CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Guard rail, sometimes referred to as guide rail or railing, is a system designed to keep people or vehicles from straying into dangerous or off-limits areas. A handrail is less restrictive than a guard rail and provides both support and the protective limitation of a boundary.[1]

Most public spaces are fitted with guard rails as a means of protection against accidental falls. Any abrupt change in elevation where the higher portion is accessible makes a fall possible. Due to this responsibility and liability, rails are placed to protect people using the premises. Guardrails are generally required by code where there is a drop of 30" or more.[1]

In traffic engineering, guardrails prevent vehicles from veering off the roadway into oncoming traffic, crashing against solid objects or falling into a ravine and also absorb the impact from the car and at the same time reduce the probability of severe injury by increase the contact time in the impulse reaction. A secondary objective is keeping the vehicle upright while deflected along the guardrail. In most cases guardrails would not be able to withstand the impact of a vehicle just by the strength of the individual posts in the area hit by the vehicle. Instead, the guardrail is effectively one strong band that transfers the force of the vehicle to multiple posts beyond the impact area or into a ground anchor at the end of the guardrail.[1]

1.2 PROBLEM STATEMENT

The problem with the current guardrail is that its optimum height for a car. However, it might not keep a truck from toppling over it, while a motorbike might slip under a higher rail. In most cases guardrails would not be able to withstand the impact of a vehicle just by the strength of the individual posts in the area hit by the vehicle. Plus, the current material which is W-steel beam and the material could just give more severe injuries to the driver when vehicle hit a big impact to the guardrails. Other countries used concrete barriers. The material is tough and satisfies almost all vehicles on roadway. However, in term of impact, concrete barriers give a huge impact or momentum when accidents occurred. Even a minor scrape can result in extensive damage to the vehicle bodywork. Consequently, the maintenance to repair the concrete barriers is also expensive than W-steel beam maintenance.

Figure 1: Broken guardrail from the Rawang express bus accident
(http://transitmy.org/2009/12/26/sani-express-tragedy-have-we-learned-anything/

1.3 OBJECTIVES AND SCOPE OF STUDY

1.3.1 Objectives

The objectives of this study are:

- To modify the current guardrails design to be the safer.
- To compare the alternative design to the current one by comparing the effect on the meat samples and also the deformation on the scale models.

1.3.2 Boundaries of Work

The scopes of study for this project are:

- Selection on the current guardrails design and modifying it.
- Conduct experiment for the worst-case scenario and record videos to compare the occupant risk and guardrail post-impact of the two designs.

1.4 THE RELEVANCY OF THE PROJECT

The project is relevant to mechanical engineering application under manufacturing process, material specialization area. It is relevant for us to be find alternatives to improve the road users' safety on highways especially with the increasing of vehicle manufacturing nowadays.

CHAPTER 2

LITERATURE REVIEW

2.1 GUARDRAIL

A roadside guardrail is anchored in gravel beside a roadway to eliminate the risk of severe injuries during accidents with hazardous roadside objects. Unfortunately, the guardrails designed still have not met the requirement to provide safety to road users nowadays. The main objective in installing safety fencing is to restrain a vehicle within the confines in the carriageway on which it is travelling and prevent it from rebounding into the carriageway, thus causing additional hazard.[4] Safety fences are designed to 'give' when hit in order to absorb as much as possible, of the energy of the impact and to redirect the vehicle along the line of fences. [4]

The type of safety fence to be installed will be determined by containment level and the working width.[4] The containment level of each type of fences varies, being dependent on its design. The working width is the distance between the face of the fence and the obstruction. There are several types of guardrail; crash barrier, rigid concrete barrier, flexible wire rope barrier, and steel beam barrier. For this investigation of this project, the author will look at wire rope safety barrier system.

2.2 TYPES OF GUARDRAILS

There are three general types of highway guardrail[1]:

- Wire rope barrier
- Concrete barrier
- W-beam steel

2.2.1 W-Beam Steel Guardrail Performance

Although these original W-beam guardrail designs were successfully developed to contain and safely redirect full-size sedans and later small cars, one research study indicated a performance weakness for standard guardrail designs. The evaluation criteria for full-scale vehicle crash testing are based on three appraisal areas [6]:

- Structural adequacy
- Occupant risk
- Vehicle trajectory after collision

Criteria for structural adequacy are intended to evaluate the ability of the barrier to contain, redirect, or allow controlled vehicle penetration in a predictable manner. Occupant risk evaluates the degree of hazard to occupants in the impacting vehicle. Vehicle trajectory after collision is a measure of the potential for the post-impact trajectory of the vehicle to cause subsequent multi-vehicle accidents.[7] In the report of Performance of Steel-Post, W-Beam Guardrail Systems (Paper No. 07-2642), although the authors are comparing between the modified G4(1S) W-beam guardrail system and the Midwest Guardrail System (MGS), still, the W-beam still showing how critical the impact is. Refer Figure 1,2,3 and 4. Plus, refer Figure 5 for impact effect to the motorcyclist. Refer to the report “Motorcycle impacts into roadside barriers – real world accidents studies, crash tests and simulations carried out in Germany and Australia”, the author of the report mentioned after the dummy hit the W-beam, It directly impacted a sigma post at 47 km/h that broke and was bent down to the ground. Immediately after this first primary impact the motorcycle was stopped and remained stuck underneath the guard rail. Due to the hard impact into the post, the left shoulder joint of the dummy was broken

Figure 2.0: The rider slides until hit the exposed post[9]

2.2.2 Rigid concrete barrier

Concrete barriers have been used for a considerable length of time, although now their usage is generally being phased-out on high-speed roads, primarily because the rigidity of the concrete results in peak deceleration rates which can result in fatalities.

A further disadvantage is that even minor scrapes can result in extensive damage to the vehicle bodywork. Limited success has been achieved in introducing greater flexibility into concrete barriers by the incorporation of reinforcing steel; this, however, has also created the new problem of how to repair the barrier after impact.

In general, concrete barriers are now being limited to low-speed highly trafficked roads where the high risk associated with a vehicle crossing the central reservation outweighs the probable rise in the cost of damage-only accidents. They should never be used on high-speed roads unless it is absolutely essential to prevent a vehicle encroaching, whatever the effect on the vehicle's occupants. In a report by Raphael H Grzebieta, Roger Zou Tony Jiang for Monash University, a crash test was conducted that shows that how terrible the impact to the concrete barrier is. Refer Figure 6, 7 , 8.

Figure 3.0: The motorcycle impacts the concrete barrier protection system in a sliding position [6]

2.2.3 Flexible Wire Rope Barrier

Cable barriers in various forms have been in use for nearly 35 years as a means of easily and efficiently stopping an out-of- control vehicle. The main advantage of this barrier is that, because of its great flexibility, a cable can slowly decelerate a crashing vehicle and redirect it most easily along a path parallel to the barrier. In addition, it is comparatively simple to fix the height of the different cables so as to cater for the greatest number of the different vehicles in use today. Refer Figure 8 below.

Figure 4.0: Wire rope barrier crash test[6]

Probably their greatest disadvantage is that cable barriers cannot be used at locations with narrow safe clearances on high-speed roads because of their potential for deflection under impact. In full-scale tests, deflections of up to 4.25 m have been recorded and this, for example, would normally disqualify their usage.

Plus, a report of "*Wire Rope (Un)Safety Barrier*" by Michael Czajka, mentioned about the negative side of wire rope barrier. The author of the report proposed that concrete barrier is more effective for motorcyclist community rather than wire rope. He also proposed alternative solutions to cover the exposed posts so that the barrier becomes much safer. Several alternatives solutions are:

- Place along the bottom of wire rope barrier with mototub to prevent the riders from sliding under the barrier and hit the posts.
- Gravel, sand and other materials (such as shredded rubber) on racetracks/roads stop motorcycles, cars and trucks safely at very high speeds.
- Water filled collapsible barriers are extremely effective at dissipating extreme impact forces with minimal injury even for large vehicles.

The wire rope barrier can damage easily, for the motorcyclist, the exposed post from the barrier could cause their limbs to stuck between the wires which could give more severe injuries, it's height is could cause the rider to fling over the barrier and into oncoming traffic. A further point is that in order to allow for any movement, the cable barrier must use some form of automatic tensioning device, and this further increases the cost of this barrier. Because of the tension in the rope and the nature of the posts, the barrier cannot be used at road locations where the radius of curvature is less than 850 m.

