, Perak

Plotting the mean values of *Z* against travelling speeds *V* with standard errors, a column chart as shown in Figure 4.18 is produced. The chart shows largest error margin took place at the car travelling speed of 70 km/h which was influenced by night dew-wet long grass on trajectory path, steep slope and high vehicle speed causing higher sliding force on tyres when changing direction. The smallest error bar took place at the car travelling speed of 50 km/h which has the trajectory path with short turf condition providing good traction to the car tyres and low travelling speed assist in good car handling. Judging from the error bar caps horizontal position between travelling speeds between 50 km/h and 60 km/h, the amount of gap indicates the variation in *Z* values change significantly contributed by considerable changes in ground condition. However, the error bar caps horizontal position between travelling speeds of 60 km/h and 70 km/h overlap slightly indicating the car tyres trajectory paths for both speeds having quite similar physical properties and generated the consistent outcome for *Z* values.

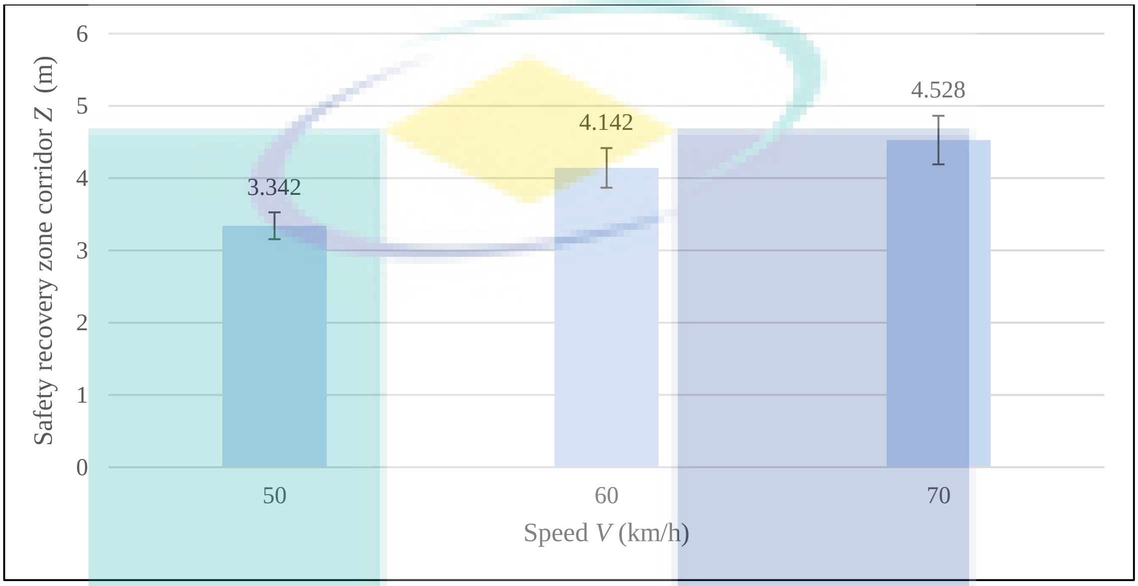


Figure 4.18 Mean of *Z* versus vehicle speed *V* for roadside fore-slope 1V:5.3H at KM 5 Simpang Empat to Kuala Kurau, Perak

Table 4.18 *Z* values based on trendline formula for test results at KM 5 Simpang Empat to Kuala Kurau, Perak

***Z* values based on $Z = 0.0593V + 0.446$ for slope 1V:5.3H**							
V (km/h)	50	60	70	80	90	100	110
Z	3.411	4.004	4.597	5.190	5.783	6.376	6.969

4.1.10 Field Experiment at KM 14 Simpang Empat to Kuala Kurau, Perak

The field experiments were carried out in accordance with the procedure prescribed in the Research Methodology in Chapter 3. The tests were carried out for the vehicle speeds of 50 km/h, 60 km/h, 70 km/h and 80 km/h. The test speed of 90 km/h and above were not executed due to car handling difficulty experienced by the driver when the travelling speed was exceeding higher than 80 km/h. The experiment was carried out in the morning in fine weather and the whole process took 5.5 hours.

The collected experiment data with computed standard deviation and standard error is shown in Table 4.19. Plotting the values for vehicle speeds *V* versus average safety recovery zone corridor widths *Z*, it produces Figure 4.19. Generally, the graph shows the safety recovery zone corridor widths *Z* increase as the vehicle speeds *V* increase. The uniformly inclined graph indicates that the tests were successfully carried out. The linear model shows the relationship between *V* and *Z* as $Z = 0.0629V + 0.7746$ with R^2 value of 0.96. The model 96% value informs that *Z* values can safely be predicted from the model equation. Based on the equation, the predicted values of *Z* for the tested vehicle speeds of 50 km/h, 60 km/h, 70 km/h and 80 km/h, and the values of *Z* for the untested vehicle speed of 90 km/h, 100 km/h, and 110 km/h are shown in Table 4.20.

Table 4.19 Field experiments results for the roadside fore-slope gradient of 1V:4.6H at KM 14 Simpang Empat to Kuala Kurau, Perak

Speed *V* *km/h*	**Safety Recovery Zone Corridor Width *Z* (m)**						**Standard Deviation**	**Standard Error**
	Test 1	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Mean**		
50	3.52	4.24	3.90	3.21	4.31	3.836	0.470	0.210
60	4.54	3.96	5.10	4.72	5.43	4.750	0.560	0.250
70	5.21	4.83	5.34	4.7	4.98	5.012	0.264	0.118
80	5.52	6.13	5.62	6.34	5.61	5.844	0.367	0.164
90	Site condition does not permit safe testing						-	-

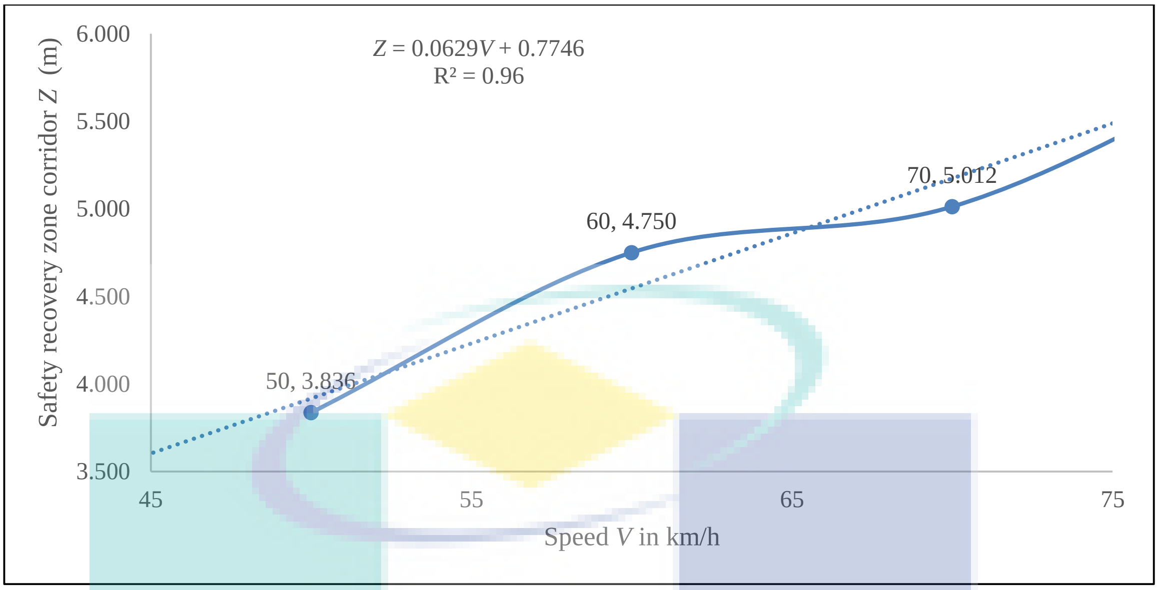


Figure 4.19 Roadside safety recovery zone corridor widths *Z* versus speeds *V* for roadside fore-slope gradient of 1V:4.6H at KM 14 Simpang Empat to Kuala Kurau, Perak

Plotting the mean values of *Z* against travelling speeds *V* with standard errors, a column chart as shown in Figure 4.20 is produced. The chart shows largest error margin took place at the car travelling speed of 60 km/h which was influenced by overnight dew wetted long grass on the trajectory path causing higher skidding force on the car tyres generated significant variation in *Z* values. The smallest error bar took place at the car travelling speed of 70 km/h which has the trajectory path with short dry turf condition providing good traction to the car tyres and low travelling speed lead to good car handling. It can be noticed from the chart that the error bar caps horizontal position between travelling speed of 60 km/h to that of 70 km/h is almost overlapping indicates that the nature of their ground is quite similar. On the other hand, the error bar caps horizontal position between a car travelling speed of 50 km/h to that of 60 km/h and between 70 km/h to that of 80 km/h have a significant difference which indicates those pairs have a contrasting ground condition causing the inconsistent outcome.

Table 4.20 *Z* values based on trendline formula for test results at KM 14 Simpang Empat to Kuala Kurau, Perak

***Z* values based on *Z* = 0.0629*V* + 0.7746 for slope 1V:4.6H**							
***V* (km/h)**	50	60	70	80	90	100	110
Z	3.920	4.549	5.178	5.807	6.436	7.065	7.694

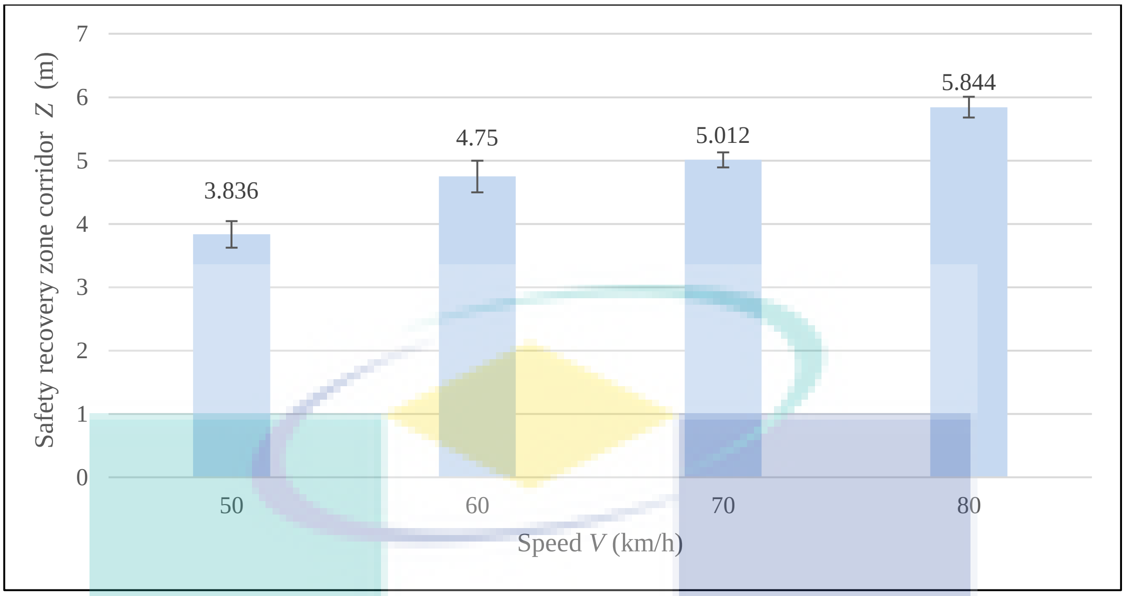


Figure 4.20 Mean of Z versus speeds V for roadside fore-slope gradient of 1V:4.6H at KM 14 Simpang Empat to Kuala Kurau, Perak

4.1.11 Summary and Analysis of Collected Experiments Data

Integrating the values of safety recovery zone corridor widths Z for the various vehicle travelling speeds V and roadside slope gradients S from Table 4.2, Table 4.4, Table 4.6, Table 4.8, Table 4.10, Table 4.12, Table 4.14, Table 4.16, Table 4.18 and Table 4.20, Table 4.21 was produced. The roadside slope gradients in Table 4.21 was not in bold or rounded values but with decimal numbers instead of with exception to 1V:10H. Their unrounded values were due to the existing roadside slope gradients went through the process of settlement from natural consolidations.

