# INVESTIGATION ON THE IMPACTS OF HARNESSING TRAFFIC ENERGY ON SPEED BREAKERS

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**A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons.) of Electrical and Electronic Engineering**

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# DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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# APPROVAL FOR SUBMISSION

I certify that this project report entitled **"INVESTIGATION ON THE IMPACTS OF HARNESSING TRAFFIC ENERGY ON SPEED BREAKERS"** was prepared by **GOH JIN LONG** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons.) of Electrical and Electronic Engineering at Universiti Tunku Abdul Rahman.

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Signature : _________________________

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Date : _________________________

This project is especially dedicated to
my beloved mother Tan Moon Ting, and my father Goh Chee Seng,
for their love and support.

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# INVESTIGATION ON THE IMPACTS OF HARNESSING TRAFFIC ENERGY ON SPEED BREAKERS

## ABSTRACT

All of speed breakers under the road are traffic energy harvesters in the form of compression from force of moving vehicles. Investigation on the impacts of traffic energy harvester needed to be concerned about the implementation of smart speed breakers under the road brings the convenience to the user. The purpose of the speed humps is reducing the speed of the vehicles. However, other than the conventional speed hump, the modelling of smart speed breakers such as rack and pinion mechanism speed breaker, hydraulic speed breaker, roller mechanism based speed breaker as well as combination of rack and pinion mechanism with hydraulic speed breaker have obtained throughout this research by method of finite element analysis (FEA) in Solidworks. The traffic energy obtained from those smart speed breakers is not as famous as the other renewable energy like solar and wind system. Apart from that, susceptive stress, displacement and vibration of the internal components of smart speed breaker reduce the performance of the devices due to the faulty components held within the systems. It requires verification from the review of possible impacts during the harnessing of traffic energy from speed breakers. The modelling of conventional and smart speed breakers performed by analysing the durability of the surface for both smart and conventional speed breakers. There is also comparison about the impacts between conventional and smart speed breakers with different type of vehicles in this project. In conclusion, the durability of smart speed breakers are lower than the conventional speed breaker.

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# LIST OF SYMBOLS / ABBREVIATIONS

| | |
|---|---|
| *dB* | decibel |
| $F$ | applying force from vehicle, N |
| $k$ | compression spring constant, N/m |
| $\delta$ | deflection of the coil, m |
| $G$ | modulus of rigidity of spring material, N/m$^2$ |
| $d$ | diameter of wire coil, m |
| $R$ | mean radius of spring, m |
| $\tau$ | shear stress, N/m$^2$ |
| $A$ | cross-sectional area of material with area perpendicular to applied force vector, m$^2$ |
| $v$ | linear velocity, m/s |
| $r$ | radius of roller, m |
| $\omega$ | angular velocity, rad/s |
| $f$ | frequency, Hz |

| | |
|---|---|
| DC | Direct Current |
| FEA | Finite Element Analysis |
| ITE | Institute of Transportation Engineers |
| DOE | Department of Environment |
| ASTM | American Society for Testing and Materials |
| DIN | German Institute for Standardization |
| AISI | American Iron and Steel Institute |
| URES | Displacement Resultant |
| AMPRES | Amplitude Resultant |

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# CHAPTER 1

# INTRODUCTION

## 1.1 Background

The concept of energy harvester under the road is the new technology implemented to recapture energy in the form of vibration and compression under the moving vehicles' tyres. There is tremendous amount of wasted energy by road when vehicles passed through it. The vehicular growth is increasing dramatically year by year. The manufacturing of the intelligent speed breaker can channelize the wasted energy from vehicles and road to some useful work.

Among all of the energy related human activities, the most expensive energy is characterized by great waste of the fuel potential which is used by the vehicles and the rest of it is dissipated in decelerating phases from the vehicles. Energy harvesting of speed breaker may capture the renewable energy by referring to the capturing and storage or direct use of ambient energy for human purposes. The overall efficiency of the speed breaker will increase if there is harvested waste energy within the system. Green and efficient energy generation brought the obstacle to the transport, urban and industrial sectors as well as the intelligent devices like the speed breaker. The situation of electricity can be improved by the new innovative of the speed breaker. As usual, electricity is the form of energy that can be act as a flow of electrical power.

In 1800, the first generation of electricity generator is Faradays dynamo. Until today, the basic principles of electricity generation are remaining unchanged and there is the new generation of speed breaker generator undergoing the research. There has been wide attention in designing and developing the renewable energy conversion systems for the self-contained power generation capability.

## 1.2 Problem Statement

Nowadays, the number of accident is getting higher and higher which is necessary solved by right solution. The idea of implementing the typical speed hump and the intelligent of speed breaker helps to reduce the risk of usage on the road. Although the installation of speed hump and the smart speed breaker is forcing the user to slow down the vehicle speed within certain distance, the vehicles to the smart speed breaker as well as speed hump caused some possible impacts to the environment. There are many impacts have been discussed in Chapter 2.

In Malaysia, there are many types of power plant have co-operated with Tenaga Nasional Berhad in order to supply the significant electricity for the whole country. The cost to generate electricity is high due to the high price of the resources that needed to power up the turbine. In term of economy, cheaper resources to reduce the usage of the expensive resources can replace it.

Due to the large consumption of electricity within the country, there is necessary to implement an alternative solution especially for the small electricity that can generate electricity power. The extent of the knowledge, there are no studies about the disadvantages of the speed breaker. This is because most of researches are more concentrated in harnessing traffic energy from speed breaker. This leads to more and more impacts rose due to the continuous development of intelligent speed breaker. Therefore, the intelligent of speed breaker in this research is compare the impacts among the conventional speed humps to improve the electricity generation. The finding of this study is able to provide important information for the developers in stabilizing and forecasting the performance on both conventional and intelligent speed breakers.

## 1.3 Aim and Objectives

The main aim of this study is to investigate the impact of harnessing traffic energy on speed breaker. It can be the useful information for the researches to make the energy harvester powered up without making the harmful effect to the living environment. The testing and evaluation of the effectiveness for this system is to determine the impact from the speed breaker and solve the faced challenges within the system.

Several specific scopes identified in this study and has stated as follow:

(i) To perform the modelling of speed breakers for intelligent and conventional using Solidworks.

(ii) To apply the Finite Element Analysis (FEA) to the internal components of intelligent speed breakers and surface for both conventional and intelligent speed breakers.

(iii) To investigate the helical spring’s stress analysis under ideal loading of moving vehicle.

(iv) To evaluate displacement analysis to the piston of hydraulic speed breaker in order to discover the effect of deflection.

(v) To examine the vibration analysis of chain sprocket within roller mechanism based speed breaker that related to natural frequency.

(vi) To find out the maximum load on the surface of both conventional and intelligent speed breakers before the crack happens to it throughout bucking analysis.

(vii) To compare and analyse the result between conventional and intelligent speed breakers with different vehicles.

## 1.4 Chapter Outline

Chapter 1 introduces the background study for the energy harvester used by renewable energy for electricity generation, follow by the discussion of the problems statement, aim and objectives and lastly the chapter outline of this study.

Chapter 2 consists of the brief review of impacts to the typical speed humps and the impacts on a few concepts of intelligent speed breakers. The critical points of literature review have conducted within this study.

Chapter 3 presents the methodology used in this project by evaluating the fatigue level of the spring contributed within rack and pinion mechanism speed breaker and the displacement analysis of the piston within hydraulic air compressor based speed breaker. The vibration analysis of roller mechanism based speed breaker as well as the shear stress analysis on the surface of both conventional and intelligent speed breakers also examined throughout this study. Both of them are the significant impacts to the speed breaker. Finite Element Analysis (FEA) is to evaluate the impacts on both type of speed breakers within this chapter.

Chapter 4 demonstrates the results and discussion by assigning the materials to the components of the speed breaker. All of the simulated results from Solidworks have conducted to do the comparison in between the car and motorcycle. This is because the force applied by car is different from motorcycle. The impacts brought by car and motorcycle in some situation is different but there is also the similarity in different types of vehicle. The comparison between conventional speed breaker and intelligent speed breaker also carried out in this chapter.

Chapter 5 conducts the conclusion for the overall studies on the impacts of speed breakers. The contributions mention about the proper way of choosing software with the aid of FEA method to obtain the accurate results using the right techniques and parameters. The recommendations also provided to improve the performance of speed breakers for future references.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

A number of journals have reviewed regarding this topic. This study shows that harnessing of traffic energy on speed breakers have become the favourites for the researchers to target the impacts on such generating system, which can convert the force exerted by moving vehicles on the road surface into usable electrical energy.

The number of vehicles transverse over the speed breaker on the roads is getting larger and larger. There is some dissipation of heat and friction generated large amount of wasted energy to the normal speed breaker. The tapping energy by making speed breaker to be a power generator unit is an indication of the growth of a nation. Hence, the information about the normal speed hump and the intelligent speed breakers is explained in this chapter.

## 2.2 Road with Typical Speed Hump

The formation of speed hump is a vertical speed control for the users to reduce the vehicle's speed, as they need to traverse the hump comfortably. The aim of designing speed humps is to create rocking motion for the users to feel discomfort when the vehicle crossing speed is high. Figure 2.1 shows the typical speed humps for vehicles to move over the obstacle on the road.

**Figure 2.1: Typical Speed Hump**

In the country like Unite States, the design of speed humps is developed by following the standard guidelines (ITE Traffic Engineering Council, 1997). The construction materials to design a speed hump are necessary to take into consideration by determining the placement and spacing of the hump. The effectiveness of speed humps in reducing vehicle speeds caused the reduction speed of emergency response vehicles (Montgomery County, 2001). The speed humps in living environment of residential area shows the traffic noise is concerned to be the effect of speed humps (Botteldooren et al., 2011). The construction materials, spacing and placement, emergency response as well as the traffic noise are needed to be considered and they are discussed in more details.

### 2.2.1 Construction Materials

Speed humps are usually made by concrete or asphalt as well as recycled rubber. Speed humps classified into two types such as permanent speed hump and temporary speed hump. Temporary speed humps that made by recycled rubber were the representative impact for the permanent speed humps due to there is only 0.75-inch lip on the temporary speed humps. When there is heavy rainfall to the temporary speed hump, the rubber mats caused the additional lifting and curling at the edges of surface. There is distortion of speed hump in shape as it is caused by the movement of vehicle and the variation of temperature (Templeton and Res, 2001; Tebinka, 2001).

### 2.2.2 Placement and Spacing

Speed humps are normally located throughout the surface of the road especially they are placed on the local of residential areas by following the general guidelines (ITE Traffic Engineering Council, 1997).

Speed hump is necessary to be placed in suitable location in order to prevent vehicles face to it unexpectedly during the high velocity. The sight distance has to be issued out during nighttime.

There is the greatest impact on the effectiveness for speed bump such as the spacing of the slow points. It is necessary to determine the maximum acceptable operating speed of all vehicles. If the spacing of the speed humps is short, it will waste the resources and cause the unnecessary nuisance to the users.

### 2.2.3 Traffic Noise

Speed humps will affect the living environment like the increasing of traffic noise between the tyre and road interactions, which are the major issue for residential life quality (Archer et al. 2008). The noise is generated from the braking of moving vehicles when moving toward to the speed hump and moving away from it in high acceleration. Department of Environment (DOE) from Malaysia mentioned that daytime and night time noise levels in residential areas are higher than the permissible limits (Rosli and Kadar Hamsa. 2013). The existing noise levels of 69-79 dB are comparing to the daytime's permissible limit at 55 dB whereas the nighttime noise level is 45 dB is comparing to the existing noise levels of 68 dB.

Table 2.1 shows the classification of noise levels for residential areas (Zannin et al. 2002), the US department of housing and urban development.

**Table 2.1: Noise Level Classification**

| Range | Classification |
|---|---|
| $L_{Aeq} \leq 49dB\ (A)$ | Clearly Acceptable |
| $49 \leq L_{Aeq} \leq 62dB\ (A)$ | Normally Acceptable |
| $62 \leq L_{Aeq} \leq 76dB\ (A)$ | Normally Unacceptable |
| $L_{Aeq} > 76dB\ (A)$ | Clearly Unacceptable |

Survey for the installation of vertical measures and textured pavements will produce even higher noise levels to the entire area due to the lack of consideration on the noise levels at acceleration and deceleration points throughout the traffic scheme (Hidas et al. 1998).

### 2.2.4 Emergency Response

There is the impact brought by speed hump especially reduce the speed of the emergency vehicle and cause the increasing of the service time. The amount of delay incurred the emergency response is depending on the emergency vehicle. For instance, in Montgomery County Emergency Response Services study, a tiller style ladder truck, a pumper fire engine, an ambulance and an aerial tower truck have the various high operating speed as they have to perform the emergency service for the needy (Montgomery County, 2001). It will slow down the service time for the emergency response services.

## 2.3 Road Implemented with Intelligent Speed Breakers

There is wide attention of researchers in development of intelligent speed breaker such as piezoelectric sensors generation device, which involved in mechanical vibration as the electric charge accumulates within solid materials due to the applied mechanical stress (Holler et al., 2007). Besides, there is also rotational motion, which can generated energy from translational base excitation in roller mechanism. Another type of speed breaker, which is the underground air compressor of the compressor, can compress the air in order to reduce the volume of isolated air. It has the piston rod that can rise up the surface of the speed breaker and reciprocate to the cylinder. Both of the intelligent speed breakers after being used in long period has the possible impacts on the lifetime and durability. All of the mechanisms of intelligent speed breakers and the corresponding impacts are discussed below.

### 2.3.1 Piezoelectric Sensors

The invention of piezoelectric on the road is a method to generate the electrical power by using traffic energy. Moving vehicles to the device of the road is the significant energy demand as it acts as the energy harvester by converting the pressure exerted from moving vehicles. Those moving vehicles above the embedded piezoelectric material convert the corresponding result to electrical current. Figure 2.2 shows the piezoelectric road generator of electric voltage that embedded beneath the roadbed.

**Figure 2.2: Piezoelectric Road Harvester for Electricity**

Due to the road is embedded with pressure plates and asphalt for piezoelectric generators; it will cause the effect of mechanical strain to the piezoelectric and interrupt the conversion of electrical current or voltage. The deformation and compression caused by the mechanical force, which is exerted by the wheel of moving vehicle. The friction between the road and wheel will destroy the harvester system as shown in Figure 2.3.

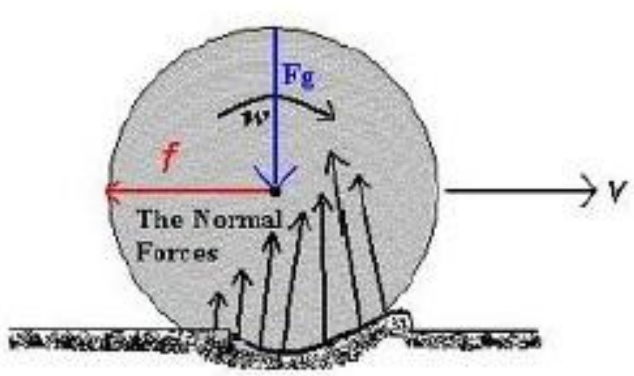



**Figure 2.3: Deformation of Road due to Friction**

### 2.3.2 Roller Mechanism

There is a roller is fitted in between of the grip on the speed breaker for moving vehicle to pass over it and make the rotation to the roller. The circular motion to the roller will give the rotation to the shaft that connected together with D.C. generator with the aid of chain drive.

However, this kind of system give troubles for technician due to the maintenance is difficult as it will cause the collision to the chain drive and the roller of the speed breaker. It will easily get rusty and corrosion as the roller is opposed to the air and environment humidity that might be caused by rain. Figure 2.4 shows the side view of roller mechanism for the speed breaker while Figure 2.5 demonstrates the top view of the roller mechanism that opposed to the air.

