SAFETY RECOVERY ZONE CORRIDOR FOR MALAYSIAN ROADS DERIVED FROM LIVE FIELD EXPERIMENTS

[1]Ahmad Kamal, Kunji
[2]Datin Prof. Dr. Nasly, Mohamed Ali
[3]Prof. Madya Adnan, Zulkiple

[1]PhD scholar University Malaysia Pahang, ***MALAYSIA***
[2]Lecturer, University Malaysia Pahang, ***MALAYSIA***
[3]Lecturer, University Malaysia Pahang, ***MALAYSIA***

[1]kamaliem12@gmail.com
[2]nasly@ump.edu.my
[3]adnanz@ump.edu.my

ABSTRACT

The increasing number of high impact run-off-road accidents has alarmed institutions to carry out studies to formulate roadside geometric design guideline that could reduce the number of fatalities and severe injuries. Currently, Malaysia has not issued a roadside geometric design guide that requires provision of roadside safety recovery zone corridor. Establishing a configuration and dimension of the roadside slope cross-section that allow straying off from travel lanes will reduce run-off-road fatal accidents or severe injuries for motorists safe traversing back into driving lanes. Live field experiments were carried out to determine the optimum roadside safety recovery zone corridor widths for roads in Malaysia. The ten test locations were selected from four states namely Pahang, Johor, Selangor and Perak of Malaysia with various roadside slope gradients and ground surface conditions. The study shows that safety recovery zone corridor widths increase with the increase of the roadside slope gradients and vehicle travelling speeds. Depending on the road design standard types, the safety recovery zone corridor widths for both rural and urban roads range between 1.52 to 8.06 metres for vehicle speed between 50 km/h to 110 km/h and roadside gradients between 1V:10H and 1V:4H.

INTRODUCTION

The United States recorded in 2008, 23.1% of the fatal crashes were run-off-road crashes (AASHTO RDG., 2011). European Union countries recorded in 1998, 33.8% of all fatalities were the result of run-off-road accidents (D06, 2006). Run-off-road vehicles accidents mostly resulted in fatal crashes due to high crash impacts caused by a combination of high vehicle travelling speed, steep roadside slope gradient and obstructing objects such as trees, utilities and signs poles etc. Realising the problem, America has over 30 years introduced a safe roadside geometric design guide that require provision of roadside clear zone or safety recovery corridor which consist of an area made up of road shoulder, a recoverable slope, a non-recoverable slope and a clear-run out area (AASHTO RDG 2011). Roadside safety recovery zone corridor allow space for errant driver a second chance to save his or her life by traversing back into carriageway upon skidding. Introduction of 9 m or more roadside clear zone corridor in United States permits 80% of run-off-road errant vehicles recovered back into driving lanes (AASHTO RDG 2011: Graham J.L., and Hardwood D.W., 1982).

Currently, Malaysia has not established a design guideline on a forgiving roadside geometry known as safety recovery zone corridor that comprise of wide and gentle roadside slope and free of hard obstructing objects. The provision of safety corridor is to allow safe traversing by skidding errant vehicles for recovering back to travel lane. The steady increase of run-off-road fatal crashes rates indicate a need for improvement to the present design practice. This study is to recommend the optimum safety recovery zone corridor design for roads in Malaysia as derived from live field experiments. Most of the fatal crashes could have been avoided if the construction of roadside safety recovery zone corridor were implemented.

VEHICLE'S EXIT ANGLE EMPLOYED FOR LIVE FIELD EXPERIMENT

Determination of vehicle's exit angles based on accidents records is a real-time information. The exit angles were generated from real situation and their angular values accounted for combination of vehicle's natural exit angle with the human factor contributed by the driver's intervention and producing modified vehicle's path. Currently, Malaysia has not published any statistics on run-off-road accidents records that register vehicle's exit angles. The only practical option that is available for this study is based on America's vehicle's exit angle derived from accident records.

Integrating data from Hutchinson and Kennedy with that of Cooper (1980), Sicking and Ross (1986) computed a probability of vehicle's exit angle as shown in Table 1. Interpolating the figures for 70% cumulative percentage of accidents, the corresponding upper limit vehicle's exit angle obtained is 20 degrees. Hence, all the executed live field experiments employed the 20 degrees vehicle's exit angle in obtaining optimum size of roadside safety recovery zone corridor design to represent majority of accident cases.