Table 4.21 Safety recovery zone corridor corridor widths *Z* in metres for various speeds *V* and roadside fore-slope gradients *S*

Speed *V* (km/h)	**Roadside Fore Slope Gradient *S***									
	1V:10H or 10%	1V:8.5H or 11.77%	1V:7.1H or 14.8%	1V:6.7H or 14.93%	1V:5.8H or 17.24%	1V:5.6H or 17.86%	1V:5.3H or 18.87%	1V:5H or 20%	1V:4.8H or 20.83%	1V:4.6H or 21.74%
50	1.643	2.121	2.190	2.726	2.759	3.167	3.411	3.475	3.562	3.920
60	2.324	2.830	2.850	3.427	3.547	3.856	4.004	4.052	4.214	4.549
70	3.005	3.539	3.510	4.128	4.335	4.545	4.597	4.629	4.866	5.178
80	3.686	4.248	4.170	4.829	5.123	5.234	5.190	5.206	5.518	5.807
90	4.367	4.957	4.830	5.530	5.911	5.923	5.783	5.783	6.170	6.436
100	5.048	5.666	5.490	6.231	6.699	6.612	6.376	6.360	6.822	7.065
110	5.729	6.375	6.150	6.932	7.487	7.301	6.969	6.937	7.474	7.694

Malaysian industrial practice addresses a particular slope gradient with a rounded (non-decimal) figure to facilitate application in construction. In order to suit the practice, a set of *Z* values in the form of 1V:4H, 1V:5H, 1V:6H, 1V:7H 1V:8H, 1V:9H and 1V:10H was established by reconfigured the data in Figure 4.21. The roadside slope gradients steeper than 1V:4H were not applied as these range of slopes regarded as non-recoverable i.e. upon skidding a vehicle cannot be manoeuvred back to travel lane or not safe for practice (AASHTO, 2011). In order to determine rounded values for the roadside slopes gradients, a general equation of relationship of safety recovery zone corridor widths *Z* versus roadside slope gradients *S* for the various vehicle travelling speeds were determined. In completing the exercise, the available gradients of 1V:10H, 1V:8.5H, 1V:7.1H, 1V6.7H, 1V:5.8H, 1V:5.6H, 1V:5.3H, 1V:5.0H, 1V4.8H and 1V:4.6H were converted to percentages of 10%, 11.77%, 14.8%, 14.93%, 17.24%, 17.86%, 18.87%, 20%, 20.83% and 21.74% as shown in Table 4.21.

Plotting the values for safety recovery zone corridor widths Z versus various roadside slope gradients S at the vehicle travelling speed V of 50 km/h from Table 4.21, Figure 4.21 was obtained. The scattered coordinates indicated the presence of variables due to data collected were from ten different test locations had varying site conditions. The generated statistical trend line equation is given by $Z = 18.474S - 0.207$. In reconfiguring to rounded figures for roadside slope gradients at the vehicle travelling speed V of 50 km/h, the values of Z were computed by applying the equation for the slope of 1V:4H through 1V:10H, and the outcome as shown in Table 4.22.

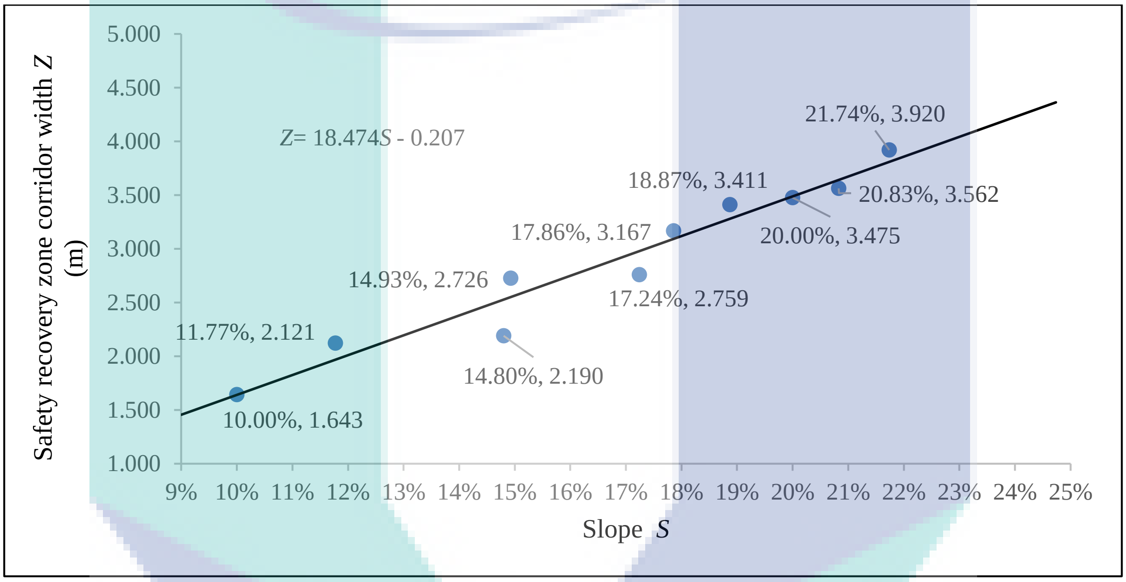


Figure 4.21 Safety recovery zone corridor width Z versus roadside fore-slope gradients S at vehicle travelling speed V of 50 km/h

Table 4.22 Safety recovery zone corridor widths Z for specified roadside fore-slope gradients S at vehicle speed V of 50 km/h

Speed V km/h	**Safety recovery zone corridor width Z (m) based on the statistical trendline equation of $Z = 18.474S - 0.207$**						
	1V:10H (10%) or less	1V:9H (11.1%)	1V:8H (12.5%)	1V:7H (14.3%)	1V:6H (16.7%)	1V:5H (20%)	1V:4H (25%)
50	1.640	1.844	2.102	2.435	2.878	3.488	4.412

Plotting the values for safety recovery zone corridor widths *Z* versus various roadside slope gradients *S* at the vehicle travelling speed *V* of 60 km/h from Table 4.21, Figure 4.22 was obtained. Similar to the earlier case, the scattered coordinates indicated the presence of variables due to data collected from ten different test locations having different site conditions. The model generated statistical trend line equation was given by $Z = 17.759S + 0.581$. In transforming the roadside slope gradients *S* from decimal form to rounded figures, the values of *Z* were calculated based on the equation for the slope of 1V: 4H through 1V:10H and the results produced as shown in Table 4.23.

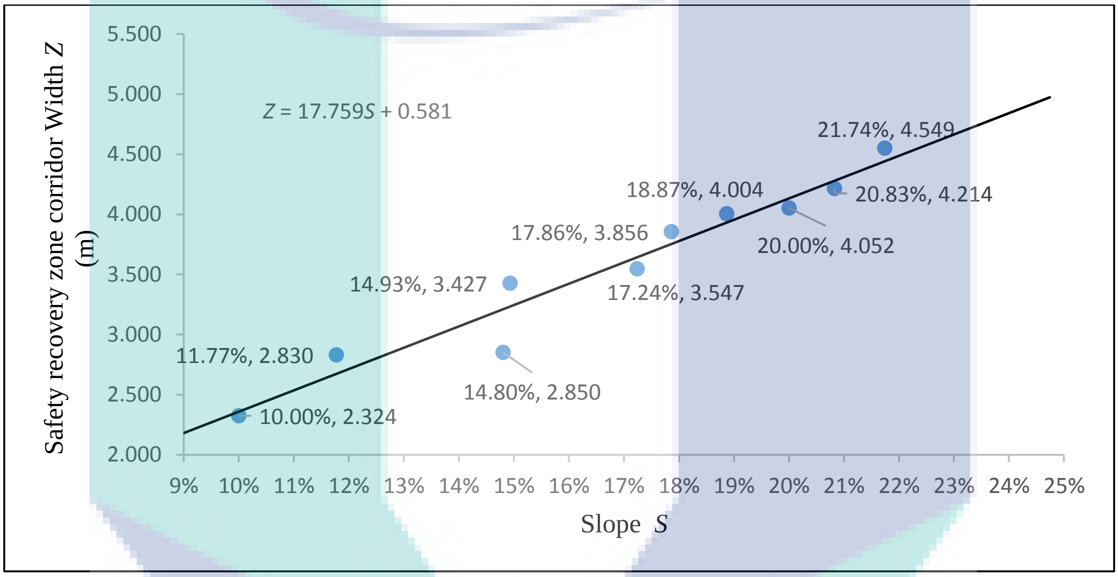


Figure 4.22 Safety recovery zone corridor width *Z* versus roadside fore-slope gradients *S* at vehicle travelling speed *V* of 60 km/h

Table 4.23 Safety recovery zone corridor widths *Z* for specified roadside fore-slope gradients at vehicle speed of 60 km/h

Speed *V* km/h	**Safety recovery zone corridor width *Z* (m) based on the trendline statistical equation of $Z = 17.759S + 0.581$**						
	1V:10H (10%) or less	1V:9H (11.1%)	1V:8H (12.5%)	1V:7H (14.3%)	1V:6H (16.7%)	1V:5H (20%)	1V:4H (25%)
60	2.357	2.552	2.801	3.121	3.547	4.133	5.021

Plotting the values for safety recovery zone corridor widths Z versus various roadside slope gradients S at the vehicle travelling speed V of 70 km/h from Table 4.21, Figure 4.23 was obtained. The linear model generated statistical trend line equation is given by $Z = 17.0445S + 1.3691$. Working on the equation, the values of Z based on the roadside slope gradients of 1V:4H through 1V:10H as given in the Table 4.24.