Type of barrier	Advantage	Disadvantage
W-beam	• Deflected when impact happened although not as much as wire rope • Low maintenance	• Cannot absorb enough impact energy • Has exposed post that could kill

	cost compared to concrete barrier	motorcyclist
Concrete barrier	• Has no exposed post • Reduce light glare at night • Prevent more cross-over accidents	• High maintenance cost • No deflection when impact happened
Flexible wire rope	• Function well with typical vehicle • Low maintenance cost • High deflection	• Cause severe injuries to motorcyclist • High maintenance cost if installed in high accident rate

Table 1.0: Brief comparison between the barrier

Standard	**W-beam steel**	**Concrete barrier**	**Flexible wire rope**
Post spacing	**2.0m and 4.0m**	**N/A**	**2.4m**
Post height	**710mm**	**810mm**	**710mm**

Table 2.0: The barrier standard specification

2.3 GUARDRAIL: HAZARDOUS OBJECTS ON ROADSIDE

According to the data from Tung et.al (2003) unveiled that guardrail has the highest involvement (32.7%), followed by tunnel wall (22.9%), drainage and kerfs (12.2%), tree (5.6%), street-lighting post (5.6%), traffic sign poles (3.7%), concrete wall (3.7%), fences pole (1.1%), concrete column (1.1%), and non-fixed objects. The odd ratio analysis shows that a roadside-object related motorcycle crash is 2.0 times more likely to be a fatal crash than a non roadside-object related motorcycle crash. Refer Table.

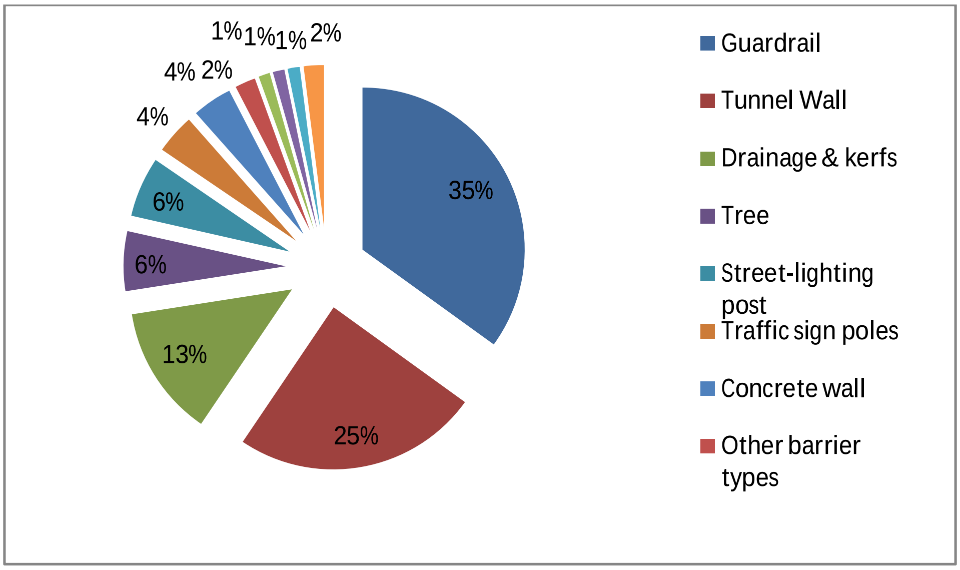

Figure 5.0: Object on Roadside Cause Injury during Accident [10]

Injury severity roadside	Objects related motorcycle crash	Non-roadside objects related motorcycle crash
Fatal	17 (15.9%)	34 (6.6%)
Serious Injury	37 (34.6%)	205 (40.0%)
Minor Injury	53 (49.5%)	274 (53.4%)
Total	**107 (100%)**	**513 (100%)**

Table 3.0: The distribution of injury severity for roadside-object related and non-roadside-objects related motorcycle crashes along exclusive motorcycle lane[10]

According to Tung et.al (2003), 30 motorcycle crashes were recorded involving guardrails. Out of the total number of these crashes, 13.3% were reported as fatal. The fatality involving guardrails represented 23.5% of all fatal crashes involving roadside objects. Refer table for odd ratio analysis.

Injury Severity	Guardrail related motorcycle crashes	Non-object related motorcycle crashes	Total	Odds Ratio

Severe Injury	18	239	257	1.7
Minor Injury	12	274	286	
Total	**30**	**513**	**543**	

Note = $x^2 = 2.60, df=1, p<0.10$

Table 4.0: The comparison of guardrails and non-object related motorcycle crashes along exclusive motorcycle lanes.[10]

2.4 SANI EXPRESS TRAGEDY

10 people were killed when SANI Express, a double-decker bus hit a road divider which is happened to be a W-beam steel guardrail. Although the main reason for this horrible accident is because of the fatigue driver, one of the fatalities were recorded at the lower deck on the side of the bus which had been ripped off like an opened sardine can by the piercing impact of the rigid, sharp edges of the metal guardrail barriers of the North-South Expressway, quoted from TRANSIT website. Refer to Figure 2. What makes it more fatal was that the height or the level of the guardrail is the same as the level of the bus lower deck. If the bus lower deck level is higher than the guardrail height, several lives could be saved.

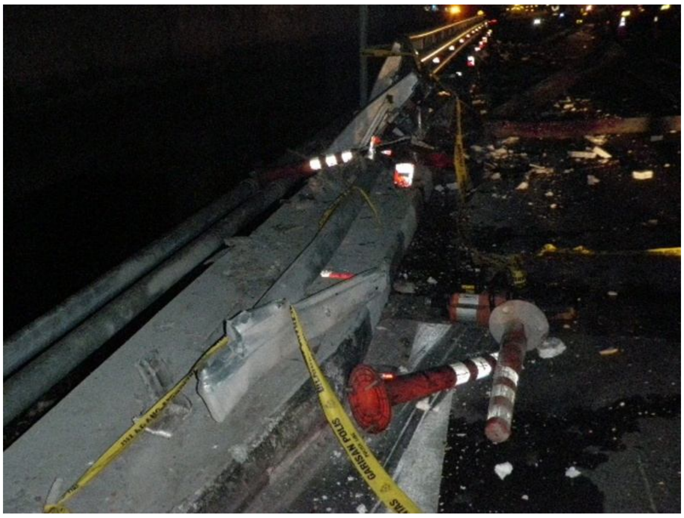

Figure 6.0: W-beam steel guardrail is broken completely

(http://zermyeadnan.blogspot.com/2009/12/analisa-kemalangan.html)

Figure 7.0: SANI Express bus after the accident
(http://zermyeadnan.blogspot.com/2009/12/analisa-kemalangan.html)

Figure 8.0: Close up to the bus lower deck

(http://zermyeadnan.blogspot.com/2009/12/analisa-kemalangan.html)

2.5 SIGNIFICANCE OF THE PROJECT

The outcome of this project is to select which guardrail that minimizes the occupant risk and maximize the time of impact. When deal with time of impact, the deflection higher to give longer time of impact. This is because the longer the impact time, the lesser the impact force. Therefore**,** when barrier is warranted, the selection of a barrier system should be based on the one that offers the required degree of shielding at the lowest cost for the specific application. Based the Table 2, provides information regarding the maximum deflection for the various types of barrier. The deflections shown provide guidance on what types of barrier can be used in certain situations. The deflections in the table are based on NCHRP 350 TL-3 testing, measured deflections based on prior crashes, and the *Roadside Design Guide*. (Roadside Safety Manual, Bernie Clocksin).

