DECELERATION PERFORMANCE COMPARISON FOR PASSENGER CAR UNDER ON-ROAD AND OFF-ROAD DRIVING CONDITION.

MOHD KHAIRIL ASRI BIN KAMALUDDIN

BACHELOR OF ENGINEERING

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DECELERATION PERFORMANCE COMPARISON FOR PASSENGER CAR UNDER ON-ROAD AND OFF-ROAD DRIVING CONDITION.

MOHD KHAIRIL ASRI BIN KAMALUDDIN

Report submitted in partial fulfilment of the requirements
for the award of the degree of
Bachelor of Mechanical Engineering with Automotive Engineering

Faculty of Mechanical Engineering
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NOVEMBER 2010

UNIVERSITI MALAYSIA PAHANG

FACULTY OF MECHANICAL ENGINEERING

I certify that the project entitled "Deceleration Performance Comparison for Passenger Car under On-road and Off-road Driving Condition" is written by Mohd Khairil Asri Bin Kamaluddin. I have examined the final copy of this project and in my opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. I herewith recommend that it be accepted in partial fulfilment of the requirements for the degree of Bachelor of Mechanical Engineering with Automotive Engineering.

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SUPERVISOR'S DECLARATION

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Date:	6 DECEMBER 2010

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged. The thesis has not been accepted for any degree and is not concurrently submitted for award for other degree.

Signature : …………………………………………………………..
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ID Number : MH 07058
Date : 6 DECEMBER 2010

IN THE NAME OF ALLAH, THE MOST BENEFICENT, THE MOST MERCIFUL

A special dedication of This Grateful Feeling to My…

Beloved parents, for giving me full of moral support and financial support. It is very meaningful to me in order to finish up my degree's study. Do not forget also to my loving sister, brother and also to my beloved one, and last but not least to all my lovely lecturers and friends.

Thanks for giving me Love, Support and Best Wishes.

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ABSTRACT

In deceleration, there are many factors that influent the deceleration performance. The factors are like brake system and the road condition. Other than that, how the driver pressed the brake pedal also influenced the deceleration performance and also the safety during braking. This must be considered during designed the brake system of the car. The objectives of this project are to collect the data of the passenger car during decelerates using the UMP's test car under on-road and off-road driving condition and to analyze the deceleration performance of passenger car for difference deceleration test. This report describes the few type of deceleration by run the test. The test was divided into two sections which are on road and off road. For the on road test, the initial speed of the car before decelerate was varies and control the stopping distance. Base on the theory, the higher the initial speed of the car, the longest time and distance needed to stop safely but for this test, the stopping distance is constant so that the stopping time will decrease if the initial speed is increase. Other than that, the brake system also needs to absorb greater energy and power if the car decelerates from the high speed. For the off road test, the stopping time and stopping distance want to be study base on the initial speed of the car. Finally, some calculations need to be performed using related formulas and equations to know the difference between all the decelerations types. Some graphs was plotted to show the trends and pattern of the result. The results concluded that the braking techniques and ways to reduce the car speed will affect the stopping time, stopping distance, and power and energy absorb by the brake system. Therefore, the road condition also is the main factor that influent the deceleration performance of the passenger car. The results indicate difference deceleration behavior for passenger car under various speed in on-road and off-road condition, which is an important study to develop difference braking techniques.

ABSTRAK

Dalam nyahpecutan, terdapat banyak factor yang mempengaruhi prestasi nyahpecutan. Antara faktor yang mempengaruhi prestasi nyahpecutan adalah sistem brek dan juga bergantung kepada keadaan jalan. Selain itu, cara pemandu menekan pedal brek juga boleh menjadi salah satu faktor yang mempengaruhi prestasi nyahpecutan dan juga keselamatan ketika nyahpecutan. Ini adalah perkara penting yang harus dipertimbangkan apabila mahu mereka sistem brek kereta. Objektif kajian ini adalah untuk mendapatkan data nyahpecutan kereta penumpang menggunakan kereta uji milik UMP di jalan berturap dan jalan tidak berturap dan untuk menganalisa data prestasi nyahpecutan kereta penumpang bagi setiap kes nyahpecutan yang berbeza. Kajian ini menerangkan beberapa jenis nyahpecutan melalui ujikaji. Ujikaji dibahagi kepada dua bahagian iaitu di jalan berturap dan jalan tidak berturap. Bagi ujikaji di jalan berturap, halaju awal kereta sebelum nyahpecutan dibezakan dan jarak untuk kereta berhenti dimalarkan. Berdasarkan teori, kereta yang bergerak dengan kelajuan yang tinggi memerlukan lebih banyak masa dan jarak untuk berhenti dengan selamat tetapi dalam ujikaji ini, jarak kereta berhenti dimalarkan menyebabkan masa nyahpecutan akan berkurang dengan peningkatan halaju awal kereta. Selain itu, sistem brek juga perlu menyerap tenaga dan kuasa yang lebih besar jika kereta mengalami nyahpecutan daripada kelajuan yang tinggi. Untuk ujikaji di jalan tidak berturap, masa nyahpecutan dan jarak kereta berhenti hendak dikaji berdasarkan perbezaan halaju awal kereta. Akhirnya, beberapa pengiraan perlu dilakukan menggunakan formula dan persamaan yang berkaitan untuk mengetahui perbezaan diantara setiap jenis nyahpecutan. Beberapa graf diplotkan untuk menunjukkan corak dan keadaan hasil kajian. Hasil kajian merumuskan teknik membrek dan cara untuk mengurangkan kelajuan kereta akan mempengaruhi masa kereta berhenti, jarak kereta berhenti, dan kuasa dan tenaga yang diserap oleh sistem brek. Walaubagaimanapun, keadaan jalan juga merupakan factor utama yang mempengaruhi prestasi nyahpecutan bagi kereta penumpang. Hasil kajian ini menunjukkan perbezaan keadaan nyahpecutan untuk kereta penumpang pada halaju yang berbeza di jalan berturap dan tidak berturap merupakan satu kajian yang penting untuk menghasilkan perbezaan kaedah nyahpecutan.

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LIST OF SYMBOLS

mm	Milimeter
m	Meter
sec	Second
kg	Kilogram
rpm	Revolution per minute
M	Mass of vehicle
M_s	The torques acting on the wheel calculated from the center of the wheel
F_b	Total brake force of front and rear wheels
F_t	The force acting on the wheel (actually the tire) from the ground as it slides
F_{xt}	Total of all longitudinal deceleration force on the vehicle
F_{br}	The force acting on the brake disc from the brake pad in the caliper
F_{xf}	Front axle braking force
F_{xr}	Rear axle braking force
r_w	The radius of the wheel inclusive tire
r_{br}	The radius of the brake disc
V	Forward velocity
V_f	Final velocity
V_o	Initial velocity
D_A	Aerodynamic drag
D_x	Linear acceleration
a	Acceleration rate

$-a_x$	Linear deceleration
d	Distance traversed during acceleration (braking distance)
e	Perpendicular distance from actuation force to pivot
N_A	Normal force between lining A and drum
N	Perpendicular distance from lining friction force to pivot
m	Perpendicular distance from the normal force to the pivot
W	Vehicle weight
g	Gravitational acceleration
ϴ	Uphill grade
t_s	Time for the velocity change
C	Aerodynamic drag factor

LIST OF ABBREVIATIONS

M/T	Manual transmission
USB	Universal Serial Bus
ABS	Antilock brake system
F1	Formula One
SD	Stopping Distance
DAS	Data acquisition system

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Acceleration and deceleration are two terms that have quick similar meaning but have a few different in term of sign of it magnitude. Many car manufacturers were produces car with high performance during speeding or acceleration without think about the deceleration performance. Actually, many accidents happen because of the car or driver cannot brake or slow down the car in the correct time. The deceleration technique is more important compare to the acceleration technique. Many people know the acceleration technique but less skill in deceleration technique. The wrong braking and deceleration technique will effect to the car structure and also can make the car loss control and accident. Besides that, the correct deceleration technique will increase the lifetime of the tires and will affect the fuel consumption.

The brake is the system that functions as a tool to stop the car or make the car decelerate. But many people do not know how to use the brake correctly, that is will give less impact to the car structure and protect from accident. In this report, the mechanism when the brake pedal was press is analyzed and the value of stopping time, stopping distance and energy and power absorb by the brake system will be determined.

1.2 PROBLEM STATEMENT

Increasing the numbers of accident happens become one of the biggest challenge and the important thing that must be thinking by engineers or designer in automotive sector (Georg, 2009). The effect that influent this matter happen must be counter and minimize. Many of accident happen because of the brake of car malfunction or the brake system cannot stop the car in the short time (Mustafa, 2005). In the other words, many accidents happen because the car cannot decelerate correctly. Also, unstable condition of the car when the car was suddenly braked will cause the car unbalance and accidents happen.

Besides, many car manufacturers not focus and highlight about the deceleration performance like they are encourage about the acceleration performance. It can be seen on the broacher of the car, they clearly show the acceleration performance of the car without stated any info or details about the deceleration performance (Georg, 2009).

Other than that, the important thing with the brake system is the ability of the brake system to stop the car in the short distance without slip. When the car or vehicle move with high speed, it will take more time to stop safely because of the car's momentum and inertia principle. The brake system functions as a component that make the car decelerate or facing the decreasing of velocity. The deceleration also can happen naturally, without the force from brake. The deceleration of the car will happen under various conditions. The technique of braking is important for difference speed and road condition. It is important to know the relation between braking skill or technique with the distance and time to the car stop.

1.3 OBJECTIVES

The objectives of this project are:

i) To collect the performance data of the passenger car during decelerates using the UMP's test car under various type of deceleration.

ii) To analyze the deceleration performance data for passenger car.

1.4 PROJECT SCOPES

The scopes of this project are:

i) Literature review of relevant and related information about this study.

ii) Test car system installation like sensors involve and data storage system.

iii) Experiment setup of the testing design, road and method selection.

iv) Data collection by run the testing to get the data for analyzes.

v) Deceleration performance analysis to reach the aim or objective of this study.

vi) Final report preparation.

1.5 HYPOTHESIS

In deceleration, when the stopping distance is constant, the car moving with high speed will have shortest stopping time, greater energy and power absorb by the brake system and also high vibration impact compare to the car moving with low speed.

1.6 PROJECT FLOW CHART

In order to achieve the aim and the objective of the project, a methodology was constructed to have a proper guidance for a successful experimentation. The flow chart for the project is as follow:

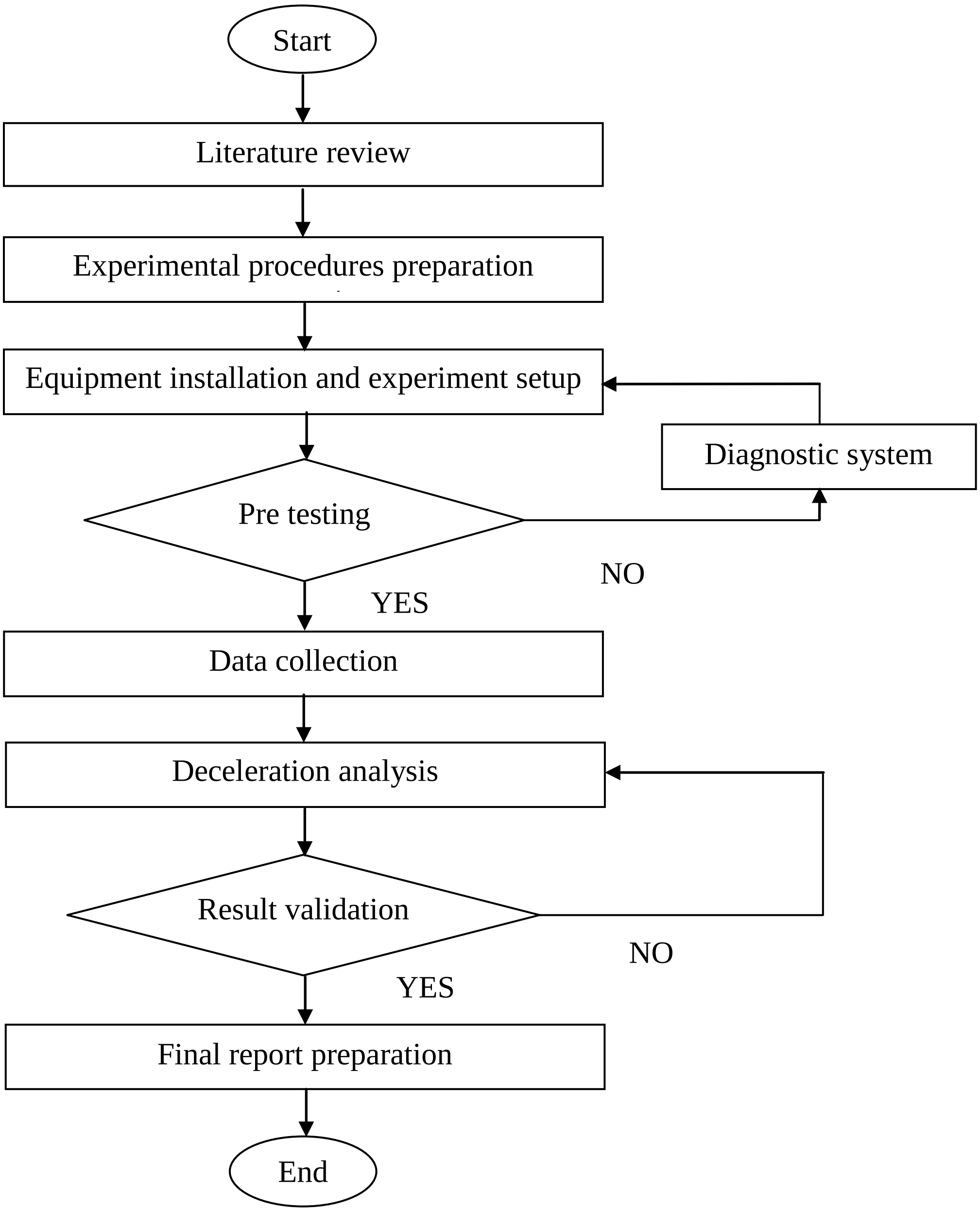

Figure 1.1: Flow chart of the project

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The process of braking is important in automotive performance, which impacts the safety of traffic. Several parameters of braking can be determined on stationary test stands, however, more accurate data that can be used in a more simple way in practise are gained by doing tests on the road. One of the causes of traffic accidents is the technical condition of automobiles. The key characteristic of an automobile’s technical condition, which impacts the safety of traffic, is the brake system and the effectiveness of its performance which the period and the distance needed to stop an automobile depend on. One of the ways to reduce a number of traffic accidents is to improve the methods and ways of controlling the parameters of braking or decelerating for automobiles. The effectiveness of parameters of braking does not mostly depend on the age of automobiles, but on the technical condition of the brake system of the automobiles (Dainis, 2009).

The braking system constitutes an integral part of an automobile. Failure of the automobile brake system at the time of emergency can lead to accidents, property damage or even death of an individual (Newcomb and Spurr, 1967). In recent years, braking systems have undergone tremendous changes in terms of performance, technology, design and safety (Dainis, 2009). Today, the brake engineer has two challenges (DaimlerChrysler, 2002):

i) Create enough deceleration to stop the car as quickly as the driver wishes, without exceeding the drivers comfort level with regard to pedal effort or pedal travel.
ii) Manage the resulting heat energy so as not to damage the brake system or the rest of the vehicle.

Anti lock brake systems are the most sought after these days, which are now used in almost all the vehicles. A review of the literature was performed to identify studies relevant to the topic.