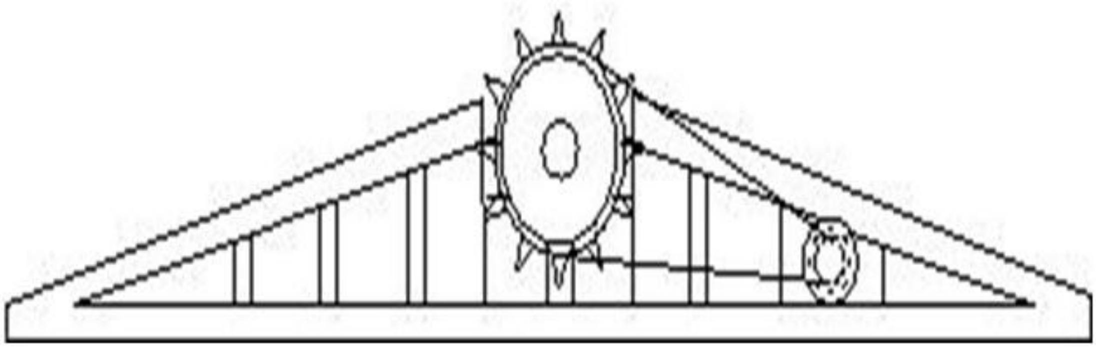


**Figure 2.4: Side View of Roller Mechanism**

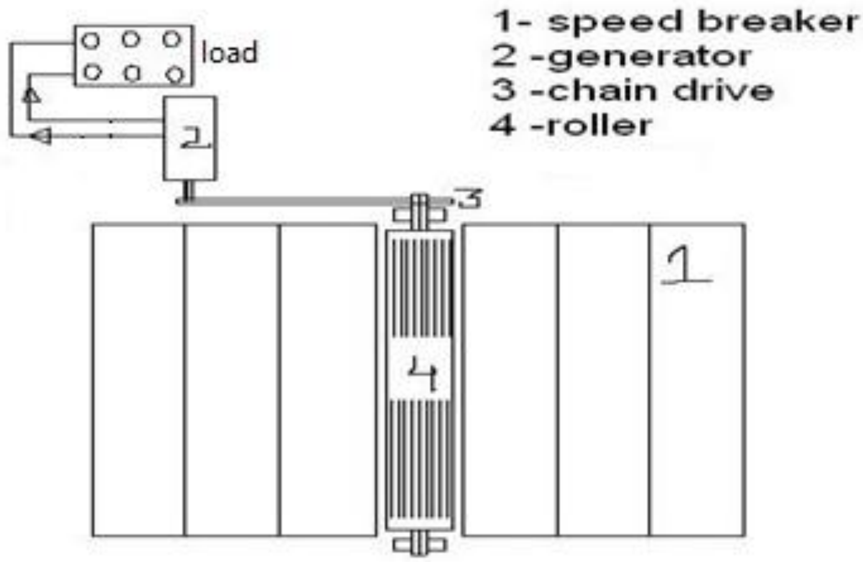



**Figure 2.5: Top View that Opposed to the Air**

### 2.3.3 Air Compressor

The speed breaker made together with air compressor allows the rack to move downward in order to join the piston rod that reciprocating in the cylinder when there is moving vehicles stepped over this speed breaker. The reciprocating motion is a kind of air compression, which increases the pressure in the restricted volume and allows more air move towards to the reservoir.

In contrast, there will be undesirable impurities of compressed air act as a fluid medium to the pneumatic system by changing the moisture content of the system into vapour form. The condensation of moisture caused by the changing in temperature of compressed air harms the system and causes the corrosion. Thus, the dilute lubricants froze in compressed air line totally deteriorate the system performance. Figure 2.6 is the system of speed breaker implemented with air compressor.

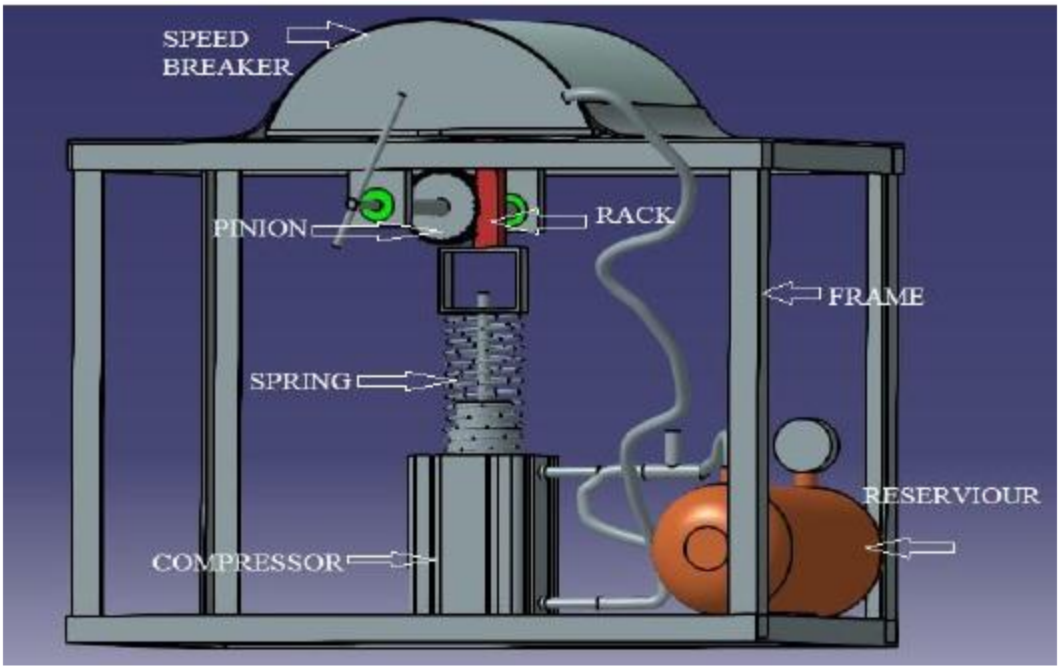



**Figure 2.6: Speed Breaker with Underground Air Compressor**

### 2.3.4 Lifetime due to Deformation

The speed breaker which act as energy harvester is similar to solid state materials as they will degrade over time that result to the reduction of output and the response of the time. The degradation is relevant to all methods implemented within the speed breaker.

Impacts which influenced the degradation to the speed breaker are due to the stresses are larger than the load and uneven stress of bending movements on the surface of speed breaker. Stresses to the speed breaker will crack and fracture the brittle material. Thus, under test of ASTM E9, Standard Test Methods of Compression Testing of Metallic Materials at Room Temperature, have been cited the testing procedure for abrasion resistance of pavements to characterize the lifetime that direct impact to the energy harvester.

### 2.3.5 Durability of Components

There is external weather act as buried environment to the road with speed breaker causes the water exposure to the surface of speed breaker. ASTM B117, Standard Practice for Operating Salt Spray Apparatus, have been cited by using weathering performance that involved in temperature, salt water exposure, ultraviolet light exposure and dry or wet cycles on testing to the intelligent speed breaker. Waterproofing as long as water resistance become the major challenges faced within the advanced technology as it substrate the impacts of durability to the speed breaker which built under the road to prevent any corrosion to the speed breaker.

## 2.4 Summary

If the term of usage for the functional component of energy harvester system does not handle well, the associated electronics, frame and structural components within the speed breaker gave the failure to the system. Besides, the auxiliary components such as force multiplying mechanisms, wiring and circuitry are destroyed under harsh conditions.

Failure rates of the energy harvesters is a direct impact for the system's ability to generate energy due to the decay mechanisms of the power or energy generated over time will be decreased. It is caused by the accumulative increase of unit failures and degradation to the entire system.

Power generation device has the relationship with traffic volume due to the vehicle's weight influenced the performance of the intelligent speed breaker as well as the conventional speed breaker. Levelized cost of electricity (LCOE) required traffic characteristics that are reliable in order to make power generation system viable. It is necessary to know the vehicles per day, which is needed to assess for the cost effectiveness of the intelligent and conventional speed breaker.

There is probability of the moving vehicles will not pass on the speed breaker due to asymmetrical position of the road. All of the vehicles can freely change the roadway. Thus, the energy generated is not consistent due to the quantity of moving vehicles is not constant. The contact to the intelligent speed breaker will also be decreased.

In addition to, the downtime is related to maintenance or replacement. The maintenance affected the return on investment due to the increasing of labour costs and strain maintenance budget.

Therefore, the possible impacts on conventional and intelligent speed breakers have been carried out to clear the doubts of society. The review of this chapter has been summarized and emphasized that material used to implement speed breakers must be promoted to increase the efficiency and save the green energy for the environment.

# CHAPTER 3

# METHODOLOGY

## 3.1 Overview

This chapter outlines the method of study on research methodology to achieve the aim and objectives of the study.

The equation of coefficient for spring constant can be used with appropriate material to determine the fatigue level of the helical spring within rack and pinion mechanism speed breaker when uncommon forces exert on it. Forces of moving vehicles affect the deflection on the piston rod within hydraulic air speed breaker. The linear velocity of moving vehicles is related to angular velocity of roller which is attached within the roller mechanism speed breaker causes the limitation of endurance for this speed breaker due to formation of the vibration. Besides, the surface area for smart and intelligent speed breakers is not distributed evenly, it caused the appearance of the traction on the surface, which gives the shear stress to the surface and affects the lifetime of the speed breakers. Last but not least, the Finite Element Analysis (FEA) has the compatibility function to obtain the displacement analysis, stress analysis, frequency analysis, fatigue analysis and buckling analysis by using Solidworks.

## 3.2 Data Collection Methods

This study has been conducted by using following methods throughout Solidworks:

(i) Obtain compression spring constant to act as parameter for helical spring, which is needed to be used in the modelling of intelligent speed breaker.

(ii) Exclude the other components of the corresponding speed breaker and run the fatigue analysis to the helical spring.

(iii) Investigate the speed breaker involved in hydraulic air compressor mechanism with piston rod.

(iv) Perform the displacement analysis to the piston rod by determining effect of deflection between the surface of speed breaker and piston rod.

(v) Examine the chain sprocket within roller mechanism speed breaker to obtain frequency analysis, which can be suffered under vibration by natural frequency.

(vi) Analyse the surface of smart speed breaker by using the model of combination rack and pinion mechanism with hydraulic speed breaker.

(vii) Evaluate the conventional speed breaker by seeking the loading force exerted on the surface of it.

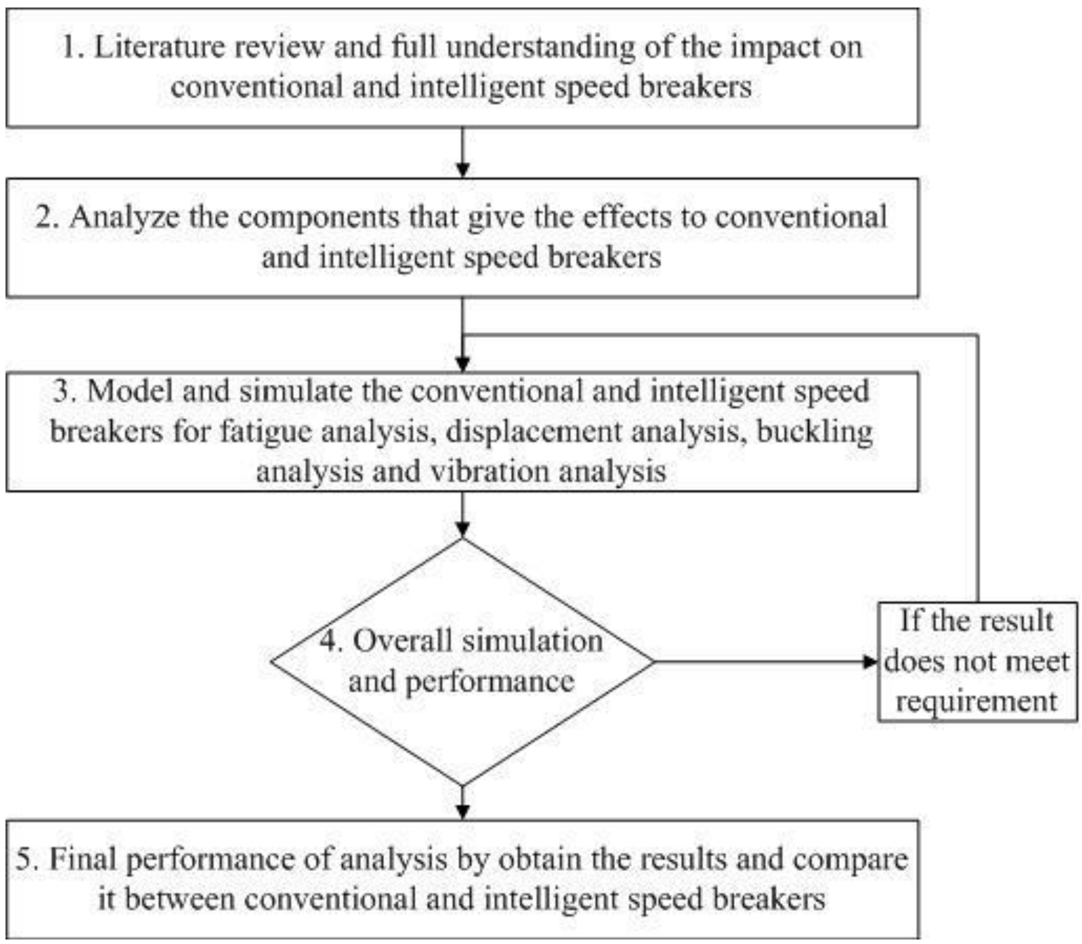
(viii) Run the bucking analysis under FEA to determine maximum load to the surface of smart speed breaker and conventional speed breaker before crack happens to it.

### 3.3 Literary Survey

According to the Burger King fast food restaurant on U.S. highway, customers are at least pulling in and out throughout each day. There are roughly 50,000 cars visit the drive-thru service per year. The mechanized speed bump is installed to slow down the vehicles and harvest some of the energy from it.

From the point of view from the engineer of motion power system developed for the intelligent of speed breaker, the weight of a vehicle is used to throw a lever as there is instantaneous power being generated.

### 3.4 Flow Chart of Project



## 3.5 Fatigue Analysis for Compression of Helical Spring in Speed Breaker

A coil spring can be in the helical coils shape, which is used for compression and intelligent speed breaker. Helical spring is exerted by the load and cause the deflection to the energy harvester system. The assembly of spring in intelligent speed breaker is shown in Figure 3.1.

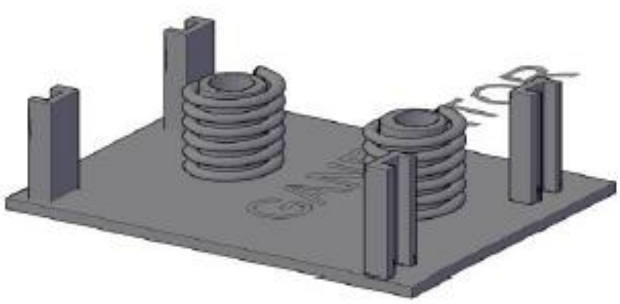


**Figure 3.1: Spring Assembly in Speed Breaker**

The compression coil springs are designed to resist compression and the ends of it is normally in ground flat. From Hooke's Law,

$$F = k\delta \tag{3.1}$$

where
F = applying force from vehicle, N
k = compression spring constant, N/m
δ = deflection of the coil, m

$$k = \frac{Gd^4}{64R^3} \tag{3.2}$$

where
k = compression spring constant, N/m
G = shear modulus of spring material, N/m$^2$
d = diameter of wire coil, m
R = mean radius of spring, m

By substituting equation 3.2 into 3.1, the equation for minimum deflection of spring is observed,

$$\delta = \frac{64FR^3}{Gd^4} \tag{3.3}$$

where

δ = deflection of the coil, m

F = applying force from vehicle, N

G = shear modulus of spring material, N/m$^2$

d = diameter of wire coil, m

R = mean radius of spring, m

## 3.6 Shear Stress Analysis on Surface of Speed Breaker

The traction on the surface of speed breaker subdivided into external force acting to the slope of the speed breaker, which produces the shear stress. The formula used to calculate average shear stress is shown below,

$$\tau = \frac{F}{A} \tag{3.4}$$

where

τ = shear stress, N/m$^2$

F = force applied by vehicle, N

A = cross-sectional area of material with area perpendicular to the applied force vector, m$^2$

## 3.7 Finite Element Analysis

Finite Element Analysis (FEA) is a technique to describe the displacement analysis, stress analysis, frequency analysis, buckling analysis, non-linear analysis and fatigue analysis for the 3D model. From this project, there are two kinds of speed breakers such as conventional and intelligent were setup to determine their impacts. It is followed by FEA pre-processing of meshing to the model in order to get the result accurately. It is necessary to do the separation for each of the components from each of the speed breakers to allow FEA solver simulate the corresponding problem.

### 3.7.1 Rack and Pinion with Helical Spring Speed Breaker

By applying the model of helical spring speed breaker with rack and pinion mechanism, the rest of the part has to be excluded from the model and left the only helical spring to do for the mesh analysis. Figure 3.2 shows the model needed to be investigated the impacts from Solidworks.