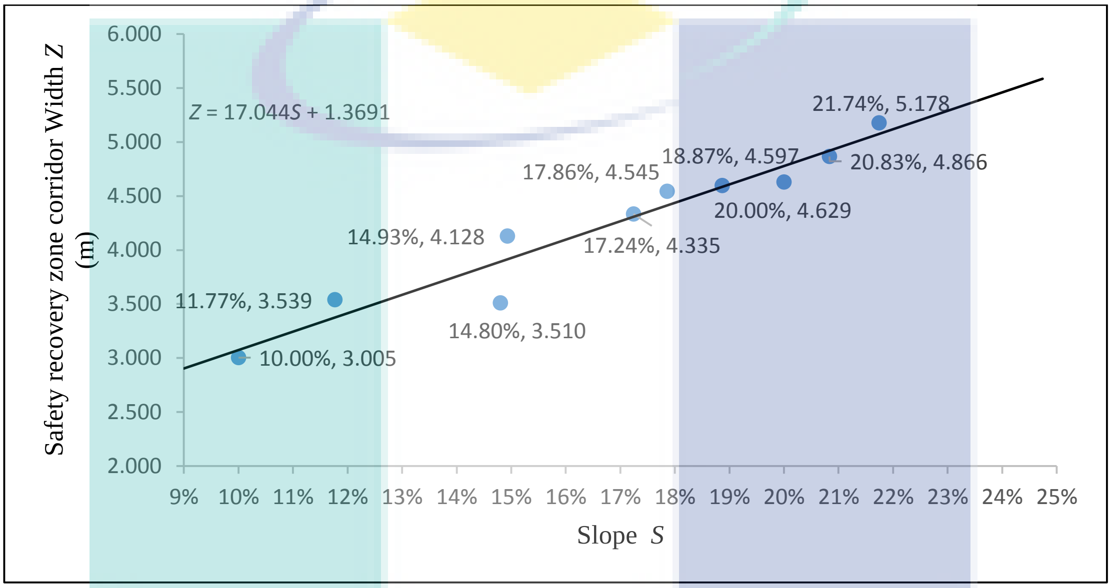


Figure 4.23 Safety recovery zone corridor width Z versus roadside fore-slope gradients S at vehicle travelling speed of 70 km/h

Table 4.24 Safety recovery zone corridor widths Z for specified roadside fore-slope gradients S at vehicle speed of 70 km/h

Speed V (km/h)	**Safety recovery zone corridor width Z (m) based on the statistical trendline equation of $Z = 17.044S + 1.3691$**						
	1V:10H (10%) or less	1V:9H (11.1%)	1V:8H (12.5%)	1V:7H (14.3%)	1V:6H (16.7%)	1V:5H (20%)	1V:4H (25%)
70	3.704	3.261	3.500	3.806	4.215	4.778	5.630

Plotting the values for safety recovery zone corridor widths Z versus various roadside slope gradients S at the speed V of 80 km/h from Table 4.21, Figure 4.24 was obtained. The software generated a statistical trend line equation was given by $Z = 16.329S + 2.1571$. Based on the equation, the computed values of Z for rounded roadside gradients of 1V:4H through 1V:10H as shown in Table 4.25.

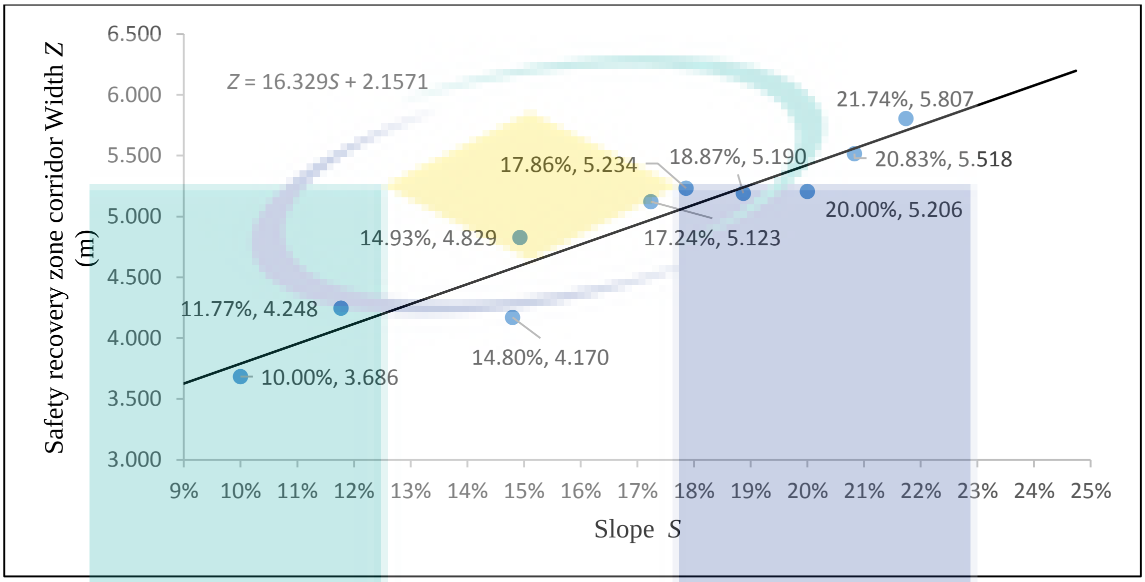


Figure 4.24 Safety recovery zone corridor width Z versus roadside fore-slope gradients S at vehicle travelling speed V of 80 km/h

Table 4.25 Safety recovery zone corridor widths Z for specified roadside fore-slope gradients S at vehicle speed V of 80 km/h

Speed *V* (km/h)	**Safety recovery zone corridor width *Z* (m) based on the statistical tradeline equation of $Z = 16.329S + 2.1571$**						
	1V:10H (10%) or less	1V:9H (11.1%)	1V:8H (12.5%)	1V:7H (14.3%)	1V:6H (16.7%)	1V:5H (20%)	1V:4H (25%)
80	3.790	3.970	4.198	4.492	4.884	5.423	6.239

Plotting the values for safety recovery zone corridor widths Z versus various roadside slope gradients S at the vehicle travelling speed V of 90 km/h from Table 4.21, Figure 4.25 was obtained. The linear model generated statistical trend line equation was given by $Z = 15.614S + 2.9451$. Working on the equation, the values of Z at 90 km/h for the rounded slope of 1V:4H through 1V:10H, Table 4.26 was produced.

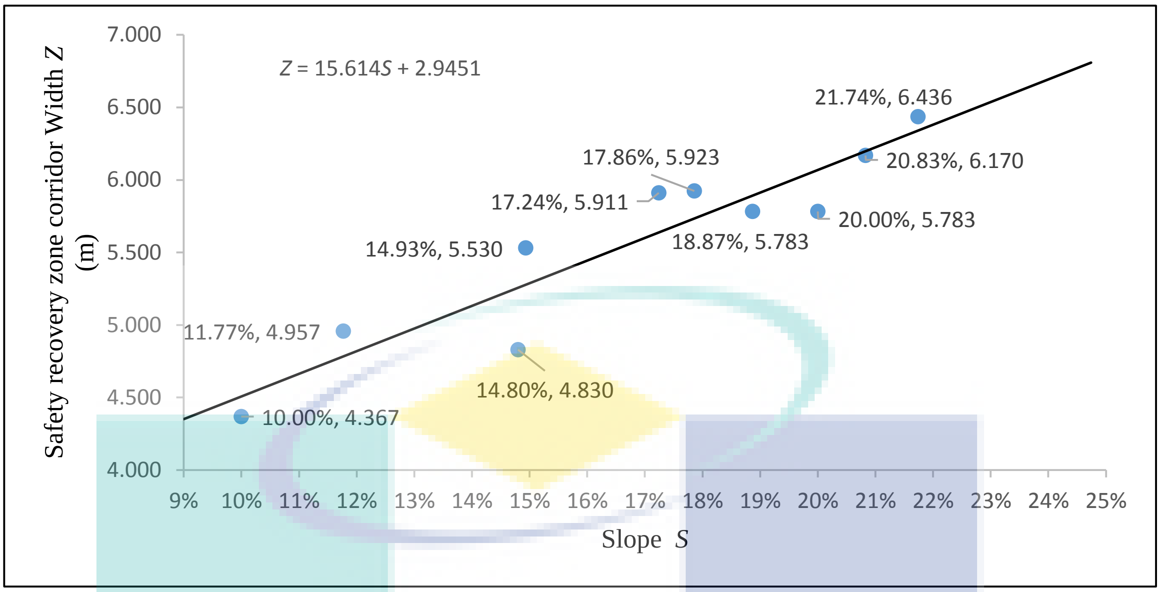


Figure 4.25 Safety recovery zone corridor width *Z* versus various roadside fore-slope gradients *S* at vehicle travelling speed *V* of 90 km/h

Table 4.26 Safety recovery zone corridor widths *Z* for specified roadside fore-slope gradients *S* at vehicle speed of 90 km/h

Speed *V* (km/h)	Safety recovery zone corridor width *Z* (m) based on the statistical trendline equation of $Z = 15.614S + 2.9451$						
	1V:10H (10%) or less	1V:9H (11.1%)	1V:8H (12.5%)	1V:7H (14.3%)	1V:6H (16.7%)	1V:5H (20%)	1V:4H (25%)
90	4.507	4.678	4.897	5.178	5.553	6.068	6.849

Plotting the values for safety recovery zone corridor widths *Z* versus various roadside slope gradients *S* at speed *V* of 100 km/h from Table 4.21, Figure 4.8 is obtained. The generated linear model statistical trend line equation was given by $Z = 9.5706S + 4.4287$. The computed values of *Z* based on the given equation for the slope of 1V:4H through 1V:10H gave Table 4.27.

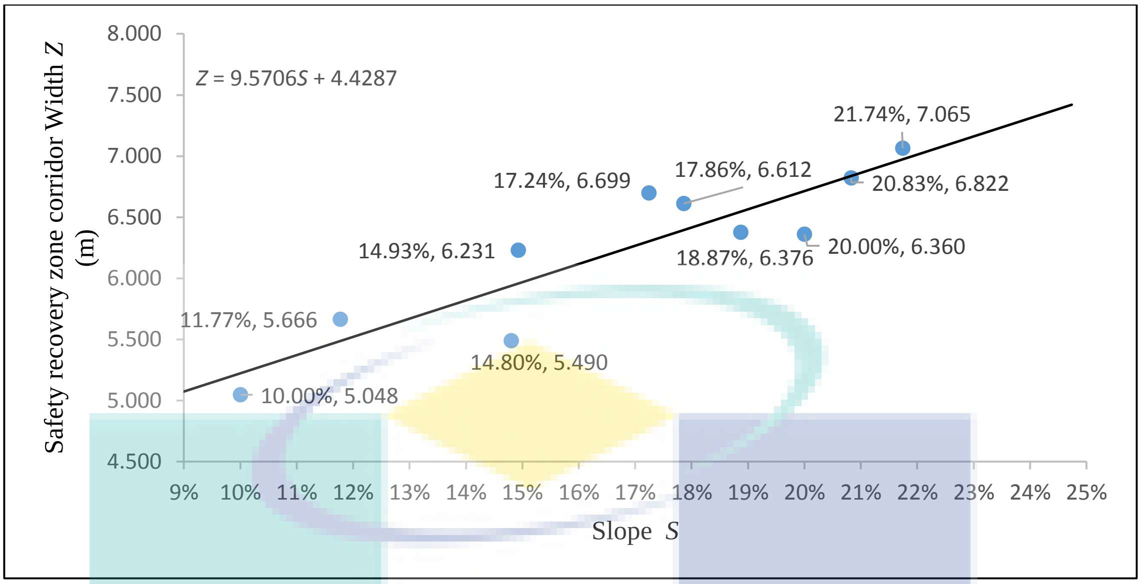


Figure 4.26 Safety recovery zone corridor width *Z* versus various roadside fore-slope gradients *S* at vehicle speed *V* of 100 km/h

Table 4.27 Safety recovery zone corridor widths *Z* for specified roadside fore-slope gradients *S* at vehicle speed *V* of 100 km/h

Speed *V* (km/h)	**Safety recovery zone corridor width *Z* (m) based on the statistical trendline equation of $Z = 9.5706S + 4.4287$**						
	1V:10H (10%) or less	1V:9H (11.1%)	1V:8H (12.5%)	1V:7H (14.3%)	1V:6H (16.7%)	1V:5H (20%)	1V:H (25%)
100	5.386	5.491	5.625	5.797	6.027	6.343	6.821

Plotting the values for safety recovery zone corridor widths *Z* versus various roadside slope gradients *S* at speed *V* of 110 km/h from Table 4.21, Figure 4.27 was formed. The generated linear model statistical trend line equation was given by $Z = 14.185S + 4.5212$. The computed values of *Z* based on the model equation for the slope *S* of 1V:4H through 1V:10H, Table 4.28 was produced.