2.2 PASSENGER CAR BRAKE SYSTEM

The brake system is one of the important aspects that can influent the deceleration performance of a vehicle. The braking system constitutes an integral part of an automobile. Besides that, failure of the automobile brake system at the time of emergency can lead to accidents, property damage or even death of an individual (Heinz, 2002). The passenger car can be characterize as all sedans car, coupes, and station wagons manufactured primarily for the purpose of carrying passengers or passenger cars pulling recreational or other light trailers. It can divide into a few types like below (Carlos, 2005):

i) Mini (PC/Mi) (680-899 kg curb weight)
ii) Light (PC/L) (900-1129 kg curb weight)
iii) Compact (PC/C) (1130-1359 kg curb weight)
iv) Medium (PC/Me) (1360-1599 kg curb weight)
v) Heavy (PC/H) (1600 kg and over. Curb weight.)
vi) Sport utility vehicles (SUV)
vii) Pickup trucks (PU)
viii) Vans (VAN)

Braking system comprises from several parts such as brake pads, brake booster, brake discs, brake calipers, brake cylinders, brake drums, brake wires, wheel studs, clutches, valves, brake hoses, vacuum pumps, brake rotors, sprockets, brake pads, brake levers and brake shoes (Peter, 2009). Some of the functions of the brake component are show in Table 2.1 below:

Table 2.1: Brake component

Component	Description
Brake pad	The important part that cans influent the braking performance or brake quality
Brake booster	Is designed to create a greater braking force from a minimum pedal effort, using a difference in atmospheric pressure and the engine's manifold vacuum.
Disc brake or rotor	Device for slowing or stopping the rotation of a wheel.
Brake caliper	The key component of cars brake system, the brake caliper operates just like a small hydraulic clamp designed to grip the brake rotor and bring car to a halt.
Drum brakes	Are really similar to disc brakes, but instead of pads they use shoes.
Brake pedal	Is located on the left side of the accelerator pedal and it slows down or stops the vehicle.
Brake shoes	Are found inside of drum brakes, which serve the same function in a slightly different way with caliper in the disc brake system.

Source: Peter, (2009)

The worldwide automobile brake system market is flooded with advanced, modern and cost effective brake system technologies. Canada (21.73%), Mexico (19.22%), Japan (16.33%), China (13.56%) and Brazil (6.54%) are the largest manufacturing countries of automobile brake systems in the world (Thomas, 2006). In recent years, braking systems have undergone tremendous changes in terms of performance, technology, design and safety (Huei and Jeffrey, 1995). The brake system market today were produce many new and innovative technologies such as electronic brakes, anti lock brakes, cooling brakes, disc brakes, drum brakes, hand brakes, power brakes, servo brakes and brake by wire. These studies are only focus to the disc brake system and drum brake system.

2.2.1 Disc Brakes

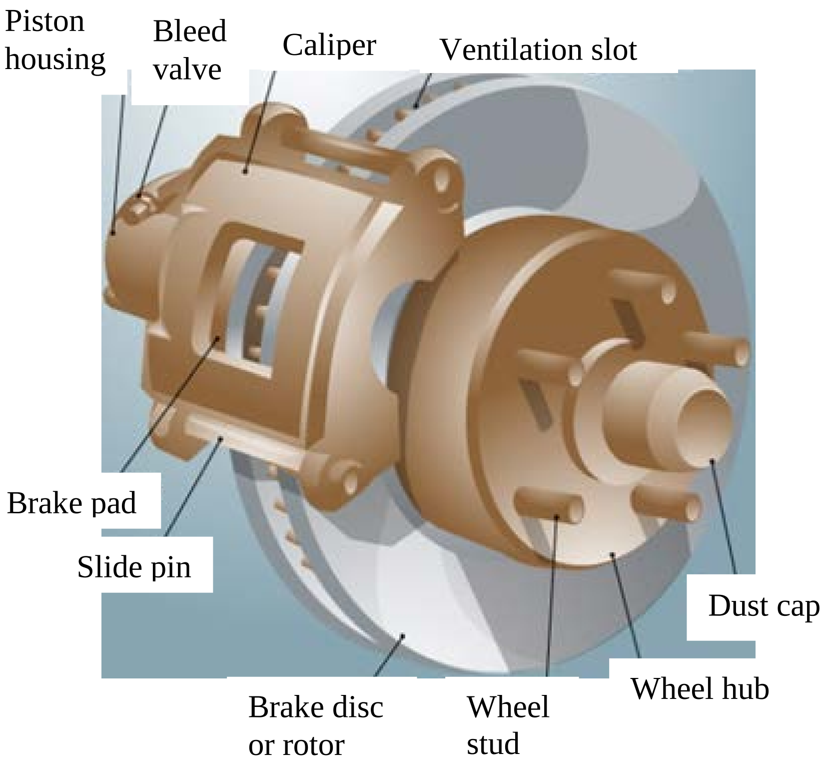

Figure 2.1: Disc Brake

Source: Huei and Jeffrey, (1995)

Though disc brakes rely on the same basic principles to slow a vehicle (friction and heat). Disc brakes system use a slim rotor and small caliper to halt wheel movement. Within the caliper are two brake pads, one on each side of the rotor, that clamp together when the brake pedal is pressed. Once again, fluid is used to transfer the movement of the brake pedal into the movement of the brake pads. The disc brake system allow heat to build up inside the drum during heavy braking, the rotor used in disc brakes is fully exposed to outside air. This exposure works to constantly cool the rotor, greatly reducing its tendency to overheat or cause fading (Huei and Jeffrey, 1995). Not surprisingly, it was under racing circumstances that the weaknesses of drum brakes and the strengths of disc brakes were first illustrated. Racers with disc brake systems could carry their high speed into a corner and apply greater braking force at the last possible second without overheating the components. Eventually, as with so many other automotive advances, this technology filtered down to the cars driven by everyday people on public roads.

2.2.2 Drum Brakes

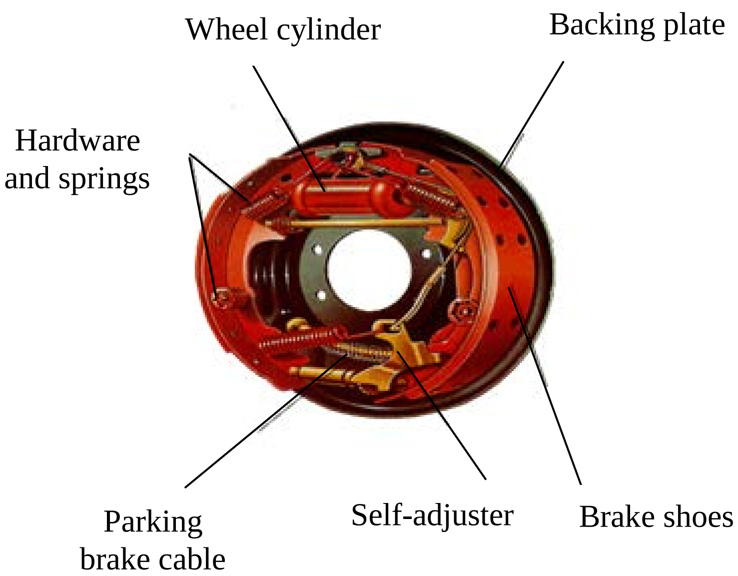

Figure 2.2: Drum Brake

Source: Huei and Jeffrey, (1995)

Early automotive brake systems, after the era of hand levers of course, used a drum design at all four wheels. They were called drum brakes because the components were housed in a round drum that rotated along with the wheel (Huei and Jeffrey, 1995). Inside was a set of shoes that, when the brake pedal was pressed, would force the shoes against the drum and slow the wheel. Fluid was used to transfer the movement of the brake pedal into the movement of the brake shoes, while the shoes themselves were made of a heat-resistant friction material similar to that used on clutch plates. This basic design proved capable under most circumstances, but it had one major flaw (Limpert, 1971). Under high braking conditions, like descending a steep hill with a heavy load or repeated high-speed slow downs, drum brakes would often fade and lose effectiveness. Usually this fading was the result of too much heat build-up within the drum. Remember that the principle of braking involves turning kinetic energy (wheel movement) into thermal energy (heat). For this reason, drum brakes can only operate as long as they can absorb the heat generated by slowing a vehicle's wheels. Once the brake components themselves become saturated with heat, they lose the ability to halt a vehicle, which can be somewhat disconcerting to the vehicle's operator.

2.3 BRAKE PARAMETERS

2.3.1 Braking Performance

Brake performance is a measurement of stopping distance or deceleration as a function of brake pedal force or air pressure when applicable. The test can measure the stopping distance or deceleration for a given brake pedal force or air pressure, or the brake pedal force or pressure required to attain a certain stopping distance or deceleration. Other conditions that determine the specific brake application include:

i) Total vehicle weight
ii) Vehicle weight distribution on the different axles
iii) Braking speed
iv) Release speed
v) Control parameter: brake pedal force, parking brake control force, brake pressure, output torque or deceleration
vi) Initial brake temperature
vii) Cycle-time between brake applications
viii) Brake history or condition during the brake application: green, post-burnish, pre-fade, hot, postfade, and post-recovery.

The braking performance wills influent the qualities of braking. The speed of an automobile and the safety of traffic significantly depend on the qualities of braking. Qualities of braking are the ability of the automobile to reduce its speed fast and to come to a stop within a short distance of road, to keep the necessary speed when driving downhill, and to stay immobile under the impact of external forces (Dainis, 2009).

2.3.2 Deceleration value or rate

The deceleration value is depending to the stopping time of the car. Figure 2.3 below show the comparison of deceleration value for a few type of car on asphalt road and the gravel road test. The largest deceleration rate of braking on asphalt road is registered for VW Transporter that is 7.43 m s^{-2}, whereas Audi 80 and Audi 100 have the smallest deceleration rates of braking, respectively 5.48 and 5.49 m s^{-2}. On the gravel road, VW Passat has the largest deceleration rate of braking with 5.71 m s^{-2}, but the smallest one is registered for VW Transporter is 3.98 m s^{-2}.

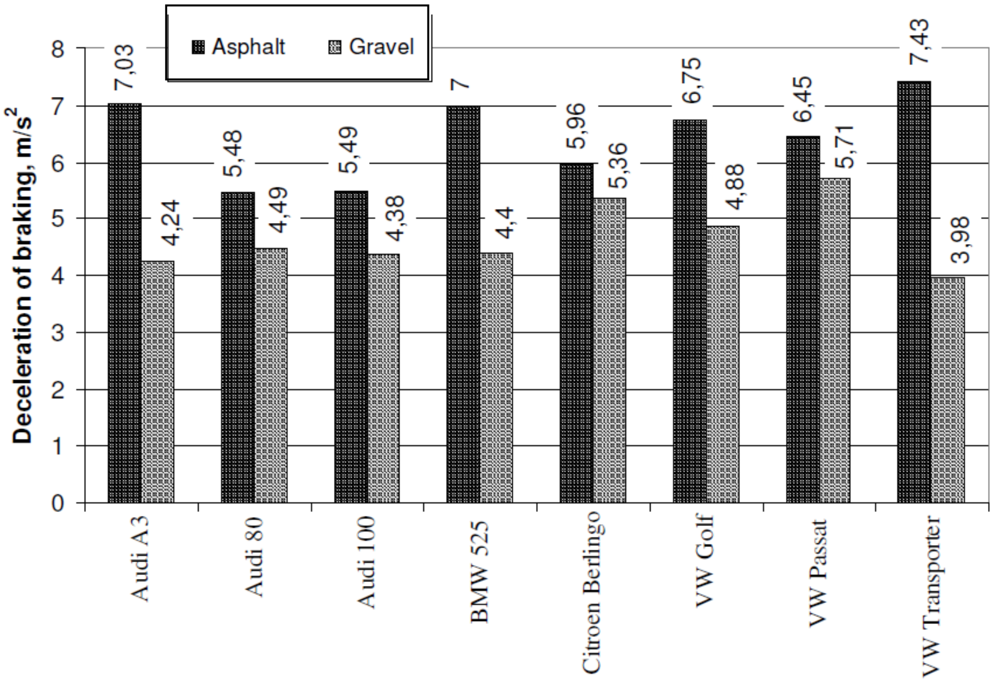

Figure 2.3: Comparison of average deceleration rates of braking for cars

Source: Dainis, (2009)

2.3.3 Brake Size

The installation of bigger brakes can improve the performance of the car deceleration process. Higher quality brakes will improve braking some, with more vents (drilling), slotting and maybe more pistons. But the thing that will really improve braking performance is size (Peter, 2009). Size as in larger diameter discs and bigger, multi-piston calipers. There are two main reasons why a bigger brake is the key to getting more stopping power.

The first is bigger brakes (discs) have more surface area and can therefore get rid of more heat than smaller brakes, and heat is a brakes worst enemy. The heat can do three things: Melt the surface of the brake pads (glazing) which makes them smooth and reduce the friction between pad and rotor. Heat can make the calipers so hot that the brake fluid boils; boiling creates air bubbles and bubbles are compressible, which in turn allows driver to press the brake pedal to the floor without any significant effect on the car's speed. And last but not least a high temperature is not good for the brake discs: Discs will tolerate heat up to a certain temperature, but higher than that they will warp, or even crack if the temperature is high enough. That is unless have carbon brake discs like the ones used on F1 cars. The second is bigger brakes have more leverage on the tire so less braking force from the brake makes for more stopping power at the tire.

2.3.4 Heat Dissipation During Braking

One of the two reasons for bigger brakes is heat. The bigger discs will get rid of more heat than smaller discs because of it's increased surface area. It's fair to say that most of the heat will dissipate from the area of the brakedisk that is wented. I.e the surface the brakepad touches and the surface inside the vent channels in the disk. And of course the area of the holes in the disk if it's cross drilled. If we assume that the standard disc of 278mm and a 340mm disc have the same height where the pad touch the disk (which is 55 mm for the standard disc) then the area dissipating heat will increase by almost 28%. Of course the new bigger disc will probably be drilled, and have a larger area inside of the braking-surface that also helps. All these factors combined will probably increase the amount of heat the disc can dissipate by about 40%. To discover why the bigger discs are even more than 40% better.

2.3.5 Braking Distance

The braking distance is the distance that a vehicle travels while slowing to a complete stop. The braking distance is a function of several variables. First, the slope (grade) of the roadway will affect the braking distance. When going uphill, gravity assists in the attempts to stop and reduces the braking distance. Similarly, gravity works against when are descending and will increase the braking distance. Next, the frictional resistance between the roadway and the tires can influence the braking distance (DaimlerChrysler, 2002). The research done by DaimlerChrysler show that the type of tires can effect the stopping distance of passenger car (Figure 2.4) . The last parameter that we will consider is the initial velocity. Obviously, the higher speed the longer it will take to stop, given a constant deceleration.

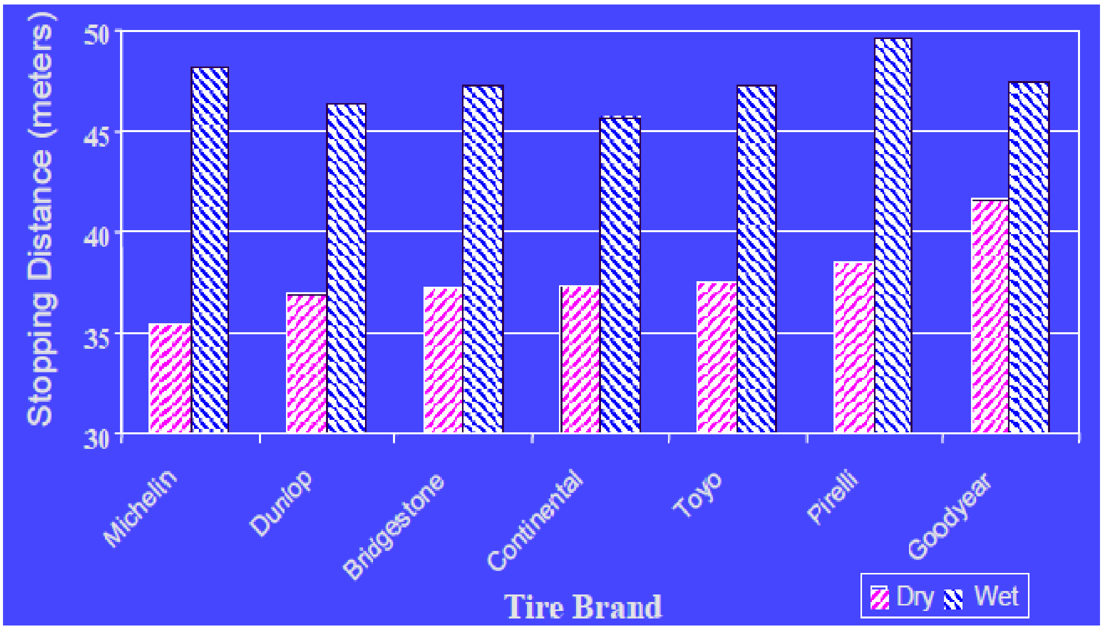

Figure 2.4: Tire type against stopping distance

Source: DaimlerChrysler, (2002)

Figure 2.5 below show the graph of the distance of braking for a few type of car. Most of the car is the high performance car in the world that produced by the great car maker company. From the graph, the car VW Transporter has the shortest distance of braking on asphalt road that is 32.88 m, whereas the car Audi 80 has the longest distance of braking that is 44.92 m. On the gravel road, the shortest distance of braking is registered for the car VW Passat that is 43.04 m, while the longest is the car VW Transporter with 69.96 m (Dainis, 2009).