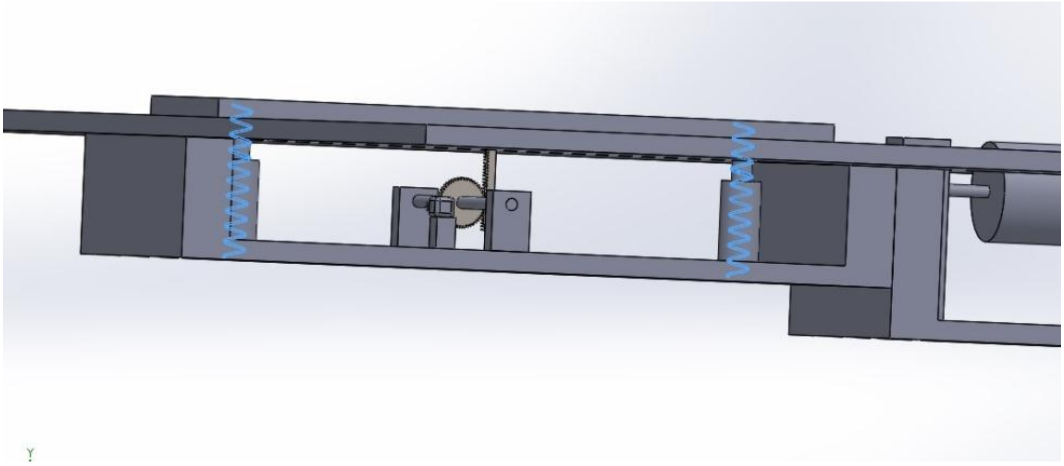


**Figure 3.2: Model of Helical Spring Speed Breaker with Rack and Pinion Mechanism**

By excluding the other components from the model, Figure 3.3 shows the mesh analysis of helical spring.


**Figure 3.3: Mesh Analysis of Helical Spring**

### 3.7.2 Hydraulic Speed Breaker System

Hydraulic speed breaker required compression cylinder and piston to displace the hydraulic fluid by forcing the fluid flow into pressure vessel in order to create compressed air for pneumatic-electrical generator. Figure 3.4 shows the model for the hydraulic speed breaker.

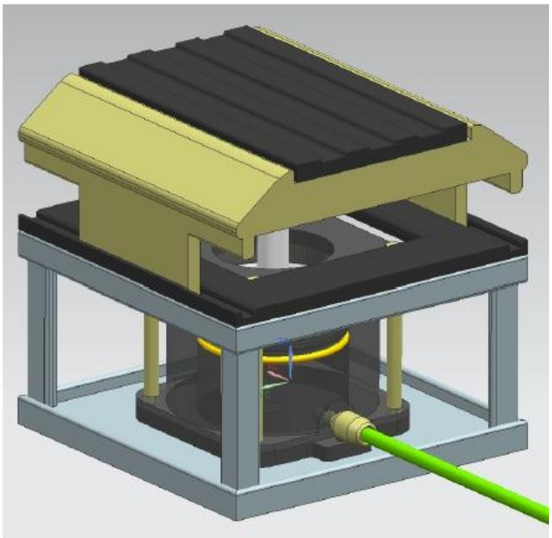


**Figure 3.4: Hydraulic Speed Breaker with Piston**

By excluding the housing of the hydraulic speed breaker, there is only piston needed to undergo for the mesh analysis in order to investigate the impacts from all dimensions of piston in Figure 3.5.

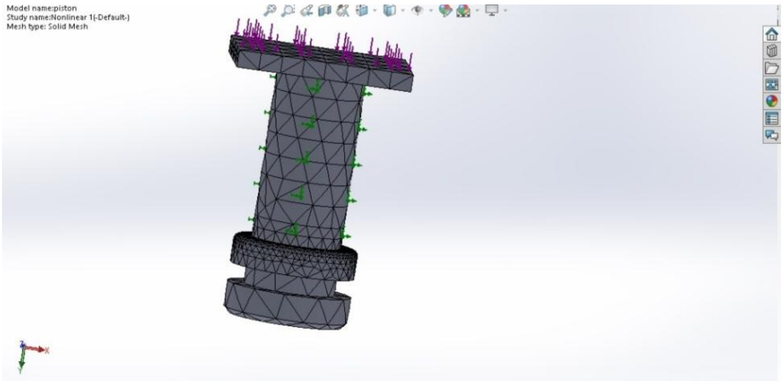



**Figure 3.5: Mesh Analysis of Piston**

### 3.7.3 Roller Mechanism Speed Breaker

Roller mechanism speed breaker consists of roller, which is fitted together with the surface of the road as it can make the rotation when there is vehicle moves over it. The shaft of the roller is combined together with the large sprocket, which is interconnected, with the small sprocket of the shaft of D.C. generator by the help of chain drive. Figure 3.6 shows the model of roller mechanism speed breaker while Figure 3.7 shows the concept of the shaft of roller linked by the chain drive to the corresponding sprockets.

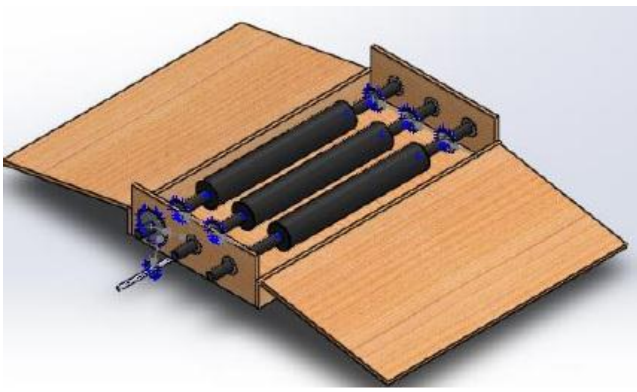


**Figure 3.6: Model of Roller Mechanism Speed Breaker**

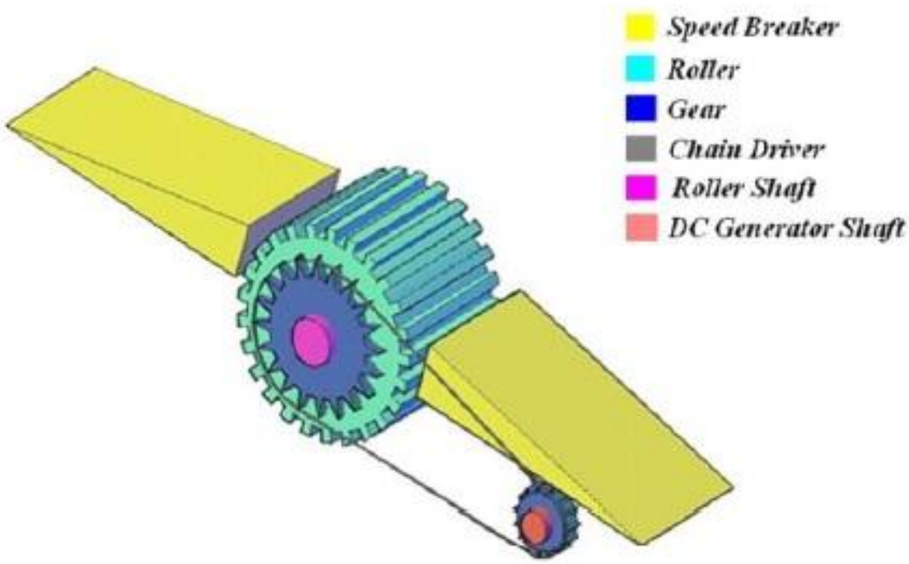



**Figure 3.7: Concept of Chain Drive Linked with Sprockets**

The mesh analysis to the large and small sprockets in together with the chain drive has been shown in Figure 3.8.

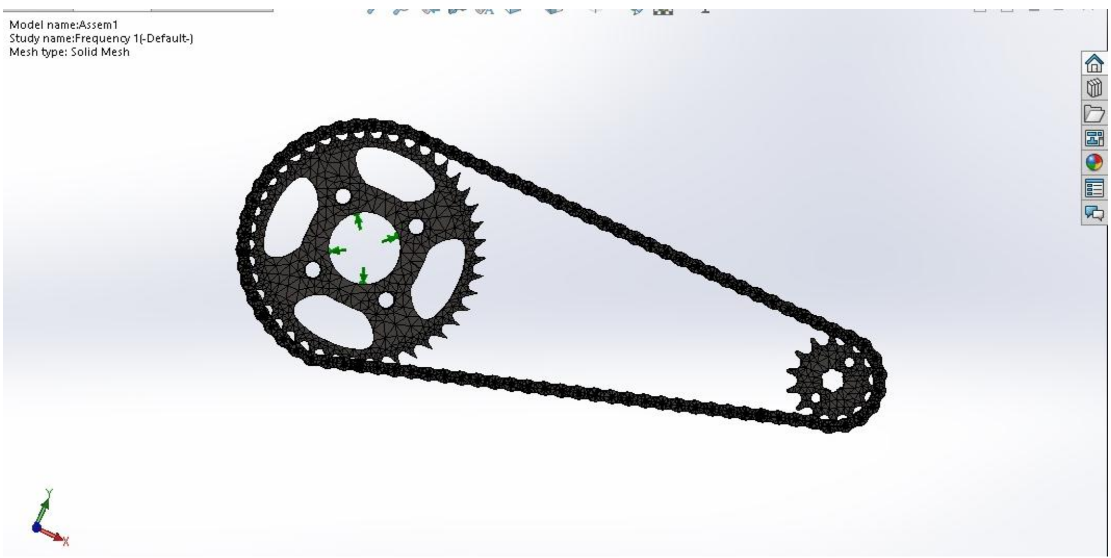



**Figure 3.8: Mesh Analysis of Chain Drive with Sprockets**

### 3.7.4 Rack and Pinion Mechanism with Hydraulic Speed Breaker

Combination of rack and pinion mechanism with two hydraulic of the supporter for the surface of speed breaker is designed to analyse the impact of the surface for this system. It has to do the comparison in between this system and conventional speed breaker with same horizontal and vertical dimensions of the entire hump. Figure 3.9 shows the module for this combination mechanism speed breaker.

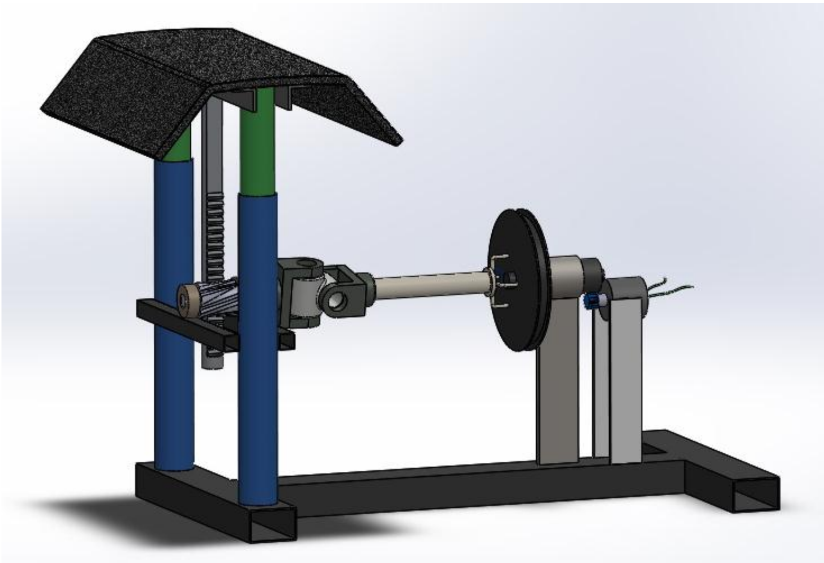


**Figure 3.9: Rack and Pinion Mechanism with Hydraulic Speed Breaker**

This speed breaker system consists of coupling which can be turned to generate electricity for the dynamo at the end. The turning of the coupling is worked by rack and pinion mechanism. When the moving vehicles stepped over the upper surface of the speed breaker, the rack will move down by making the rotation to the pinion. However, the purpose for the hydraulic is used to recover the surface of the speed breaker to original position. It is also acted as the supporter for the surface.

By excluding the other components of this system and left the only upper part of the surface in order to apply for the FEA. Figure 3.10 shows the mesh analysis on the surface of smart speed breaker.

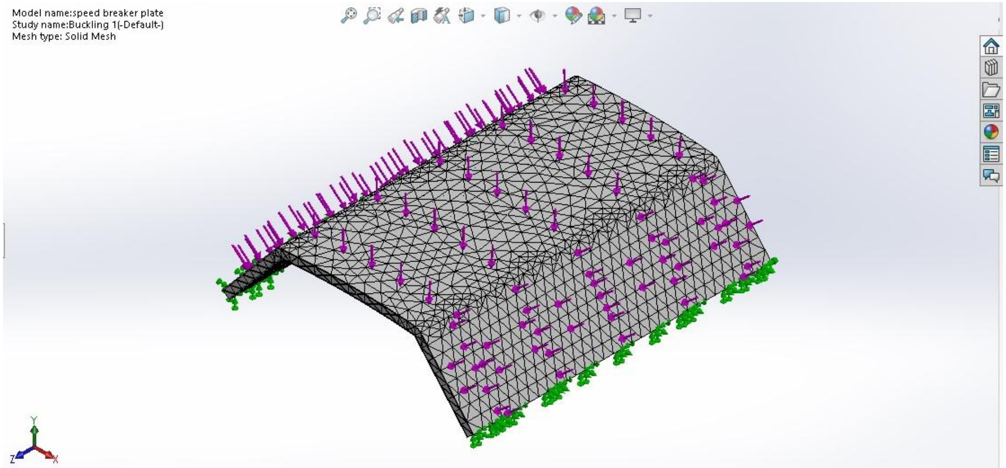



**Figure 3.10: Mesh Analysis of Surface of Smart Speed Breaker**

### 3.7.5 Conventional Speed Breaker

The typical as known as conventional speed breaker is designed to analyse and obtain the impact from the surface of the speed breaker. Figure 3.11 shows the typical modelling of speed breaker that can be seen on the road.

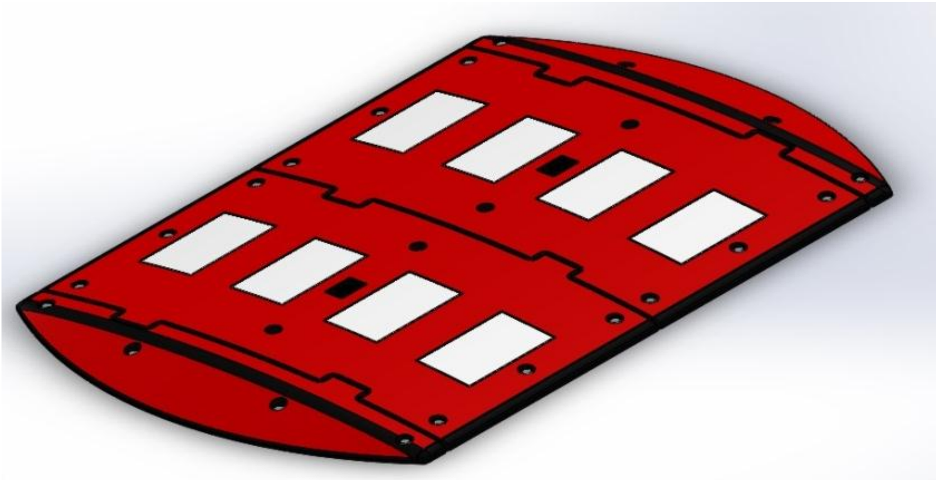


**Figure 3.11: Typical Model of Speed Breaker**

Typical speed breaker is analysed by meshing in order to determine the maximum loading which can be suffered by the surface of this speed breaker. Figure 3.12 shows the mesh analysis for the conventional speed breaker.

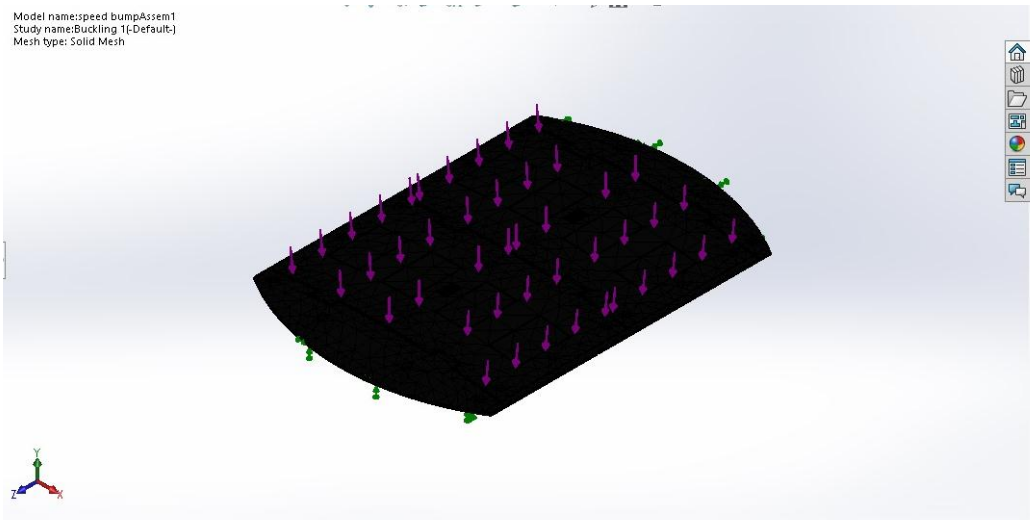



**Figure 3.12: Mesh Analysis of Conventional Speed Breaker**

## 3.8 Properties of Materials for FEA

Properties of materials chosen for each of the components of the conventional and intelligent speed breakers are being investigated before any analysis has been performed. The following factors affected the corresponding results were listed.