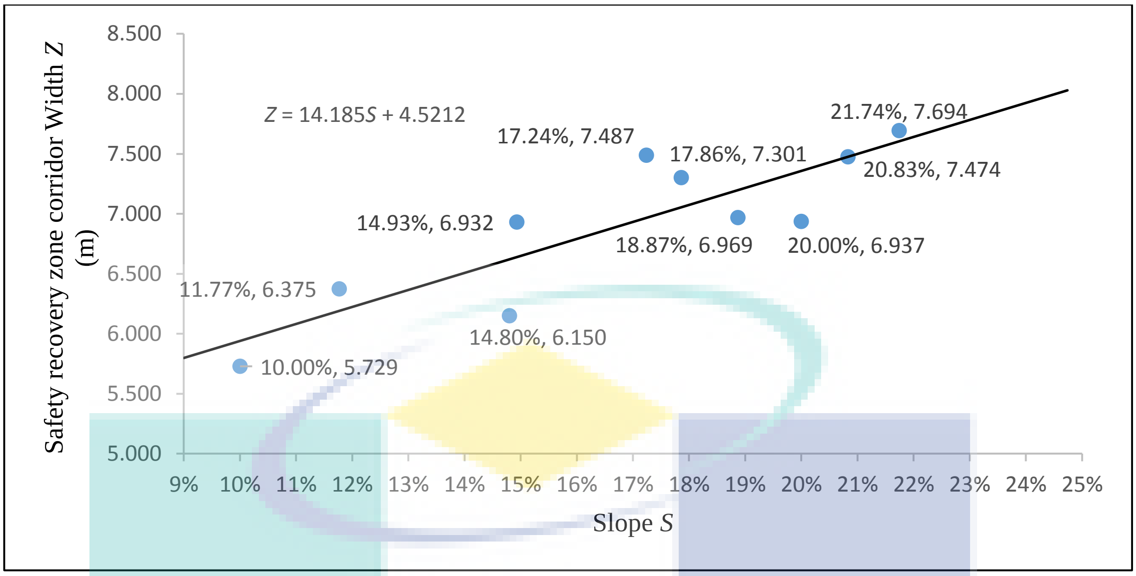


Figure 4.27 Safety recovery zone corridor width *Z* versus various roadside fore-slope gradients *S* at vehicle speed *V* of 110 km/h

Table 4.28 Safety recovery zone corridor widths *Z* for specified roadside fore-slope gradients *S* at vehicle speed *V* of 110 km/h

Speed *V* (km/h)	**Safety recovery zone corridor width *Z* (m) based on the trendline statistical equation of *Z* = 14.185*S* + 4.5212**						
	1V:10H (10%) or less	1V:9H (11.1%)	1V:8H (12.5%)	1V:7H (14.3%)	1V:6H (16.7%)	1V:5H (20%)	1V:4H (25%)
110	5.940	6.096	6.294	6.550	6.890	7.358	8.067

Summarizing the values of safety recovery zone corridor widths *Z* for various speeds *V* and roadside slopes gradients *S* from Table 4.22 through Table 4.28, Table 4.29 was produced. It can be seen from the table that it satisfied the need that all *S* values were in rounded numbers and suit easy construction application.

Table 4.29 concluded the study on safety recovery zone corridor for Malaysian soil for design speeds from50 km/h to 110 km/h in interval or step of 10 km/h. The table covered the entire traversable slopes from 1V:4H to the flat ground or from the slope angle of 25 to 0 degrees. The roadside slope gradients steeper than 1V:4H were not applied due to their range of slopes are classified as non-recoverable or non-traversable by skidding vehicles (AASHTO, 2011). All the figures in three decimal places, but will be reduced to two decimal places in the Malaysian design template in the following section. It is a universal outcome associate between safety recovery zone corridor widths as a dependent variable with that of travelling speeds and roadside slope gradients as independent variables. The Laws of Malaysia Act 333 known as Road Transport Act 1987 (Road, 1987) sets minimum speed limit to 60 km/h which does not imply that road design standard for 50 km/h is no more applicable. However, its representation in the tables is for design application because JKR has not withdrawn the R1 and U1 design standard. The symbol R1 and U1 in the design table denotes rural road and urban road respectively for a design speed of 50 km/h.

Table 4.29 Safety recovery zone corridor widths *Z* for specified roadside slope gradients *S* at various speeds *V* with *S* in rounded numbers form

Speed *V* (km/h)	**Safety Recovery Zone Corridor Width or *Z* (m)**						
	1V:10H (10%) or less	1V:9H (14.3%)	1V:8H (12.5%)	1V:7H (14.3%)	1V:6H (16.7%)	1V:5H (20%)	1V:4H (25%)
50	1.640	1.844	2.102	2.435	2.878	3.488	4.412
60	2.357	2.552	2.801	3.121	3.547	4.133	5.021
70	3.074	3.261	3.500	3.806	4.215	4.778	5.630
80	3.790	3.970	4.198	4.492	4.884	5.423	6.239
90	4.507	4.678	4.897	5.178	5.553	6.068	6.849
100	5.386	5.491	5.625	5.797	6.027	6.343	6.821
110	5.940	6.096	6.294	6.550	6.890	7.358	8.067

This study is intended to share with Malaysian engineers in designing roads with an application of roadside safety recovery zone corridor concept. In meeting this intention, transforming the study outcome in Table 4.29 into Malaysian rural road design standard template is a smart approach. The relevant Malaysian road design guidelines were discussed in Chapter 2 Literature Review to facilitate readers understanding of the following transformation from Table 4.29 to Table 4.30. The Malaysian various design standards were based on design speeds, with design standard R1 to R6 for design speeds from 50 to 100 km/h. Thus, shifting the values of *Z* from Table 4.29 to Table 4.30 were based on the common ground of design speeds.

Table 4.30 Safety recovery zone corridor widths *Z* for rural roads

Design Standard	**Category of Road**	**Design Speed (km/h)**	**Safety Recovery Zone Corridor Width *Z* (m)**						
			1V:10H or less	1V:9H	1V:8H	1V:7H	1V:6H	1V:5H	1V:4H
R1	Minor	50	1.64	1.84	2.10	2.44	2.88	3.49	4.41
R2	Minor	60	2.36	2.55	2.80	3.12	3.55	4.13	5.02
R3	Secondary	80	3.79	3.97	4.20	4.49	4.88	5.42	6.24
R4	Primary & Secondary	90	4.51	4.68	4.90	5.18	5.55	6.07	6.85
R5	Highway Primary	100	5.39	5.49	5.63	5.80	6.03	6.34	6.82
R6	Expressway	110	5.94	6.10	6.29	6.55	6.89	7.36	8.07

The Malaysian design guide (REAM-GL 2, 2002) categorises urban roads into three types. Firstly, type I urban roads is for relatively free in road location with very little problems as regards land acquisition, affected buildings or other socially sensitive areas. Secondly, type III road is for very restrictive in road location with problems as regards land acquisition, affected buildings and other sensitive areas. Finally, type II road is for intermediate between I and III. Design speeds for urban roads is ranging between 40 km/h to 100 km/h.

The designated design limit for area Type I is between 40 km/h to 100 km/h. Despite the new minimum speed is 60 km/h, the representation for a design speed of 40 km/h and 50 km/h are still applicable as the design standard type U1 and U2 have not been withdrawn. Re-organise the values in Table 4.29 in the format of Malaysian road design standards for urban roads Type I, Table 4.31 is produced.

Table 4.31 Safety recovery zone corridor widths *Z* for urban roads of area Type I for Malaysian Design Standard

Design Standard	**Category of Road**	**Speed (km/h)**	**Safety Recovery Zone Corridor Width *Z* (m)**						
			1V:10H or less	1V:9H	1V:8H	1V:7H	1V:6H	1V:5H	1V:4H
U1 **U2**	Local Streets	40 50	1.64	1.84	2.10	2.44	2.88	3.49	4.41
U3	Collectors Local Streets	60	2.36	2.55	2.80	3.12	3.55	4.13	5.02
U4	Collector Local Streets	70	3.07	3.26	3.50	3.81	4.22	4.78	5.63
U4 **U5**	Arterials Collectors	80	3.79	3.97	4.20	4.49	4.88	5.42	6.24
U5	Arterials	90	4.51	4.68	4.90	5.18	5.55	6.07	6.85
U6	Expressway	100	5.39	5.49	5.63	5.80	6.03	6.34	6.82

The Malaysian design speeds for Type II area is between 50 km/h and 90 km/h except for design speed 80 km/h is not applicable. Re-organize the values in Table 4.29 in the format of Malaysian road design standards for urban roads Type II, Table 4.32 is produced.

Table 4.32 Safety recovery zone corridor widths *Z* for urban roads of area Type II for Malaysian Design Standard

			Safety Recovery Zone Corridor Width *Z* (m)						
Design Standard	**Category of Road**	**Speed (km/h)**	1V:10H or less	1V:9H	1V:8H	1V:7H	1V:6H	1V:5H	1V:4H
U1 **U2** **U3**	Local Streets Collectors	50	1.64	1.84	2.10	2.44	2.88	3.49	4.41
U4	Arterials Collector Local Streets	60	2.36	2.55	2.80	3.12	3.55	4.13	5.02
U5	Arterials Collectors	70	3.07	3.26	3.50	3.81	4.22	4.78	5.63
U6	Arterials	90	4.51	4.68	4.90	5.18	5.55	6.07	6.85

The Malaysian design speeds for Type III area is between 40 km/h and 90 km/h except for design speed 70 km/h is not applicable. Re-organize the values in Table 4.29 in the format of Malaysian road design standards for urban roads Type III, Table 4.33 is produced.