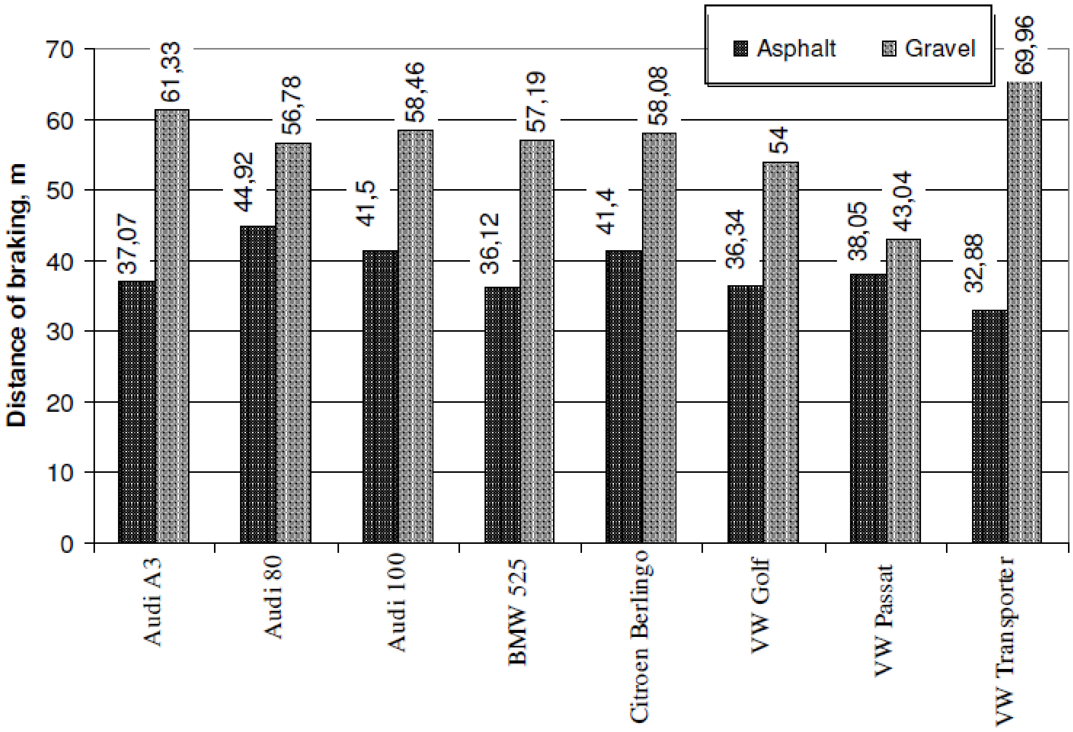

Figure 2.5: Distances of braking for test cars on asphalt road and gravel roads

Source: Dainis, (2009)

The equation used to calculate the braking distance is a child of a more general equation from classical mechanics (Thomas, 2006). The parent equation is given below.

$$V_f^{\,2} = V_o^{\,2} + 2ad \tag{2.1}$$

When calculating the braking distance, assume the final velocity will be zero. Based on this, the equation can be manipulated to solve for the distance traversed during braking.

$$d = (V_{f^2} - V_{o^2})/2a \tag{2.2}$$

Notice that the distance will be positive as long as a negative acceleration rate is used.

The deceleration of a braking vehicle depends on the frictional resistance and the grade of the road. From knowledge of the frictional force, know that the acceleration due to friction can be calculated by multiplying the coefficient of friction by the acceleration due to gravity. Similarly, know from inclined plane problems that a portion of the car's weight will act in a direction parallel to the surface of the road. The acceleration due to gravity multiplied by the grade of the road will give us an estimate of the acceleration caused by the slope of the road.

The final formula for the braking distance is given below. Notice how the acceleration rate is calculated by multiplying the acceleration due to gravity by the sum of the coefficient of friction and grade of the road (Thomas, 2006).

$$d = {V_o}^2/2\left(\frac{F_{xt}}{M}\right) \tag{2.3}$$

The braking distance and the brake reaction time are both essential parts of the stopping sight distance calculations. In order to ensure that the stopping sight distance provided is adequate, a more in-depth understanding of the frictional force is needed. The value of the coefficient of friction is a difficult thing to determine. The frictional force between the tires and the roadway is highly variable and depends on the tire pressure, tire composition, and tread type (Thomas, 2006). The frictional force also depends on the condition of the pavement surface. The presence of moisture, water, sand, mud, snow, or ice can greatly reduce the frictional force that is stopping the car. In addition, the coefficient of friction is lower at higher speeds. Since the coefficient of friction for wet pavement is lower than the coefficient of friction for dry pavement, the wet pavement conditions are used in the stopping sight distance calculations (DaimlerChrysler, 2002). This provides a reasonable margin of safety, regardless of the roadway surface conditions. The Table 2.2 below gives a few values for the frictional coefficient under wet roadway surface conditions (AASHTO, 1984).

Table 2.2: Coefficient of Friction base on Speed

Design Speed (km/h)	Coefficient of Friction (f)
30	0.40
50	0.35
65	0.32
95	0.29

Source: AASHTO, (1984)

2.3.6 The Braking or Stopping Time

The Figure 2.6 below shows the periods of braking for cars on asphalt road and gravel roads for a few types of car. VW Transporter has the shortest period of braking on asphalt road with 2.99 s. The longest periods of braking on asphalt road are registered for the cars Audi 80 that is 4.06 s and Audi 100 is 4.05 s. On the gravel road, VW Passat has the shortest period of braking with 3.44 s, but VW Transporter is the longest one or 5.57 s (Dainis, 2009).

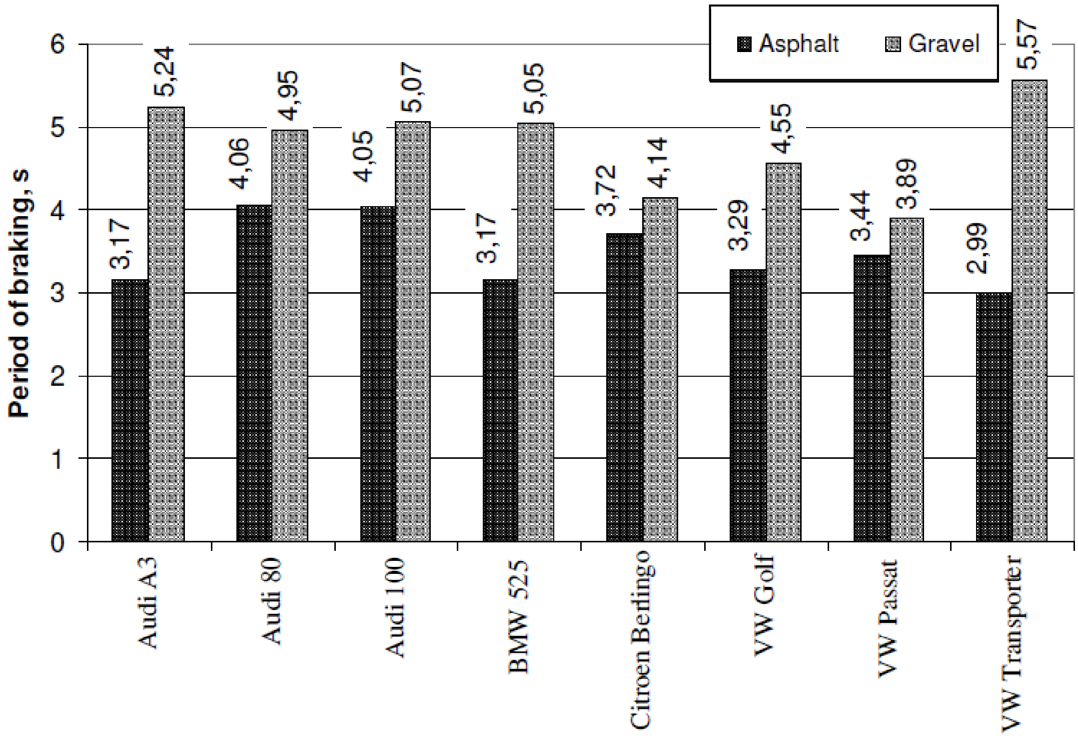

Figure 2.6: Period of braking for test cars on asphalt road and gravel road test

Source: Dainis, (2009)

2.4 BRAKE FORCE

2.4.1 Forces on The Disc Brake

The exactly at the time when the wheel has stopped rotating and slides over the concrete ill calculate. The wheel is stationary (stationary here means not rotating, but still sliding), that the sum of the torques acting on the wheel is zero (if not, it would rotate).

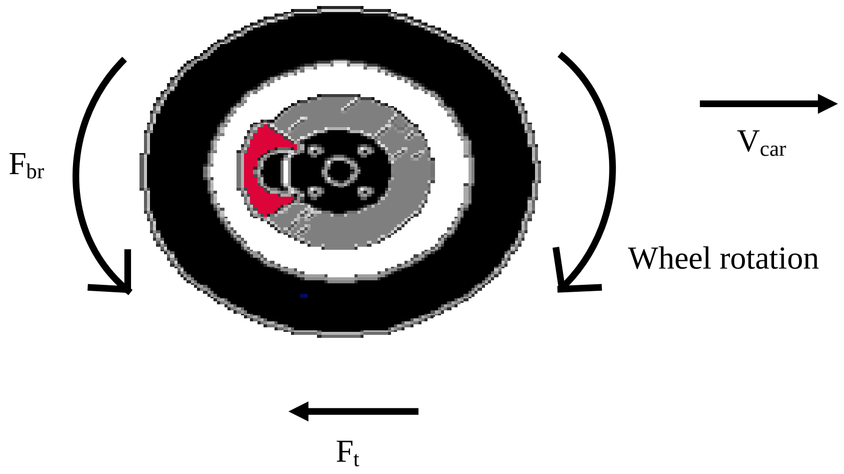

Figure 2.7: Force on the brake disc

Source: Huei and Jeffrey, (1995)

$$\Sigma M_s = F_t \, . r_w + F_{br} \, . r_{br} = 0 \tag{2.4}$$

Solved the equation this way so can look at the forces acting on the brake disc, and therefore the wheel, from the brake pads (as a result of the pressure of the pistons on the pads inside the caliper). The negative sign just means that the force acting on the brake disc from the brake pad acts in the opposite direction of the force acting on the tire from the ground, or else the wheel would not stop.

There are 4 factors which will influent the stopping power:

i. The radius of the wheel which is dependent on wheel size and tire size.
ii. The radius of the brake disc.
iii. The force acting on the tire from the ground (only stickier tires will improve this).
iv. The force acting on the brake disc from the brake pad, which will increase with bigger, higher quality brakes.

Besides, there are other sources that may arise the brake force of a car. The sources are brakes system, rolling resistance, aerodynamic drag, driveline drag and the road grade.

2.4.2 Force on the Drum Brake

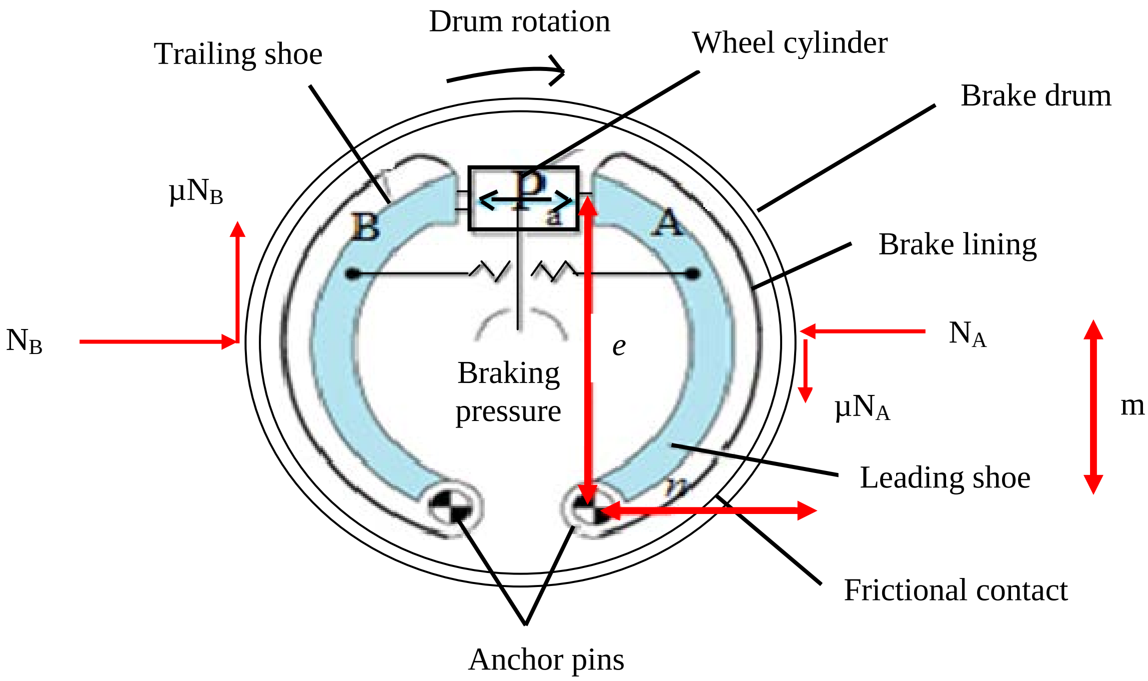

Figure 2.8: Drum Brake (Brake factor)

Source: Huei and Jeffrey, 1995

Taking moments about the pivot point for shoe A:

$$\Sigma M_p = eP_a + n\mu N_A - mN_A = 0 \tag{2.5}$$

The friction force at each brake shoe is:

$$F_A = \mu N_A \quad \text{and} \quad F_B = \mu N_B \tag{2.6}$$

and

$$\frac{F_A}{P_a} = \frac{\mu e}{m-\mu n} \quad \text{and} \quad \frac{F_A}{P_a} = \frac{\mu e}{m-\mu n} \tag{2.7}$$

2.5 DECELERATION TYPES

The general equation for braking performance may be obtained from Newton's Second Law written for the x-direction (Thomas, 2006). The forces on the vehicle are generally of type show below:

$$Ma_x = -\frac{WD_x}{g} = -F_{xf} - F_{xr} - D_A - W\sin\theta \tag{2.8}$$

2.5.1 Constant Deceleration

Simple and fundamental relationship can be derived for the case where it is reasonable to assume that the forces acting on the vehicle will be constant throughout a brake application. The simple equations that result provide an appreciation for the basic relationships that govern braking. For constant deceleration, the equation can be derived and show below:

$$D_x = \frac{F_{xt}}{M} = -\frac{dV}{dt} \tag{2.9}$$

Then, the equation can be integrated (because F_{xt} is constant) for a deceleration from initial velocity, V_o to final velocity, V_f.

$$V_o - V_f = \frac{F_{xt}}{M}\, t_s \tag{2.10}$$

In the case where the deceleration is a full stop where the V_f is zero, the stopping distance, SD and stopping time are given in the equation 2.14 and 2.15 below:

$$SD = \frac{{V_o}^2}{2\left(\frac{F_{xt}}{M}\right)} = \frac{{V_o}^2}{2D_x} \tag{2.11}$$

$$t_s = V_o/(F_{xt}/M) = V_o/D_x \tag{2.12}$$

Thus, all other things being equal, the time to stop is proportional to the velocity, whereas the distance is proportional to the velocity squared (doubling the velocity doubles the time to stop, but quadruples the distance required).