Table 1 **:** Vehicle's Exit Angle Versus Cumulative Percentage of Accidents by Sicking and Ross (1986)

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

ROADSIDE SAFETY RECOVERY ZONE CORRIDOR WIDTH

Road shoulder is a component of roadside, and its width and type have played a key role in roadway safety (Jorgenson, 1978 ; Zeegar et al., 1987). The geometric design requirement for roadside safety recovery zone corridor area is that once the area is encroached, an errant driver could manoeuvre his vehicle to get back to the travel way to save his life. If the situation is in the recovery mode, then we address it as a driving error tolerable or forgiving roadside geometric design. It is hard to deduce correlation between influencing factors and fatalities (Rohayu et al., 2012). Forgiving roadside geometric design comprises of two main elements namely a generous roadside corridor space free of obstruction and a gentle roadside slope gradient. The obstruction free corridor is to allow the skidded errant vehicle to traverse and recover his journey back to travel lane for the purpose of saving his life. The safety recovery zone corridor width (herein denote as *Z*) is defined as a width adjacent to travel way measured perpendicularly and horizontally from the edge of carriageway that is clear of fixed objects to permit uninterrupted safe passage of encroaching errant vehicle. Zedgeer et al., (1988) reported that for generally unobstructed flat ground, provision of 1.5 metres to 6.2 metres of roadside safety recovery corridor width may reduce accident rate between 13% to 44%.

SELECTION OF EXPERIMENT SITES

In observing drivers and public safety, all roads for testing works were selected from remote locations with low traffic volume, and having sufficient clear area for safe skidding vehicle travesability. The selection criteria include having roadside slope with gentle gradient and not steeper than 1V:4H to permit vehicle's climbing capability in traversing back to the travel lane. The road test safety requires sufficient length of straight stretch portion to enable safe driving test speeds between 50 km/h and 90 km/h. The ten selected sites that complied with the set test criteria were from four states of Malaysia namely Pahang (Pantai Sepat, Bukit Ibam, Kampung Lanjut and Bandar Muadzam Shah), Johor (Bandar Tenggara), Selangor (Rawang, Serendah, Sg. Tengi) and Perak (Kuala Kurau-2 locations).

EXECUTION OF FIELD EXPERIMENTS

Malaysia's statistic from the year 2007 through 2010 for passenger vehicles having three and above fatalities and commercial vehicles with one fatality and above, reported that passenger cars represent dominant vehicle with fatal accidents (Ahmad Noor Syukri ZA et al., 2012). Hence, the executed field experiments with four wheels motorcars and the results obtained are representing majority of vehicles on Malaysian roads. Three units of four wheels motorcars and five drivers were employed for the testing works.

Selection of test speeds was based on range of speeds listed in Malaysia's design standard (REAM-GL 2/2002). The standard specifies speeds for Malaysia's roads ranging from 50 km/h to 110 km/h in the interval of 10 km/h. The field preparation includes painting the road edge with red line vehicle exit angle and the roadside corridor ground pegged with wooden sticks laid at 0.5 metre intervals measured horizontally and perpendicular to the road. The live field experiments were carried out with each speeds tested five rounds and the manually measured tyre marks between the wooden pegs from the road edge for safety recovery zone corridor average values *Z* were recorded. Taking into consideration the available site condition and the safety of the drivers and public, the safe vehicle speeds employed were between 50 km/h to 90 km/h in the interval of 10 km/h. The safety recovery zones corridor widths *Z* for the speeds of 100 km/h and 110 km/h were statistically obtained to complete the range of values required. However, some of the tests were carried out below 90 km/h due to poor site condition that may risk higher speed driving.