Barrier Type		Post Spacing		Maximum Design Deflection	
Rigid	Concrete Barrier	NA	NA	0'	(0.0 m)
Semi-Rigid	Double Thrie Beam Guardrail	3'-1 ½"	(0.95 m)	0'-9"	(0.2 m)
	Thrie Beam Guardrail	3'-1 ½"	(0.95 m)	1'-9"	(0.5 m)
		6'-3"	(1.9 m)	2'-6"	(0.7 m)
	Double W Beam Guardrail	6'-3"	(1.9 m)	3'-0"	(0.9 m)
	W Beam Guardrail	3'-1 ½"	(0.95 m)	2'-0"	(0.6 m)
		6'-3"	(1.9 m)	3'-3"	(1.0 m)
Flexible	Three Cable Guardrail	4'-0"	(1.2 m)	7'-0"	(2.1 m)
		8'-0"	(2.4 m)	8'-0"	(2.4 m)
		12'-0"	(3.7 m)	9'-6"	(2.9 m)
		16'-0"	(5.0 m)	11'-6"	(3.5 m)

Table 5.0: Maximum Design Deflection of a barrier[13]

Referring to the table above, the cable guardrails has the highest deflection among others. The Brifen Wire Rope Safety Fence (WRSF), a tensioned 4-cable guardrail system, received NCHRP 350 certification for use on US highways [4]. The system has already been used for several years by several Europe countries, and it is known for its effectiveness and easy, low-cost maintenance and repair. Other than that, a journal report by Amree Ahmad and Abd. Razak Osman in KOSMO newspaper, Malaysia also has used the wire rope system in several highways such as in Butterworth and Jln. Mak

Mandin, Pulau Pinang. The system is able to absorb the impact of a vehicle with the mass of 10,000 kg.

Although wire rope seems to have quite excellent performance in terms of deflection, maintenance cost, lighter than concrete barrier and can absorb impact energy, but stills, the barrier need to consider when it comes to motorcyclist community. The wire rope barrier performs it function quite well when it comes to typical vehicle like sedan, pick up truck. However, for the riders, it is consider as the most hazardous barrier among other barriers.

Plus, a report of "*Wire Rope (Un)Safety Barrier*" by Michael Czajka [6], mentioned about the negative side of wire rope barrier. The author of the report proposed that concrete barrier is more effective for motorcyclist community rather than wire rope. He also proposed alternative solutions to cover the exposed posts so that the barrier becomes much safer. Several alternatives solutions are [6]:

- Place along the bottom of wire rope barrier with mototub to prevent the riders from sliding under the barrier and hit the posts.
- Gravel, sand and other materials (such as shredded rubber) on racetracks/roads stop motorcycles, cars and trucks safely at very high speeds.
- Water filled collapsible barriers are extremely effective at dissipating extreme impact forces with minimal injury even for large vehicles.

CHAPTER 3

METHODOLOGY & PROJECT WORK

3.1 METHODOLOGY

Throughout this project period, several approaches will be taken in order to fulfill the requirement and to make sure the project can be accomplished.

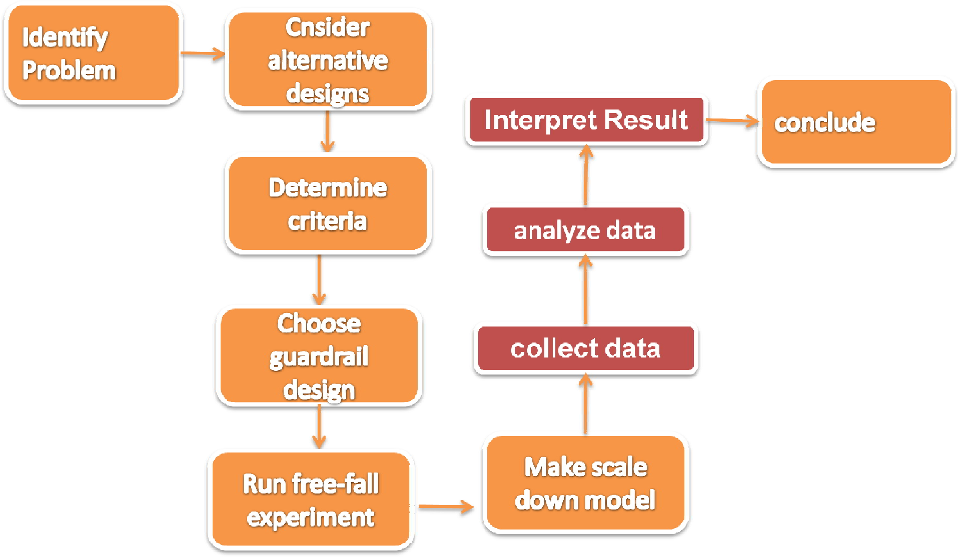

Figure 9.0: Project Flow diagram

First, the author needs to identify the problem statement to this project. From there, the author can generate some ideas on what to look for from journals, articles, books, and internet in order to understand detail about guardrails; what are types of guardrails, the materials used, disadvantage and advantage of each barrier types. After that, the author had defined the objective of the project as well as the scope of study.

Next, the author has to do further research as well discussion with lecturers and colleague regarding the project in order to find the possible solution to the problem mentioned in this project. The main concern here is to choose the best type of guardrails and modified the design to increase the time of impact and also reduce the occupant risk during crash. Therefore, it is very important for the author to understand which method is more applicable to this project, experimental or analysis software.

Once the author has decided on the type of barrier that she wants to focus on, the next step is to identify the specification for the designed guardrail. The specification that needs to be defined is such the post spacing, diameter of the wire rope, height of the post, and distance between the wires. All the specification are according the manual guidelines that provided by Road Engineering of Malaysia.

Based on the risk and hazard faced by the road users on the wire rope barrier, the author needs to design the alternatives for the guardrail. The designs were drawn using the AutoCAD 2004 Software. The designs were drawn according to the specification needs.

The author need to do the quantitative and qualitative analysis one more time in order to choose which alternative designs would be the best choice to be compared with the current wire rope barrier design in the experiment. After one alternative design has been selected, the author needs to conduct an experiment to test the performance of the design guardrails and compare it with the current design in term of post-impact deformation and the effect on the sample of meat

After doing the experiment, the author will compare the result by video analysis, the effect on the sample of meat and also deformation of the working model. The project is done when the author obtain all the result from the two experiment conducted.

One of the important tools in designing process is Gantt chart. The Gantt chart is used as a guideline and planning to complete this project. It is very important for the author to make sure the work progress is in line with planned. The Gantt chart for this project is shown in the Appendices.

3.2 TOOL REQUIRED

3.2.1 Video Camera

It is used to record the experiment and analysis the deflection based from the video. It also can be used to take pictures of the cheese-cutter effect on the sample of meat and also deformation of the both working models.

3.2.2 Clamper

It is used to clamp the model to the ground so that when a mass is dropped at a specific height, the model won’t be bounce back.

3.2.3 Lab Equipment

It is used to fabricate both current wire rope barrier model and alternative model. The equipment required is drilling tools, welding tools, abrasive cutter machine, and rivet.

3.2.4 Computer

It is used as a medium to install software that will draw the alternative designs.

3.2.5 Sample of meats

The meat is used to show the cheese-cutter effect. The meats represent as the occupant and the effect on the meat is showed to be the injury of the occupant.

3.3 PROJECT WORK

The progress for the project is completed and the results are obtained. From the result obtained, the author then can showed that the current wire rope barrier is fatal and need serious modification.

CHAPTER 4

RESULT AND DISCUSSION

Before the author proceed any further, she needs to do qualitative and quantitative analysis in order to choose what type barrier does she wants to further study on and which alternative design is the best design to be compared its result with the current design. A survey of barrier type and alternative design selection has been made to the 20 respondents and the respondents will evaluate the barrier type and alternative designs selection by giving them scores for each option.