Table 4.33 Safety recovery zone corridor widths *Z* for urban roads of area Type III for Malaysian Design Standard

Design Standard	**Category of Road**	**Speed (km/h)**	**Safety Recovery Zone Corridor Width *Z* (m)**						
			1V:10H or less	1V:9H	1V:8H	1V:7H	1V:6H	1V:5H	1V:4H
U1 **U2**	Local Streets	40	1.64	1.84	2.10	2.44	2.88	3.49	4.41
U3	Collectors Local Streets	50	1.64	1.84	2.10	2.44	2.88	3.49	4.41
U4	Arterials Collector Local Streets	60	2.36	2.55	2.80	3.12	3.55	4.13	5.02
U5	Arterials Collectors	70	3.07	3.26	3.50	3.81	4.22	4.78	5.63
U6	Arterials	90	4.51	4.68	4.90	5.18	5.55	6.07	6.85

Generally, all ten fields selected for car testing grounds have about same conditions of roadside slopes, i.e. sandy clay soil topped with cow grass with traces of sand and laterites filled the grass interstices. Obstructions or hazards found within the safety recovery zone corridor were trees, electrical poles, drains, signboard and steep roadside slopes as they were part of roadside design structures. The severity of problems at all the ten fields from four states is about the same. However, the four drivers experienced the severity of problems began to differ when the roadside slopes were getting steeper, and tyres glided when in contact with long grass or sandy ground surfaces.

Table 4.34 is a list of R-squared values given by graphs produced from the field's tests data for all the four states. The table informs the sites locations, roadside slope gradients, model equations and R-squared values.

Table 4.34 R-squared values given by graph produced from ten table field's test data for all the four states

Locations	Roadside Gradient	Equations	R-squared Values (R2)
		PAHANG	
Pantai Sepat	1V:7.1H	$Z = 0.066V - 1.1098$	0.91
Bukit Ibam	1V:5.6H	$Z = 0.0689V - 0.278$	0.99
Pantai Lanjut, Rompin	1V:5.8H	$Z = 0.0788V - 1.1813$	0.99974
KM 71 Muadzam-Kuantan	1V:4.8H	$Z = 0.0652V + 0.3018$	0.90
		JOHOR	
Bandar Tenggara, Kota Tinggi	1V:6.7H	$Z = 0.0701V - 0.7793$	0.99795
		SELANGOR	
Rawang to Kuala Selangor	1V:5H	$Z = 0.0577V + 0.59$	0.99
Kg. Chuang, KM 8.2 Rasa-Bukit Beruntung	1V:8.5H	$Z = 0/0709V - 1.4238$	0.96
Kg. Fajar, Sungai Tengi	1V:10H	$Z = 0.0681V - 1.762$	0.98
		PERAK	
KM 5 Simpang Empat to Kuala Kurau	1V:5.3H	$Z = 0.0593V + 0.446$	0.96
KM 14 Simpang Empat to Kuala Kurau	1V:4.6H	$Z = 0.0629V + 0.7746$	0.96

R-squared is a goodness-of-fit measure or strength of relationship for a linear model which indicates the percentage of the variance of a dependent variable against an independent variable. In the context of the fields' experiments carried out, their values being influenced by the ground conditions and drivers' reactions. The table shows R-squared varied from 0.90 to close to 1.0 for all states informed that the percentage of consistency is above 90 percent. The percentage informed the sites were well selected, and the test successfully carried out in term of consistency of driving performance.

The lowest value of R-squared 0.90 was given by Pahang at KM 71 Muadzam-Kuantan with roadside slope gradient 1V:4:8H. The lowest value of R-squared contributed by steep roadside slope and undulating ground surface condition. The driver complained he could not carry out the test at higher than 80 km/h. due to car handling problem. The second lowest value of R-squared 0.91 contributed by Pantai Sepat test site due to very sandy ground surface despite the fact that it was the lowest roadside slope gradient. The third lowest R-squared value of 0.96 contributed by two states with one site from Selangor, Kg. Chuang, KM 8.2 Rasa-Bukit Beruntung with roadside slope 1V:8:5H and two sites from Perak, KM 5 Simpang Empat-Kuala Kurau with roadside slope 1V:5:3H and KM 14 Simpang Empat-Kuala Kurau with roadside slope 1V:4:6H. The fourth lowest R-squared value of 0.98 contributed by Kg. Fajar, Sungai Tengi with roadside slope 1V:10H. The fifth lowest R-squared value 0.99 and above contributed by three states with two sites from Pahang, Bukit Ibam with roadside slope 1V:5:6H, Pantai Lanjut, Rompin with roadside slope 1V:5:8H, one site from Johor, Bandar Tenggara, Kota Tinggi with roadside slope 1V:6:7H, and one site from Selangor, Rawang-Kuala Selangor with roadside slope 1V:5H. Overall assessment severity of risks highest for roadside slope due to the sandy ground surface caused the car to slide on the slippery ground surface. The second highest risks contributed by steep roadside gradient with an undulating surface.

The proposed safety recovery zone corridor requirement is to have a roadside slope gradient not steeper than 1V:4H for the safety of car handling. The experience of the drivers who carried out the live field experiments informed that the car became unstable when traversing on the steep roadside slope support the study. It can be concluded that the public drive better on a gentle slope.

4.2 Case Study

Case studies were carried out to validate the problem statements and the outcome of safety recovery zone corridor widths accomplished in this study. The following sections discussed on obstructions or hazards found located within safety recovery zone corridor had interfered with passage of skidding vehicles in making their safe trajectory. The problem areas were highlighted, evaluated and recommended with solutions. The solution given to the problems were mainly based on about forty years of personal working experience. Solutions that require the application of industry's products, findings on industry current practise were referenced to ensure the solutions proposed were in the best possible form.

4.2.1 Case Study on Trees

Problem

Figure 4.28 shows a tree with a stem diameter of 490 mm at KM 5 Gambang-Kuantan Road, the tree size has grown from the original diameter of less than 100 mm. The tree diameter has multiplied nearly five times of their original size in over 15 years period. Its presence on the roadside has now been classified as a hazard because they are located in the safety recovery zone corridor. When first planted, the size of the tree was less than 100 mm diameter, the size if struck by a car will cause the tree to rupture, unfortunately, as it is now the car will rupture instead.

The large-diameter trees are common in old Malaysian roads. Conversely, small diameter trees are found on newer Malaysian roads. Most of them were planted immediately adjacent to emergency lanes. One can conclude that the problem of the trees planted in safety recovery zone corridor is applied nationwide. Not until the safety recovery zone corridor is addressed in road design guide, all new roads will be installed with trees, and old roads trees kept growing in the safety zone. Once the policy of safety recovery zone corridor is implemented by the road authority, all new roads will not be planted with trees in the safety zone, and trees on old roads that are within the safety zone will be removed in stages as corrective measures to the current problem.

A tree uprooted and fell on a car and killed a woman driven by her sister when travelling along Jalan Kampung Lata Kasah, Jerantut on July 8, 2019. This tragedy suggests that planting of trees close to roads are unsafe to traffic (Thesun, 2019).

Figure 4.28 A tree with 490 mm diameter is located 3.8 metres away from the travel lane located at KM 5 Gambang-Kuantan road, Pahang. The tree root spans about 1 metre towards the travel lane

The tree location was about 3.8 metres away from the edge of the travel lane, but the effective distance from the travel lane reduced to 2.8 metres due its root length is nearly a metre was spanning toward the travel lane. It can be concluded that the effective safety recovery zone corridor width available was 2.8 metres encroached into this study safety zone width of 3.79 metres, a dimension suggested by for the speed limit of 80 km/h having roadside slope gradient of less than 1V:10H as shown in Table 4.30. Besides the tree, the root itself was a hazard, as motorbike will lose control running over it. It was evidenced that the skinned off part of the tree was the mark of the previous vehicle struck onto it. Figure 4.29 shows some of the trees along the same abovesaid road have grown up to 800 mm and 600 mm stem diameters, located at behind and in front of the car respectively. They were remains of the trees cut but not uprooted, and became hazards to the roadside. The projected stems 300 mm and 320 mm for the 800 mm and 600 mm diameters trees respectively may cause a colliding vehicle to be airborne and plunge into the nearby drain. All the planted trees spaced at 12 metres interval along the roadside of the main road are hazards to traffics.

Figure 4.29 The 800 mm with 300 mm projection and 600 mm with 330 mm projection tree stumps behind and in front of the car at KM 4 Jalan Gambang, Kuantan, Pahang

The sling road or collector local street trees shown on the left of Figure 4.30 were hazards as they were planted within the safety recovery zone corridor of 2.36 metres width specified for the road speed limit of 60 km/h and roadside slope gradient less than 1V:10H. They were planted at the edge of the road, which is hardly 0.5 metres away from the travel lane. The initiative was carried out under National Landscape Policy (National, 1996) for the development area with the vision of transforming Malaysia into a beautiful garden nation by the year 2020.

Planting 1000 trees in private property away from traffics such as the one carried out on 7 March 2019 at the International Islamic University of Malaysia campus at Kuantan, Pahang was excellent practice (IIUM, 2019). Promoting terrestrial ecosystems will sustain a good life for the people on the campus and in Kuantan. The similar and bigger exercise was carried out by Tenaga National Berhad in collaboration with local municipals planted 11,000 trees in 11 selected locations in the Peninsula public parks (Star, 2019). These were activities of concern and commitment towards sustainability of environment to countermeasure negative impacts from development.

Figure 4.30 The photo taken from KM 5 facing Kuantan city showing left row of tree along the main road and right row of trees along the sling road

Figure 4.31 shows fresh skin at the bottom part of the tree indicates it was recently struck by a vehicle as evidenced by the broken pieces of vehicle scattered nearby the tree’s bottom part. This tree and the earlier in Figure 4.27 were located along the same road of accidents prone area. It is improper for planting trees in the safety recovery zone corridor. Based on the diameter of the tree that was nearly 600 mm, the tree could have been planted when the policy of planting trees along the roadsides introduced. The road speed limit was 80 km/h, upon high impact from crashes it could stand the force and put the colliding car broken into pieces. The road is the main road connecting between Kuantan and Gambang under the jurisdiction of the state road authority. It serves a high volume of traffic throughout the day.

Figure 4.31 The fresh skin at the bottom part of the tree indicates that it was recently struck by a vehicle and the broken pieces of vehicle scattered nearby

Figure 4.32 A car damaged after it rammed a tree and the driver was killed on the spot at Kidurung, Bintulu, Sarawak in August 2012
Source: Borneo (2012)

Figure 4.33 shows a car crashed into a tree and killed five in a family at Kampung Pengkalan Atap, Batu Rakit, Terengganu on 9 February 2019 (Utusan, 2019). The tree in the figure has a stem size about 500 mm diameter and was planted within the 3 metres specified clear zone for an urban area in accordance with Malaysia's landscape guideline. At the time of planting, the tree size was less than 100 mm diameter as permitted by the design guide and could be broken by the car on collision after planting. At the time of the car crash, its diameter was about 500 mm, and the car was broken instead. Based on this study, for primary and secondary rural road design standard R4 with the rated speed limit of 90 km/h traversing on the roadside slope of 1V:10H, the recommended roadside safety zone corridor is 4.51 metres. If the tree was planted outside the corridor of 4.51 metres safety zone corridor, the car might escape from the accident.