DATA COLLECTION AND ANALYSIS

All the data collected from the ten field experiments were plotted with software and a sample for Pantai Sepat, Kuantan, Pahang is shown in Figure 1. The scattered coordinates indicate non-uniform ground condition and the influence of varying drivers' reaction during route recovery traversing. The graphical line and its equation represent statistical relationship between safety recovery zone corridor horizontal widths *Z* and vehicle's travelling speeds *V* at a fore-slope gradients *S*. Having obtained the trendline statistical equations, a set of refined values of *Z* for all vehicles' speeds could be calculated. Computing the safety recovery zone corridor widths with the software generated statistical trendline equations in Figure 1 and the other nine figures from other sites at vehicle speeds ranging from 50 km/h through 110 km/h, the corresponding values of safety recovery zone corridor widths are summerised in Table 3. The values of roadside slope gradients *S* shown in Table 3 are in decimal forms and need to be redefined to bold numbers (non-decimal) of 1V:4H through 1V:10H in order to be in-line with industry's practice that ease construction work. In obtaining roadside fore-slope *S* in bold numbers (non-decimal), re-modelling by way of replotting the values in the Table 3 has to be performed to produce new generalised equations of *Z*, *S* and *V*.

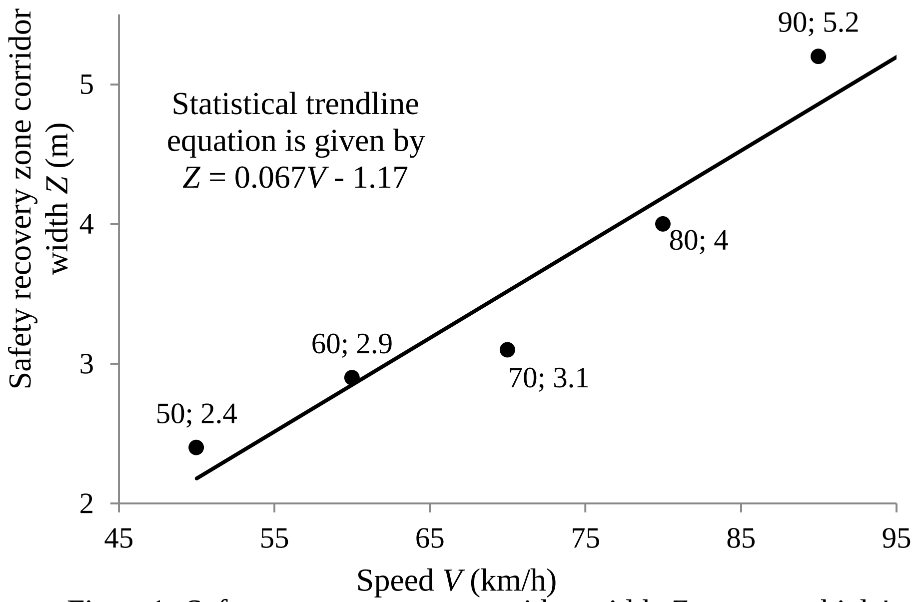

Figure1. Safety recovery zone corridor width *Z* versus vehicle's speeds *V* for roadside fore-slope gradient 1V:7.1H at Pantai Sepat, Kuantan, Pahang.

Table 3. Safety recovery zone corridor widths for specified fore-slope gradients *S* for various vehicle's speeds *V*.

Speed *V* (km/h)	Safety Recovery Zone Corridor Width *Z* (m)									
	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	1.54	2.12	2.29	2.68	2.78	3.17	3.32	3.48	3.52	3.92
60	2.54	2.70	2.87	3.43	3.53	3.87	4.10	4.05	4.19	4.54
70	3.04	3.78	3.48	4.18	4.28	4.57	4.62	4.62	4.86	5.16
80	3.6	4.10	4.12	4.93	5.03	5.27	5.31	5.19	5.53	5.78
90	4.36	4.93	4.77	5.68	5.78	5.97	5.96	5.76	6.2	6.4
100	5.03	5.63	5.44	6.43	6.53	6.67	6.61	6.33	6.87	7.02
110	5.71	6.33	6.13	7.18	7.28	7.37	7.26	6.70	7.54	7.64

Re-plotting the values in Table 3, a set of trendline statistical equations are obtained with one of them for vehicle speed of 50 km/h is shown in Figure 2. Based on the given trendline equation in Figure 2 and the other six figures for speeds ranging from 60 km/h through 110 km/h, the calculated refined values of safety recovery zone corridor widths *Z* versus vehicle travelling speeds *V* and varying roadside slope gradients S in bold numbers are obtained as in Table 4.