4.1 BARRIER TYPE QUANTITAVE ANALYSIS

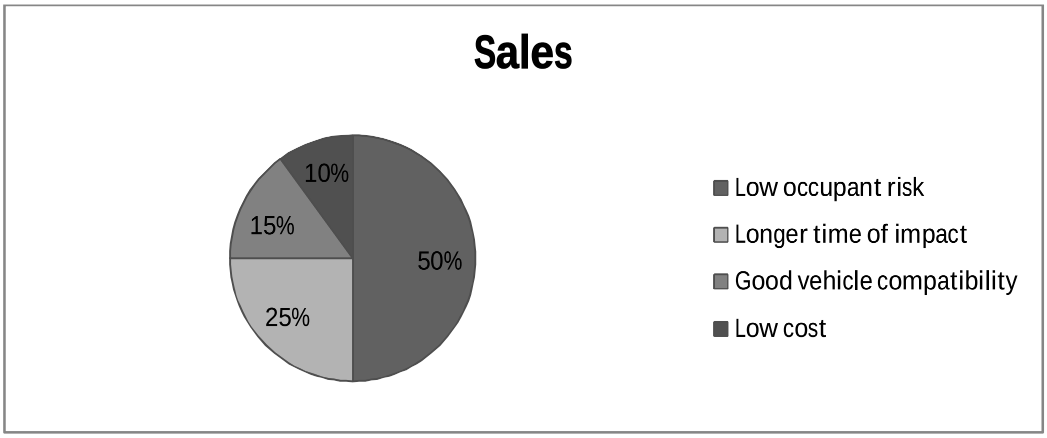

Figure 10.0: Result of the respondent survey on the criteria priority

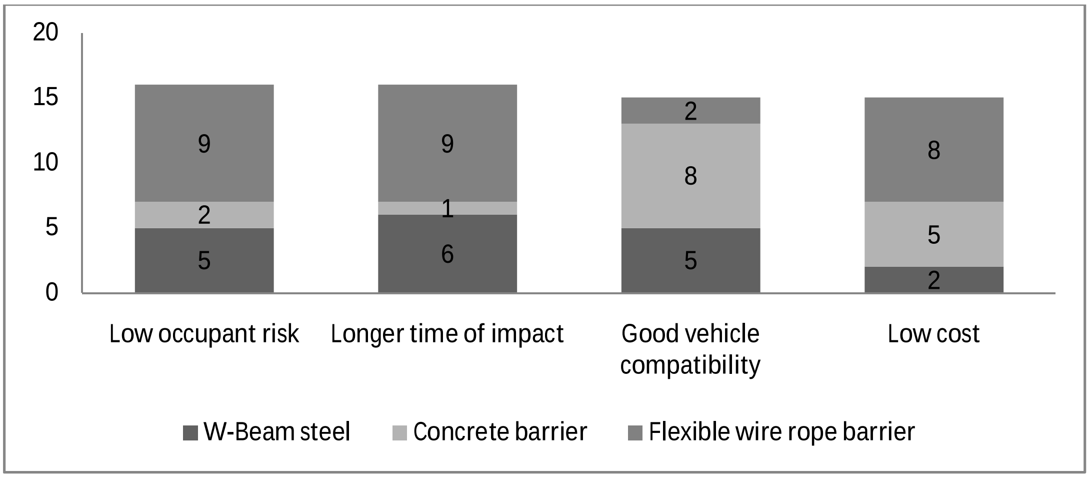

Figure 11.0: Respondents survey on scoring barrier type for each criteria

Table 6.0: Weighted Decision Matrix

		W-beam steel		Concrete Barrier		Flexible Wire rope	
Criteria	Weight	Score	S*W	Score	S*W	Score	S*W
Low occupant Risk	4	5	20	2	8	9	20
Longer time of Impact	3	6	18	1	3	9	27
Good Vehicle compatibility	2	5	10	8	16	2	4
Low Cost	1	2	2	5	5	8	8
		Weighted		Weighted		Weighted	
		Total	50	Total	32	Total	59

- For a Poor (undesired) value, use low numbers such as 1 – 3,
- For Medium (less desirable) value, use numbers such as 4 – 7
- For Good (preferred) value, use numbers such as 8 – 10.

For low occupant risk, according to the respondents review, they picked flexible wire rope because the cable barrier can deflect the vehicle back to the road. While there were some respondents prefer W-beam steel because the barrier is easily bend and there is a reason why it is use widely in Malaysia’s highway. For the concrete barrier, the respondents did not prefer it as the barrier that can low the occupant risk. For longer time of impact criteria, the respondents prefer the flexible wire rope once again because of its great flexibility that can increase the time of impact. Thus, lower the impact force. There were some who also favored W-beam steel because they mentioned that the W-beam steel has been widely use in Malaysia highway. Therefore, they were being quite pessimistic about flexible wire rope barrier can actually deflect the vehicle back to the road. While for concrete barrier, it has the lowest score because it does not have deflection at all. Next, the majority of the respondents favored the concrete barrier as good compatibility with most of vehicle. This is because the rigid barrier can avoid the vehicle from going to the other side of the road after an impact occurred. The barrier type that has the second highest votes from the respondents was the W-beam steel. This is because its height is not really compatible to bus and trucks. However, it is compatible with sedans, small cars and motorcycle. The flexible wire rope has the lowest votes among the respondents because some of the respondents have seen the cable barrier and they mentioned about its height which is sufficient for a motorcyclist can toppling over it and worst thing could happen if large vehicle such as bus or trucks hit the barrier. In the low cost criteria, most of the respondents voted on the flexible wire rope barrier. The second highest was voted on the concrete barrier because compared to w-beam steel, steel is much expensive material to purchase.

4.2 BARRIER TYPE QUALITATIVE ANALYSIS

4.2.1 Low Occupant Risk

Refer to the SANI Express tragedy section; we could see how fatal W-beam steel barrier can do to the occupants. Apart from the driver's fatigue being the root cause of the accident, one important thing that was recorded was that the w-beam steel guardrail has ripped the passengers off like a can of sardine. When the steel guardrail deformed because of an impact, the broken guardrail could act as one of the fatal and sharp objects in vehicle crashes. If the steel guardrail can rip off the lower deck of a bus, for a smaller vehicle, the result will be more fatal.

For concrete barrier, because of the rigidity, the vehicle will deform in an impact. However, the occupant has higher chance to survive the crash. This is because concrete barrier avoid the vehicle from getting to the other side of the road and vehicle tend to slide along the barrier in a low-medium speed crash. For flexible wire rope barrier, this barrier has a great flexibility. It will able to decelerate a crashing vehicle and redirect it most easily along a path parallel to the barrier which gives most of the road users a chance to survive the crash. Refer Figure.

However, to motorcyclist, this type of barrier is considered as a life-threatening hazard. The exposed post from the barrier could cause their limbs to stuck between the wires which could give more severe injuries, it's height is could cause the rider to fling over the barrier and into oncoming traffic. In addition, they have higher risk to face with cheese-cutter effect.

4.2.2 Time of Impact

If you jump to the ground from any height, you bend your knees upon impact, extending the time of collision and lessening the impact force. Therefore, increasing in deflection will act in the same way. It will extend the time of collision and hence, lessen the force. According to Roadside Safety Manual by Bernie Clocksin, for semi rigid barrier type like W-beam steel guardrail, the barrier has its own deflection range of 0.2m-1.0m. When there is deflection, there is time of impact. However, the deflection of semi-rigid type is not longer compared to the flexible barrier type. For concrete barrier, as a rigid barrier type, it has no deflection at all. For flexible wire rope barrier, it has the highest deflection of 3.5m.

4.2.3 Vehicle Compatibility

It is important for a barrier design to be compatible with most of the vehicles on the road. This is because if the barrier is not road-friendly, then it is no use to install the guardrails on the road. For the semi-rigid type which is W-beam steel guardrail, the barrier is fit to almost all types of vehicles which it has been used widely in the highway around the world. For concrete barrier, it also compatible with most of vehicle types on the road. The reason why it is not widely used especially in a high-speed roadway is because it can cause extensive damage to the vehicle in high-speed crash. For flexible wire rope barrier, the height of the barrier is not suitable with most of the vehicles. It is too small for trucks, and has a lot of exposed post which is a deadly risk to the motorcyclist. Usually sedans and smaller cars fit with almost all types of barrier.

4.2.4 Cost

When it comes to cost, it usually related with the installation and maintenance cost. For W-beam steel guardrail, it is quite expensive to install and since it easily to bend, the cost to maintain the barrier is also quite high. For concrete barrier, concrete is not really an expensive material. For maintaining it, since it is rigid and not easily to be damaged compared to the flexible and semi-rigid type, the cost to maintain it is cheaper. For flexible wire rope barrier, the installation and maintenance cost is cheaper than both of the barriers mentioned previously. This is because the wire ropes are anchored in a concrete foundation underground. Therefore, when a crash happened, the only thing that is damage is the post and to reinstall the post is not that expensive.

Based from the quantitative and qualitative analysis, the author has decided to select flexible wire rope barrier to be further studied in this project. This is because wire rope is light, low maintenance cost where only needed to repair the damage posts, high deflection among others. However, the wire rope has its disadvantages itself. The wire rope barrier can damage easily, for the motorcyclist, the exposed post from the barrier could cause their limbs to stuck between the wires which could give more severe injuries, it’s height is could cause the rider to fling over the barrier and into oncoming traffic, refer Figure 9. Therefore, the author will try to look into modification designs that could reduce the severity injuries of the rider and reduced exposed posts.