The energy and power absorbed by the brake system can be substantial during a typical maximum-effort stop. The energy absorbed is the kinetic energy of motion for the vehicle, and is thus dependent on the mass. The energy absorbed by the brake system during braking will given by the equation 2.13 below:

$$\text{Energy} = \frac{M}{2}({V_o}^2 - {V_f}^2) \tag{2.13}$$

The power absorbed will vary with the speed, being equivalent to the braking force times the speed at any instant of time. Thus, the power dissipation is greatest at the beginning of the stop when the speed is highest. Over the entire stop, the average absorption will be energy divided by the time to stop. The power absorbed by the brake system during braking is calculate using the equation 2.14 below:

$$\text{Power} = \frac{M}{2}\frac{{V_o}^2}{t_s} \tag{2.14}$$

2.5.2 Deceleration with Wind Resistance

For the deceleration with wind resistance, the total braking force is the summation of total brake force from the axles and the drag force from the wind resistance. The air drag that facing by the car must be considers in order calculating the amount of total longitudinal deceleration force on the vehicle. The equations were like below:

$$\Sigma F_x = F_b + CV^2 \tag{2.15}$$

The equation can be integrated to obtain the stopping distance:

$$\int_0^{SD} dx = M \int_{V_o}^{0} Vdv/(F_b + CV^2) \tag{2.16}$$

$$SD = \frac{M}{2C} \ln[\frac{F_b + CV_o{}^2}{F_b}] \tag{2.17}$$

2.6 SUMMARY

Table 2.3: Previous Research

Author	Year	Title	Discription
Dainis Berjoza, Arnis Mickevics	2009	Research In Parameters Of Braking For Automobiles	Consideration parameters: i. Disc brake and drum brake temperature. ii. Weight of the car,load and passenger. iii. Engine brake. iv. Initial speed. v. The road slope. vi. Road types.
Carlos E. Agudelo	2005	Technical Overview Of Brake Performance Testing For Original Equipment And Aftermarket Industries	The test procedure outlines the following parameters for each section during the test: i. Number of stops/snubs, ii. Braking-release speed iii. Control level iv. Initial brake v. Temperature for the brake application vi. Cycle time/distance between brake applications vii. Performance requirements when applicable.
David L. Smith	2003	Analysis Of Braking And Steering Performance In Car-Following Scenarios	The analysis of last second braking performance showed that the quantified boundaries of the driving states strongly depend on the dynamic scenario encountered in the driving environment.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

The basic concept for the title has been covered in this stage. The concept must be understood before proceeded to next stage. The information can be found from internet and reference books. The review of others research also be done in this stage. By defining the objectives and scopes of the project, is to have a clear picture of the project and it will be easier to do the project.

3.2 TEST CAR SPECIFICATION

The test vehicle used for this project is Proton Persona Elegance 1.6 (M/T), a 4-door sedan provided by Universiti Malaysia Pahang. Proton Persona is manufactured by National car maker Proton Holdings Berhad. The test car used the all standard specification for proton Persona Elegance 1.6 (M/T). This vehicle is installed with various sensors for vehicle dynamics testing including the Brake Pedal Sensor, Suspension Displacement Sensor and computer host for data acquisition system. The specification of the test car shows in the Table 3.1 below and Figure 3.1 shows the car that be used in this project.

Figure 3.1: UMP Test Car

Table 3.1: The Test Car Specification

Car Specification	Types
Manufacturer	Proton
Model	Persona Elegance 1.6 (M/T)
Bodystyle	4-door sedan
WheelBase (mm)	2600
Overall Length (mm)	4477
Overall Width (mm)	1725
Overall Height (mm)	1438
Front Track (mm)	1475
Rear Track (mm)	1470
Min. Turning Radius (m)	5.4
Kerb Weight (kg)	1215
Engine displacement	1597
Valve mechanism	16-V DOHC
Maximum output	82kW/6000 rpm
Maximum torque	148Nm/4000 rpm
Seating capacity(person)	5
Fuel tank capacity	50 litre
Acceleration 0-100km/h(sec)	12.0
Steering	Rack & Pinion, Hydraulic Power Assisted
Front Suspension	MacPherson strut & coil spring with Stabilizer Bar
Rear Suspension	Multi-Link and coil spring with Stabilizer Bar
Front Brakes	Ventilated Disc
Rear Brakes	Solid disc
Std. Tyre Size	190/60 R15
Std. Wheel Size	15

Source: Proton, (2010)

3.3 TEST CAR SYSTEM INSTALLATION

The test car needs to be prepared and make sure in the good condition. The entire sensor that related to the project needs to be install and standby to perform the test. The sensor that involve in this project like brake pedal sensor, gyroscopic, transducer (RAV arm sensor), absorber sensor, Miniature Attitude and Heading Reference System or MTi, and steering sensor.

3.3.1 Brake Pedal Force Sensor

In this project, the force exert to the brake pedal was determined by using the brake pedal sensor. Figure 3.2 below shows the brake pedal sensor that was used and focus in this project:

Figure 3.2: Brake pedal sensor

The Brake Pedal Sensor is used to evaluate and measured the force exert to the brake pedal. It mounts directly to the brake pedal with cable ties for easy installation and the USB port on the computer host for data acquisition system. Brake pedal force load sensor has no need of external analog amplifiers, power supplies, or display equipment, it is all handled through a USB computer port.

This device commonly used in cars and trucks to measure brake-pedal force measurement and as a high-precision trigger for brake-testing equipment (Peter G Sturgess, 2009). Though specifically designed to measure the force needed to operate a vehicle's brake, clutch, or floor-mounted emergency brake pedals, is adaptable to measure any pedal based pressure. It comes with two different mounting plates to ease installations, along with a shunt cal resistor and carrying case.

3.3.2 Computer Host for Data Acquisition System

Due to the high dynamics nature of test, the data recording is important to capture all the measured signals at high dynamics nature of the test. In order to record the all the signal at high sampling rate and course record the vehicle signal such as speed are synchronized to the measured signals the DEWETRON measurement unit in combination with the DEWEsoft acquisition software. The Figure 3.3 below shows the DEWETRON measurement unit as the main component of the test car sensor system.

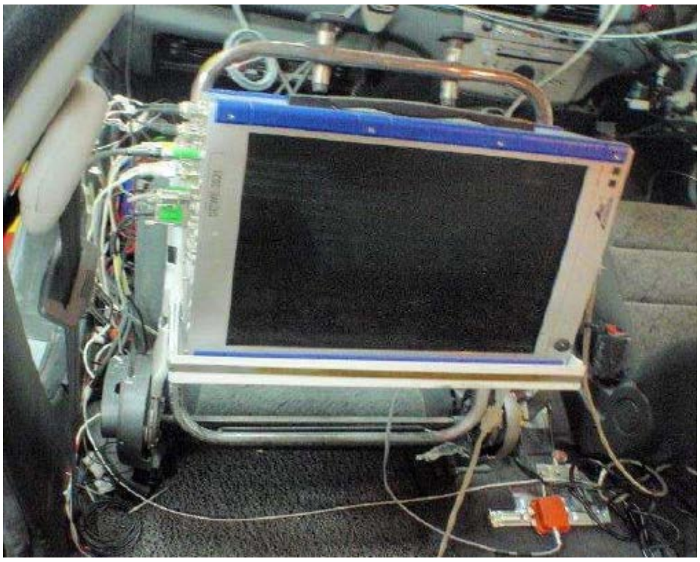

Figure 3.3: DEWETRON DAS

DEWESoft 6 is the fast and easy to use data acquisition software develops by DEWETRON. Dewesoft is taking a major role in all kinds of data recording applications in automotive industry, especially in development laboratories and test facilities, where the ability to acquire data from all different sources creates major advantage. This software not only about standard interfaces like analog, digital, counters, CAN, GPS and video channels, but made to support special devices like gyro platform from Genesys, torque wheels from Kistler, and brake pedal force sensor from Kistler everything of course perfectly synchronized with other sources.

3.3.3 Gyroscopic transducer

In order to investigate the vibration and impact to the car center of gravity position during deceleration, gyroscopic sensor was used. Figure 3.4 shows the gyroscopic sensor that was used in this project. It placed on the center of gravity of the car and movement of the center of the car will be sense. From this sensor the movement of the car exist (yaw, roll, pitch) can be measured.

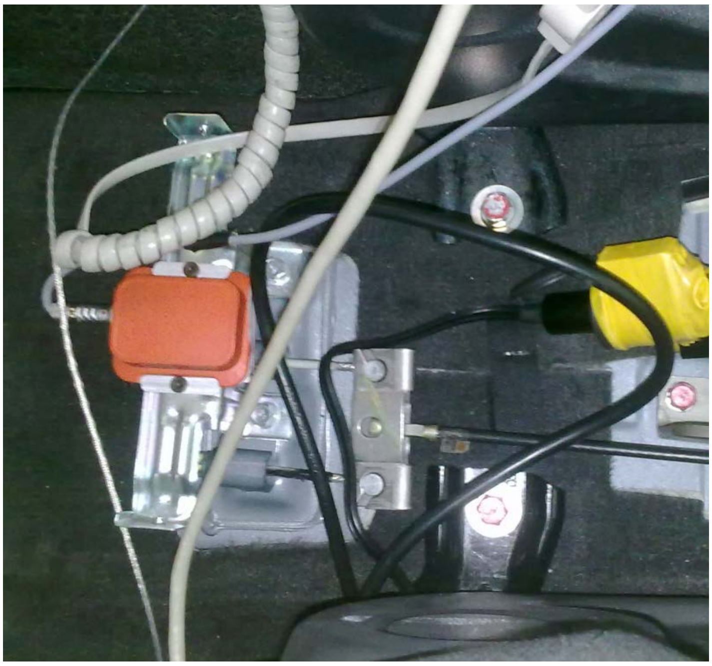

Figure 3.4: Gyroscopic transducer

3.4 DEVELOP PROCEDURE FOR TESTING

The test car must be installing with Global Positioning System (GPS), Brake Pedal Force Sensor, Gyroscopic Transducer and the data acquisition system. The procedure and collecting data method were determined. The test car parameter such as road profile range of velocity and the type of movement weather move in straight line or corner will be determine. This stage all the step and precaution are well being considered. In order to make sure the test is save and acceptable, the preliminary testing was conducted before run the real testing.

3.4.1 Preliminary Testing

The preliminary test is being done to determine the maximum speed for each test and the location of the testing depends on the traffic condition and the suitability of the testing. All of the testing was located in University Malaysia Pahang area. The safety precaution procedure is made based on this preliminary test. The sand that covers the road is noted as the unwanted thing and can reduce the traction force between the tyre and the road. The vehicle performance also is noted during the preliminary test and the optimum distance to achieve the speed can be determine. The gear shifting timing also were determine, since the RPM meter on the test car is malfunction the maximum speed for each gear is be determine. The performance of the entire sensor also is looking to make sure all the system function as well to perform the real test.

3.4.2 Testing Procedure

The testing procedure can be developing after the preliminary tests have been done. The important matters like testing location, maximum speed allowed base on car and road condition and the sensor condition were determined. A few matters need to be check as the precaution before run the test to ensure the test run smoothly and safely like:

i) Double checked all the sensor installation is correct and tightly.

ii) Checked and make sure the fuel level is enough for the testing.

iii) Switch on the power supply of the data acquisition system after starting the car engine to prevent the vehicle battery, that functional as the power source from weak and loss the power.

iv) Switch off all the computer system power supply after finish the test to avoid the car battery from lost the power.

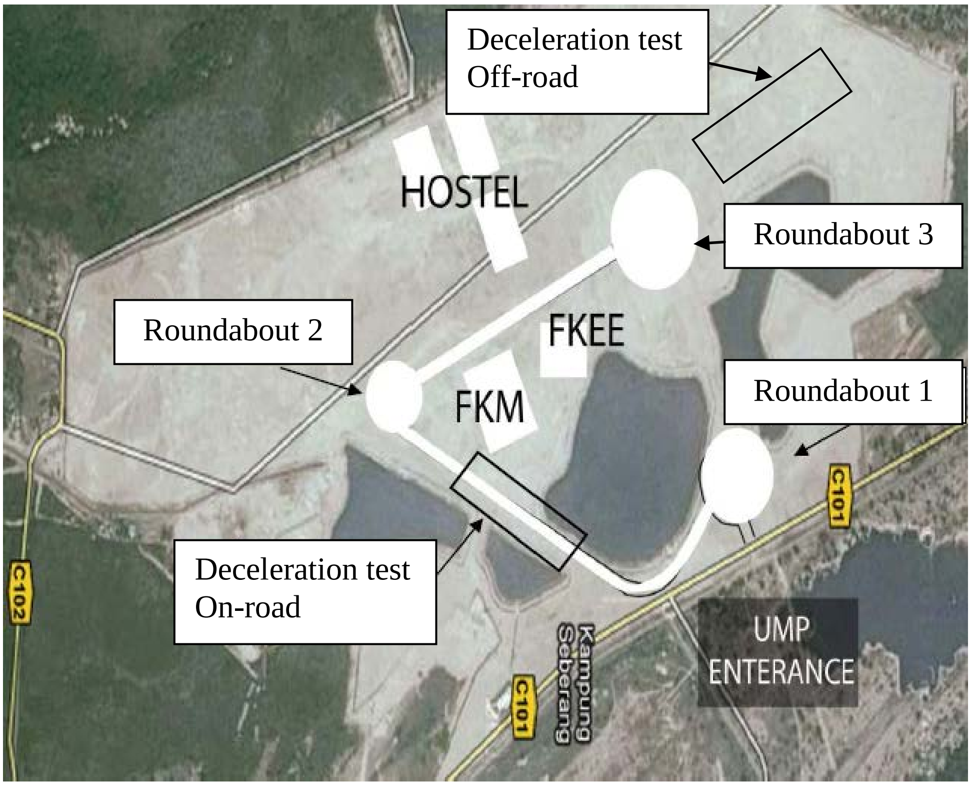

Figure 3.5: Testing Location

Source: Google Maps, (2010)

The testing location was shows in the Figure 3.5 above that is around University Malaysia Pahang Campus Pekan area. The was conduct as follow:

i) On-road Test

On-road testing was conducted in paved roads condition which is straight, plane and dry road. The particular test road for on road condition is located inside UMP with an approximately 2 km straight line road completely paved with tar. This road provides a safe distance for the deceleration test that is required a straight line road and some distance for the car to decelerate from the initial velocity of maximum 90 km/h. Figure 3.6 below show the straight line paved road for the deceleration. The road grade is assumed zero as the road is flat and no inclination is found along this testing road. The Figure 3.7 below shows the road for deceleration tests for on road testing.

Figure 3.6: On-road test (Paved, straight and dry road)

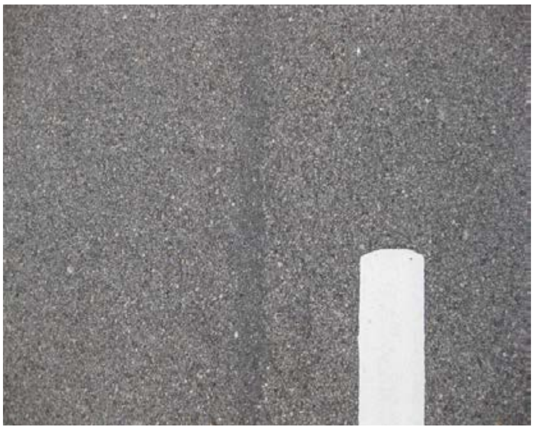

Figure 3.7: Paved road with tar and dry

The on-road testing was setup with three deceleration types that is deceleration from 40-0km/h, 60-0km/h and 90-0km/h. The satellite reading is being sure at least 8 before start the data recording. For the deceleration of 40km/h to 0 km/h the vehicle must maintain the speed of 40km/h before reach the first reference point (i). Once the vehicle enters the section (i) the recording data was started. The vehicle is driven along the cone path. The recording data is being stopped, when the car is completely static at the third reference point (iii). Figure 3.8 below shows the road setup for the on road test. The recording is considered failed when the vehicle is moving more than the velocity range. The run for each speed is repeated in 5 times for the purpose of data accuracy and validation. The same procedure was repeated for the speed of 60km/h and 90km/h. The stopping distance was setup with in 40m for all tests to measure the braking time by control the stopping distance.