1. Elastic Modulus
2. Poisson's Ratio
3. Shear Modulus
4. Mass Density
5. Tensile Strength
6. Yield Strength
7. Thermal Expansion Coefficient
8. Thermal Conductivity
9. Specific Heat

It is necessary to understand the factors and abilities of material, which affect the function during analysis. Selection of material for the internal components of intelligent speed breaker and surface of conventional speed breaker is significant during modelling and implementation for the speed breakers.

The following Table 3.1 shows the material assigned for the helical spring, which is used in rack and pinion mechanism speed breaker.

**Table 3.1: Material for Helical Spring**

| **Property** | **DIN Stainless Steel 1.4310 (X10CrNi18-8)** |
|---|---|
| | **Value** |
| **Elastic Modulus** | 0.2 $TNm^{-2}$ |
| **Poisson's Ratio** | 0.28 |
| **Shear Modulus** | 79 $GNm^{-2}$ |
| **Mass Density** | 7 900 $kgm^{-3}$ |
| **Tensile Strength** | 0.5 $GNm^{-2}$ |
| **Yield Strength** | 195 $MNm^{-2}$ |
| **Thermal Expansion Coefficient** | 11 $\mu K^{-1}$ |
| **Thermal Conductivity** | 14 $Wm^{-1}K^{-1}$ |
| **Specific Heat** | 440 $Jkg^{-1}K^{-1}$ |

For the hydraulic speed breaker, the internal component such as the piston is assigned to use the material that shown in Table 3.2.

**Table 3.2: Material for Piston**

| **Property** | **Aluminium Alloys 6061 Alloy** |
|---|---|
| | **Value** |
| **Elastic Modulus** | 0.69 $GNm^{-2}$ |
| **Poisson's Ratio** | 0.33 |
| **Shear Modulus** | 0.26 $GNm^{-2}$ |
| **Mass Density** | 2 700 $kgm^{-3}$ |
| **Tensile Strength** | 124 084 $kNm^{-2}$ |
| **Yield Strength** | 55 148.5 $kNm^{-2}$ |
| **Thermal Expansion Coefficient** | 24 $\mu K^{-1}$ |
| **Thermal Conductivity** | 170 $Wm^{-1}K^{-1}$ |
| **Specific Heat** | 1 300 $Jkg^{-1}K^{-1}$ |

One of the internal components used by roller mechanism is chain sprocket together with chain drive. Both of them are assigned by the materials, which has been shown in Table 3.3.

**Table 3.3: Material for Chain Sprocket and Chain Drive**

| **Property** | **Steel**<br>**AISI 1035 Steel**<br>**Value** |
|---|---|
| **Elastic Modulus** | 0.204 999 998 4 $TNm^{-2}$ |
| **Poisson's Ratio** | 0.29 |
| **Shear Modulus** | 79.999 999 87 $GNm^{-2}$ |
| **Mass Density** | 7 850 $kgm^{-3}$ |
| **Tensile Strength** | 585 000 002.9 $Nm^{-2}$ |
| **Yield Strength** | 282 685 049 $Nm^{-2}$ |
| **Thermal Expansion Coefficient** | 11 $\mu K^{-1}$ |
| **Thermal Conductivity** | 52 $Wm^{-1}K^{-1}$ |
| **Specific Heat** | 486 $Jkg^{-1}K^{-1}$ |

In order to do comparison between smart speed breaker and conventional speed breaker, the material used for the upper surface of rack and pinion mechanism with hydraulic speed breaker system has shown in Table 3.4.

**Table 3.4: Material for Upper Surface of Smart Speed Breaker**

| **Property** | **Iron**<br>**Ductile Iron**<br>**Value** |
|---|---|
| **Elastic Modulus** | 0.12 $TNm^{-2}$ |
| **Poisson's Ratio** | 0.31 |
| **Shear Modulus** | 77 $GNm^{-2}$ |
| **Mass Density** | 7 100 $kgm^{-3}$ |
| **Tensile Strength** | 861 695 $kNm^{-2}$ |
| **Yield Strength** | 551 485 $kNm^{-2}$ |
| **Thermal Expansion Coefficient** | 11 $\mu K^{-1}$ |
| **Thermal Conductivity** | 75 $Wm^{-1}K^{-1}$ |
| **Specific Heat** | 450 $Jkg^{-1}K^{-1}$ |

Table 3.5 shows the material assigned for the surface of conventional speed breaker.

**Table 3.5: Material for Surface of Conventional Speed Breaker**

| **Property** | **Rubber** <br> **Natural Rubber** |
|---|---|
| | **Value** |
| **Elastic Modulus** | 10 $kNm^{-2}$ |
| **Poisson's Ratio** | 0.45 |
| **Mass Density** | 960 $kgm^{-3}$ |
| **Tensile Strength** | 20 $MNm^{-2}$ |

All of the components of intelligent speed breaker as well as the surface of conventional speed breaker were used to predict the response from FEA by Solidworks simulation software. These responses are influenced by the force exerted by moving vehicle, the velocity of moving vehicle is related to the natural frequency which causing the vibration within the system.

This simulation software is used to determine whether the speed breakers can be maintained their performance by fitting to their own design and implementation. Both of the speed breakers are compared by using a car with a motorcycle in order to predict the quality and condition without causing many impacts to the speed breakers.

## 3.9 Conclusion

With the aid of the corresponding software as well as the equations of components, impacts of conventional and intelligent speed breakers were investigated. Applying the correct analysis from Solidworks, the simulated data about the impacts can be obtained accurately. It is necessary to acquire further understanding on the specific terms, which are obtained during simulation.

# CHAPTER 4

# RESULTS AND DISCUSSION

## 4.1 Introduction

The proposed methods that used to investigate the possible impacts with the aid of the material properties were acquired. In this chapter, the simulation results were based on the exerting force by the moving vehicles over both intelligent and conventional speed breakers. At the moment, the causes of vibration from moving vehicle to the internal components of intelligent speed breaker also collected and calculated by using appropriate equations. Displacement and susceptive stress of the internal components as well as the durability about the surface of speed breakers are performed throughout this chapter.

## 4.2 Working Principle of Intelligent Speed Breakers

Helical spring involved in rack and pinion mechanism speed breaker, which is depending on the stiffness of the spring. The deflection of the spring is the limitation for the spring to be compressed when the moving vehicles travel across to the upper surface of this speed breaker.

For the hydraulic speed breaker, it consists of the hydraulic jack, which is installed under the speed breaker. The inner part of hydraulic jack has the piston, which is used to compress the inner pressure for pneumatic-electrical generator.

There is inner pressure distributed at the bottom of piston, which might be encountered by the force from the upper horizontal part of the piston as the force is exerted by moving vehicle. It causes the shear stress to the upper part of the piston.

In roller mechanism speed breaker, the roller is rotated by moving vehicle. The rotational velocity for the roller is depending on the angular velocity of the tyre from moving vehicle. The rotational of roller is related to the natural frequency and this kind of frequency makes the vibration to the roller as long as the chain sprocket, which is attached, with the roller. The vibration must be maintained in steady state in order to generate required electricity for traffic energy.

## 4.3 Analysis on Helical Spring within Rack and Pinion Speed Breaker

A car with the force of 6100 N and motorcycle with force of 920 N passed through the rack and pinion mechanism speed breaker is equal to the force exerted on the helical spring.

Applying equation 3.2 and referring Table 3.1, the shear modulus is 79 $\mathrm{GNm^{-2}}$, the design of mean radius of spring is 0.8 m with the diameter of coil is 0.2 m. The compression spring constant is calculated as

$$k = \frac{Gd^4}{64R^3} = \frac{(79\ \mathrm{G})(0.2)^4}{64(0.8)^3} = 3.857\ \mathrm{MNm^{-1}}$$

From equation 3.1, the minimum deflection of the coil for car is

$$\delta = \frac{F}{k} = \frac{6100}{3.857\ \mathrm{M}} = 1.582\ \mathrm{mm}$$

For the motorcycle, the minimum deflection of the coil is

$$\delta = \frac{F}{k} = \frac{920}{3.857\ \mathrm{M}} = 0.239\ \mathrm{mm}$$

Both of the minimum deflection value as well as the exerted force are inserted to the Solidworks in order to run the simulation by using the following analysis.

### 4.3.1 Stress Analysis with Car

Stress analysis is the analysis when a force exerted on the component and causes the stress distribute to the certain part of the component.

Result of the stress analysis from car is specified in Figure 4.1. The bottom surface of the helical spring is set by fixed geometry, which is in green arrow. The body of helical spring is set by surface-to-surface contact. The exerted force from car inserts the upper part of the helical spring, which is in purple colour arrow.

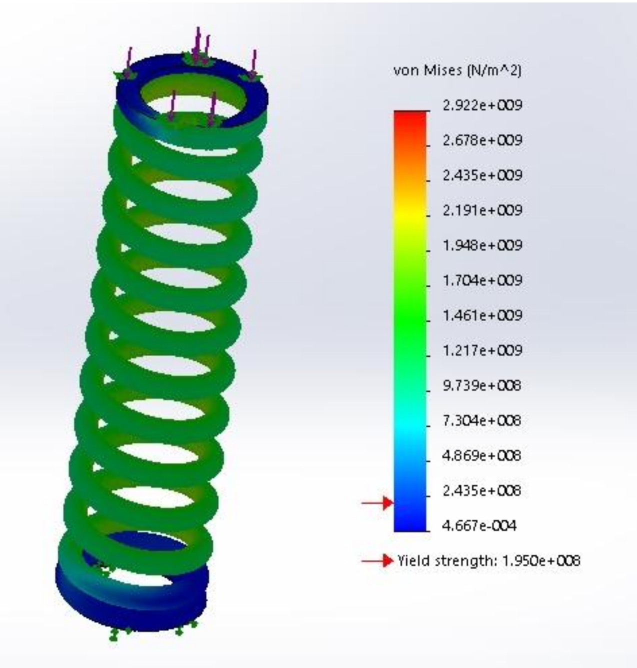



**Figure 4.1: Stress Distributed to the Helical Spring by Car**

There is the reading of the range about the von Mises stress in various colour. It shows the red colour is the most severe case while the blue colour is the normal case. The stress only influences the body part of the helical spring.

Figure 4.1 shows the body part of helical spring, which is in green colour and located at the middle range of von Mises stress reading range. It proved that the helical spring, which is implemented within the rack and pinion speed breaker, is suffering the stress from moving vehicle. If there is no stress, the colour of the spring should be in blue colour.

By referring Table 3.1, the yield strength for the material used in helical spring is 195 $MNm^{-2}$, which is within the range of von Mises stress reading. The red arrow indicated the current yield strength for the helical spring and it can be observed from Figure 4.1. Therefore, the force exerted by car to helical spring is safe. The maximum von Mises stress, which can be sustained by force of 6100 N from car, is 2922 $MNm^{-2}$.

### 4.3.2 Stress Analysis with Motorcycle

Stress analysis from motorcycle of the exerted force at 920 N is simulated and the result is shown in Figure 4.2.

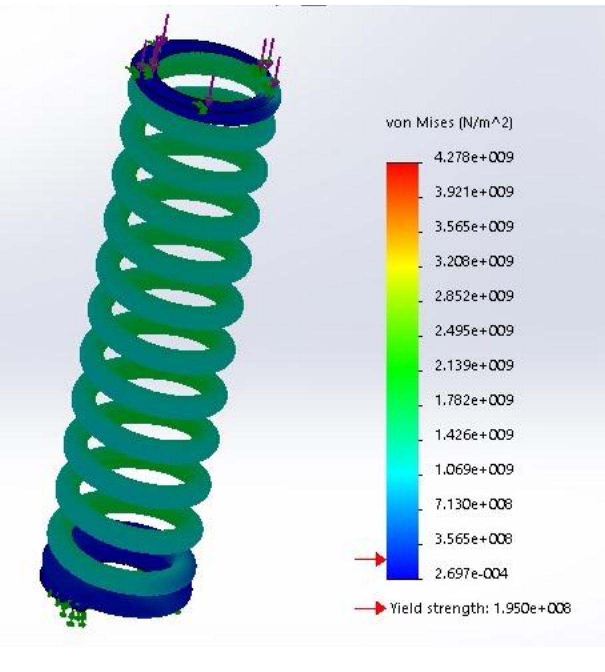



**Figure 4.2: Stress Distributed to the Helical Spring by Motorcycle**

The body colour of spring from the case of motorcycle is in greenish-blue, which is better than green colour. The maximum of von Mises stress is 4278 $MNm^{-2}$. The yield strength of material used by spring is within the range and it is in blue colour. The loading condition for this moment is not severe. Therefore, this design is suited for motorcycle to travel over speed breaker due to the stress does not reach to the limitation.

### 4.3.3 Comparison about Stress Analysis between Car and Motorcycle

By comparing the force of 6100 N from car as well as the force of 920 N from motorcycle, the comparison of the result is shown in Figure 4.3.

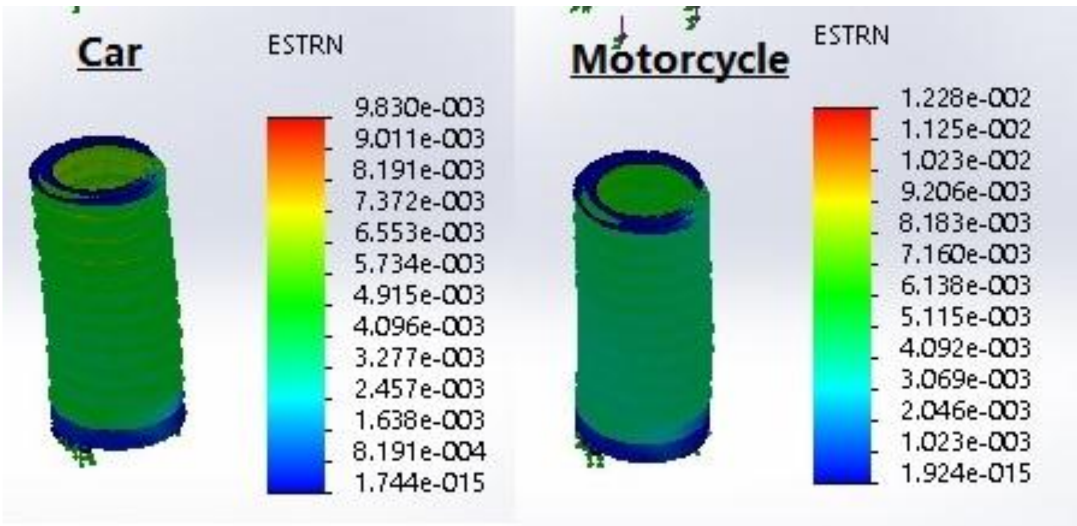



**Figure 4.3: Comparison about the Strain between Car and Motorcycle**

ESTRN stands for equivalent strain from Figure 4.3. When the helical spring is compressed by car and motorcycle, the maximum reading, which is in red colour from the case of car, is smaller than the case of motorcycle. Therefore, the helical spring cannot sustain much more of the force from car. The overall colour for the case of motorcycle is in the range of greenish-blue colour while the colour for the case of car exerted to helical spring is in green colour. This is because the force exerted by car is larger than motorcycle, the force and strain is inversely proportional.

When the force is exerted to the helical spring is small, the strain suffered by the helical spring is large. Therefore, the strain distributed to helical spring from the case of motorcycle is higher than the case of car. It helps to decrease the burden of the spring within the rack and pinion mechanism speed breaker.

### 4.3.4 Comparison about Contact Force between Car and Motorcycle

Contact force is generated in between the surface-to-surface contact of compressing helical spring. It is also known as friction force for the spring. The contact force versus time for the car to exert the force to the helical spring within 0.35 s is shown in Figure 4.4. Besides, the contact force versus time for motorcycle also shown in Figure 4.5 within 0.35 s.