4.3 DESIGN QUANTITATIVE ANALYSIS

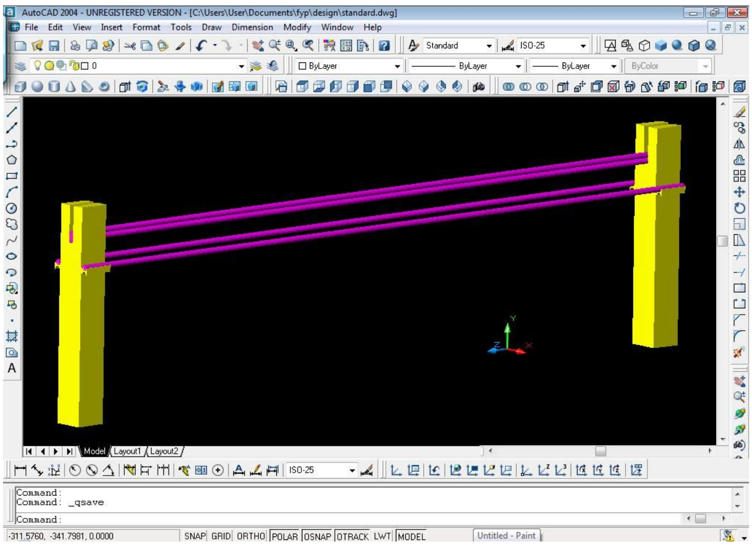

Figure 12.0: Current wire rope barrier design

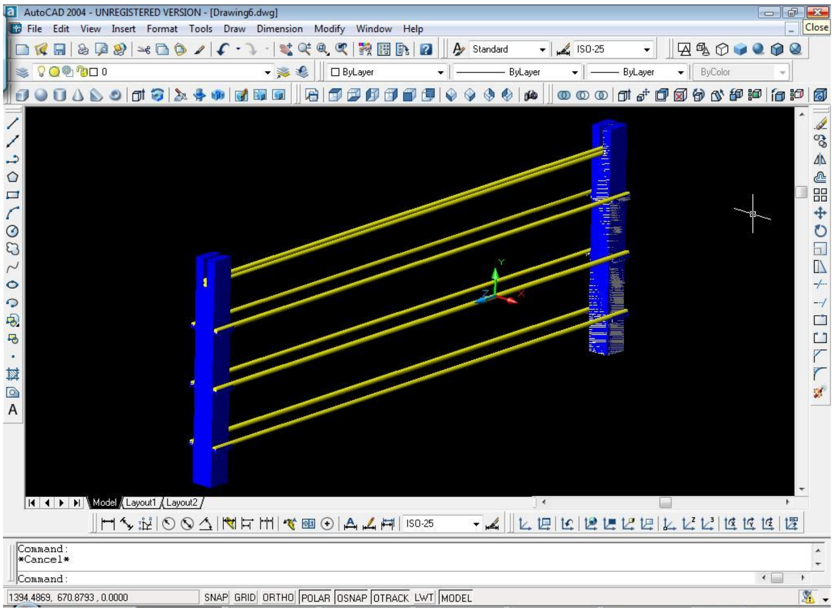

Figure 12.1: Design A

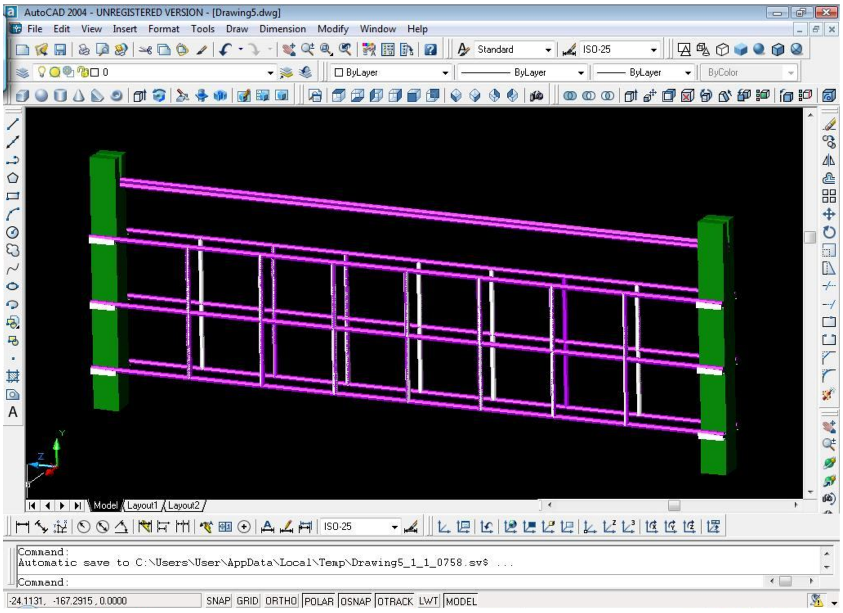

Figure 12.2: Design B

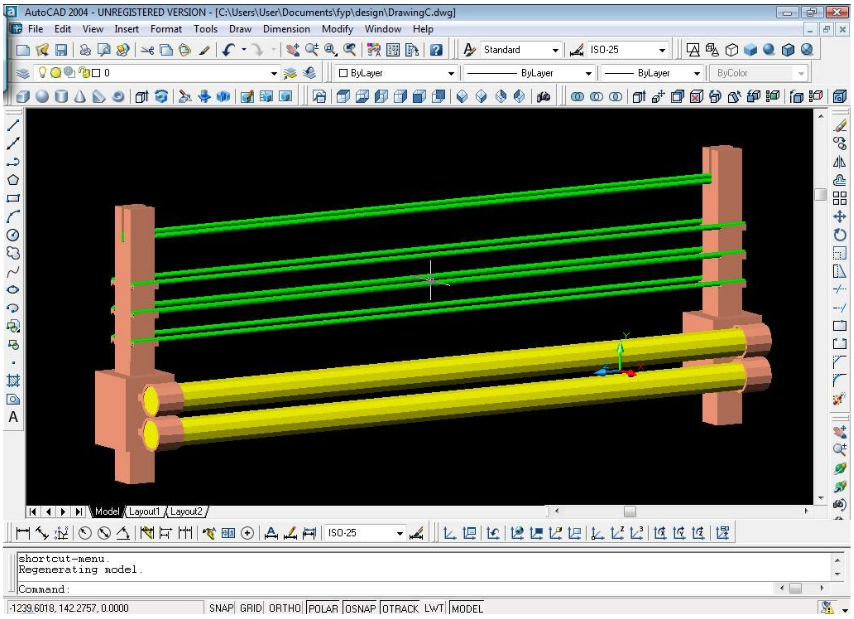

Figure12.3: Design C

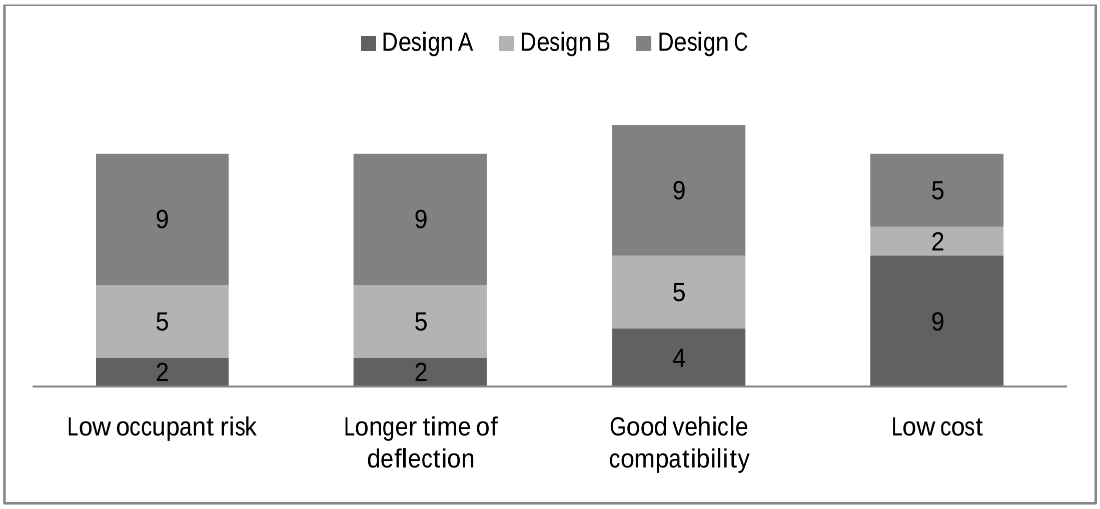

Figure 13.0: Respondents survey on scoring alternative designs for each criteria

		Design A		Design B		Design C	
Criteria	Weight	Score	S*W	Score	S*W	Score	S*W
Low Occupant Risk	4	2	8	5	20	9	36
Longer Time of Impact	3	2	6	5	15	9	27
Good Vehicle	2	4	8	5	10	9	18

compatibility				
Low Cost	1	9 9	2 2	5 5
		Weighted	Weighted	Weighted
		Total 31	Total 47	Total 86