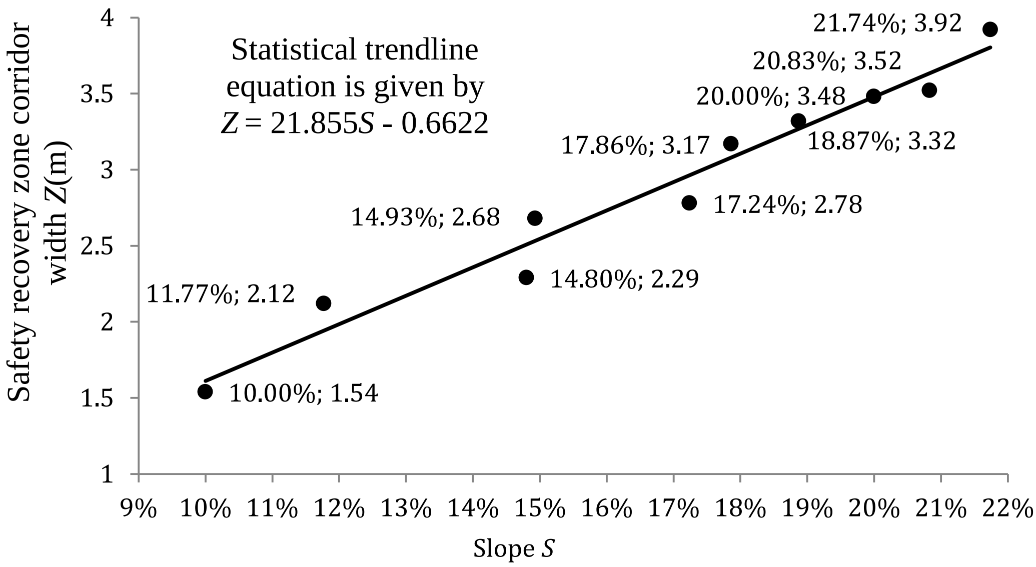

Figure 2. Safety recovery zone corridor widths *Z* versus roadside fore-slope gradients *S* at vehicle speed of 50 km/h for all sites

Table 4. Safety recovery zone corridor widths Z for specified roadside slope gradients S in bold (non-decimal) numbers at various vehicle speeds.

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	1.52	1.76	2.07	2.46	2.99	3.71	4.80
60	2.33	2.55	2.84	3.20	3.68	4.34	5.35
70	3.10	3.29	3.57	3.90	4.35	4.97	5.90
80	3.71	3.90	4.14	4.45	4.87	5.44	6.31
90	4.51	4.68	4.90	5.19	5.57	6.09	6.88
100	5.22	5.39	5.60	5.91	6.24	6.74	7.5
110	5.96	6.12	6.31	6.56	6.90	7.36	8.06

The roadside slope gradients steeper than 1V:4H were not applied in producing Table 4 due to these range of slopes are classified as non-recoverable or non-traversable by skidding vehicles (AASHTO RDG 2011). Re-organise a set of values for safety recovery zone corridor widths for vehicle's speeds ranging between 50 km/h through 110 km/h from Table 4 in the format of Malaysian rural road design standard (REAM-GL 2/2002), Table 5 is produced.

Table 5. Safety recovery zone corridor widths Z for specified roadside slope gradients S at various vehicle speeds for rural roads of flat terrain in Malaysian design standard format.

Design Standard	Category of Road	Speed V (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	1.52	1.76	2.07	2.46	2.99	3.71	4.80
R2		60	2.33	2.55	2.84	3.20	3.68	4.34	5.35
R3	Secondary	80	3.71	3.90	4.14	4.45	4.87	5.44	6.31
R4	Primary & Secondary	90	4.51	4.68	4.90	5.19	5.57	6.09	6.88
R5	Highway Primary	100	5.22	5.39	5.60	5.91	6.24	6.74	7.5
R6	Expressway	110	5.96	6.12	6.31	6.56	6.90	7.36	8.06

The Malaysian design guide (REAM-GL 2/2002) categorise urban roads into three types, firstly Type I for relatively free in road location with very little problems as regards to land acquisition, affected buildings or other socially sensitive areas, secondly Type III for very restrictive in road location with problems as regards to land acquisiton, affected buildings and other sensitive areas, and thirdly Type II for intermediate between Type I and Type III. The design speeds for urban roads are ranging between 30 km/h to 100 km/h. Re-organise a set of values for safety recovery zone corridor widths for vehicle's speeds *V* ranging between 50 km/h through 100 km/h from Table 4 in the format of Malaysian urban roads Type I, Table7 is produced. In similar way Type II and Type III design tables can be produced.