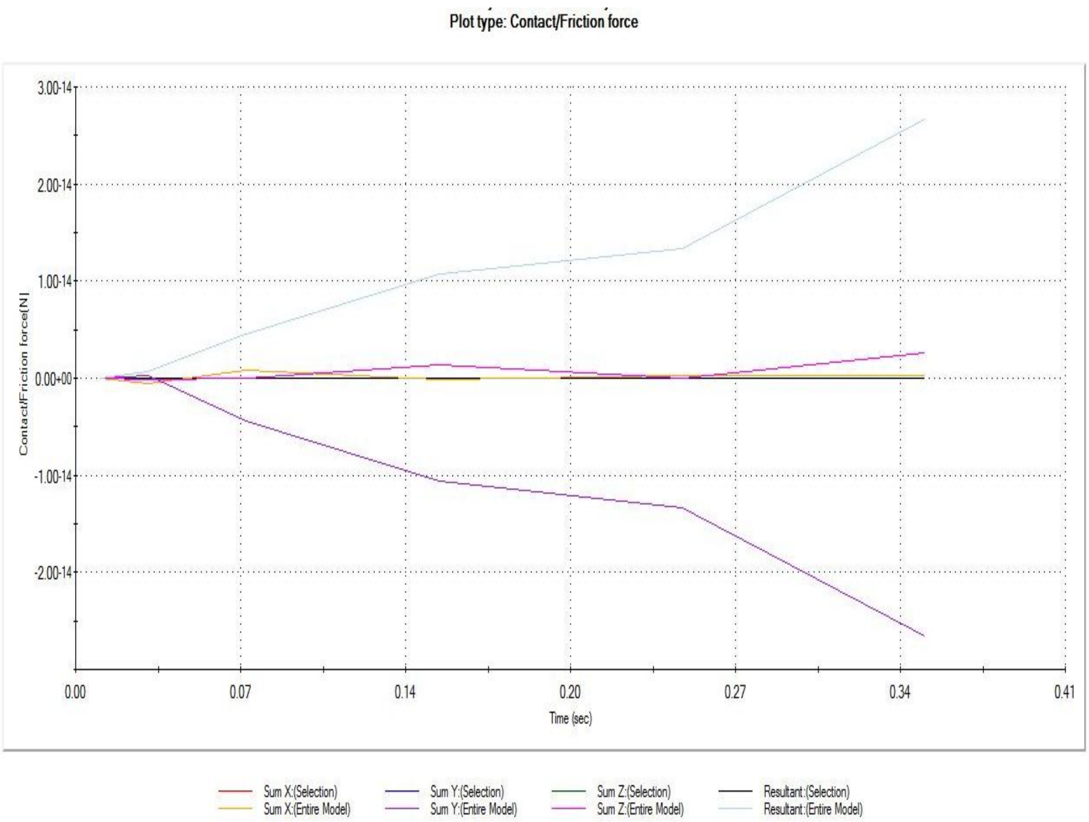



**Figure 4.4: Graph of Friction Force versus Time of Helical Spring by Car**

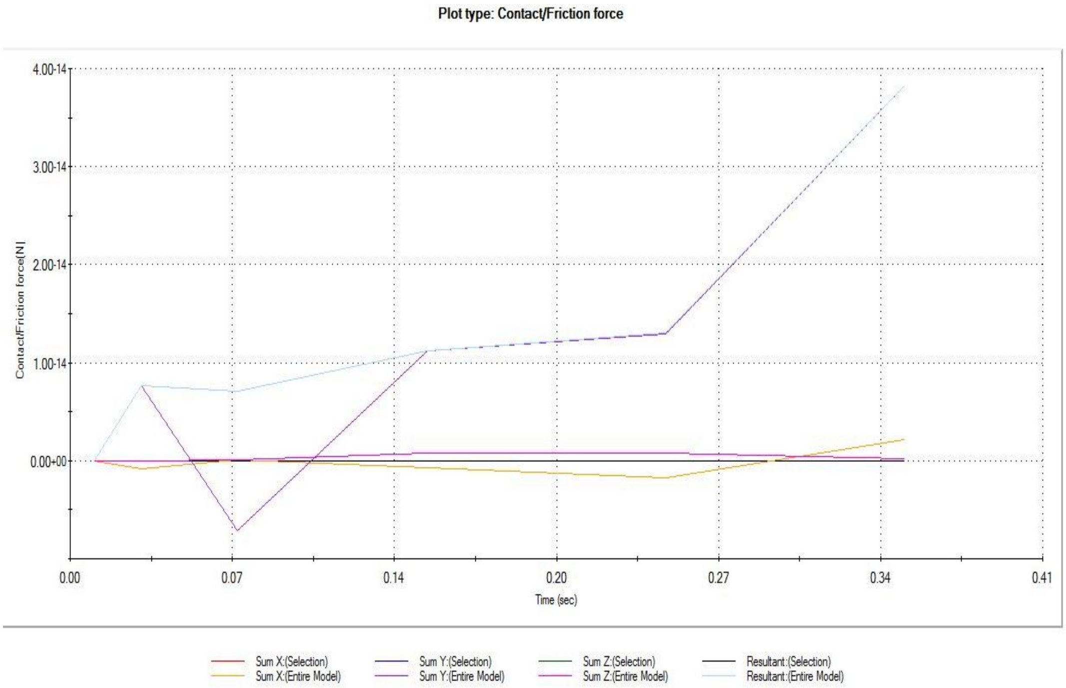



**Figure 4.5: Graph of Friction Force versus Time of Helical Spring by Motorcycle**

There is total resultant force of the friction has been shown in Figure 4.4 and Figure 4.5 which is indicated as purple colour line. Both figures show the line is in light blue colour, which is the original exerted force from car and motorcycle respectively. In Figure 4.4, the purple line is the total friction force produced by the contact surface of the helical spring during compression of the car and this force is in opposite direction as compare to the light blue line. It can be said that the compressed spring is hard to recover back to original position due to the negative direction of friction force is produced by helical spring. In contrast, Figure 4.5 shows the total friction force produced by spring from motorcycle is in positive direction during compression. It can be said that the spring can easily to return to original position within the stated time as the purple line is almost coincided with the entire light blue line. Thus, it can be concluded that the strain experienced by helical spring for the case from car is larger than the case from motorcycle.

## 4.4 Analysis on Piston within Hydraulic Speed Breaker

Hydraulic speed breaker consists of internal component such as the piston is used to compress the pressure within the system in order to transmit the corresponding fluid to pneumatic-electrical generator. The force caused to the compression is exerted by a car and motorcycle with force of 6100 N and 920 N respectively.

### 4.4.1 Displacement Analysis with Car

Piston within the hydraulic speed breaker has been modelled and it is run for the simulation. The result of displacement is generated and shown in Figure 4.6. Displacement analysis is used to determine the displaced position of the component from the origin.

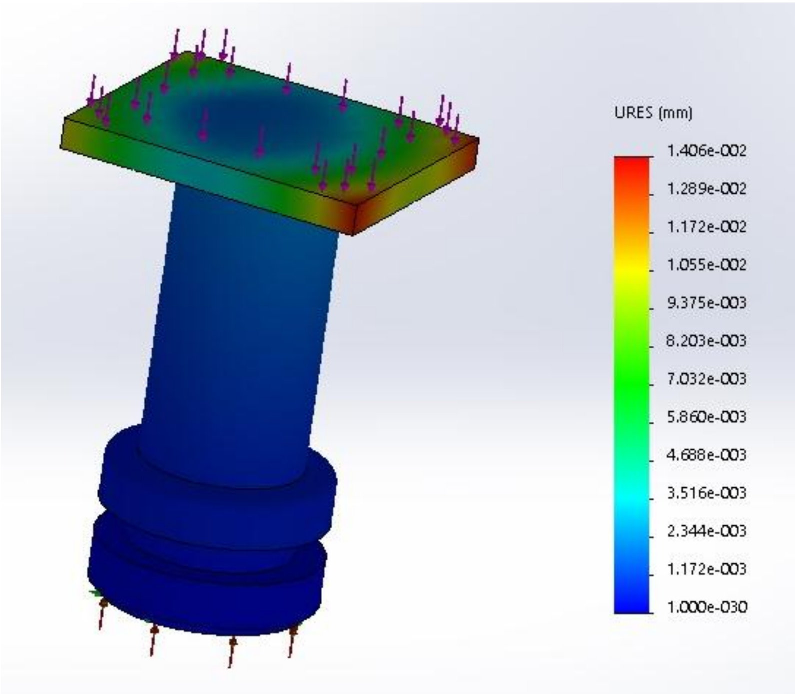



**Figure 4.6: Displacement Analysis of Piston by Car**

In Figure 4.6, the edges of the horizontal plate are the most severe part for car to travel over it frequently. Right hand side of the horizontal plate is the starting point for the car's wheel to touch on it, thus right hand edge of plate shows red colour. It can be said that the edge of it is weak and easily are displaced by car. From the colour reading range, URES represents the displacement resultant in the model. The maximum URES is in red colour, which is indicated as 0.01406 mm. Although the value obtained is small, the severe part has to suffer for long period of usage and the accumulation of the small value in long period will become large. However, at the middle of the horizontal plate is showing that blue colour due to the area is the stanchion for the plate, which prevents the displacement for the entire piston.

### 4.4.2 Displacement Analysis with Motorcycle

Before performing the displacement analysis to the piston, it needs to add on the force from motorcycle to the horizontal plate. The lower part of the piston is inserted by pressure then only can start to perform the mesh and run for the simulation. Figure 4.7 shows the displacement analysis by motorcycle with force of 920 N.

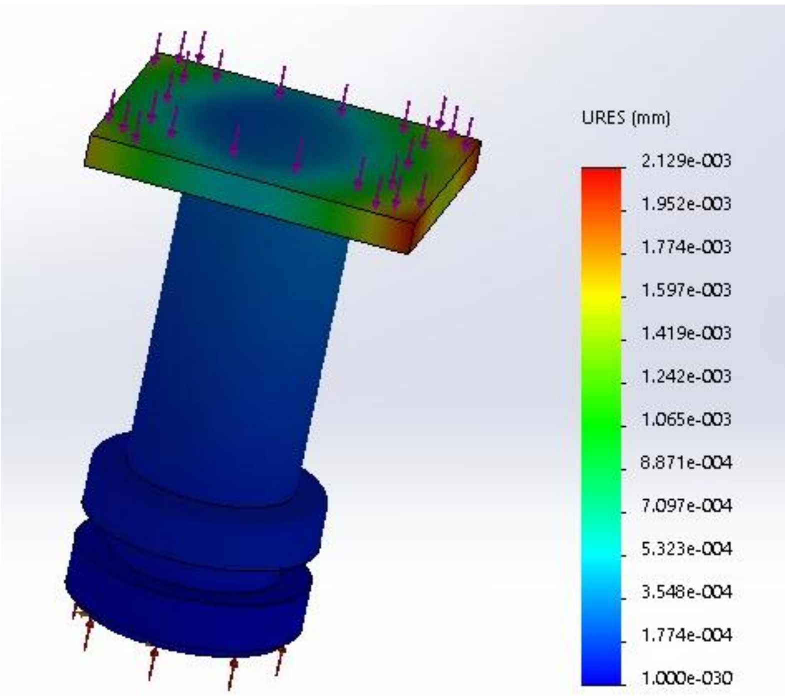



**Figure 4.7: Displacement Analysis of Piston by Motorcycle**

Figure 4.7 shows the maximum URES is 0.002 129 mm. It is mostly distributed around the corner of the horizontal plate. The distribution of the colour is starting from the centre of the horizontal plate to the edges of horizontal plate. The colour changes are starting from blue to light blue, light blue to green, green to yellow, yellow to orange and orange to red. URES is calculated by taking the node at the edge of horizontal plate, which is applying the concept of magnitude vector in three-dimension. It takes the mean magnitude displacement from three-dimension of the corresponding node on model.

### 4.4.3 Comparison about Displacement Analysis between Car and Motorcycle

As in Figure 4.6, the maximum displacement resultant by car to the piston is 0.01406 mm. It is larger than the maximum displacement resultant by motorcycle to the piston. In Figure 4.7, the maximum URES is 0.002129 mm. It can be concluded that the larger the force being exerted to the horizontal plate, the larger the maximum displacement resultant being experienced by the horizontal plate. Therefore, the plate is under burden when there is heavier car travels over it and causes larger displacement to the internal component of this system.

## 4.5 Analysis on Chain Sprocket of Roller Mechanism Speed Breaker

Roller mechanism speed breaker consists of roller, which is attached with large sprocket, and the large sprocket is connected with chain drive to make the rotational for small sprocket. Angular velocity causes the roller to produce rotational to the large sprocket. Angular velocity is related to the linear velocity of moving vehicle. The radius of roller is designed as 0.1 m for this mechanism to provide better performance. Applying the least velocity of 10 m/s to travel over the roller mechanism speed breaker and the calculation is performed below.

By applying equation 4.1,

$$v = r\omega \tag{4.1}$$

where
v = linear velocity, m/s
r = radius of the roller, m
ω = angular velocity, rad/s

From equation 4.1, when linear velocity is 10 m/s,

$$\omega = \frac{v}{r} = \frac{10}{0.1} = 100 \text{ rad/s}$$

$$\because \omega = 2\pi f$$

$$\therefore f = \frac{\omega}{2\pi} = \frac{100}{2\pi} = 15.915 \text{ Hz}$$

Thus, the frequency obtained from the moving vehicle with linear velocity of 10 m/s is 15.915 Hz and it has to insert into the Solidworks simulation to perform the frequency analysis. This is because the vibration of the component within the roller mechanism speed breaker is caused by frequency.

### 4.5.1 Frequency Analysis with Velocity of Moving Car and Motorcycle

As for normal user of the car and motorcycle, velocity with 10 m/s is the reasonable velocity to pass over the slanted speed breaker. It requires the moving vehicle to slow down the velocity.

Figure 4.8 shows the frequency analysis about the vibration for the chain sprocket by moving vehicle at the velocity of 10 m/s.

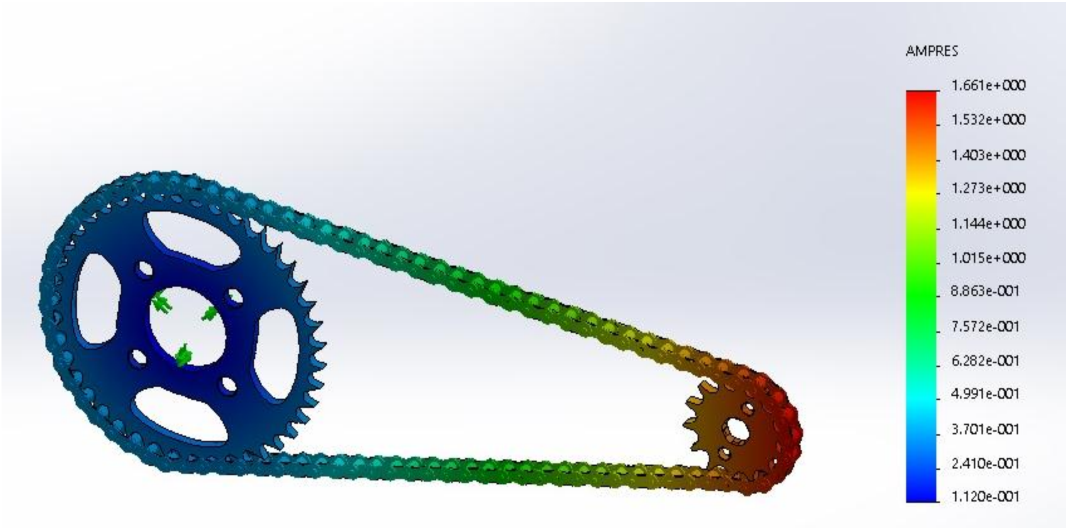



**Figure 4.8: Frequency Analysis at Velocity of 10 m/s**

Figure 4.8 represents the large sprocket is fixed by hinge and the hinge is attached to the roller. The effect of vibration is depending on the linear velocity of moving vehicle. Figure 4.8 shows the vibration of the large sprocket causes the neighbour chain drive to vibrate and at the end of the chain drive is linked by small sprocket. Small sprocket is the component affected by the severe vibration, which is in red colour. AMPRES stands for amplitude resultant of the vibration for this component. However, the large sprocket remained in blue colour due to it is attaching with the roller. It does not affect large vibration as compared to small sprocket.

In contrast, if there is moving car or motorcycle with the linear velocity of 30 m/s travels over the roller mechanism speed breaker, the frequency will be increased and generate large amount of vibration to the chain sprocket. The following detail is the calculation for velocity of vehicle at 30 m/s with radius of roller at 0.1 m.

From equation 4.1,

$$\omega = \frac{v}{r} = \frac{30}{0.1} = 300 \text{ rad/s}$$

$$\because \omega = 2\pi f$$

$$\therefore f = \frac{\omega}{2\pi} = \frac{300}{2\pi} = 47.746 \text{ Hz}$$

Figure 4.9 shows the result of frequency analysis that affected by frequency at 47.746 Hz due to the velocity is increased to the 30 m/s.