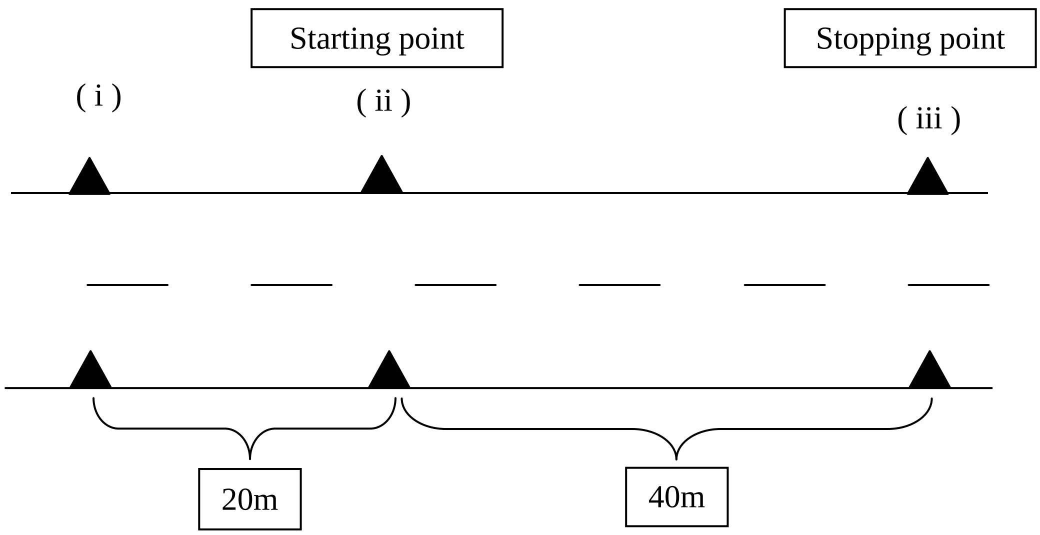

Figure 3.8: Road setup for on-road deceleration test

ii) Off-road Test

Off road testing was conducted in unpaved roads condition which is straight, plane, sandy and dry road. The particular test road for off road condition is located inside UMP which is there is an approximately 0.5 km straight line unpaved road with sandy. This testing road is actually the project site for the construction of UMP

Pekan. The sandy characteristic of this road give the variation in the tire-road friction to extend the study of vibration behavior. This is shown in Figure 3.9 below.

For off road test, the maximum permitted velocity for test is 60 km/h. This is due to the safety precaution because the potential of car accident is typically high due to the soft sand. Higher speed may cause the test car unstable in this soft sandy because of that the traction is generally low. The road grade is assumed zero as the road is flat and no large road inclination is found along this testing road.

The initial speeds before deceleration are 25km/h, 35km/h, 40km/h and 60km/h. For this experiment, the time and stopping distance are the parameters that depend to the initial speed of the car. The unpaved sandy road was show in the Figure 3.10 below. For the purpose of the data accuracy and validation, for all of the condition that mention above will be evaluated at least five test run.

Figure 3.9: Off-road (Sandy and Unpaved road)

Figure 3.10: Sandy with holes and irregular surfaces

3.5 EXPERIMENTAL DATA COLLECTION

By run the test, the data was display on the computer screen of data acquisition system and store inside the device. The raw data is taken out from the device on the test car for analysis. By using the DEWESoft 64 program, the data will be import either to the Microsoft Office Excel workbook or Flexpro 7. The analysis will be used the real data instead by using the reduce data. The reason of performing the analysis using the real data is the data has the rescission time of 0.02 second, while the reduce data only give the precision time of 2 second.

3.6 RESULT ANALYSIS ON DECELERATION PERFORMANCE

3.6.1 On-road Test

The deceleration analysis for on road test was performed to know the deceleration rate, stopping time, energy and power absorb by the brake system of the car and vibration occur during deceleration. The deceleration experiment is to investigate the yaw, pitch and roll response to the vehicle during the braking. By plotted some graph, and perform some calculation using related formula, the deceleration behaviour of the car was investigated. For on road testing, the test was assumed as the constant deceleration test for the purpose of analysis. The deceleration rate was calculated using the Equation 2.9 (Thomas, 2006).

Then, the stopping time can directly get from the test data in the storage system. Other than that, the value of stopping time also can be calculated using the formula in Equation 2.12. Thus, all other things being equal, the time to stop is proportional to the velocity, whereas the distance is proportional to the velocity squared (doubling the velocity doubles the time to stop, but quadruples the distance required) (Thomas, 2006).

The energy and power absorbed by the brake system can be substantial during a typical maximum-effort stop. The energy absorbed is the kinetic energy of motion for the vehicle, and is thus dependent on the mass. The energy and power absorbed by the brake system during braking will given by the Equation 2.13 and Equation 2.14. The power absorbed will vary with the speed, being equivalent to the braking force times the speed at any instant of time. Thus, the power dissipation is greatest at the beginning of the stop when the speed is highest. Over the entire stop, the average absorption will be energy divided by the time to stop.

The vibration occur during deceleration can be measured by examining the changes in the suspension system and the center of gravity of the car during the test. In this project, the analysis only used the center of gravity of the car without take any reading of suspension system. The study about the center of gravity will show the pitch, roll and yaw characteristic of the car during deceleration but in this report, only pitch characteristic was analyzed because in deceleration the pitch having high movement.

3.6.2 Off-road Test

The deceleration analysis for off road test was performed to know the stopping time, stopping distance and vibration occur during deceleration. Some graph was plotted to show the pattern, trend and view of the result. The stopping time and stopping distance can directly get from the test data in the storage system. The simple math calculation was performing to get the value

The vibration occur during deceleration can be measured by examining the changes in the suspension system and the center of gravity of the car during the test. In this project, the analysis only used the center of gravity of the car without take any reading of suspension system. The study about the center of gravity will show the pitch, roll and yaw characteristic of the car during deceleration but in this report, only pitch characteristic was analyzed because in deceleration the pitch having high movement.

3.6.3 Comparison between On-road and Off-Road Test

The comparison between on-road and off-road test was done after the analysis of performance for on-road and off-road. In this part, the brake pedal force was be analyzed to investigate and study the behavior of the brake force for both road conditions. The difference between the both tests was discussed.

CHAPTER 4

RESULT AND DISCUSSION

4.1 THE ON-ROAD (PAVED, PLANE, STRAIGHT AND DRY)

4.1.1 Stopping Time

The stopping time value can be getting directly from the real data of the test. It was measured starting from the speed of the car starting to decrease that is when the car starting the deceleration process until the car fully stop, which is the velocity of the car equal to zero. The results for all velocity tests are shows in Table 4.1 below:

Table 4.1: Stopping time

Initial Velocity (km/h)	**Test Number**	**Stopping Time (s)**	
			Average
40	1	7.888	7.949
	2	8.043	
	3	7.684	
	4	8.165	
	5	7.963	
60	1	6.160	6.279
	2	6.310	
	3	5.904	
	4	6.612	
	5	6.408	
90	1	5.092	5.074
	2	4.940	
	3	5.372	
	4	5.242	
	5	4.726	

From the table 4.1, the stopping time for 90km/h initial speed is shortest since the distance was fix all test that is 40m. Since the stopping distance is constant, the stopping time is depending to the initial speed of the car. The graph in Figure 4.1 belows shows the pattern of the stopping time for on road test.

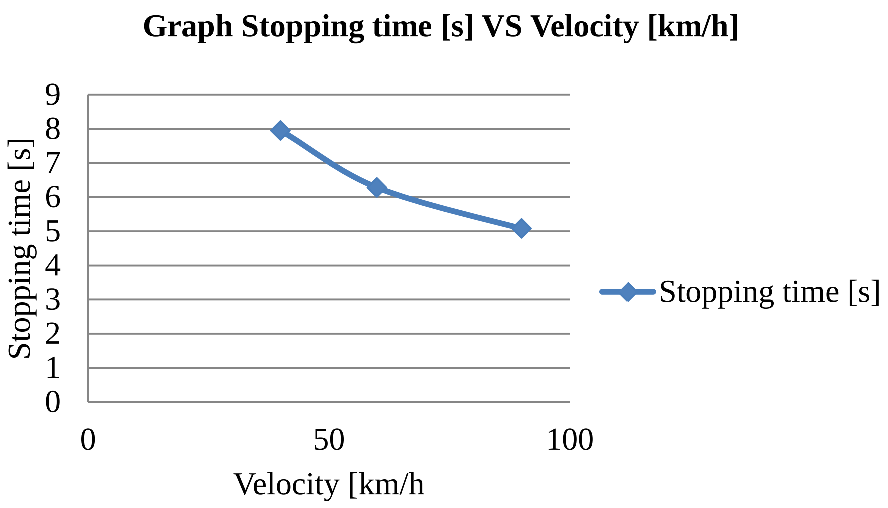

Figure 4.1: Graph Stopping Time VS Velocity for On Road Test

4.1.2 Energy and power absorbed

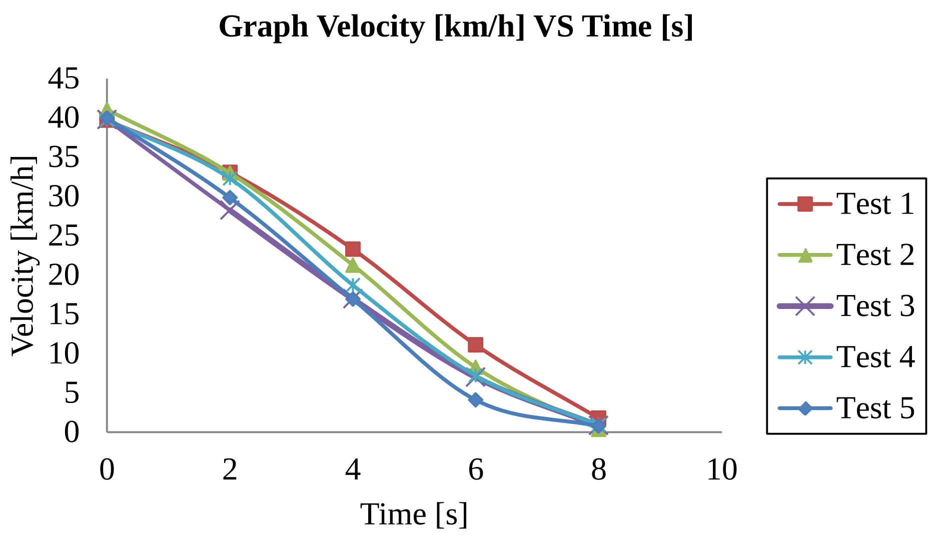

Figure 4.2: Graph Velocity VS Time for 40-0km/hr Deceleration Test

The figure 4.2 above shows the graph for deceleration 40-0km/h for normal road condition. From the velocity versus time graph, by assume that this is the constant deceleration test, the slope or gradient of the graph will be the deceleration of the car based on the Equation 2.9.

The unit of velocity must be converting from km/h to m/s before substitute into the equation. The deceleration values are 1.25 m/s^2, 1.67 m/s^2, 1.39 m/s^2, 1.51 m/s^2, and 1.42 m/s^2 for each of test. The average value for deceleration is **1.45 m/s^2** for test 40 km/h to 0 km/h.

Using the Equation 2.10, the total of all longitudinal deceleration forces on the vehicle can be estimate. Know that the mass of the car is 1430kg. So:

The total of all longitudinal deceleration force on the vehicle are 1789.86N, 2400.54N, 1992.36N, 2160.20N, 2038.88N and the average value is **2076.37N**.

The energy absorbed is the kinetic energy of motion for the vehicle, and thus dependent on the mass of the vehicle. The energy and power absorbed by the brake system during a typical maximum-effort stop or deceleration can be determined by the Equation 2.13.

The energy absorbed by the brake system during maximum-effort stop for deceleration 40km/h to 0km/h are 89.51 kJ, 95.56 kJ, 90.01kJ, 90.63kJ, and 95.68 kJ. The average value is **92.28 kJ**.

The power absorbed will vary with the speed, being equivalent to the braking force times the speed at any instant of time. Thus, the greatest of power dissipation are at the beginning of the deceleration when the speed is higher. Over the entire stop, the average power absorption will be the energy divided by the time to stop like Equation 2.14.

The powers absorbed for the deceleration from 40km/h to 0km/h are 10.08 kJ/s, 14.58 kJ/s, 11.19 kJ/s, 12.42 kJ/s, and 12.00 kJ/s for each test. The average value is **12.05 kJ/s**.

The result for deceleration 60-0km/h and 90-0km/h show in the figure 4.3 and 4.4 below:

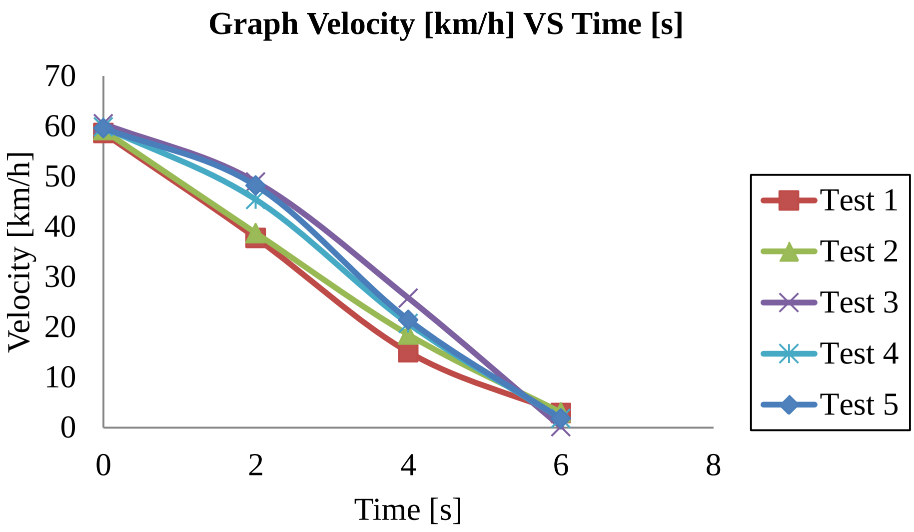

Figure 4.3: Graph Velocity VS Time for 60-0km/h Deceleration Test

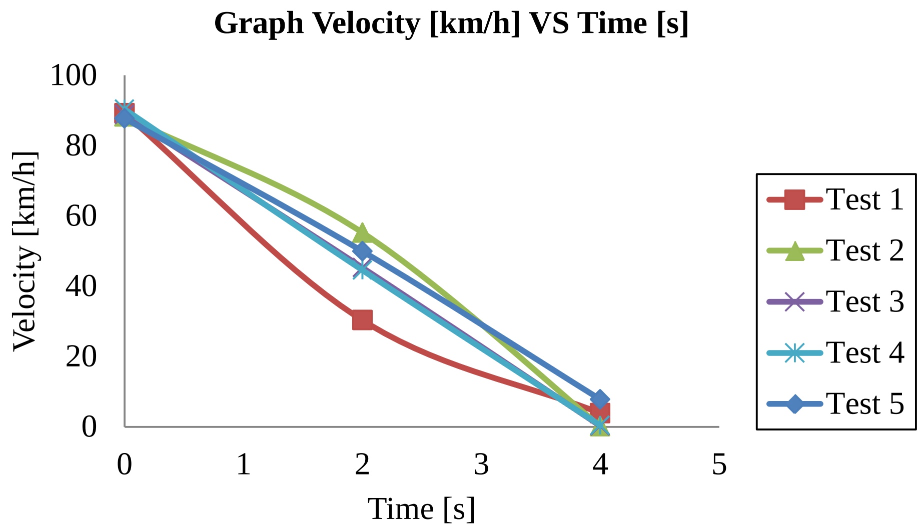

Figure 4.4: Graph Velocity VS Time for 90-0km/h Deceleration Test

All the calculations above are performed for deceleration 60-0km/h and 90-0km/h to determine the difference between each deceleration types and the result show in the Table 4.2 below. The Table 4.2 shows that the greater initial velocity will have the greater deceleration values because the stopping distance was setup at 40m for all tests. Then, the total longitudinal force, energy and power absorbed by the brake system also higher for the bigger initial velocity.