Figure 4.33 A car crashed into a tree and killed five in a family at Kampung Pengkalan Atap, Batu Rakit, Terengganu on 9 February 2019

Source: Utusan (2019)

Solution

The clear zone provision in the Malaysian landscaping design guide known as Intermediate Guideline to Road Reserve Landscaping issued by Cawangan Jalan Ibu Pejabat JKR was intended to restrict planting of trees bigger than 100 mm diameter, (JKR, 1997). It was stated in the guide that the clear zone width for rural and urban to be 9 and 4 meters respectively, and the zone implied to no planting of trees having bigger diameter than 100 mm. The reason was for the tree to be less than 100 mm diameter because it can be easily broken upon collision with a vehicle. It can be concluded that leaving trees having a diameter larger than 100 mm in the specified corridor is a wrong practice. In the context of highway and roadway design, trees are green belts to reduce noise pollution (Onder, S. and Kocbeker, Z., 2012), hence keeping trees too close to travel lane defeats the purpose because tree leaves are the absorbing character not so much for its stem. Besides being classified as a hazard, trees are most effective for noise barrier when placed outside the safety recovery zone corridor.

Study on cases shown in Figure 4.28 to Figure 4.33 informed that trees along main roads were within the region of safety recovery zone corridors and hazardous to traffic. Therefore, the trees to be removed from the roadsides. The sling road trees in Figure 4.30 were planted as required under National Landscape Policy (National, 1996) for the development area with the vision of transforming Malaysia into a beautiful garden nation by the year 2020. The sling road trees were beside collector local streets with speed limit of 50 km/h and roadside slope of 1V:4H shall be replanted to 2.36 metres from travel lane because their distances were about 0.5 metres.

The drain between the two opposing lanes in Figure 4.32 is recommended to be converted to swale with sub-surface perforated high-density polyethylene pipe drainage as discussed in Chapter 2 Literature Review. The sub-surface drainage system is usually applied to golf course drainage, which is traversable by cars and very forgiving upon collided with traffic. Once the sub-surface drainage system is introduced, the water ponding is no more visible, and the drainage capacity is increased.

It is recommended that the Malaysian landscape design guide text Clause 4.1 which reads as "Clear zones is defined as the area adjacent to the road pavement to the first tree (of diameter greater than 100 mm) planted" shall be redefined as "Clear zones is defined as the area adjacent to the road pavement to the first tree planted" i.e. with the elimination of the phrase "(of diameter greater than 100 mm)". In addition, to remove the last paragraph under the same section which reads as "Only shrubs and trees of diameter less than 100 mm are recommended to be planted within the clear zone".

4.2.2 Case Study on Poles and Posts

Problem

Figure 4.34 shows a car struck into a lighting pole at Persiaran Selatan Putrajaya, causing two killed and 1 injured (Mstar, 2014). The pole was installed within safety recovery zone corridor instead of outside. The road is under the category of a primary rural road with a speed limit of 100 km/h or design type R5 in Malaysian standard, and having a roadside slope less steep than 1V:10H. The pole made of metal pipe was impacted by the side of the travelling car, causing splitting effect and folded the car. Side of a car was a soft spot and unable to absorb the impacting force as compared to front and rear having bumper designed to cushion the crash impact.to front and rear having bumper designed to cushion the crash impact.

Figure 4.34 A car struck into a lighting pole at Persiaran Selatan Putrajaya causing 3 killed and 1 seriously injured
Source: Mstar (2014)

The car in Figure 4.35 rammed into a lighting pole, splitting the car into two at Dengkil/Cyberjaya Exit (Cinta, 2010). The pole was positioned into the ground at 3 metres away from the travel lane. The driver was killed as the extent of impact was very forceful.

Figure 4.35 A car ramped into lighting pole splitting the car into two killing the driver at Dengkil/Cyberjaya Exit
Source: Cinta (2010)

Sign and luminaire are typical highway accessories. Placing them appropriately may save some lives. Having them installed too near to the roadway, they will become obstructions to skidding vehicle. Figure 4.36 shows a car crashed into a signboard pillar, causing five in family killed on 02 May 2013 at North-South Expressway, Kulai Jaya, Johor (Dailyimage, 2013).

Figure 4.36 A car crashed into a road signboard pillar causing five in a family killed on 2 May 2013 at North-South Expressway, Kulai Jaya, Johor
Source: Dailyimage (2013)

Figure 4.37 and Figure 4.38 show a metal signboard girder collapsed onto a passing car after a trailer crashed into its post on 10 October 2015 at km 399.8 Tanjung Malim/Behrang, North-South Highway (Astro, 2015). The accident caused three in the family died. Typically, the signboard girder was supported on metal pipe column and positioned at about 5 meters away from the edge of a travel lane. The position of the girder columns was too close to the travel lane contributed to the accident. Numerous similar structures are found in Malaysian streets and require their layouts to be evaluated and corrected as necessary.

Figure 4.37 A signboard girder collapsed onto a passing car after a trailer crashed into its post caused 3 in the family died on 10 October 2015 at KM 399.8 Tanjung Malim/ Behrang, North-South Highway
Source: Astro (2015)

Signboards along roads display information are necessary for road users. However, proper design and installation are required to ensure traffic safety. Most accidents were contributed by the unsafe placement of pillars too near to travel lanes. Road safety audit by road authorities on a roadside pillar and recommends corrective action may help to solve the problems.

Figure 4.38 A passing by car that carried the 3 deceased vehicle occupants
Source: Astro (2015)

Solution

The road in Figure 4.34 was a primary rural road design type R5 according to Malaysian standard with specified speed limit of 100 km/h. The car traversed on roadside slope less than 1V:10H, for which based on outcome of this study as shown in Table 4.30, it recommended roadside safety recover zone corridor width of 5.39 metres for the travelling speed of 100 km/h. If the lighting pole was installed outside the safety corridor of 5.39 metres instead of 3 metres from the travelling lane, the car could have escaped from hitting the lighting pole. The case in Figure 4.35 was similar to the case of Figure 4.34, where if the pole was placed at 5.39 metres instead of 3 metres away from the travel lane, the accident could be avoided and the driver survived.

The signboard pillar shown in Figure 4.36 shall be kept away from the travel lane as far as the width of safety recovery zone corridor. Based on the study outcome, for rural expressway travelling speed of 110 km/h and roadside slope of 1V:4H, the required free of obstruction corridor width is 8.07 metres compared to the signboard post position of about 6 meters away from the travel way. The recommended solution is to redesign with cantilevered structure with pillar shifted by 2.07 metres further away from the travel lane. The car might escape from the accident if the signboard was located outside the 807 metres safety recovery zone corridor recommended in the study.

Case study to problem in Figure 4.37 and Figure 4.38 on signboard metal girder collapsed informed that the signboard nearest column 5 metres away from the edge of travel lane was located inside safety zone corridor. Based on the outcome of this study in Table 4.30 the width of safety recovery zone corridor for the region was 6.89 metres, the value for rural design standard R6 expressway with speed limit 110 km/h and having roadside slope of 1V:6H. Could the girder signboard pillar was built outside the safety zone, the lorry may had escaped from hitting the steel column and avoided the signboard collapsed and saved the three passengers life. Design of the girder pillar can be improved by providing deeper stump to provide counter moment from impact and bottom part of the pillar be shielded with crash cushion made of boxed-sand or metal barrier.

Upon future implementation of safety recovery zone corridor concept proposed in this study, it is anticipated that all roadside poles will be installed outside the safety recovery zone corridor resulting with crashes eliminated if not minimised. If limitation arise, three options are available in reducing the potential impacted force, firstly is by installing shielding object, secondly by using a slip-base pole mechanism and thirdly is by increasing their bottom stems diameter and using thin wall section to be impact absorbing pole.

4.2.3 Case Study on Drains and Culverts

Problem

A roadside drain is among significant hazards for Malaysian road. Figure 4.39 shows skidding car where the driver could not control the car due to steep roadside slope of 1V:1H i.e. the gradient is steeper than 1V:4H a non-traversable slope, and hitting the hard surface drain's rubble pitching wall and bounced back causing three passengers died and one severely injured at KM 5 Kuantan-Gambang, Kuantan, Pahang Highway (Kosmo, 2015).

Figure 4.39 Roadside drain is a hazard to road users. Kuantan, 19 August 2014 – 3 passengers died and 1 severely injured at KM 5, Jalan Gambang-Kuantan.
Source: Kosmo (2015)

Figure 4.40 shows a bus skidded into a roadside drain located at less than 2 metres away from the travel lane (Ammboi, 2013). The bus was avoiding collision with the oncoming car encroaching into its lane, but unfortunately, the roadside drain was too near to travel lane causing the bus got into the drain. The roadside emergency lane was undersized, and the drain was constructed within the safety zone corridor, causing an impossible situation for the bus to stop or traverse back into the carriageway.

Figure 4.40 Roadside drain is a hazard to road users. Avoiding a car coming to its lane, the bus got into roadside drain at Kampung Gerai, Jertih, Terengganu
Source: Ammboi (2013)

It is prevalent in the Malaysian practice for culverts or concrete boxes to traverse across the road when carriageway elevation is higher than surrounding to allow under-passage of the water stream or underside road crossing from one side of the road to the other. The current practice of building a road with a minimum of one to two metres higher elevation above flood level has caused an increasing number of the culverts usage to allow under-passage of stream in ensuring balancing level of flood on both sides of the road.

It is typical for a road crossing culvert design to comprise of the tubing section and headwalls complete with wings at both ends. The headwall and wings are introduced for backing earth behind them. Figure 4.41 shows a car plunged into headwall culvert opening at the south of Gympie, Queensland, Australia (Gympie, 2012). Most of the culverts in Malaysia are having openings that are not closed with a metal grating as shown in Figure 4.42 in view to no statutory requirement to do so. The projection of the concrete head and wing walls above ground surface worsen the condition as the vehicle can be airborne upon striking them. Some culverts discharging into the flood-prone area has got their inlet closed with steel grating as in Figure 4.43 to prevent rubbish built-up, mainly serves as a flood mitigation measure.

Figure 4.41 A car plunged into culvert opening at South of Gympie, Queensland, Australia on 17 November 2012

Source: Gympie (2012)

Figure 4.42 Concrete culvert at KM 5 Gambang-Kuantan Highway, Kuantan, Pahang

Figure 4.43 The culvert discharging to the stream is provided with steel screen to trap rubbish at the side of KM 5 Gambang-Kuantan, Kuantan, Pahang

Solution

Referring to a case study shown in Figure 4.39, should the one-sided rubble line wall be with turfed earth and 1V:1H inside slope in place of the nearly vertical embankment, the accident may probably not be fatal but with injuries. If the approaching slope (the drain slope closest to the road) having a slope of 1V:1H was built with the study recommended minimum slope of 1V:4H, there was a possibility the skidding car may traverse back into the driving lane, and the passengers may have survived from death. If the roadside tree and the drain were positioned outside the study recommended safety recovery zone corridor, there was a very high chance that the passengers may survive both deaths and injuries. The tragedy was evident that the drain design was not forgiving and needed to be redesigned and reconstructed with a forgiving design concept. The solution to Figure 4.44 is to ensure the drain is constructed outside safety recovery zone corridor or reform to forgiving design type as discussed in the following section.