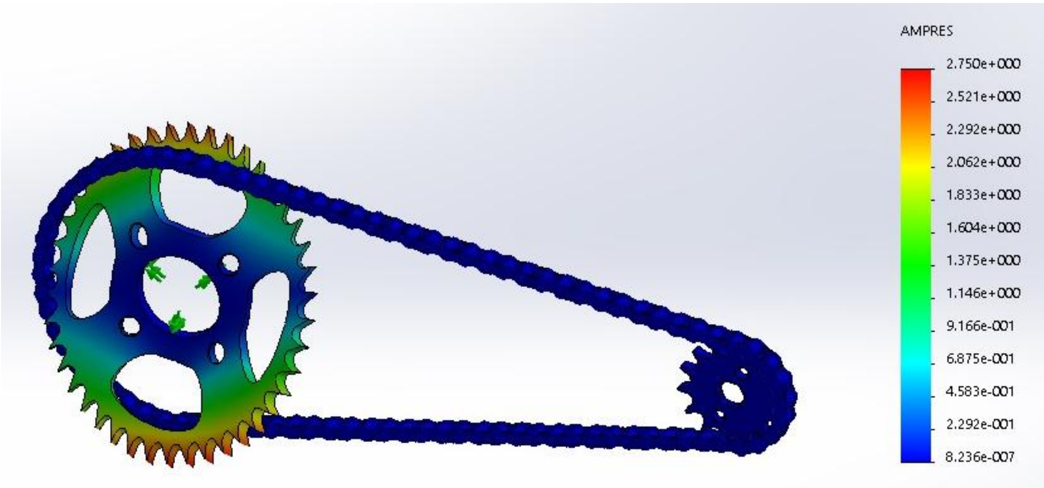



**Figure 4.9: Frequency Analysis at Velocity of 30 m/s**

Figure 4.9 shows the large sprocket was turned out from the chain drive due to the frequency of 47.746 Hz can generate huge amount of vibration to the large sprocket. Thus, the large sprocket is hit to the maximum AMPRES at 2.75 mm. A small deviation of the connection between large sprocket and chain drive causes the phenomenon of the large sprocket turns out from chain drive. The red colour region is distributed at the upper and lower part of the large sprocket. This is because the large sprocket, which is attached with roller, is under compression from car or motorcycle.

### 4.5.2 Comparison about the Various Velocities for Frequency Analysis

Normal velocity of 10 m/s from moving vehicles to the roller mechanism speed breaker does not give much vibration to the internal components for roller mechanism speed breaker. This vibration is fitted for the large sprocket to drive the chain drive and the chain drive makes the rotation to the small sprocket. This is the continuous action for the roller mechanism to generate electricity by the rotation of small sprocket. Small sprocket is attached to the DC generator shaft, which required rotational motion from large sprocket. Thus, Figure 4.8 showed the vibration of small sprocket is larger than large sprocket at normal velocity.

However, when the velocity of moving vehicle is increasing linearly, the vibration, which is affected by the roller, exceeds the limitation. When a higher velocity vehicle passes through roller mechanism speed breaker, the large sprocket, which is attached to the roller, turns out from chain drive. It caused the system down due to the DC generator shaft cannot be rotated anymore. Thus, it is required to perform the maintenance at this scenario. The large sprocket, which is turned out from chain drive, has been shown in Figure 4.9. It is necessary to bear in mind, as the velocity of the moving vehicle cannot be too high. It might cause inconvenience for the technician to fix the internal components of the roller mechanism speed breaker.

## 4.6 Analysis on Surface of Smart Speed Breaker

Surface of smart speed breaker, which needed to contact with moving vehicle, is located at the upper part of the smart speed breaker. The bottom part of the generating system is excluded and left the only upper surface of smart speed breaker to be investigated in different loads and forces, which may cause the degradation to the surface.

### 4.6.1 Fatigue Analysis of Surface from Smart Speed Breaker

When the smart speed breaker is developed continuous, there will be large number of usage on it to generate electricity. By setting the life cycle for the surface of smart speed breaker, it will cause the deterioration to the entire surface and the result is shown in Figure 4.10.

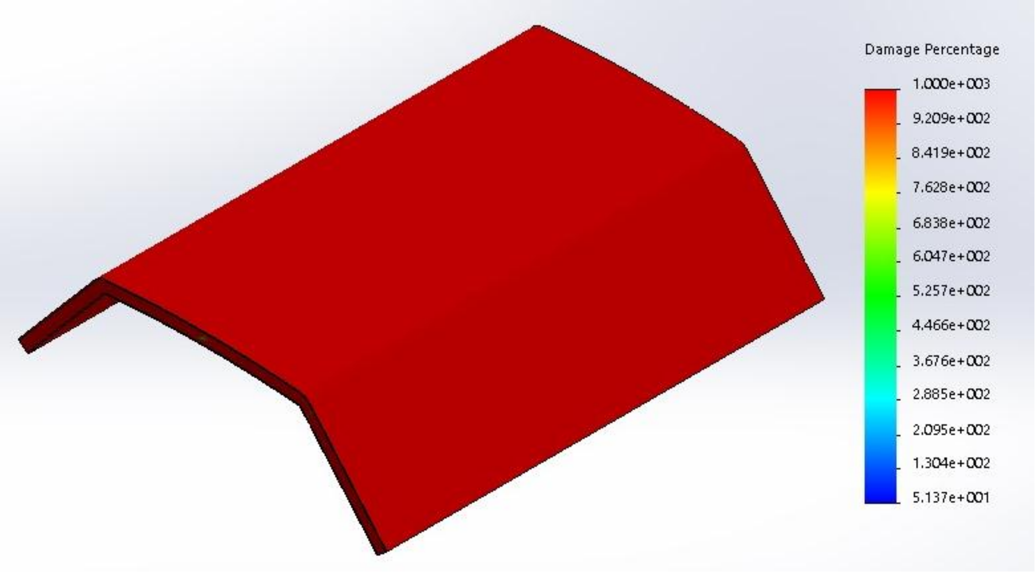



**Figure 4.10: Fatigue Analysis on Surface of Smart Speed Breaker**

Figure 4.10 shows the entire surface of smart speed breaker in in red colour by referring the chart at the right hand side. It stated the Damage Percentage in Figure 4.10 is in between the range of 10 % and 9.209 %. It can be concluded that the surface is completely damaged when the usage for it is increased day by day.

### 4.6.2 Buckling Analysis on Surface of Smart Speed Breaker with Car

Using the same type of car with force of 6100 N to the surface of smart speed breaker, the result has been shown in Figure 4.11.

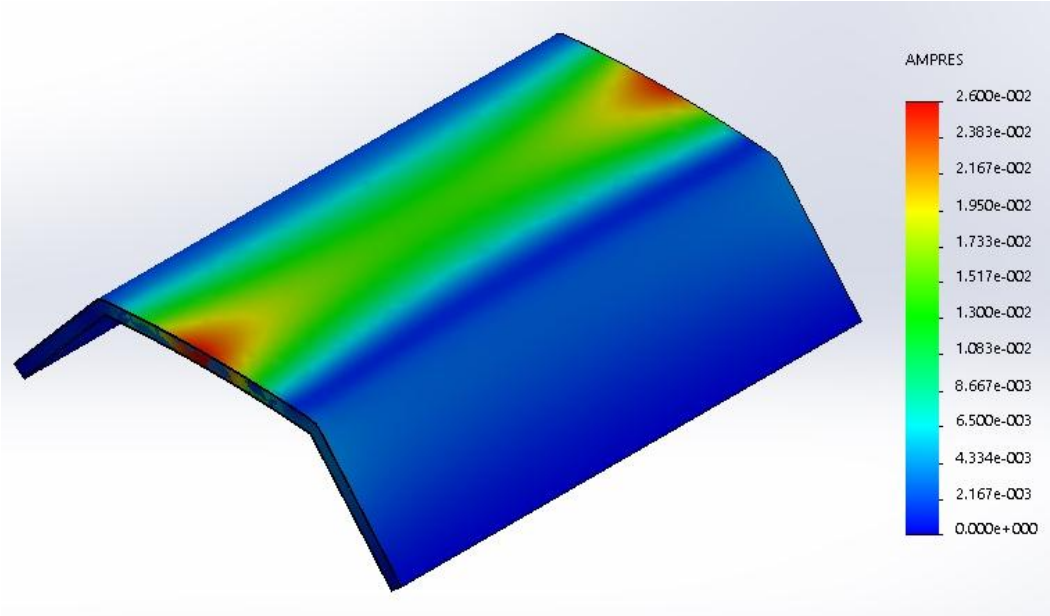



**Figure 4.11: Buckling Analysis on Surface of Smart Breaker by Car**

AMPRES as known as the amplitude resultant is distributed to the entire surface of smart speed breaker. The slope of the surface is not in pure blue colour due to there is some exerted force causing the stress at that region. However, the surface, which is experienced by largest stress, is distributed at the two sides. This is because there are two hydraulic supporters below of the red colour areas. When the force from moving vehicle acted on the upper surface, it caused two supporters generated the reaction force to encounter with the force from surface. Thus, these regions are the most severe stress to the surface of smart speed breaker.

### 4.6.3 Buckling Analysis on Surface of Smart Speed Breaker with Motorcycle

Besides, the surface of smart speed breaker also undergoes for buckling analysis with another type of vehicle, which is motorcycle. Motorcycle has the force of 920 N, which is lesser than the car. Figure 4.12 shows the result for the buckling analysis by motorcycle to the surface of smart speed breaker.

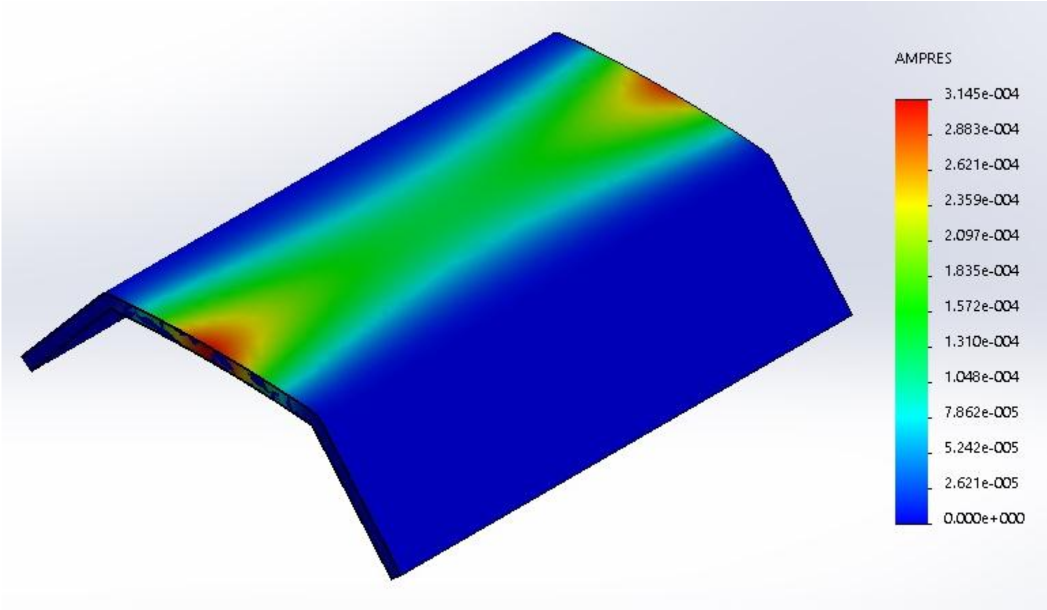



**Figure 4.12: Buckling Analysis on Surface of Smart Speed Breaker by Motorcycle**

As from Figure 4.12, the slanted surface showed in blue colour as these areas do not endure any stress from motorcycle due to the force of motorcycle is small. Besides, the upper surface of smart speed breaker showed the maximum amplitude resultant (AMPRES) at the colour of orange. It does not reach to red colour. Thus, the force from motorcycle does not give much stress to the surface of smart speed breaker.

### 4.6.4 Comparison about the Analysis on Smart Speed Breaker between Car and Motorcycle

Figure 4.12 shows the maximum AMPRES to the surface of smart speed breaker is in depth of 0.3415 mm, which is lesser than the maximum AMPRESS with depth of 26 mm that obtained from Figure 4.11. This is because the total shear stress exerted by the car to the smart speed breaker is larger than the motorcycle.

By applying equation 3.4, total surface area of upper part of smart speed breaker is same for the both cases of motorcycle and car to travel over. The shear stress, $\tau$ is directly proportional to the force applied by motorcycle or car. When the force exerted by vehicle is less, the shear stress contributed to surface of speed breaker will also be less. It can be concluded that the red colour region is lesser in motorcycle than the car. Therefore, it can be said that the motorcycle does not give much stress to the smart speed breaker.

However, when the number of usage for smart speed breaker is high, the structure will be started to degrade and make the surface rougher than before which give more friction for moving vehicles. The degradation of surface of smart speed breaker is distributed among the entire surface of smart speed breaker. From Figure 4.10, the most severe area is the entire surface of smart speed breaker due to the entire surface is under stress by moving vehicles. When the surface of smart speed breaker is damaged, it is necessary to inform the technician to replace the surface in order to recover the electricity generation.

## 4.7 Analysis on Surface of Conventional Speed Breaker

Surface of conventional speed breaker will be in crack situation when the moving vehicles traverse over it frequently. The natural rubber is assigned for surface of conventional speed breaker, as it is the common material to construct the typical speed breaker.

### 4.7.1 Fatigue Analysis of Surface from Conventional Speed Breaker

Conventional speed breaker is the common speed breaker used in low speed zone in order to slow down the moving vehicle in the safety speed. It helps to reduce the number of accident happened per day.

Number of usage for conventional speed breaker is uncountable. By setting the number of cycle usage to the conventional speed breaker, the result is simulated and shown in Figure 4.13.

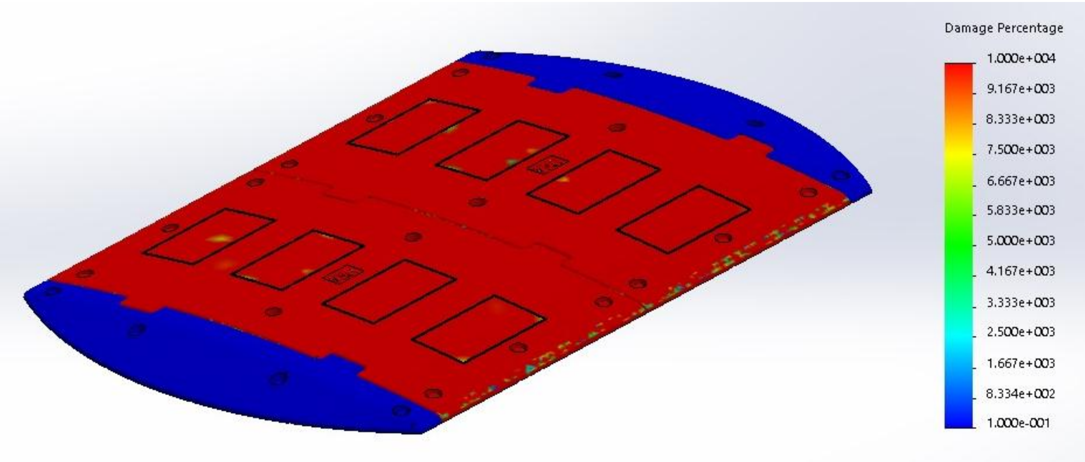



**Figure 4.13: Fatigue Analysis on Surface of Conventional Speed Breaker**

Figure 4.13 shows the middle part of the conventional speed breaker was totally damaged as it is in red colour according to the Damage Percentage reading range. Two sides of the speed breaker are remaining blue due to this region is the least force exerted by moving vehicle. At the red region, it consists of some tiny doted in colour of greenish-yellow. This is because the surface of conventional speed breaker will become rougher surface after long usage.

### 4.7.2 Buckling Analysis on Surface of Typical Speed Breaker with Car

A car with force of 6100 N not only exerts the stress to the surface of conventional speed breaker but also causes the surface to become fracture when large forces and long cycles of usage encounter it.

Figure 4.14 demonstrated the result for the surface of conventional speed breaker when a car traversed over it.

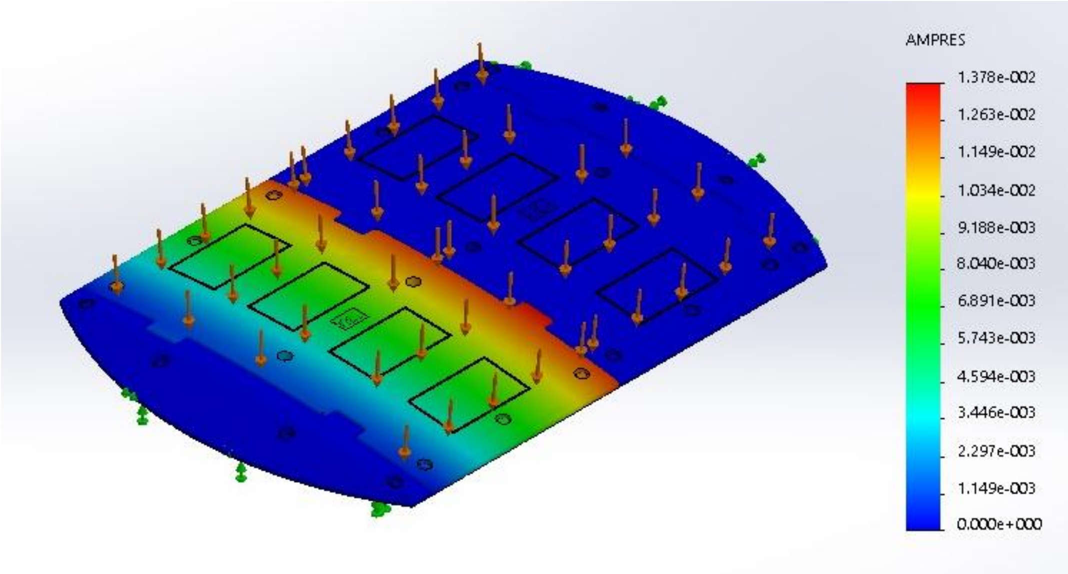



**Figure 4.14: Buckling Analysis on Surface of Typical Speed Breaker by Car**

Figure 4.14 shows the middle part of the conventional speed breaker is in red colour zone due to the region is the inter-connection for the speed breaker with two pieces of natural rubber humps. If this conventional speed breaker continues use for long term of period, it will fracture the middle part of the rubber hump into half.