Table 4.2: Deceleration data (on road)

Road	Deceleration type	Test no.	Deceleration (m/s^2)		Total longitudinal force, F_{xt} (N)		Energy absorbed by the brake system (kJ)		Power absorbed by the brake system (kJ/s)	
				Average		**Average**		**Average**		**Average**
On road (Paved, dry, plane and straight)	40-0 km/h	1	1.25165	1.452006	1789.8595	2076.36858	89.51246	92.279256	10.07796	12.05465
		2	1.67870		2400.541		95.55878		14.58467	
		3	1.39326		1992.3618		90.01057		11.19256	
		4	1.51063		2160.2009		90.63223		12.41878	
		5	1.42579		2038.8797		95.68224		11.99928	
	60-0 km/h	1	2.23801	2.507012	3200.3543	3585.02716	207.81963	204.425068	27.33030	30.364444
		2	2.54100		3633.6300		211.72532		31.33886	
		3	2.67629		3827.0947		202.70899		32.28878	
		4	2.72959		3903.3137		201.71989		32.82133	
		5	2.35017		3360.7431		198.15151		28.04295	
	90-0 km/h	1	4.57794	4.935854	6546.4542	7058.27122	453.03647	452.59274	88.97024	90.155814
		2	5.59850		8005.8550		453.59244		100.84314	
		3	4.55243		6509.9749		451.92607		81.90034	
		4	4.93750		7060.6250		453.40691		88.97310	
		5	5.01290		7168.4470		451.00181		90.09225	

From the graph above, the follow graphs (Figure 4.5 until Figure 4.8) was plotted to show the trend and pattern of the deceleration, energy absorb and also the power absorb by the brake system base on the initial speed of the car. The trend for all graphs is same where the graph shows increasing pattern with increasing of initial velocity. That means, the car move with the high speed will have higher deceleration, energy absorb and power absorb by brake system. This is because of the momentum and inertia principle that when the car moves, there have some forces that protect it motion from changing call inertia force. Higher speed of car will have bigger inertia force and momentum.

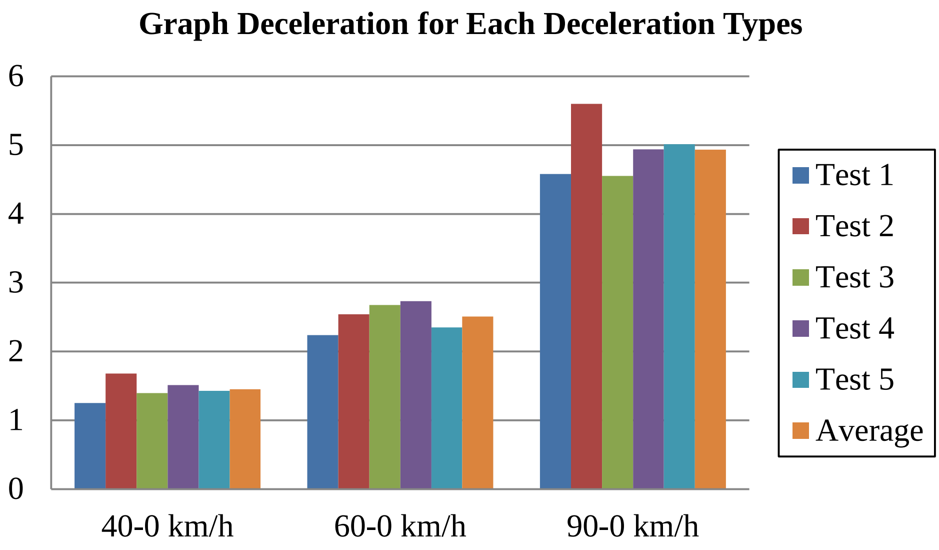

Figure 4.5: Graph Deceleration for Each Deceleration Types

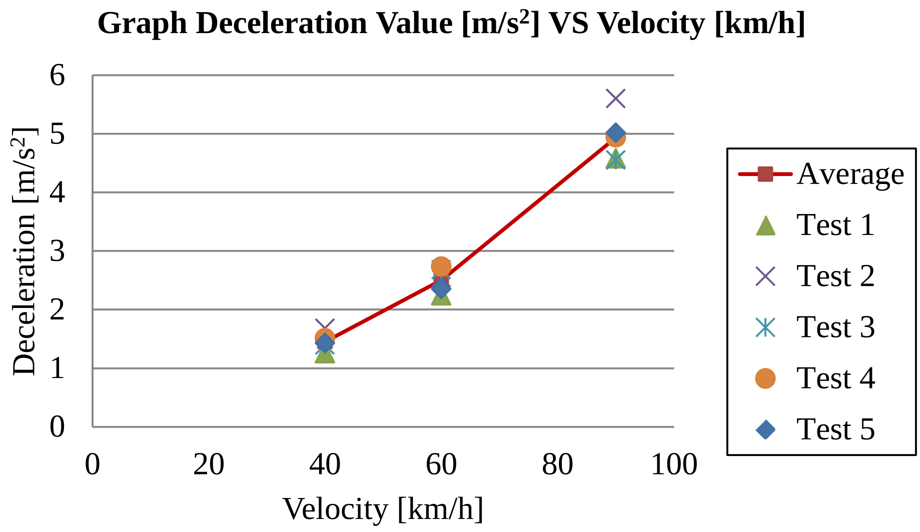

Figure 4.6: Graph Deceleration Value VS Velocity

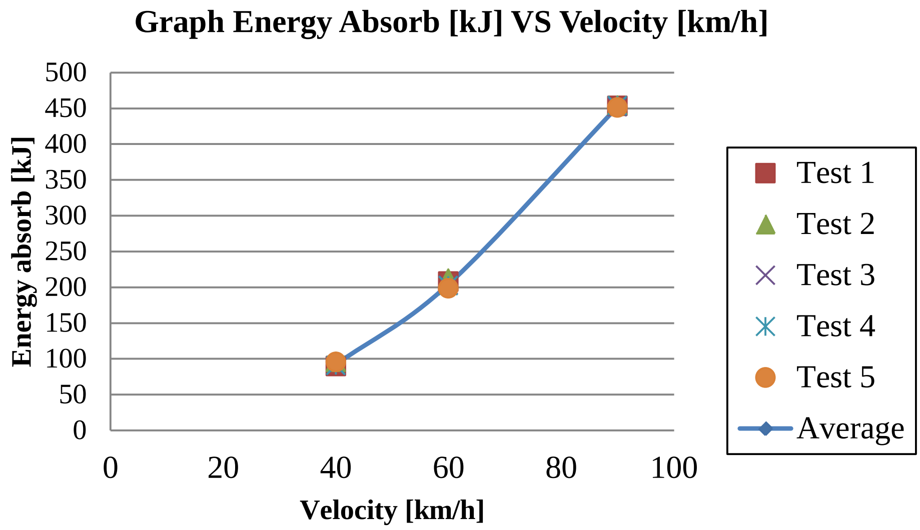

Figure 4.7: Graph Energy Absorb VS Velocity

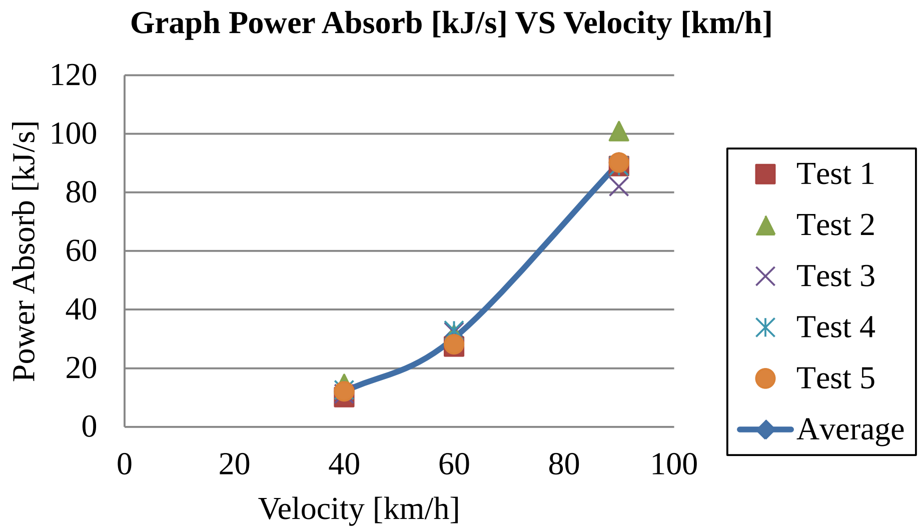

Figure 4.8: Graph Power Absorb VS Velocity

4.1.3 Brake Pedal Force

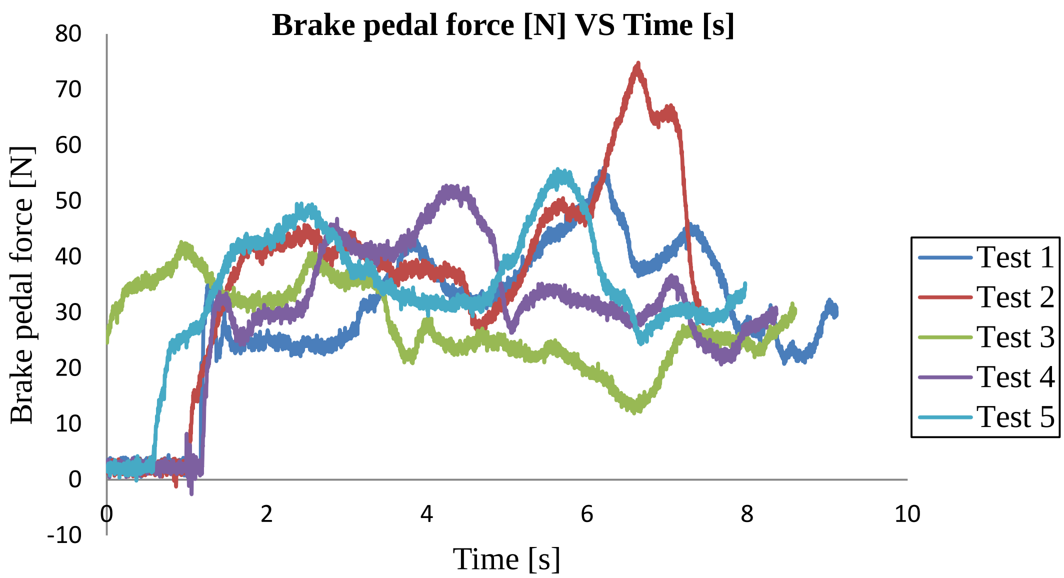

Figure 4.9: Graph Brake Pedal Force VS Time for 40-0km/h Deceleration Test

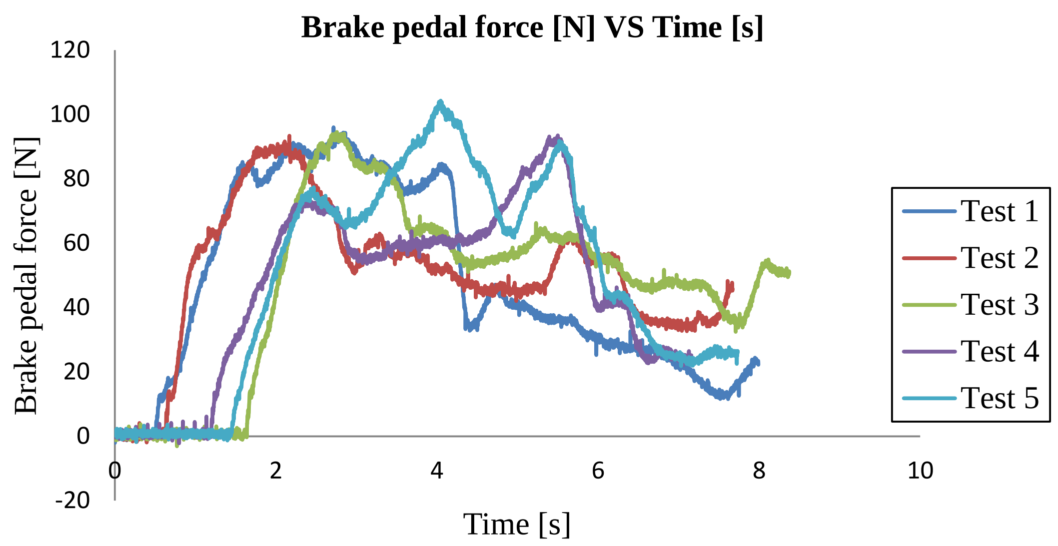

Figure 4.10: Graph Brake Pedal Force VS Time for 60-0km/h Deceleration Test

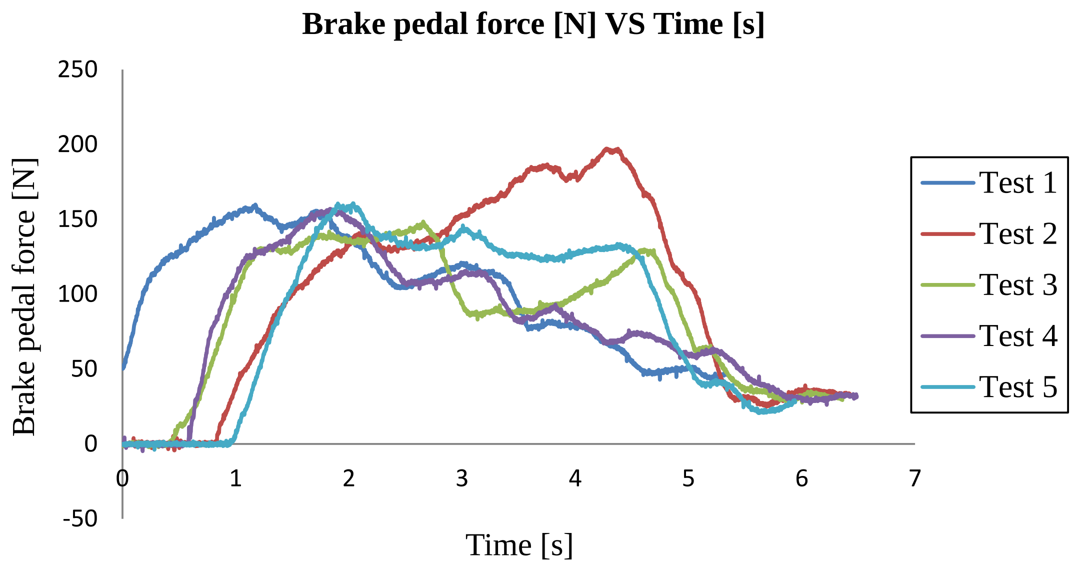

Figure 4.11: Graph Brake Pedal Force VS Time for 90-0km/h Deceleration Test

Figure 4.9, 4.10 and 4.11 show the force exerted on the brake pedal for the deceleration 40-0km/h, 60-0km/h and 90-0km/h. After take the average graph and ignore the unequal graphs, all three graphs show the same pattern that is lower force at the first and increase until the end of the graph. This indicates that the force exerted on the brake pedal is highest at the beginning of deceleration and decreased in parallel with the reduction of vehicle speed.