Table 7: Weighted Decision Matrix

- For a Poor (undesired) value, use low numbers such as 1 – 3,
- For Medium (less desirable) value, use numbers such as 4 – 7
- For Good (desirable) value, use numbers such as 8 – 10

For low occupant risk, according to the respondents review, they picked Design C because the design has additional safety accessories. They believe the elasticity of the rubber can avoid vehicle and motorcycle safe from the cheese cutter effect. While there were some respondents prefer Design B because the design has better force distribution and the amount of exposed area is smaller. Therefore, the impact force can be reduced. For the Design A, the respondents did not prefer it because it has sufficient gap for the cheese-cutter effect and it has larger exposed area. For longer time of impact criteria, the respondents prefer Design C once again because of the elasticity properties of the rubber material used for the safety accessories. The rubber elasticity can increase the time of impact. Thus, lower the impact force. There were some who also favored Design B because it better force distribution. While for Design A, it has the lowest score because it has no safety accessories or better force distribution that can increase the time o impact. Next, the majority of the respondents favored the Design C as good compatibility with most of vehicle. This is because for this alternative design, the height is increased from 710mm to 960mm. Plus, with additional of safety accessories, it makes the design more compatible with motorcycle community. The alternative design that has the second highest votes from the respondents was Design B. This is because the respondents believe that its wire rope arrangement can avoid motorcyclist from cheese-cutter effect. Design A has the lowest votes among the respondents once again because some of the respondents believed that it is not quite compatible with the motorcyclist community. Its height has been increased from 710mm to 960mm, however, its design still risky for the motorcyclist. In the low cost criteria, most of the respondents voted on Design A. The second highest was voted on the Design C because compared to Design B, the complex wire rope arrangement in Design B could affect the cost to fabricate it.

4.4 DESIGN QUALITATIVE ANALYSIS

4.4.1 Occupant Risk

Using the same criteria, it is getting tougher to evaluate for every wire rope barrier alternative and current designs. When we deal with occupant risk that is related with wire rope barrier is the cheese-cutter effect. Cheese-cutter effect is the effect where the wires act as guillotine, cuts through anything that hits them. Referring to Figure below, human's neck will not stand much of chance to survive.

Figure 14.0: Cheese-cutter effect[7]

Referring to the picture above, clearly the current two-wire ropes barrier is a life-threatening hazard. It is not only can cause fatal injuries to the motorcyclists, but also to vehicle users. One of the reasons that can cause this effect is the area of exposed post. Refer Figure 17.0 below.

Figure 15.0: The exposed post area

When a crash occurs, the exposed post at the bottom of the barrier does not provide any covers to decelerate the vehicles or even avoiding the rider from sliding under the rail and hitting the post. The fate of the occupant is relying on the two wire ropes performance and nothing more. For Design A, the height of the guardrail is increased since the current design is not high enough for motorcyclist community, 3 pairs of lower ropes is added to avoid motorcyclist from sliding under the wire rope barrier and hit the post. However, although the risk of sliding under the rail and hitting the post has been reduced, there is still a sufficient gap between the wires that still can cause the cheese-cutter effect. For Design B, the main focus is to reduce the cheese-cutter effect. As a statistic quoted "European Union study had found that 80 per cent of motorcyclists hitting wire barriers at more than 70 km/h lost limbs." Therefore, the exposed post area is reduced more by designing a checkered-alike design. For Design C, it is more combination of reducing exposed post area, cheese-cutter effect and providing longer impact time. This is because apart from gap between the wire ropes at the upper side of the barrier has been reduced; the author has designed to put two rubber tubes at the bottom of the barrier as the alternative to cover the exposed post area.

4.4.2 Time of Impact

The current wire rope barrier is flexible and already has high deflection compared to other barrier type like semi-rigid and rigid type. For design A, the time of impact is a little bit longer than the current barrier because of the additional couple of wire rope pairs at the bottom. For design B, the time of impact is much longer than the current barrier and also design A. This is because of the checkered-alike for the wire rope arrangement at the bottom of the barrier. Therefore, the force distribution is better and longer impact time. For design C, although its wire rope arrangement is not the same like design B, however, the design also has longer impact time by having the rubber tubes at the bottom. The elasticity of the rubber provides better and longer impact time.

4.4.3 Vehicle Compatibility

As mentioned in the previous quantitative and qualitative analysis on the barrier type. Flexible wire rope barrier, the height of the barrier is not suitable with most of the vehicles. For design A, the height has been increased from 710mm to 960mm. This height is applicable to other two alternative designs. What separates the design C from the other three designs is that the availability of the rubber tubes make it more compatible with motorcycle especially and other road users. The height is increased, and with additional safety accessories of rubber tubes, there is a possibility that the design is also compatible with trucks.

4.4.4 Cost

For the current flexible wire rope barrier, the installation and maintenance cost is cheaper than both of the barriers mentioned previously. However, this barrier will be a high cost on high accident rate area. Therefore, it is important for the alternative designs to have the cost as low as possible. For design A, the cost is will be more than the current barrier. This is because of the additional three pairs of wire ropes and the cost to maintain it is about the same as the current wire rope barrier. For design B, the complicated wire rope arrangement will add another cost beside installation and maintenance. For design C, the cost is not that expensive compared to other two alternative designs. This is because this design will have additional cost on the safety accessories and two pairs of wire ropes. However, rubber material is not expensive. Applying the rubber elasticity, avoid the design to be damaged frequently and hence, the maintenance cost can be reduced.

Based from the quantitative and qualitative analysis, the author has decided to select design C to be tested on its performance and compared it with the current wire rope barrier performance.

4.5 EXPERIMENT MODEL SET-UP

The author has conducted a free-fall experiment. The objective of this experiment is to investigate at the impact of the guardrail on 90º at 100km/h. A mass of 16 kg is dropped at height of 0.4m. The difference in free-fall time obtained from the stopwatch will distinct the 100km/h experiment with 120km/h. Apart from that, the author can predict the possible risk to the occupant from the effect on the sample of meat. The experiment is scaling down by 10 from the real dimension. Two speeds have been chosen to be tested, 100km/h and 120km/h. Videos were recorded and pictures were captured to compare both o the models performance. Refer Figure below.