Table 7. Safety recovery zone corridor widths *Z* for specified roadside slope gradients *S* at various vehicle speeds for urban roads of area Type I in Malaysian design standard format.

Design Standard	Category of Road	Speed *V* (km/h)	Safety Recovery Zone Corridor Width *Z* (m)						
			1V:10 H or less	1V:9H	1V:8H	1V:7H	1V:6H	1V:5H	1V:4H
U1 U2	Local Streets	40 50	1.52	1.76	2.07	2.46	2.99	3.71	4.80
U3	Collectors Local Streets	60	2.33	2.55	2.84	3.20	3.68	4.34	5.35
U4	Collector Local Streets	70	3.10	3.29	3.57	3.90	4.35	4.97	5.90
U4 U5	Arterials Collectors	80	3.71	3.90	4.14	4.45	4.87	5.44	6.31
U5	Arterials	90	4.51	4.68	4.90	5.19	5.57	6.09	6.88
U6	Expressway	100	5.22	5.39	5.60	5.91	6.24	6.74	7.5

CONCLUSION AND RECOMMENDATION

The live field experiments at ten locations were successfully carried out with full considerations in terms of driver and public safety, without damage to property and satisfactory data collection. In line with the research objective, the recommended design parameters for Malaysian road safety recovery zone corridor widths *Z* for various vehicle's speeds *V* and roadside slope gradients *S* are accomplished as shown in Table 6 for rural roads and Table 7 for urban roads of area Type I. Depending on the road design standard types, the safety recovery zone corridor widths for Malaysian roads range between 1.52 to 8.06 metres for the speed limit between 50 km/h to 110 km/h and roadside gradients between 1V:10H and 1V:4H. The study shows that safety recovery zone corridor widths increase with the increase of the roadside slope gradients and vehicle speeds.

Further, it is recommended that as far as practicable all existing trees, utilities poles, signs and the like to be relocated outside from the roadside safety recovery zone corridor in accordance with designated design tables. In a situation where relocation of the existing obstructing objects are not possible, provide treatment such as fixing breakaway devices, install shielding or crash cushion. In addition, it is recommended that the Malaysian authorities concerned should maintain a register of roadside accident records, and undertake or provide information for future refined research work on the optimum roadside safety recovery zone corridor size. Finally, the introduction of safety recovery zone corridor chapter in the future Malaysian design guideline will drive toward a forgiving roadside geometric design that could saves human lives.

References

Ahmad Noor Syukri ZA., Siti Atiqah MF, Fauziana L and Abdul Rahmat AM (2012) : MIROS Crash Investigation and Reconstruction Annual Statistical Report 2007-2010, MRR 05/2012, Kuala Lumpur : Malaysian Institute of Road Safety Research.

AASHTO RDG (2011) : AASHTO *Roadside Design Guide* 4th. Edition 2011.

D06 (2006): European Best Practice for *Roadside Design Guide* lines for Roadside Infrastructure on New and Existing Roads.

Graham J.L., and Hardwood D.W. (1982) : National Cooperative Highway Research Program Report 247: Effectiveness of Clear Recovery Zones. NCHRP Transportation Research Board, Washington, DC, 1982.

Jorgenson 1978 ; Zeeger et al., 1987 : The Relationship Between Highway Geometrics, Traffic Related Elements, And Motor Vehicle Accidents.

REAM -GL (2/2002) : A guide on geometric design of roads RE-GL 2/2002 by The Road Engineering Association of Malaysia (REAM).

Rohayu S, Sharifah Allyana SMR, Jamilah MM & SV Wong (2012), Predicting Malaysian Road Fatalities for year 2020, MRR 06/2012, Kuala Lumpur : Malaysian Institute of Road Safety Research.

Sicking D.L. and Ross H.E. (1986) : Benefit-cost Analysis Of Roadside Safety Alternatives, Transportation Research Record 1065. Washington DC USA

Zedgeer et al (1988) : Zegeer CV, Hummer J, Reinfurt D, Herf L, and W Hunter (1986) Safety effects of Cross-section Design for Two-Lane Roads – Volume i and ii. Report FHWA-RD97/008 and 009. FHWA Washington D C, USA.