Figure 4.44 shows Kuantan-Gambang highway on the left of the viewer and the right of the viewer was sling road. The drain served stormwater discharge from the main road and the sling road. It can be observed that the installed rubble pitched drain was not forgiving to traffic and contributed to a fatal accident. It is recommended that the drain be reconstructed with new traffic friendly design.

Figure 4.44 Overall elevation showing the site for accident shown in Figure 4.39 took place

The cross-section profile of the existing highway and sling roads in graphical form is shown in Figure 4.45. The proposed new design concept that will upgrade the safety of the highway and the sling road are shown in Figure 4.46. The discharge capacity of the shown swale is the combination of on the road surface discharge of both the main and sling roads and sub-surface discharge of infiltrated stormwater. The perforated high-density polyethylene pipe underside the swale and the interstices of sand and gravel shall accommodate the discharge. The volume of runoff to be served is between the centre lines of the highway and sling roads about 20 metres width.

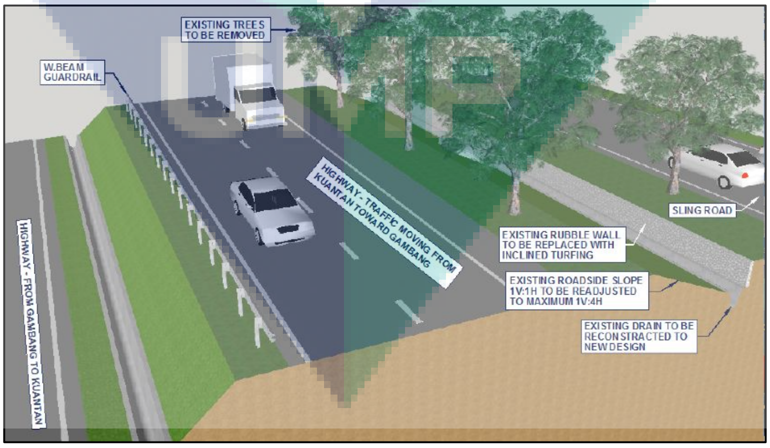


Figure 4.45 Transformed from photo in Figure 4.44 into graphical form

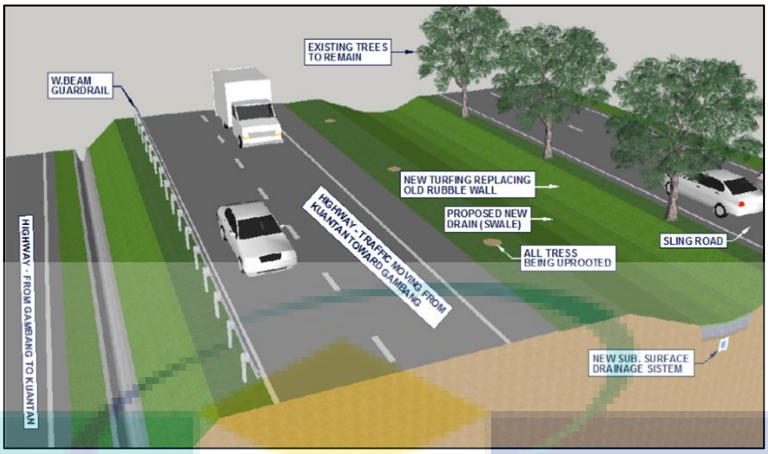


Figure 4.46 Proposed design upgrade to the existing road in Figure 4.44

It is proposed that the existing culvert inlet and outlet at the headwall, and the wing wall to be modified as shown in Figure 4.47. The metal screen has two functions, firstly for screening the rubbish, and secondly, the surface is traversable by skidding car in making trajectory to safety during an emergency. The metal blade is set to be vertical to minimize debris clinging to the grill. The recommended grating design is 12 mm metal plate thickness spaced at 100 mm centres. Both wing walls directions are set straight instead of at an angle to prevent the entry of eroded earth into the culvert despite the flushed condition of the wing and headwalls top against ground surface.

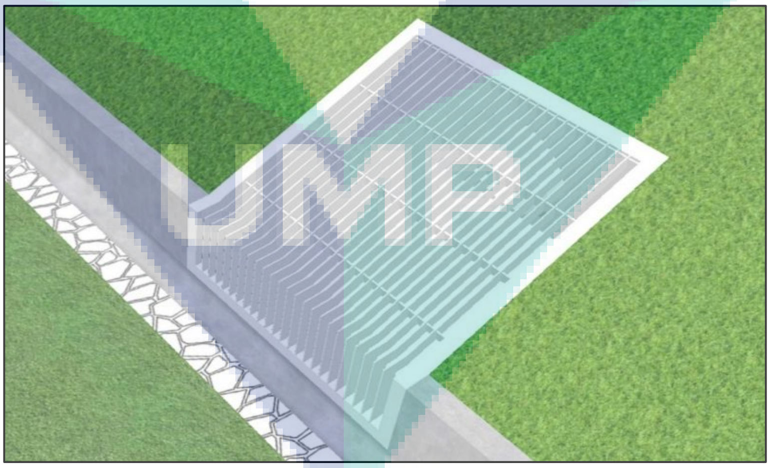


Figure 4.47 Proposed modification to the culvert shown in Figure 4.42

4.2.4 Case Study on Kerbs and Wall

Problem

Kerb, though appear to be small in size but the force of impact may cause fatal accident as in the case shown in Figure 4.48 where the car hit the kerb, airborne and hit the light pole and landed on the pedestrian path causing the driver died on 20 February 2011 at Jalan Tun Jugah, Kuching, Sarawak (Kemalangan, 2011). There were practices installing kerbs with substantial projection to facilitate future repaving without having to dismantle and replace the kerbs, a practice proven to be wrong.

Figure 4.48 The car hit kerb, then light pole and landed on pedestrian path causing the driver died on 20 February 2011 at Jalan Tun Jugah, Sarawak
Source: Kemalangan (2011)

Likewise, in the case shown in Figure 4.49, the car hit the kerb, then airborne killed four at kilometre 9.9 Elite highway Subang Jaya (Ohdunia, 2015). The kerb on the roadside was very high in elevation and having a steep vertical face for car safe climbing was unlikely to be performed. Many Malaysian streets installed with a high elevation and steep face kerbs need replacement.

Figure 4.49 An accident killed 4 at KM 9.9 Elite Highway Subang Jaya
Source: Ohdunia (2015)

Solution

Poorly designed kerbs cause damages to tyre sidewalls, wheel alignment sometimes burst and may lead to fatal accidents on prolonged usage (Septua, 2015). A sample of favourable and forgiving design kerb is shown in Figure 5.32 at Port Elizabeth, South Africa has about 25 mm drop, tapered slope to the berm. The African kerb is lined with concrete slab edging the paved road and perfectly formed a smooth channel. Similar kerb adopted to some places in Putrajaya is shown in Figure 4.51, but the kerb was not lined with a concrete slab edging the paved road that made it sub-standard as compared to the African version. Straying off from travel lane, wheel contact with kerbs could cause a vehicle to be airborne and overturn (AASHTO, 2011).

Could the kerbs in Figure 4.48 and Figure 4.49 installed with the type shown in Figure 4.50 or Figure 4.51, the driver could have drove-up the kerb instead of airborne and then manage the car steering to land the car safely. Poor engineering roadside design will not compromise motorist mistake, and sound engineering design may forgive motorist mistake. The problem discussed is typical nationwide.

Figure 4.50 Kerb is more forgiving with low drop level, tapered with the provision of slight depression for drainage at Port Elizabeth, South Africa
Source: Septua (2015)

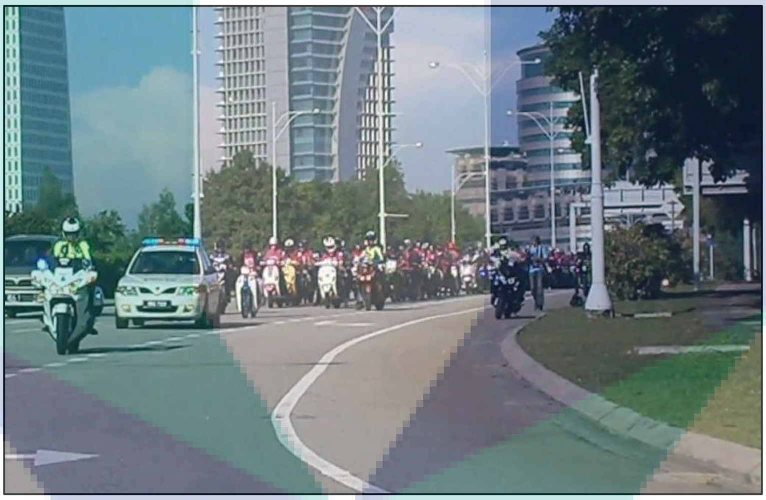


Figure 4.51 Traffic friendly low kerb implemented to some places at Putrajaya

4.2.5 Case Study on Roadside Barriers

Problem

Figure 4.52 shows a car crashed into a concrete barrier and caused two died from 5 in the family at km 256 PLUS highway on 4 October 2014 (Melvister, 2014). The concrete barrier was of the rigid type barrier, and it redirected the vehicle upon collision where dissipated energy absorbed by the vehicle and causing the car metal body to deform, and lead to the fatal accident.

Figure 4.52 A car crashed into concrete wall and caused 2 died from 5 in the family at KM 256 PLUS Highway on 4 October 2014
Source: Melvister (2014)

The roadside metal beam guardrail itself can be a hazard as shown in Figure 4.53 and Figure 4.54. It was an accident at KM 13 Jalan Kuantan-Pekan, where the bus front left tyre exploded, and the bus then crashed into roadside longitudinal safety barrier and caused the metal beam punctured through the bus (Sinar, 2014). One passenger leg was broken, and two passengers were with minor injuries. The safety barrier installed was to shield a row of trees planted 3 metres from the road edge marginal line. Should the safety recovery zone corridor of 5.39 metres width for R5 type for the rural road as recommended in this study under Table 4.30 was enforced, the barrier was not required to be installed. It was because the planting of trees in the region was not permissible, and such an accident could have been avoided. Could the colliding vehicle was a car in place of the bus, the accident could be fatal. The accident was not fatal to bus passengers because the but floor level was very much higher than the usual car's floor level. However, the tragedy has been very scary to the public till now. The road authorities must have kept all similar installation under road safety auditors check list.

Figure 4.53 A metal beam punctured through the rapid Kuantan bus at KM 13 Kuantan-Pekan, Pahang
Source: Sinar (2014)

Figure 4.54 Rear view of rapid Kuantan bus accident at KM 13 Kuantan-Pekan, Pahang
Source: Sinar (2014)

Figure 4.55 shows an errant car crushed into the guardrail causing 4 died at KM 73 Kuala Kangsar road, Gerik, Perak (Langkah, 2011). The tragedy implied that responsible Malaysian authority has great task to evaluate all existing infrastructures and if necessary, to redesign many of the existing roadside barrier system. The Guidelines on Design and Selection of Longitudinal Traffic Safety Barrier has no recommendation for providing roadside barrier to road having low lying area beside the site table (REAM-GL-9, 2006). However, it is believed that the engineer felt the need of the metal beam barrier in preventing the skidding vehicle from encroaching into the low-lying area.