### 4.7.3 Buckling Analysis on Surface of Typical Speed Breaker with Motorcycle

The total body weight of motorcycle is lighter than the car, therefore the force exerted by motorcycle to surface of conventional speed breaker is also lesser than the car. The conventional speed breaker, which is exerted by the motorcycle's force of 920 N, is executed and shown in Figure 4.15.

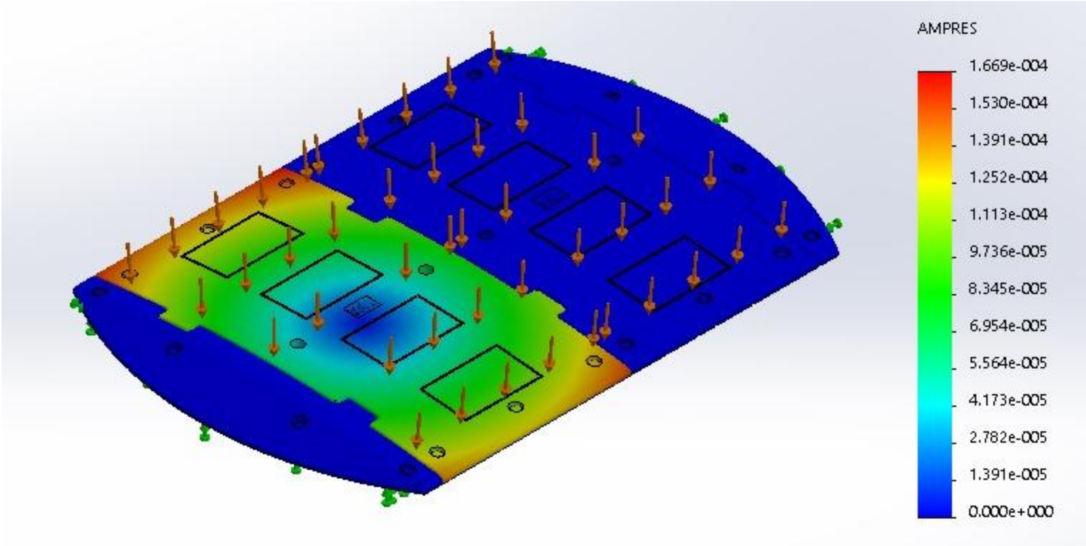



**Figure 4.15: Buckling Analysis on Surface of Typical Speed Breaker by Motorcycle**

There is the red region indicated on the side edge of conventional speed breaker by motorcycle in Figure 4.15. It shows that the tyre width of motorcycle is narrower than car, thus the force distributed to the surface of conventional speed breaker is small. The centre of the hump is suffered the least stress by motorcycle which is in blue colour.

### 4.7.4 Comparison about the Analysis on Conventional Speed Breaker between Car and Motorcycle

Figure 4.14 shows the maximum AMPRES to the surface of speed breaker is in depth of 13.78 mm, which is larger than the maximum AMPRESS with depth of 0.166 9 mm that obtained from Figure 4.15. This is because the total shear stress exerted by the motorcycle to the conventional speed breaker is smaller than the car.

By applying equation 3.4, the shear stress, $\tau$ is directly proportional to the force applied by motorcycle or car. When the force exerted by vehicle is large, the shear stress contributed to surface of speed breaker will also be large. This can be observed from Figure 4.14 and Figure 4.15. It can be concluded that the reading of red colour in case with car is larger than the case with motorcycle. Therefore, it can be said that the car gives much stress to the smart speed breaker.

However, for the long term of usage, the structural of conventional speed breaker no longer to be same as the structural of natural rubber due to the problem of aging. The structural of conventional speed breaker is started to degrade. The result of degradation of the surface of conventional speed breaker is shown in Figure 4.13. It showed the most severe surface is at the middle of speed breaker due to these areas are only the force exerted by moving vehicles. Two sides of conventional speed breaker remain in blue and the purpose of these two sides is used to fix the geometry of the speed breaker by maintaining the conventional speed breaker at original position.

## 4.8 Comparison between Conventional Speed Breaker and Intelligent Speed Breaker

Both of the car and motorcycle can generate the stress to the surface of conventional and intelligent speed breakers. Biaxiality indication defined as the ratio of smallest principal stress to the largest principal stress. The indication set by the parameter is in between value of “-1” to “1”. Pure shear is indicated as “-1” while pure biaxial state is indicated as “1”. At the middle of indication is “0” which is represented as uniaxial stress. The indication helps to provide better study for the distribution of tensile strength for surface of the conventional and intelligent speed breakers.

Figure 4.16 shows the biaxiality indication of motorcycle and car to the intelligent speed breaker.

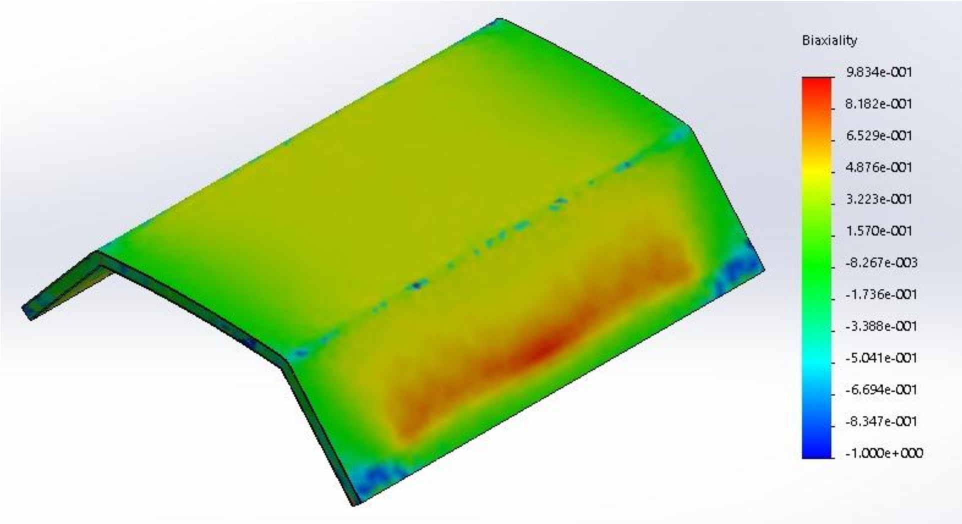



**Figure 4.16: Biaxiality Indication on Surface of Intelligent Speed Breaker**

Figure 4.16 shows majority tensile strength is at the value of between “0” and “1” which is in yellow colour. “0” is indicated as green colour at the sides of the surface. The highest biaxiality range is near to 1 which is distributed at the slanted surface. This is because the region of red colour is the tyre of the moving vehicle started to hit to the surface. Thus, these regions are the nearest region to the pure biaxial state. It is applied by the standard deviation to the location of stress changes.

Besides, there is also the simulated result about the biaxiality indication for the motorcycle and car to the conventional speed breaker in Figure 4.17.

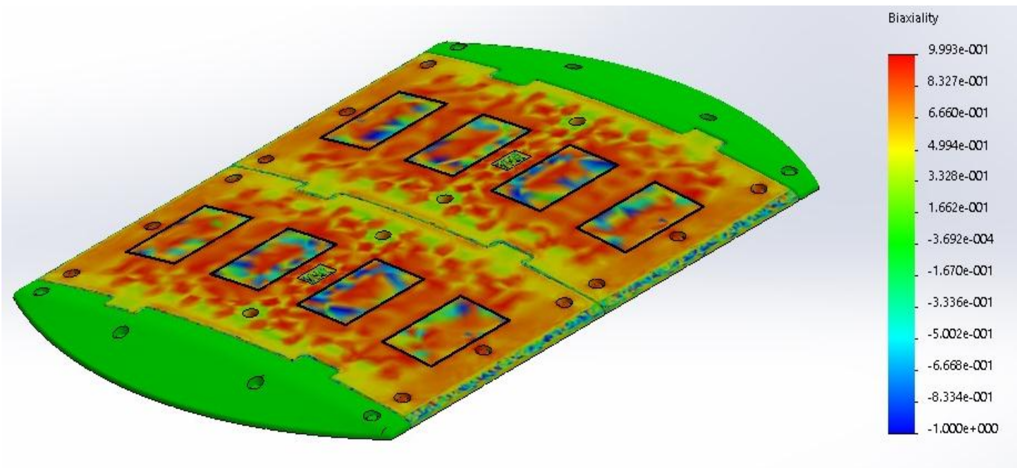



**Figure 4.17: Biaxiality Indication on Surface of Conventional Speed Breaker**

Figure 4.17 shows majority of the surface is under pure uniaxial stress, which is the value around the value of “0”. “0” is indicated as green colour at this scenario. The highest biaxiality range is near to 1 while the lowest tensile strength is at -1. Due to the non-proportional loading to the surface of conventional speed breaker, stress axiality is interpreted in average of the red colour doted region. It is depending on the forces exerted to the given surface of stress changes.

Figure 4.16 and Figure 4.17 indicated the ratio of smallest principal stress to the largest principal stress is in between the range of “0” to “1”. Both conventional and intelligent speed breakers are in between the state of uniaxial stress and pure biaxial state. It is impossible for them to be exist in pure shear state due to the pure shear is situation of the changing on dimension of the surface for both speed breakers. In can be concluded that the intelligent speed breaker can only sustain lower force thus the durability is lower. It provides additional information for the manufacturers of intelligent speed breaker to reduce the fatigue experienced by the speed breaker.

## 4.9 Conclusion

As in above simulation results, the reading of the value is based on the reference of colour changes table. It demonstrated the impacts of speed breakers, which depend on the used materials and the force exerted by the different vehicles. The comparison between motorcycle and car to the specific speed breakers were shown and discussed. There is also the comparison between conventional and intelligent speed breakers, as it needs to be concerned for further improvement.

# CHAPTER 5

# CONCLUSION AND RECOMMENDATIONS

## 5.1 Conclusions

The evaluation of the impacts from conventional speed breaker and intelligent speed breakers based on car and motorcycle have been presented throughout this project. The 3D model of conventional and smart speed breakers as well as internal components within speed breakers are developed by Solidworks. This software is able to acquire the suitable analysis when the force is applied to the models.

Helical spring within the rack and pinion mechanism speed breaker caused a drastic compression with the maximum deflection for the spring. There is the difference between the force exerted by car and motorcycle as the distribution of the contact stress from car has the tremendous increase on the helical spring. It devoted the helical spring fall into failure situation.

Besides, the model of the piston within hydraulic speed breaker is defined as the upper horizontal plate of piston has the response from displacement from moving vehicles. It can be found that the large force causes the most dominant displacement on piston's horizontal plate from car. In contrast, motorcycle does not affect much displacement to the upper part of the piston.

The chain sprocket within roller mechanism speed breaker is affected by over-speed of the moving vehicles, which generates large amount of vibration to it.

Thus, the large sprocket, which is connected with roller, is jumped out from the chain drive and discontinued the electricity generation. The vibration from roller is related to the frequency. When the linear velocity of moving vehicles is high, the frequency will be high and produces large amount of vibration to the entire system.

In addition to, surface of intelligent speed breaker and conventional speed breaker were investigated during the high usage of the period by moving vehicles such as car and motorcycle. Overall deformation to the surface of the speed breakers is occurred at the area, which is affected by the force from vehicles. The area is, affected by stress changes from vehicles, also depending on the width of vehicle's tyre. The wider the basement of the tyre, the larger the stress to be distributed on the surface of the speed breakers.

As in biaxiality simulation, it shows the surface area affected by forces is mostly under uniaxial stress. Most of the damaged node occurs at these areas are near to uniaxial stress range. It is rarely for the damaged spot happened at pure shear due to the pure shear is only happened in the case of torsional loading. Majority of the surface is in pure biaxial state due to there is the angle of 45° in between the rotational of vehicle's wheel and the surface of speed breaker. The motion of wheel was traversed fully on the surface of conventional and intelligent speed breakers. The biaxiality analysis provided the most accurate message for the stress distribution and the surface determination.

It was concluded that the moving vehicles like car and motorcycle with different weight affected the performance of every mechanism of intelligent speed breakers as well as conventional speed hump. All of the analysis such as displacement, fatigue, frequency, stress and buckling is carried out throughout the conventional and intelligent speed breakers have proved the impacts can be observed from Solidworks. Although the impacts observed are small, when the time usage is increased, the results will be the only evidence to clear the doubts of society. In a nutshell, the simulation results proved that the durability of smart speed breakers are lower than the conventional speed breaker.

## 5.2 Contributions

This dissertation has contributed the FEA can evaluate any possible analysis to the model by Solidworks. With the aid of procedures in designing the model and the performance in the simulation, the results can be easily obtained based on the reading of the colour changes in any loading conditions. It required the consumption of time to determine what will happen to the models with higher possibility. Then only can apply FEA by inserting the related parameters to the model. It was the optimum method and the idealized result can be presented by following the guideline in designing the perfect model.

## 5.3 Recommendations

There is always possibility of depth research in designing the intelligent speed breaker as well as conventional speed breaker by improving the mechanical structure. The design work for the models is recommended to consume more in time by constructing the real structure to perform the data survey. The models are suggested to be installed under the road by allowing every type of vehicles to step over it. This method provides better and accurate results to record the data daily as well as determine the possible impacts that make the speed breakers to be fracture and failure in supply traffic energy.

The intelligent speed breaker can be implemented by energy storage system as the storage act as back-up system for traffic energy when there is having the maintenance for the speed breaker. Maximum power output of module, which is converted from mechanical energy to electrical energy, must be taking into consideration to increase the efficiency of the overall system. All of the degradation factors of material from speed breaker are significant to bear in mind due the power output depends on the performance of the intelligent speed breaker. It is necessary to overcome this problem and improve the power output for the overall system.

The materials used by the speed breaker must be in marketable value as the speed breakers have to sustain large amount of force from vehicles with compact mechanisms that yield the high return of investment. By understanding the theory behind the speed breakers, solutions for encountered problems of these impacts must be achieved and carried out to encourage the society accept the new concept of renewable energy system by using the latest technology of traffic energy harvester, which is the smart speed breakers.

# REFERENCES

A. and International, A. (2016). *ASTM C627 - 10 Standard Test Method for Evaluating Ceramic Floor Tile Installation Systems Using the Robinson-Type Floor Tester*. [online] Astm.org. Available at: http://www.astm.org/Standards/C627.htm.

A. B Damor, A., V. H Chaudhari, V., P.M Tadvi, P. and R.R. Patel, R. (2012). An Experimental Study of Generation of Electricity Using Speed Breaker by Hydraulik Mechanism. *IJSR*, 2(11), pp.161-164.

Ahn, K. and Rakha, H. (2009). A field evaluation case study of the environmental and energy impacts of traffic calming. *Transportation Research Part D: Transport and Environment*, 14(6), pp.411-424.

Amol, S. F. (2015). Air Compression and Electricity Generation by Using Speed Breaker with Rack and Pinion Mechanism. *IJMER,* 5(1), pp. 23-28.

Aqsa, A. (2013). Application of Piezoelectric Materials in Smart Roads. *International Journal of Electrical and Computer Engineering*, 3(6), pp. 857-862.

Atkins, Crysttal, and Michael Coleman. (1997). The Influence of Traffic Calming on Emergency Response Times. *ITE Journal*, 67, pp. 42-46.

Archer, J., Fotheringham, N., Symmons, M., Corben, B. (2008). Changes in speed limits and the impact on mobility and the environment. *The Impact of Lowered Speed Limits in Urban and Metropolitan Areas: Monash University Accident Research Centre Report no 276.* Australia: Monash University.

Ben-Edigbe, J. and Mashros, N. (2012). Extent of Highway Capacity Loss Resulting from Road Humps. *IJET*, 4(2), pp.121-125.

Botteldooren, D., Dekoninck, L., and Gillis, D. (2011). The influence of traffic noise on appreciation of the living quality of a neighborhood. *International Journal of Environmental Research and Public Health*, 8, pp. 777-798.

E. A., L., M. E., S., Avila JÃºnior, J., Aureio Silva Carvalho, C., Fernanda Lousada Antunes, M. and Morais Junqueira, D. (2015). Evaluation of Vehicular Discomfort Measures Produced by Speed Bumps Using Numerical Simulation. *jmea*, 5(4), pp.113-123.