From the first graph (Figure 4.9), the value of force exert to the brake pedal is around 40-50N that is for deceleration 40-0km/h. The second graph (Figure 4.10) shows deceleration 60-0km/h and the value of force exert to the brake pedal is around 80-100N at the beginning of the deceleration. The third graph (Figure 4.11) show the higher value for force exert to the brake pedal that is around 140-160N for the beginning of the deceleration 90-0km/h. This shows that a car moving at high speed requires more force to reduce its speed compare to the car that moving with a low-speed. The graph also show the force is around 20 to 40N at the end of deceleration for the all tests. It is mean that the car needs around 20 to 40N force minimum exert on the brake pedal to make the car stop.

For clearly show the result of brake pedal force, all three graph was converted to brake pedal force against distance graph by taking the most suitable graph like in Figure 4.12 below. The area under the graph will represent the total energy absorb by the brake system. The highest graph will have highest amount of energy absorb.

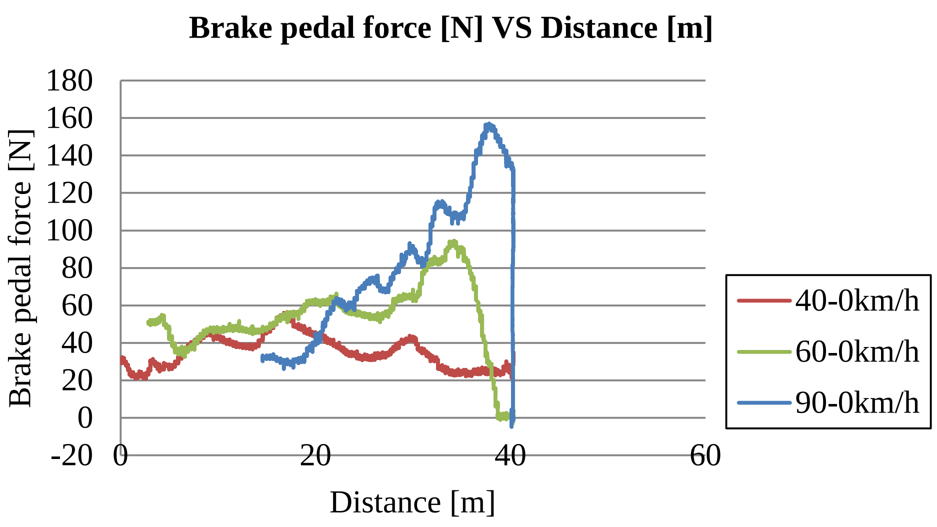

Figure 4.12: Graph Brake Pedal Force VS Distance for difference velocity

4.1.4 Effect deceleration to the car body

The reactions of the deceleration on the car body can be seen by examining the changes in the suspension system and the center of gravity of the car during the test. The suspension effect or profile will determine the characteristic of the vibration that facing by the car during deceleration. The study about the center of gravity will show the pitch, roll and yaw characteristic of the car during deceleration. In this report, the result shows only the pitch characteristic because during braking, the bigger impact occurs only to the pitch compares to roll and yaw (Dr. Georg Rill, 2009). The figures below show the pitch angular velocity for all deceleration tests.

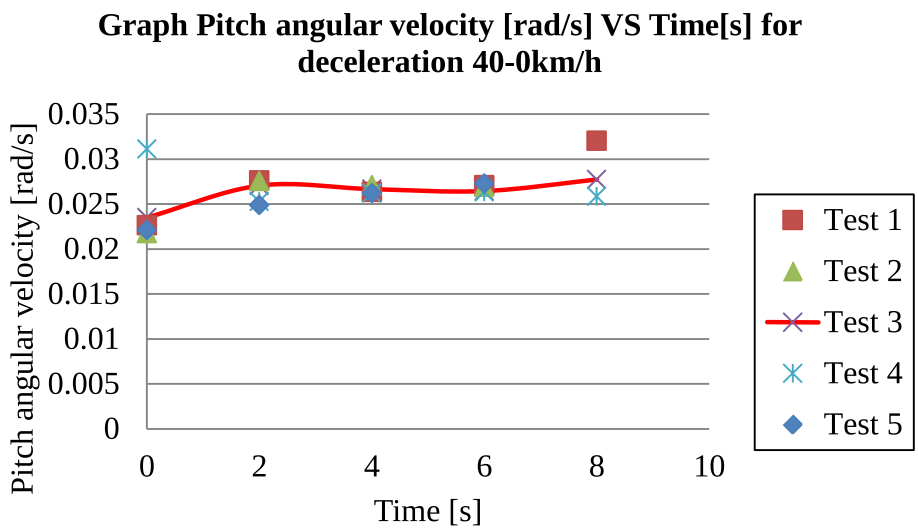

Figure 4.13: Graph Pitch angular velocity VS Time for deceleration 40-0km/h

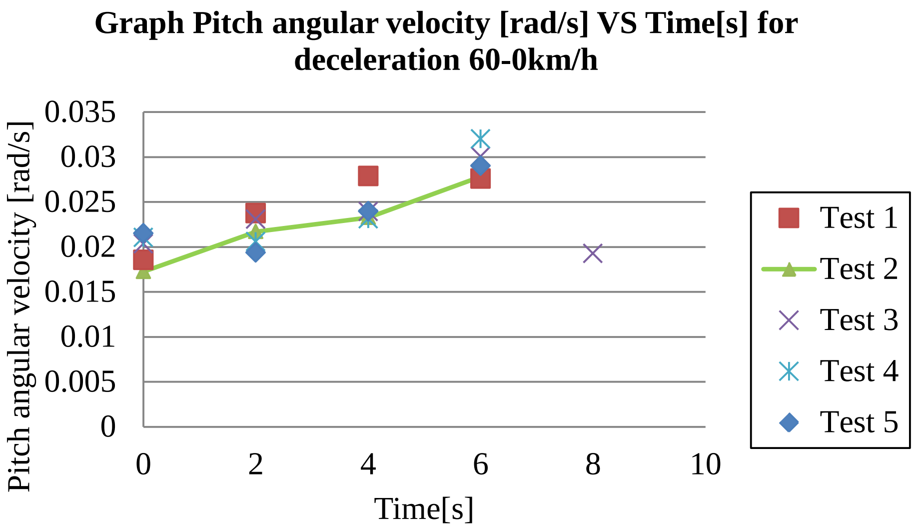

Figure 4.14: Graph Pitch angular velocity VS Time for deceleration 60-0km/h

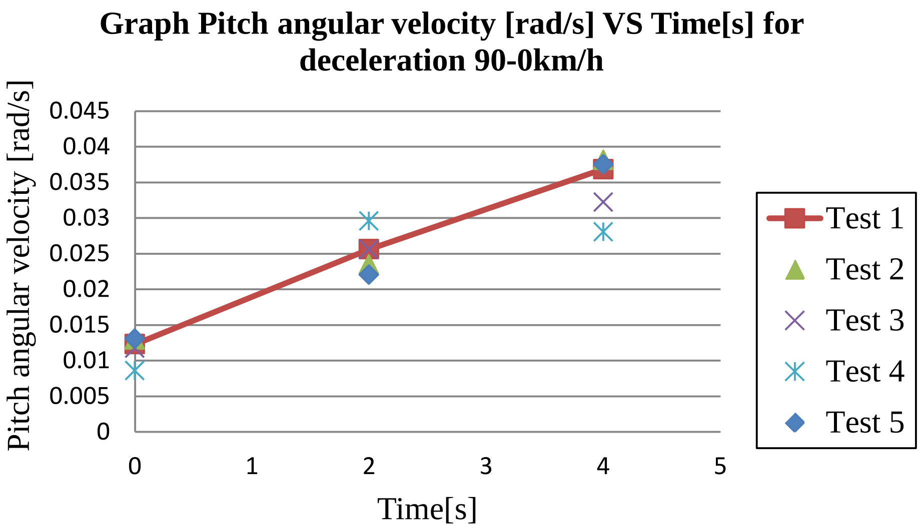

Figure 4.15: Graph Pitch angular velocity VS Time for deceleration 90-0km/h

From the above Figure 4.13, 4.14 and 4.15, the graphs show the increasing pattern with increase of time and reducing of the car speed. It means, during braking the angular speed of pitch angle of the car with increase until the car stop. The car facing the vibration with high frequency when the car having the reducing of speed. During braking, the car mass transfer to the front and the car in the dive position.

4.2 THE OFF-ROAD (SANDY, STRAIGHT, HOLES AND IRREGULAR SURFACE)

4.2.1 Stopping Time and Braking Distance

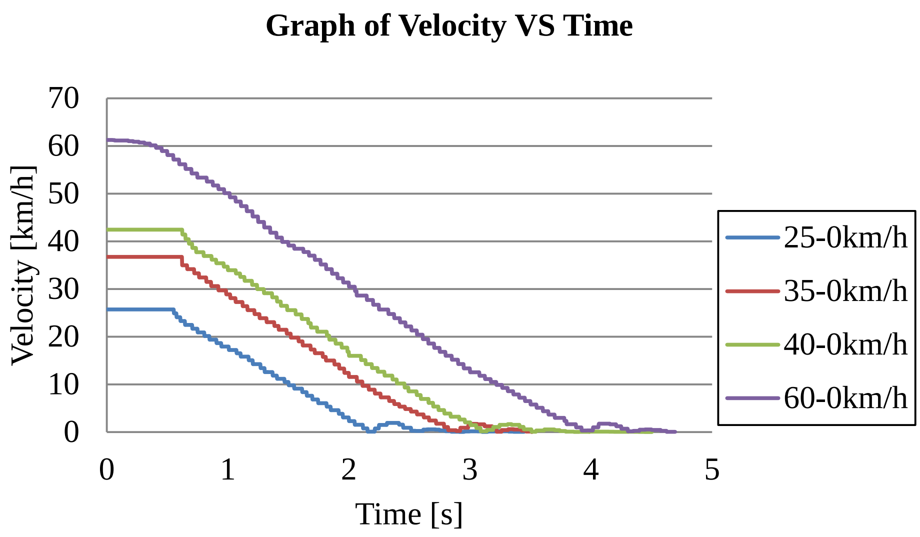

Figure 4.16: Velocity VS Time for Various Initial Speed Deceleration Tests

The above graph (Figure 4.16) shows the graph velocity against time for deceleration 25-0km/h, 35-0km/h, 40-0km/h, and 60-0km/h for sandy road. The graph shows that decreasing in speed was not uniform due to the uneven road surface, perforated, and the lack of friction between tire and road. At the end of deceleration, vehicle speed suddenly increased due to the slippage between tire and road surface. From the graph, the time to stop the car for deceleration 25-0km/h is 2.590s and the braking distance for the test based on the GPS sensor is as far as 5.81232 meters. The value of stopping time and braking distance for the other test shows in the table 4.3 below.

Table 4.3: Deceleration Data (off road)

ROAD	DECELERATION TYPE	STOPPING TIME, (s)	BRAKING DISTANCE, (m)
Unpaved sandy road (hole and irregular surface)	25-0 km/h	2.892	5.81232
	35-0 km/h	3.112	11.11315
	40-0 km/h	3.852	13.76486
	60-0 km/h	4.336	29.37860

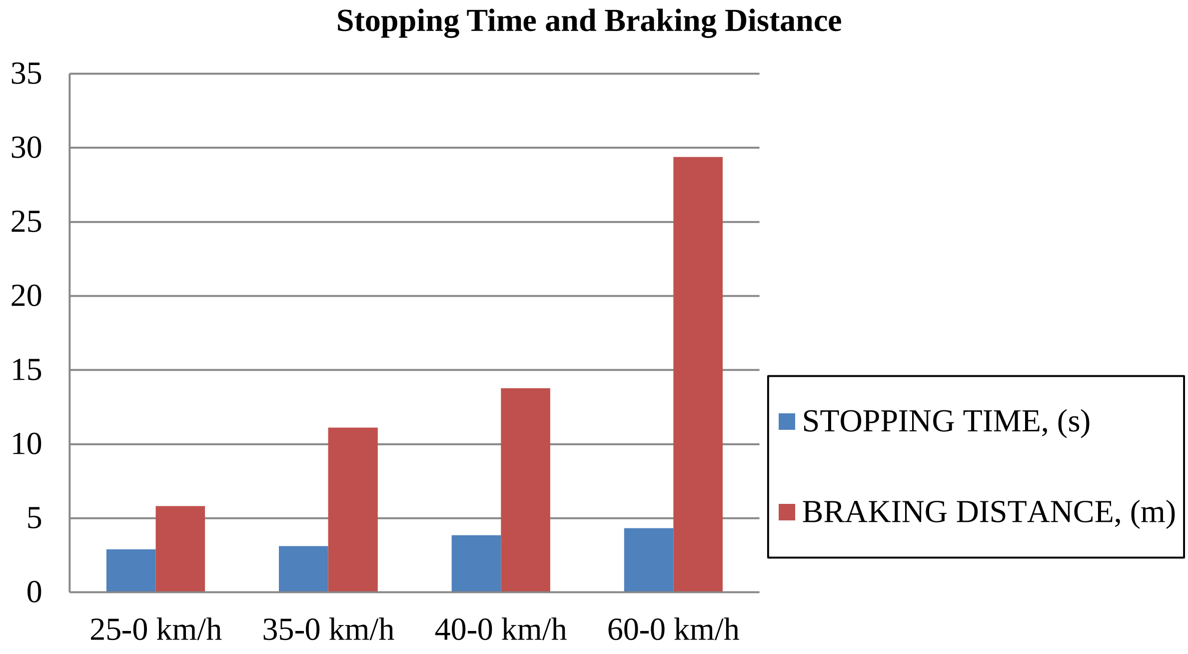

Figure 4.17: Stopping Time and Braking Distance for Various Types of Deceleration Tests

Based on Table 4.17 above, the moving car with the high speeds required longer stopping time and also braking distance. It is because of the inertia principle and momentum of the car. The car moving with high speed will have greater value of inertia and also its momentum.

4.2.2 Brake Pedal Force

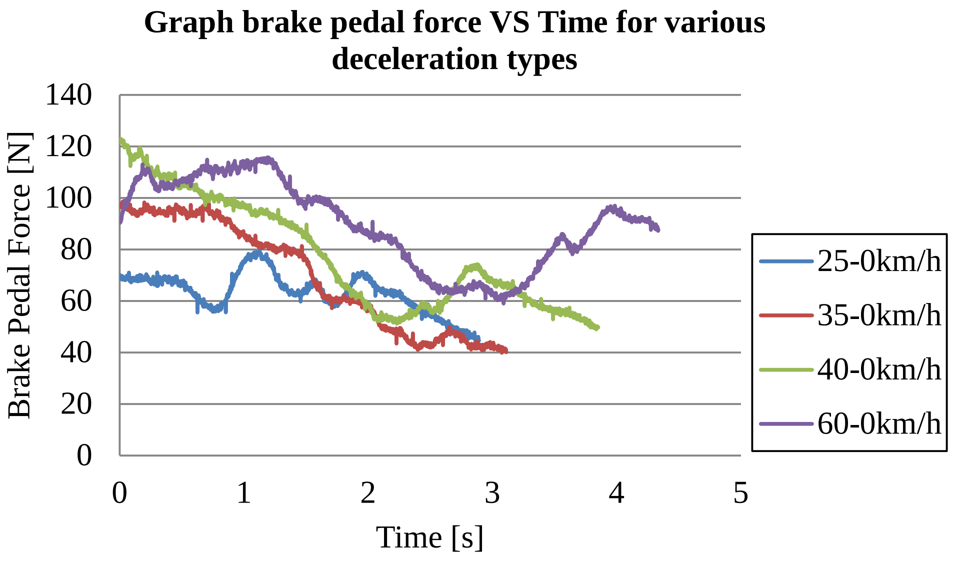

Figure 4.18: Brake Pedal Force VS Time for Various Types of Deceleration Test

The above Figure 4.18 shows the brake pedal force vs. time graph for various speed of deceleration test. The pattern of all the graphs looks similar but has a few that out of the shape. It is because of the road condition and the unequal force that apply to the brake pedal. It is difficult to give the constant force to the brake pedal. The minimum value of brake pedal force to stop the car on the sandy road is around 40N.