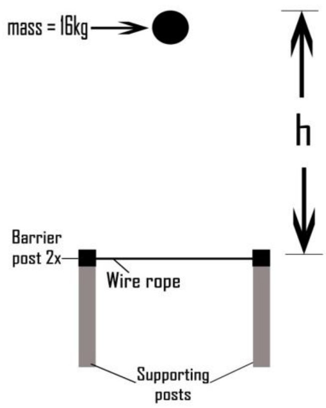

Figure 16.0: Illustration of the experiment

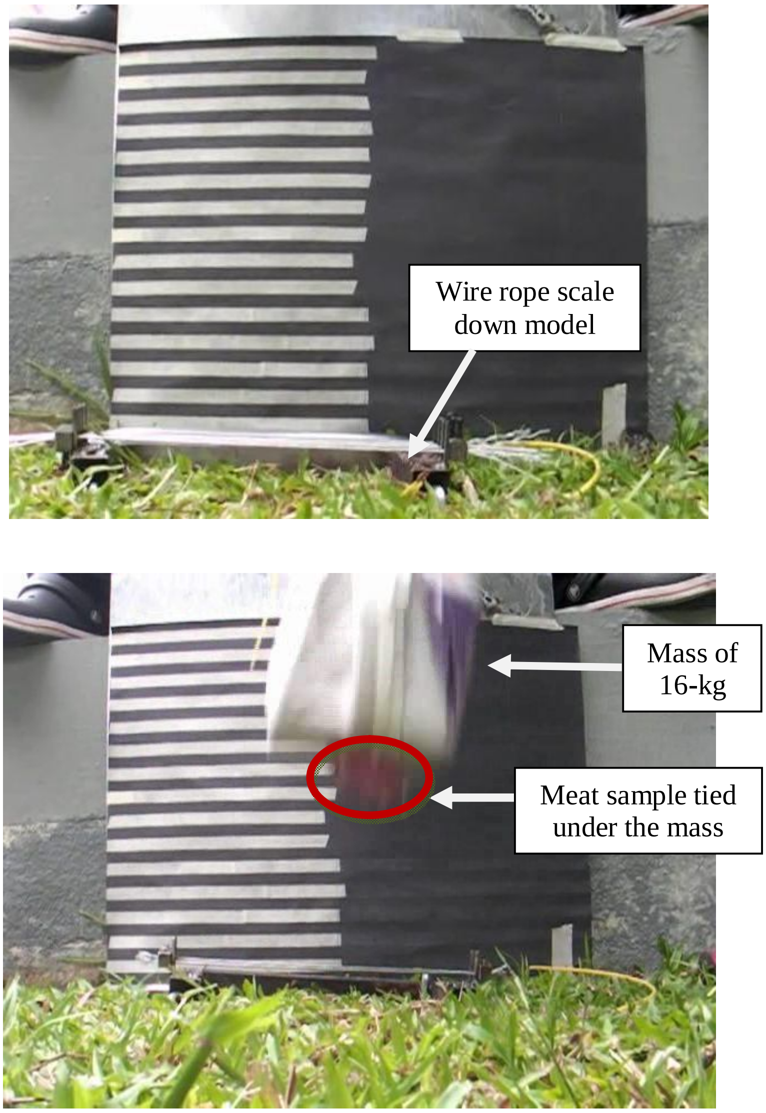

Figure 17.0: The experiment

4.6 EXPERIMENT RESULT

By scaling down the model with the factor of 10, the model is fabricated with the process of:

- Cutting the hollow steel post with the height of 15cm
- Weld the steel post to create the frame of the guardrail
- Cutting 2cm x 3cm cubes for the wire connection component
- Assemble the cable wires to the guardrail frame

- For Design C, the rubber is attached to the frame by rivet. The objective is just to illustrate the use of safety accessories.

The scale down model represented the actual model since the author has referred the actual model specification in *Guidelines on Design and Selection of Longitudinal Traffic Safety Barrier* [14]. In this experiment, the cable wires are assumed not pre-tensioned. The experiment for speed 100km/h is repeated three times and each result obtained gave the similar result. Figures below, showed the average result of the three experiments.

When a 16-kg mass is dropped on the current wire rope barrier model,

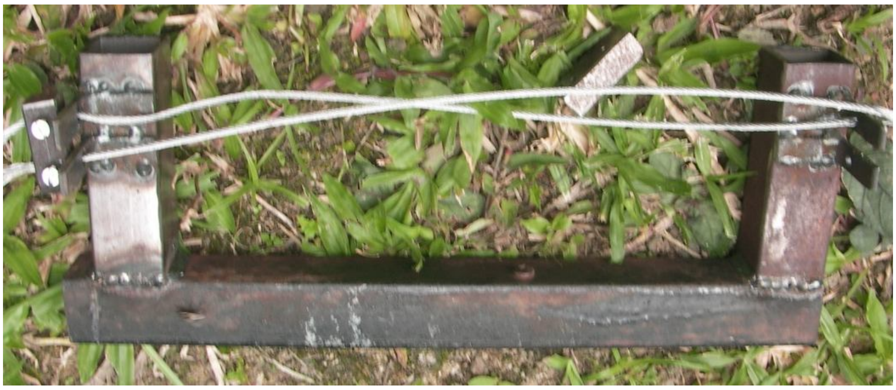

Figure 18.0: Post-deformation of current wire rope model

When Sample of meat is tied under the mass

Figure 19.0: Cheese cutter effect on the meat sample

What really happened during the experiment?

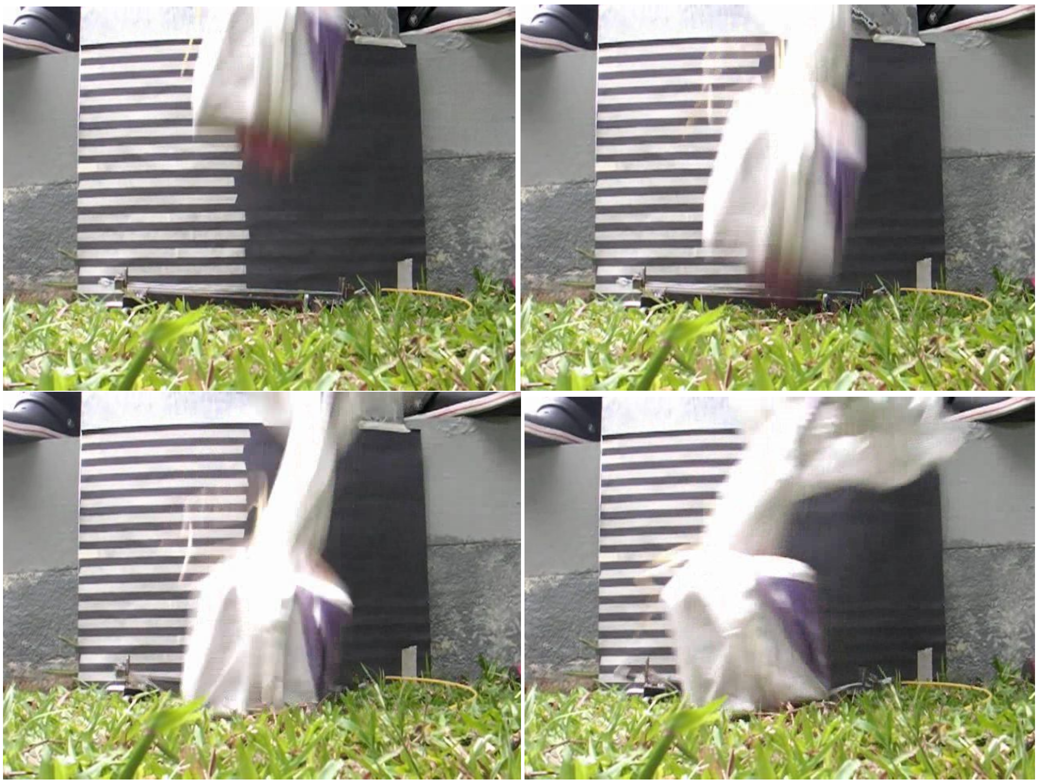

Figure 20.0: In sequence on what actually happen in during the crash

When 16-kg mass is dropped onto the alternative design model,

Figure 21.0: Post deformation of the alternative model

When meat sample is tied under the mass,

Figure 22.0: Cheese-cutter effect on the meat sample

What really happened during the experiment?

Figure 23.0: In sequence on what actually happen during the crash

Experiment is repeated with different speed, 120km/h three times to get the average result. Similarly, each result obtained gave the similar result. Figures below, showed the average result of the three experiments.

When a 16-kg mass is dropped on the current wire rope barrier model,

Figure 24.0: Post-deformation of the current wire rope model

When meat sample is tied under the mass,

Figure 25.0: Cheese-cutter effect on the meat sample

What really happened during the experiment?