Ewing, Reid, and Charles Kooshian. (1997). U.S. Experience with Traffic Calming. *ITE Journal*, 67, pp. 28-33.

Green, M. and Cebon, D. (1997). Dynamic interaction between heavy vehicles and highway bridges. *Computers & Structures*, 62(2), pp.253-264.

Hidas, P., Weerasekera, K., Dunne, M. (1998). Negative effects of mid-block speed control devices and their importance in the overall impact of traffic calming on the environment. *Transportation Research D*, 3(1): 41-50.

Hill, D., Agarwal, A. and Tong, N. (2013). Assessment of piezoelectric materials for roadway energy harvesting: cost of energy and demonstration roadmap. *[Sacramento, Calif.]: California Energy Commission.*

Holler, F. J., Skoog, D. A. and Crouch, S. R. (2007). Principles of Instrumental Analysis. *Cengage Learning*, 6, pp. 9.

Hossain, S., Das, C., Hossan, M. and Jarin, S. (2015). Electricity from Wasted Energy of the Moving Vehicle Using Speed Breaker. *Jurnal Teknologi*, 73(1).

Ilahi, T., Afroz, A., Khan, M., Zafar, A., Bakht, K. and Altaf, S. (2013). Generating Electricity through Harnessing of Kinetic Energy Using a Ramp. *IJMO*, pp.520-522.

ITE Traffic Engineering Council Speed Humps Task Force. (1997). Guidelines for the Design and Application for Speed Humps. *Institute of Transportation Engineers, Washington, D.C.*

Jiang, X., Li, Y., Li, J., Wang, J. and Yao, J. (2014). Piezoelectric energy harvesting from traffic-induced pavement vibrations. *J. Renewable Sustainable Energy*, 6(4), p.043110.

KumarPandey, A., Yadav, S. and Srivastava, T. (2013). Electrifying Roller-Coaster Ride through Speed Breakers. *International Journal of Computer Applications*, 67(21), pp.28-30.

Makarewicz, R., GaÅ‚uszka, M., GoÅ‚Ä™biewski, R. and Kokowski, P. (2012). A study on the influence of humps on road traffic noise. *Acoust. Sci. & Tech.*, 33(5), pp.310-315.

Mallick, R., Chen, B. and Bhowmick, S. (2012). Harvesting heat energy from asphalt pavements: development of and comparison between numerical models and experiment. *International Journal of Sustainable Engineering*, 5(2), pp.159-169.

Montgomery County Fire and Rescue Commission. (2001). The Effects of Speed Humps and Traffic Circles on Responding Fire-Rescue Apparatus in Montgomery County, *MD Executive Summary*. Available at: http://www.co.mo.md.us/dfrs/frc/fc97-1.html.

Novel Speed Bumps Design and Optimization for Vehicles' Energy Recovery in Smart Cities. (2012). *Multidisciplinary Digital Publishing Institute.*

Pirisi, A., Mussetta, M., Grimaccia, F. and Zich, R. (2013). Novel Speed-Bump Design and Optimization for Energy Harvesting from Traffic. *IEEE Trans. Intell. Transport. Syst.*, 14(4), pp.1983-1991.

Piyush, B., Shubham, G., Navneet, R. and Jegadesshwaran, 2014. Generation of Electricity with The Use of Speed Breaker. *International Journal of Advances in Engineering & Technology*. Available at: http://www.e-ijaet.org/media/36I20-IJAET0520963_v7_iss2_589-595.pdf.

Prakash, C., Rao, A. and Srinuvas, P. (2014). Road Power Generation by Speed Breaker. *IJETT*, 11(2), pp.75-78.

Rao, A. (2010). Power Generation from Speed Breaker by Rack and Ratchet Mechanism. *Int.J.of Curr. Engg. and Technol*, 2(2), pp.549-552.

Roess, R.P., Prassa, E. S., McShane, W. R. (2004). Traffic Engineering. *New Jersey, Pearson Education Inc.,* 3.

Rosli, N.S., Kadar Hamsa, A.A. (2013). Evaluating the effects of road hump on traffic volume and noise level at Taman Keramat residential area, Kuala Lumpur. *Proceedings of the Easten Asia Society for Transportation Studies*, 9, p.209.

Sailaja, M., Raja Roy, M. and Kumar, S. (2015). Design of Rack and Pinion Mechanism for Power Generation at Speed Breakers. *IJETT*, 22(8), pp.356-362.

Smith, D., Hallmark, S., Knapp, K. and Thomas, G. (2002). Temporary speed hump impact evaluation. *Ames, Iowa: Center for Transportation Research and Education, Iowa State University.*

Shraddha, D., Bhagyashri, K. and Aashish, J. (2016). Electricity Generation Using Speed Breaker. *IRJET*, 3(2), pp. 738-741.

Tebinka, Richard S. Fargo Traffic Calming Demonstration Project. (2001). Compendium of Papers for the 71st Annual Meeting of Institute for Transportation Engineers. *Institute of Transportation Engineers, Washington, D.C.*

Templeton, John, and Robert E Rees. (2001). Installing and Maintaining Temporary Speed Humps and Traffic Circles. Compendium of Papers for the 71st Annual Meeting of Institute for Transportation Engineers (CD-ROM). *Institute of Transportation Engineers, Chicago,* p.19-22.

Timoshenko, Stephen P. (1983). History of Strength of Material, *Courier Dover Publication*, p. 141. ISBN 0486611876.

Virginia. (2001). Traffic Calming Policy and Devices. *City of Fairfax.* Available at: http://www.ci.fairfax.va.us/services/publicworks/calmingtraffic.htm.

Watts, G. and Krylov, V. (2000). Ground-borne vibration generated by vehicles crossing road humps and speed control cushions. *Applied Acoustics*, 59(3), pp.221-236.

Xiang, H., Wang, J., Shi, Z. and Zhang, Z. (2013). Theoretical analysis of piezoelectric energy harvesting from traffic induced deformation of pavements. *Smart Mater. Struct.*, 22(9), p.095024.

Zannin, P., Diniz, F. and Barbosa, W. (2002). Environmental noise pollution in the city of Curitiba, Brazil. *Applied Acoustics*, 63(4), pp.351-358.

ZHAO, H., LING, J. and YU, J. (2012). A comparative analysis of piezoelectric transducers for harvesting energy from asphalt pavement. *Journal of the Ceramic Society of Japan*, 120(1404), pp.317-323.

# APPENDICES

## APPENDIX A: Specific Terms in Solidworks Software

### Meshing

Finite Element Analysis (FEA) provides a reliable numerical technique for analyzing engineering designs. The process starts with the creation of a geometric model. Then, the program subdivides the model into small pieces of simple shapes (elements) connected at common points (nodes). Finite element analysis programs look at the model as a network of discrete interconnected elements.

The Finite Element Method (FEM) predicts the behavior of the model by combining the information obtained from all elements making up the model.

Meshing is a very crucial step in design analysis. The automatic mesher in the software generates a mesh based on a global element size, tolerance, and local mesh control specifications. Mesh control lets you specify different sizes of elements for components, faces, edges, and vertices.

The software estimates a global element size for the model taking into consideration its volume, surface area, and other geometric details. The size of the generated mesh (number of nodes and elements) depends on the geometry and dimensions of the model, element size, mesh tolerance, mesh control, and contact specifications. In the early stages of design analysis where approximate results may suffice, you can specify a larger element size for a faster solution. For a more accurate solution, a smaller element size may be required.

Meshing generates 3D tetrahedral solid elements, 2D triangular shell elements, and 1D beam elements. A mesh consists of one type of elements unless the mixed mesh type is specified. Solid elements are naturally suitable for bulky models. Shell elements are naturally suitable for modeling thin parts (sheet metals), and beams and trusses are suitable for modeling structural members.

### Frequency Analysis

Every structure has the tendency to vibrate at certain frequencies, called natural or resonant frequencies. Each natural frequency is associated with a certain shape, called mode shape, that the model tends to assume when vibrating at that frequency.

When a structure is properly excited by a dynamic load with a frequency that coincides with one of its natural frequencies, the structure undergoes large displacements and stresses. This phenomenon is known as resonance. For undamped systems, resonance theoretically causes infinite motion. Damping, however, puts a limit on the response of the structures due to resonant loads.

If your design is subjected to dynamic environments, static studies cannot be used to evaluate the response. Frequency studies can help you avoid resonance and design vibration isolation systems. They also form the basis for evaluating the response of linear dynamic systems where the response of a system to a dynamic environment is assumed to be equal to the summation of the contributions of the modes considered in the analysis.

Resonance is desirable in the design of some devices.

A real model has an infinite number of natural frequencies. However, a finite element model has a finite number of natural frequencies that is equal to the number of degrees of freedom considered in the model. Only the first few modes are needed for most purposes.

The natural frequencies and corresponding mode shapes depend on the geometry, material properties, and support conditions. The computation of natural frequencies and mode shapes is known as modal, frequency, and normal mode analysis.

Video: Sample Mode Shapes (animation of the first few modes of a rectangular plate simply supported along its two short edges).

## Linearized Buckling Analysis

Slender models tend to buckle under axial loading. Buckling is defined as the sudden deformation which occurs when the stored membrane (axial) energy is converted into bending energy with no change in the externally applied loads. Mathematically, when buckling occurs, the stiffness becomes singular. The Linearized buckling approach, used here, solves an eigenvalue problem to estimate the critical buckling factors and the associated buckling mode shapes.

A model can buckle in different shapes under different levels of loading. The shape the model takes while buckling is called the buckling mode shape and the loading is called the critical or buckling load. Buckling analysis calculates a number of modes as requested in the Buckling dialog. Designers are usually interested in the lowest mode (mode 1) because it is associated with the lowest critical load. When buckling is the critical design factor, calculating multiple buckling modes helps in locating the weak areas of the model. The mode shapes can help you modify the model or the support system to prevent buckling in a certain mode.

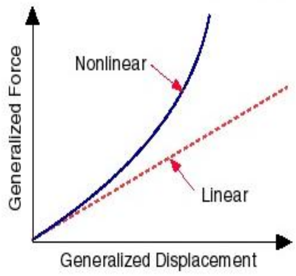
A more vigorous approach to study the behavior of models at and beyond buckling requires the use of nonlinear design analysis codes.

### When to Use Buckling Analysis

Slender parts and assemblies with slender components that are loaded in the axial direction buckle under relatively small axial loads. Such structures can fail due to buckling while the stresses are far below critical levels. For such structures, the buckling load becomes a critical design factor. Buckling analysis is usually not required for bulky structures as failure occurs earlier due to high stresses.

## Nonlinear Static Analysis Overview

Linear static analysis assumes that the relationship between loads and the induced response is linear. For example, if you double the magnitude of loads, the response (displacements, strains, stresses, reaction forces, etc.), will also double.




All real structures behave nonlinearly in one way or another at some level of loading. In some cases, linear analysis may be adequate. In many other cases, the linear solution can produce erroneous results because the assumptions upon which it is based are violated. Nonlinearity can be caused by the material behavior, large displacements, and contact conditions.

You can use a nonlinear study to solve a linear problem. The results can be slightly different due to different procedures.

In the nonlinear static analysis, dynamic effects like inertial and damping forces are not considered. Processing a nonlinear study differs from processing a static study in the following ways:

# When to Use Nonlinear Analysis

Linear analysis is based on the static and linearity assumptions and is, therefore, valid as long as these assumption are valid. When one (or more) of these assumptions fails, linear analysis will produce wrong predictions and nonlinear analysis must be used to model the nonlinearities.

The linearity assumption is true if:

- All the materials in the model comply with Hooke's law, that is stress is directly proportional to strain. Some materials demonstrate such behavior only if the strains are small. As the strains increase, the stress-strain relationships become nonlinear. Other materials display nonlinear behavior even when the strains are small. A material model is a mathematical simulation of the behavior of a material. A material is said to be linear if its stress-strain relations are linear. Linear analysis can be used to analyze models with linear materials assuming that there are no other types of nonlinearities. Linear materials can be isotropic, orthotropic, or anisotropic. Whenever a material in the model demonstrates a nonlinear stress-strain behavior under the specified loading, nonlinear analysis must be used. Nonlinear analysis offers many types of material models.
- The induced displacements are small enough so that you can ignore the change in the stiffness caused by loading. Nonlinear analysis offers a large deformation option when defining the material properties of a solid component or a shell. The stiffness matrix computations can be recomputed at every solution step. The frequency of recalculating the stiffness matrix is controlled by the user.
- Boundary conditions do not vary during the application of loads. Loads must be constant in magnitude, direction, and distribution. They should not change while the model is deforming. For example, contact problems are naturally nonlinear because the boundary conditions change when loading contact occurs. However, linear analysis offers an approximate solution for contact problems where the large deformation effect is considered.

# Fatigue Analysis

It is observed that repeated loading and unloading weakens objects over time even when the induced stresses are considerably less than the allowable stress limits. This phenomenon is known as fatigue. Each cycle of stress fluctuation weakens the object to some extent. After a number of cycles, the object becomes so weak that it fails. Fatigue is the prime cause of the failure of many objects, especially those made of metals. Examples of failure due to fatigue include, rotating machinery, bolts, airplane wings, consumer products, offshore platforms, ships, vehicle axles, bridges, and bones.

Linear and nonlinear structural studies do not predict failure due to fatigue. They calculate the response of a design subjected to a specified environment of restraints and loads. If the analysis assumptions are observed and the calculated stresses are within the allowable limits, they conclude that the design is safe in this environment regardless of how many times the load is applied.

Results of static, nonlinear, or time history linear dynamic studies can be used as the basis for defining a fatigue study. The number of cycles required for fatigue failure to occur at a location depends on the material and the stress fluctuations. This information, for a certain material, is provided by a curve called the SN curve.

## Stages of Failure Due to Fatigue

Failure due to fatigue occurs in three stages:

| | |
|---|---|
| Stage 1 | One or more cracks develop in the material. Cracks can develop anywhere in the material but usually occur on the boundary faces due to higher stress fluctuations. Cracks can occur due to many reasons. Imperfections in the microscopic structure of the materials and surface scratches caused by tooling or handling are some of them. |
| Stage 2 | Some or all the cracks grow as a result of continued loading. |
| Stage 3 | The ability of the design to withstand the applied loads continue to deteriorate until failure occurs. |

Fatigue cracks start on the surface of a material. Strengthening the surfaces of the model increases the life of the model under fatigue events.

## Fatigue Plot PropertyManager

The Fatigue Plot PropertyManager allows you to plot the results of a fatigue study.

To display this PropertyManager, run a static study. Right-click **Results** and select **Define Fatigue Plot**.

### Plot Type

| | |
|---|---|
| **Life** | Available only when the fatigue study is defined with one event.<br><br>Shows the number of cycles (for constant amplitude event studies) or the number of blocks (for variable amplitude studies) that cause fatigue failure at each location. The plot is based on SN curves and the alternating stress at each location. A block is the full load history of a variable amplitude event (including the number of repeats). |
| **Life (Time to failure)** | Available for fatigue studies based on linear dynamic - random vibration results. Shows the expected fatigue life for each location of the part (in the selected units of time).<br><br>The Time to failure is calculated by:<br><br>Life (Time to failure) = Duration of random loading input / cumulative damage ratio<br><br>For example, if a part is subjected to a random vibration loading for a duration of 4 hours, and a time to failure estimate is 2 hours at a certain location, the part is safe from fatigue failure for the first two hours of exposure to the loading. The cumulative damage ratio at the region of interest is 0.5 in this case. Failure can be expected in the part after the first 2 hours of exposure to the particular random vibration environment. |
| **Units of time** | Available for fatigue studies based on linear dynamic - random vibration results. Sets the units of time in: seconds, minutes, hours, or days for the Life (Time to failure plot). |
| **Damage** | This plot shows the percentage of the life of the structure consumed by the defined fatigue events. |
| **Damage (over event duration)**<br>• Percentage<br>• Factor | For fatigue events based on linear dynamic - random vibration results, the damage ratio is calculated over the time duration of the given random loading event. Different values for the duration of the random loading result in different estimates for the part's damage factor.<br><br>You can plot the expected damage ratio due to fatigue as a **percentage** or **factor**. A damage factor of 1.0 (100%) and above indicates that failure can be expected in the part for the given time duration of the random loading. |
| **Load Factor** | Available only when the fatigue study is defined with one event.<br><br>Shows the load factor of safety for fatigue failure at each location. A load factor of safety of 3.5 at a location indicates that the defined fatigue event will cause fatigue failure at this location if you multiply all loads defined for the static study by 3.5. |
| **Biaxiality Indicator** | Plots the ratio of the smaller alternating principal stress (ignoring the alternating principal stress nearest to zero) divided by the larger alternating principal stress. A value of –1.0 indicates pure shear, and a value of 1.0 indicates pure biaxial state.<br><br>This plot can help you determine a fatigue strength reduction factor for the study. |