The graph in Figure 4.18 was converting to brake pedal force against distance graph to clearly show the effect of brake pedal force to the energy absorb. It will show in Figure 4.19 below.

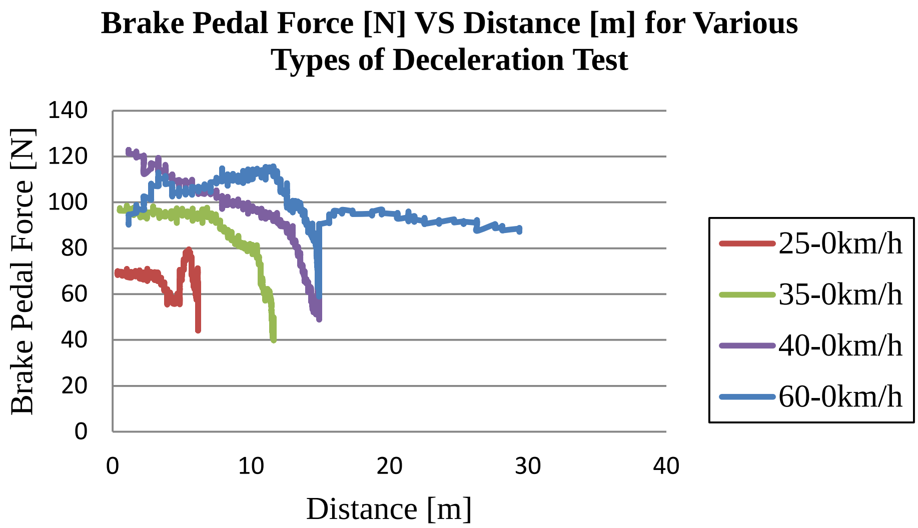

Figure 4.19: Brake Pedal Force VS Distance for Off Road Deceleration Test

4.2.3 Effect deceleration to the car body

The reactions of the deceleration on the car body can be seen by examining the changes in the suspension system and position center of gravity of the car during the test. The suspension effect or profile will determine the characteristic of the vibration that facing by the car during deceleration. The study about the center of gravity will show the pitch, roll and yaw characteristic of the car during deceleration. In this report, only the pitch characteristic was analyzed since it facing the bigger impact during deceleration. The Figures 4.20 below shows the pitch angular velocity for all deceleration tests.

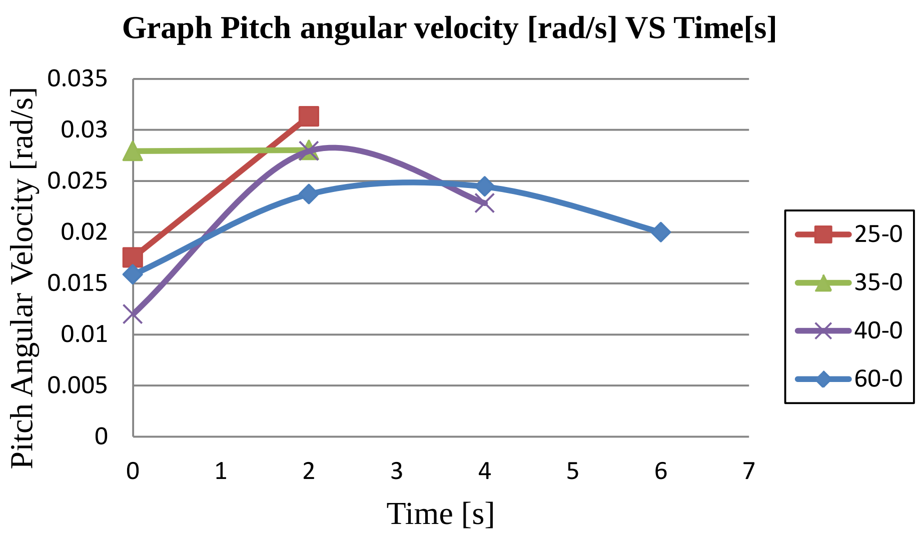

Figure 4.20: Graph Pitch angular velocity VS Time for differences initial velocity

The graph in Figure 4.19 above shows that the angular pitch velocity is increase during the braking time. At the end of braking, the car faced high frequency of vibration because of road surface. During braking, the car is in dive position which is the mass was transfer to the front of the car. The graph show the stopping time will affect the pitch angular velocity of the car during braking. Shot time of braking will increase the value of pitch angular velocity. It means high vibration is occurring if the car decelerates in the short time.

4.3 COMPARISON BETWEEN THE ON-ROAD AND OFF-ROAD DECELERATION TEST

In this part, the brake pedal force was be analyzed to investigate and study the behavior of the brake force for both road conditions. The difference between the both tests was discussed and some graph of brake pedal force was plotted. The graphs were show in Figure 4.21 and 4.22 like below:

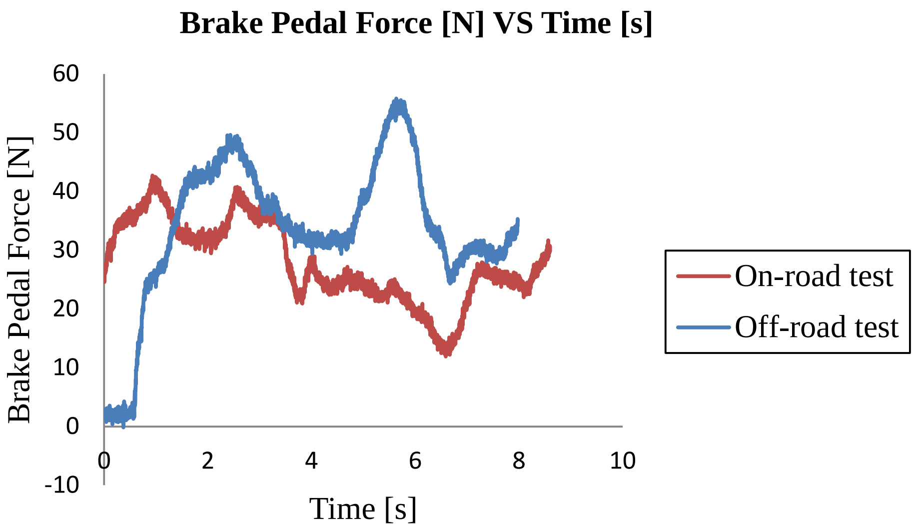

Figure 4.21: Graph Brake Pedal Force VS Time for on-road and off-road, 40-0km/h deceleration test

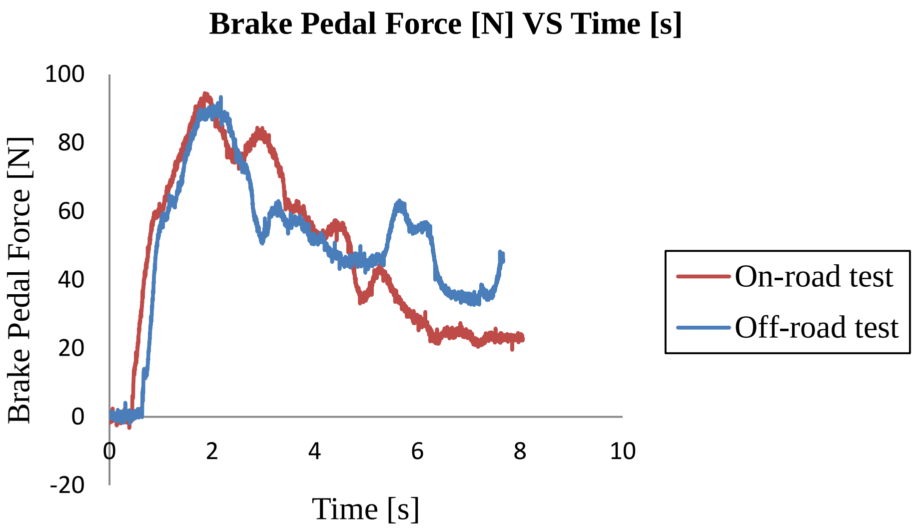

Figure 4.22: Graph Brake Pedal Force VS Time for on-road and off-road, 60-0km/h deceleration test

From the Figure 4.21 above, the graph is brake pedal force against time for deceleration 40-0 km/h test. The on-road test have less brake pedal force compare to the off-road test. The data for off-road test have more variation compare to the on-road test. It is because the surface of off-road condition produced more vibration and disturbs the driver during pressed the brake pedal. Other than that, the car required greater brake pedal force to slowdown on the off-road condition compare to on-road.

For the deceleration 60-0km/h, the graph showed in Figure 4.22. The graph was nearly the same at the beginning of the deceleration that is around 80-100N. As same with the 40-0km/h, graph for off-road test have more variation compare to the on road. At the end of deceleration, the graph for off-road test shows the increment. It is because the car need the greater force to stop on the off road effect of less friction between the road and the tire.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

In this thesis, the amount of energy and power absorb has been analyzed for on road straight line braking. Experimental data had been collected and post-processed using Flexpro 7 and Microsoft Office Excel 2010.

Deceleration is higher for a car moving at high speeds and braking in a short time. The brake system should absorb about 452.59274 kJ of energy to stop a moving car with a speed of 90km/h in a distance of approximately 40m compare to only 92.279256 kJ for the initial speed of 40km/h. The constant braking distance will cause the moving car with high speed have shorter braking time compare to the car moving with low speed.

The force exerted on the brake pedal is will affect the energy absorb by the brake system. For the off-road, the brakes need a greater force to stop the car compare to the on-road. The car needs minimum 40 N to stop the car on the off-road compare to 20 to 30N for the on-road. The off-road condition will give more variation of brake pedal force compare to the on-road.

The shortest stopping time of car produced bigger or more vibration compares to the longer stopping time. At the beginning of the deceleration and at the end of braking process, the car facing more vibration because the driver applies the force to reduces the speed of the car and the car needs bigger force to make the car stop.

5.2 RECOMMENDATION

For future work will concentrate on increasing the amount of collected data and refining data processing to establish more definitive statistical information regarding the effectiveness and sensitivity of the measurement system. It is also suggested that the experimental test should be more specific to certain study. All parameters that related to the test must take into consideration so that the data obtained is accurate.

Besides that, in this study a few factors of deceleration performance not consider because of the some reason and constrains. So, for the further work strongly recommended that this research can be extent with consider the drag coefficient and the slope of the road. Other than that, recommended that the test will consider other road behavior like cornering, junction, bumping and others.

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APPENDIX A

GANTT CHART

SEMESTER 6: Final Year Project 1

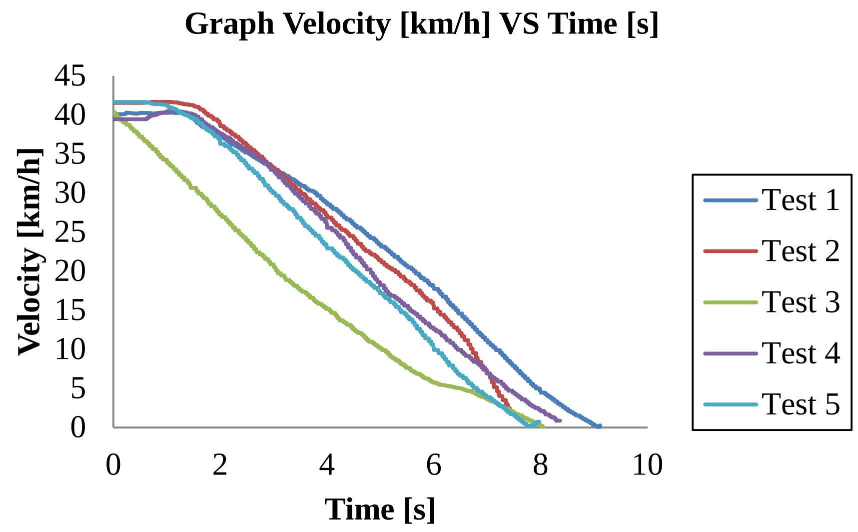
PROJECT ACTIVITIES	WEEK														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Literature review	■	■													
Deceleration theory & related formula		■	■												
Braking theory study			■	■											
GPS & brake force sensor study				■	■										
Test car system general setup						■	■	■							
GPS installation procedure								■	■	■					
Brake force sensor installation procedure										■	■				
Data acquisition system installation procedure											■	■	■		
Design of experiment														■	
Road condition evaluation														■	
Driving mode factor														■	
Velocity range selection														■	
Report preparation												■	■	■	■
Final Year Project 1 presentation															■

SEMESTER 7: Final Year Project 2.

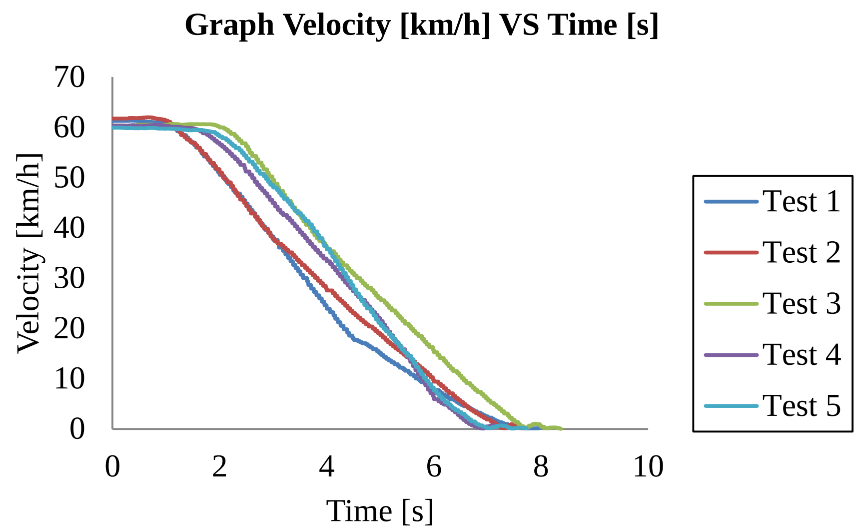
PROJECT ACTIVITIES	WEEK														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Installation & experiment setup	■	■													
GPS installation			■	■											
Brake force sensor installation			■	■											
Data acquisition system installation			■	■											
Data collection					■	■									
Data selection							■	■	■	■					
Analysis on deceleration performance											■	■	■		
Brake force calculation												■	■		
Energy losses estimation													■	■	
Final report preparation												■	■	■	■
Final Year Project 2 presentation															■

APPENDIX B

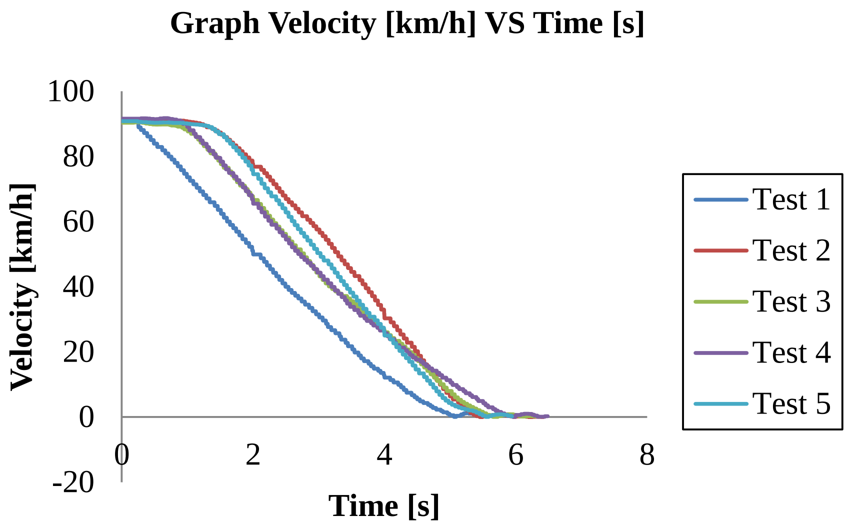
RAW DATA (GRAPH)



Graph Velocity VS Time for 40-0km/hr Deceleration Test.



Graph Velocity VS Time for 60-0km/h Deceleration Test.



Graph Velocity VS Time for 90-0km/h Deceleration Test.

APPENDIX C

TESTING PICTURES