Figure 4.55 A metal barrier penetrated into skidding car causing 4 died at KM 73 Kuala Kangsar Road, Gerik, Perak
Source: Langkah (2011)

Solution

The case in the Figure 4.52, there was no shielding provided to reduce degree of crash impact. Installation of crash cushion cylindrical high-density polyethylene barrier as shown in Figure 2.2 in such accident-prone area may have saved the passengers life. Generally, concrete barrier is applied as divider for separation of opposing lanes in order to prevent opposing car from crossing to the other side.

The cases in Figure 4.53 and Figure 4.54, the application of metal beam as roadside barrier to shield trees was not permissible in practice because they were hazards and not necessary. The Malaysian "Guidelines on Design and Selection of Longitudinal Traffic Safety Barrier" recommends engineers to consider removal or relocation, prior to application of safety barrier as a shield on the roadside (REAM-GL-9, 2006). It was very clear that the intent of the guide was not to keep trees nearby to roads and use metal beams as shield.

The case in the Figure 4.55, the metal beam barrier was installed to prevent traffic from encroaching into low lying area. The metal beam barrier was not installed according to safe engineering practice where blunt end to be provided in order to avoid beam puncturing into approaching vehicle. Application of soft and displaceable barrier is more impact tolerable than hard and semi-rigid barrier. Installing boxed-sand safety traffic barrier as shown in Figure 4.56 is cheaper and safer than the metal barrier, and giving high chance of survival for the 4 died vehicle passengers.

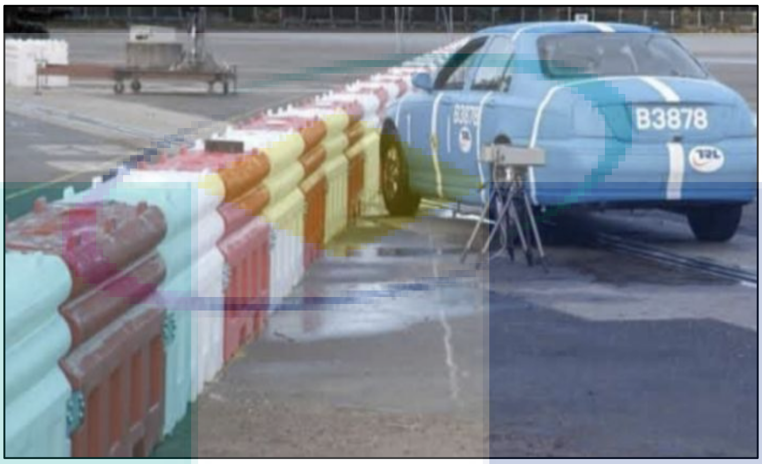


Figure 4.56 Boxed-sand for roadside safety traffic barrier
Source: http://www.bin-shop.co.uk

4.3 Summary

The study showed that the minimum safety recovery zone corridor widths measured perpendicular from travel lane increase with the increase of the roadside slope gradients and vehicle travelling speeds. The field tests demonstrated that the nature of ground surface such as long or short grass, dry or wet surfaces and percentage of sands on the surfaces, all influence the width of safety recovery zone corridors as demonstrated by the error bars in column charts. Depending on the road design types and roadside gradients, the discovered safety recovery zone corridor widths for rural and urban roads in this study is ranging between 1.64 to 8.07 metres for vehicle speeds between 50 km/h to 110 km/h. Depending on the road design types and roadside gradients, the discovered minimum safety recovery zone corridor widths applicable for the design of rural and urban roads is ranging between 1.64 to 8.07 metres for vehicle speeds between 50 km/h to 110 km/h. The present design policy titled as "A guide on geometric design of roads issued by the Road Association of Malaysia" has not addressed on the roadside safety recovery zone corridor requirement. Filling the gap with this new requirement will make our road a safer place to drive.

The case study showed that trees are major hazards on the roadside. The massive planting of trees along roadside was triggered by Malaysian government through landscape design guideline further to launching the theme that Malaysia is a garden state by 2005. Unfortunately, the landscape design guideline permit planting of trees smaller than 100 mm diameter within the roadside clear zone has resulted massive grown trees having increased diameter up to 800 mm and at presence have become roadside hazards to traffics. In order to correct the situation, the authority has to make changes to the design guideline to not permitting planting trees less than 100 mm diameter within the clear zone corridor of 9 and 4 metres for rural and urban roads respectively.

Finding from the study area has shown that trees planted on roadside along the main road and sling road within the safety recovery zone corridor are obstructions and hazards to traffic. The trees are to be removed and reinstate the affected ground condition upon uprooting activities. Some of previous cut trees were not uprooted revealed them as hazards to traffics.

Case study on poles and posts revealed that most of them were installed at the outer edge of emergency lane at a typical distance of about one metre away which is within the range of safety zone, a zone to be free of hazards. These structures had caused many fatal accidents and serious injuries, and require initiative to improve the situation. Introducing roadside safety zone in design policy will eliminate these hazards from roadside. Changing the concrete/cable system to armoured cable buried in the ground will eliminate the need for concrete poles. If keeping lighting poles and signboard posts outside safety recovery zone corridor is not possible, shielding to be provided surrounding bottom of the poles to cushion crashing impact. In addition, use of bigger pole diameter may reduce impact pressure on collision.

Case study on drains and culverts revealed that most of them were constructed just adjacent to emergency lanes which is within safety recovery zone corridor area, and had become hazards to traffic. Possible treatment to existing drains is relocate them to outside the safety zone area or convert them to sub-surface drainage system known as swale. The opening at inlet and outlet at headwall, and wing walls projections of culvert are threat to traffic safety, and shall be covered up with metal grating to enable the surface to be traversable to safety for skidding vehicle.

Case study on kerbs and walls revealed that their design of high projection above ground have been causing car to hit and get airborne and led to fatal accidents or serious injuries. The possible solution is replacement with car easy climb.

Case study on rigid type barrier made of concrete is causing fatal accident due to high impact force. It is recommended to provide rubber cushion on the concrete surface to reduce degree of impact. Metal beam barrier shielding row of trees itself has become hazard. If trees cannot be relocated, they shall be removed from roadside. The design guideline shall prohibit usage of metal beam to shield trees on a roadside.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Safety recovery zone corridor width is a measure of horizontal distance from marginal line (the white painted line at the edge of the road) or edge of the road (if a marginal line is unmarked on the road) for the maximum trajectory width made by a skidding vehicle during driving field test. Depending on the road design types and roadside gradients, the discovered minimum recommended safety recovery zone corridor widths for rural roads is ranging between 1.64 to 8.07 metres for vehicle speeds between 50 km/h to 110 km/h. On the other hand, the discovered minimum recommended safety recovery zone corridor widths for urban roads is ranging between 1.64 to 6.82 metres for vehicle speeds between 50 km/h to 100 km/h. It was observed that the width of safety recovery zone corridor increases with the increase of vehicle speed and roadside slope gradient. Compliance with this phenomenon is the indicator that tests had been properly executed. Roadside slope gradient steeper than 1V:4H is not traversable by skidding vehicle and shall not be permitted in a design where safety recovery zone corridor is to be provided. The statistic of roadside accident cases in this study justified the necessity to fill the gap in the design chapter with roadside safety recovery zone corridor in Malaysia's design guideline. Adoption of this initiative is important to reduce road traffic fatalities and serious injuries of road users in Malaysia.

The minimum width of safety recovery zone corridor from this study for vehicles' travelling speed between 60 to 110 km/h was from 2.357 to 8.067 (or rounded to 2 to 8) metres compared to American's design guide of 2 to 14 metres. The American safety zone width has increased gradually according to the vehicle travelling speeds with a safety factor of 0 to 1.7 if compared to this study. The American design guide is for global usage in the entire United States. This study proposed a minimum width of safety recovery zone corridor or unfactored with multiplier to allow the design engineer to use their own safety factor based on the local level of risk. There is no level of risk versus a design safety factor published yet. It is normal for a design engineer to apply a safety factor on own judgement of risk factor based on his road design parameters and site condition. However, the Malaysian road authority may apply a global safety factor to safety recovery zone corridor width values for the whole nation as in the case of the United States. Global safety factor often causes overdesign to non-critical areas and inflate the cost of road projects.

The study discovered that the relationship between safety recovery zone corridor width Z in metres and roadside slope S for vehicles' travelling speed of 110, 100, 90, 80, 70, 60, 50 km/h were given by $Z = 14.185S + 4.5212$, $Z = 9.5706S + 4.4287$, $Z = 15.614S + 2.9451$, $Z = 16.329S + 2.1571$, $Z = 17.044S + 1.3691$, $Z = 17.759S + 0.581$ and $Z = 18.474S – 0.207$ respectively. The property of the equations was governed by the road's specification and the roadside slope materials. All the roadside slopes were constructed based on Malaysian road authority specification issued by Jabatan Kerja Raya Malaysia. The data collected from ten test fields chosen from four states of Malaysia were built on the common specification. The study has provided reasonable coverage on the changing ground conditions to account for use in the national design policy.

Based on the design guideline known as "Intermediate Guidelines to Road Reserve Landscaping" issued in 1997, design engineers and local authorities had executed the planting of trees less than 100 mm diameter within the safety recovery zone corridors. In over 15 years, the trees have grown in size with some up to 800 mm diameters as reported in the case study. It has been shown in this study that trees less than 100 mm diameter planted within safety recovery zone corridor has become the leading road killer today, and the situation has alarmed that design guideline shall be revised. It is recommended that the guidelines Clause 4.1 which reads as "Clear zones is defined as the area adjacent to the road pavement to the first tree (of diameter greater than 100 mm) planted" shall be rephrased as "Clear zones is defined as the area adjacent to the road pavement to the first tree planted", i.e. with the elimination of the phrase "(of diameter greater than 100 mm)". In addition, to remove the last paragraph under the same section which reads as "Only shrubs and trees of diameter less than 100 mm are recommended to be planted within the clear zone”. This rephrased clause will ensure no more trees are planted within the roadside clear zone and will solve present and future problems.

It has been shown from the case studies carried out that most of the present roadside structures level of safety are critical and need to be upgraded to the forgiving design concept. Most of the roadside crashes could have been avoided if safety recovery zone corridor policy were implemented. Physical changes to roadside structures are crucial to minimising the rate of fatal accidents and serious injuries.

5.2 Recommendations for Future Research

It is recommended for future research to get a huge grant to enable the building of several sections of roads with a variety of roadside gradients in an open environment to perform high-speed field tests. The road sections have to be built in accordance with the specification of Malaysian standard in term of their geometries and materials as issued by Road Engineering Association of Malaysia. A minimum of four cars of popular models may represent a variety of models on the roads. In view to human reactions govern trajectories of vehicle paths that influence sizes of safety recovery zone corridor in the live field test, a minimum of four licenced drivers may be considered an appropriate number.

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