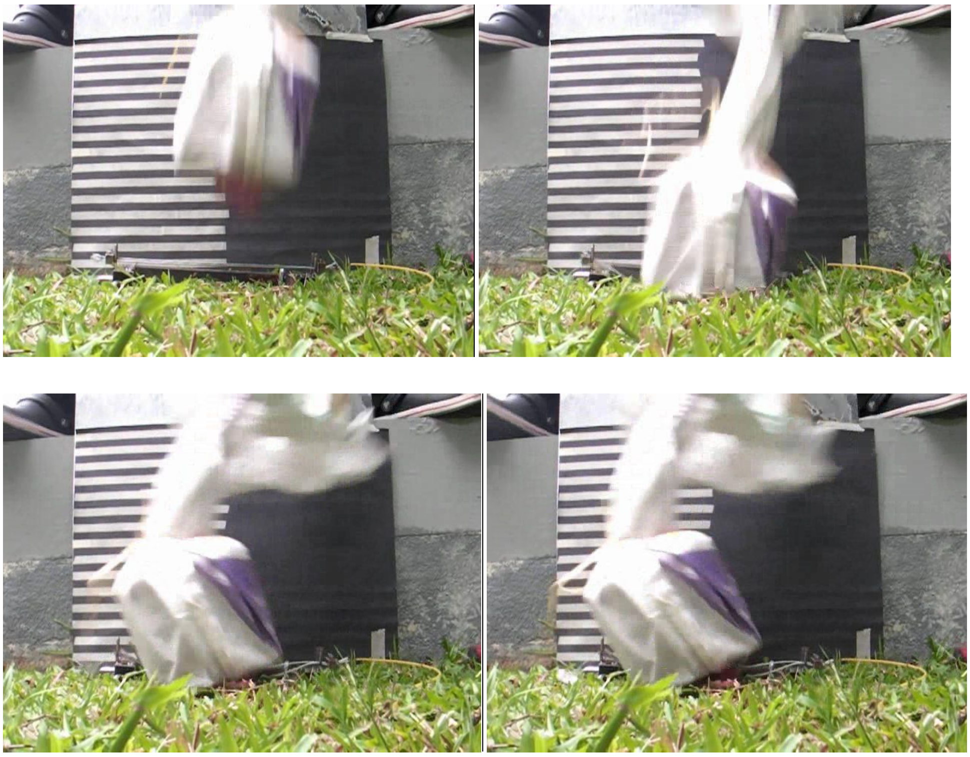

Figure 26.0: In sequence on what actually happen during the crash

When 16-kg mass is dropped onto the alternative design model,

Figure 27.0: Post-deformation of the alternative model

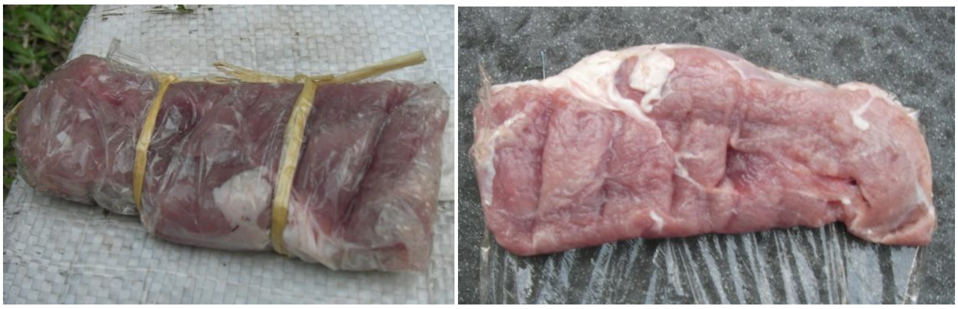

Figure 28.0: Cheese-cutter effect on the sample meat

What really happened during the experiment?

Figure 29.0: In sequence on what actually happen during the crash

4.7 FREE-FALL EXPERIMENT CALCULATION

For 100km/h

From $v^2 = u^2 + 2as$,

Representing the height of 100km/h, d = 0.39 m

Initial speed, u = 0 m/s

Gravity acceleration, a = 9.81 m/s^2

$$d = v_i * t + \frac{1}{2} * a * t^2$$

$0.40 = (0)t + (½)(9.81)t^2$

t= 0.28s

For 120km/h

From $v^2 = u^2 + 2as$,

Representing the height of 100km/h, d = 0.56 m

Initial speed, u = 0 m/s

Gravity acceleration, a = 9.81 m/s^2

$$d = v_i * t + \frac{1}{2} * a * t^2$$

$0.56 = (0)t + (½)(9.81)t^2$

t= 0.33s

Mass of motorcycle = 160 kg

Velocity of the motorcycle = 100 km/h = 27.78 m/s

Crash distance *d* which stop the motorcycle = 0.25m

KE = (1/2)mv^2

= (1/2)(160kg)((100km/h)(1000m/km)/(3600s/h))^2

=**61,278 Joule**

$F_{avg}d = -(1/2)mv^2$

$$F_{avg} = -\frac{22,222}{0.25}$$

= **246,913 N = 246.913 kN**

4.8 JUSTIFICATION FOR THE EXPERIMENT

A free-fall method was chosen for this experiment because since there is no possible situation to have a perpendicular crash impact, and we do know that perpendicular impact has the highest impact force, therefore the free-fall experiment is the best method to illustrate the worst case scenario.

Speed 100km/h hour is chosen to show what really happen to the occupant when in crash in under the speed limit. Will it be fatal, if it is, hence, what will happen to the occupant if they ride more than the speed limit. Therefore, 120km/h speed is chosen to conclude the question.

Other than that, four wire ropes have been used in the design C because the height of the post is already increased to 960mm. If just three ropes were been used, there will be sufficient gap between the wires to cause the rider's limb to stuck between the wires or allowed cheese-cutter effect to be occurred. If five or more wire ropes were being used, it does provide better force distribution. However, it will affect on the cost itself.

Sample of meat is used to illustrate as the occupant. The crash dummy is so expensive and pork meat is the best material to compare with human meat properties. But as a Muslim, pork meat is prohibited. Therefore, cow meat will be the next best choice to be tested.

Rubber tubes are used as the safety accessories because of its flexibility. Other than that, it is widely available in Malaysia since Malaysia is the biggest rubber exporter. The cost of rubber also cheaper than any other material.

4.9 DISCUSSION

A 16-kg mass is dropped at 2.78m/s on the scale down model of guardrail, simulating the scale down speed of 100km/h. For 100km/h experiment, based from the average result, the first thing that the author observed that the current wire rope barrier design has deformed completely. The wires on the right side have loosened from its connection. Which in the real accident situation, the rider would end up to be at the other side of the road. For the second observation, like its name 'cheese-cutter effect', the two wire ropes from the current design cut the meat almost into pieces. Unlikely for the alternatives design, the four wire ropes and additional of rubber tube at the bottom have saved the meat from being cut into pieces. In addition, better force distribution in design C compared to the current barrier design is also a factor in preventing the meat from being cut into slices.

For 120km/h experiment, based on the average result, the result outcome came out similarly like the 100km/h. The design C model performed better than the current barrier model. For the two wire ropes design, we can conclude that the meat is fatally ruined. Based from the two experiments from different speed, and the research that has been made about the current wire rope barrier, it proves that the current barrier design need serious modification because the current barrier design is fatal to the motorcyclist community especially. The elasticity of the rubber tubes have been performed well in the experiment. Its well-known elasticity material has provided longer impact time and hence, avoiding a large deformation on the model.

CHAPTER 5

CONCLUSION & RECOMMENDATION

5.1 CONCLUSION

In conclusion, the current wire rope barriers that are available in the Malaysia highway need a serious modification on the design part. This is to prevent from many road users being killed in the future. The current barrier has a lot of risk ‘installed’ in it. The author recommends that it is time to install safety accessories that could increase the time of impact in the wire rope barrier especially in Malaysia highway. This safety accessory can also applicable to semi-rigid type like W-beam steel guardrail. This is because the main usage for the safety accessories is to cover the exposed posts area. Table below is the recommendation by the author:

Modification	Recommendation Solution
Post height	Increased from 710mm to 960mm
Number of wire rope used	Four wire ropes for maximum post height at 960mm
Safety Accessories	Needed to cover the exposed post area

Table 8: Recommendation design

The deep research on the guardrails will improve the quality of the guardrail and will reduce the cheese-cutter effect and probability of severe injury thus save many lives. The author hope that further research can be done on the Design C and also the usage of safety accessories in Malaysia highway.

5.2 RECOMMENDATION

To improve this project in the future, it is recommended to further study on the guardrail alternative design that can have better force distribution and at the same time reduced the damage that can be done to the vehicle bodywork and also the severity of injury.

Other than that, it is also recommended to study on other potential materials such as polymer and composites. The cost is comparable to the steel nowadays. However, when it comes to the material properties, there are a little bit of problems. According to Malaysia Department of Public Work, a guardrail should at least up to 15-30 years. Polymer and composites cannot stand that kind of duration. Therefore, the author recommended that a study to increase the life time of the material should be done.

In addition, it is advisable to conduct a real crash test so that the result will become more realistic. The author could not cover the matters and matters mentioned previously because of certain limitation such as time constraint to complete this project. In addition, the budget for this project is not sufficient enough to purchase one crash dummy and conduct a real crash test.

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