ENERGY HARVESTING BY TRAFFIC LOADS USING PIEZOELECTRIC NANOGENERATORS ON FLEXIBLE PAVEMENTS, A CASE STUDY OF NUST H-12, ISLAMABAD

FINAL YEAR PROJECT UG 2014

By

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National University of Science and Technology, Islamabad, Pakistan

2018

This is to certify that the

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Has been accepted towards the requirements

For the award of Bachelor's degree

In

CIVIL ENGINEERING

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ABSTRACT

Pakistan is facing serious energy crisis since last decade. Motivation is to eliminate this curse of energy crisis as soon as possible. Efforts are being made to fight for energy crisis at earliest. Unfortunately, being a third world country we are concentrating on producing energy at the cost of environment. To meet a single demand we are utilizing a number of other resources.

Our research focuses on energy harvesting by vehicular loads using piezoelectric Nano-generators. We are not going to utilize any other additional resource rather we are engaged in capturing the energy which is being wasted at a very large scale. This form of energy is using the kinetic energy and load of the vehicles to generate electricity using piezoelectric material which converts the vehicular loads into electrical energy by distribution of electrical charges.

Pakistan emphasize on generating electricity from old-style means of hydropower, coal, thermal and nuclear. Our aim is to produce electricity by new means, as this method is becoming a source of attraction in modern world.

Before we started our project, we are well aware of the fact that this method of generating electricity is totally new in Pakistan. We are also well aware of the statistics that because of CPEC new roads are under construction. We are much motivated to propose this model at National level once we succeed in achieving the desired results. This has enabled us to gain an insight in to the problems and shortcomings faced by the energy sector in general.

DEDICATION

We would like to dedicate this project to our parents. It is only through their consistent and unwavering support that we have been able to come this far not only in our academics but also as responsible members of the society. We cannot even begin to imagine the sacrifices that they have made in order for us to follow our dreams and aspirations. Although we can never repay what they have done for us, we hope to one day be able to live up to their expectations and make them proud.

DECLARATION

It is hereby solemnly and sincerely declared that the work referred to this thesis project has not been used by any other university or institute of learning as part of another qualification or degree. The research carried out and dissertation prepared was consistent with normal supervisory practice and all the external sources of information used have been acknowledged.

ACKNOWLEDGEMENTS

"In the name of Almighty Allah, the Most Beneficent, the Most Merciful"

We are very grateful to Allah Almighty, for providing us the strength, perseverance, self-denial, hard work, and the patience to successfully complete this project.

We would like to thank Lec. Kamran Shakir for his guidance and supervision during the project. As our advisor, Lec. Kamran Shakir helped us a lot to manage out things. We are very grateful to him, and consider ourselves lucky to have worked under his professional supervision.

Lec. Ibtesam Latif also helped us throughout the duration of project. He was always available to help us, providing us with all the required information regarding Electrical Engineering. We are very grateful to Ibtesam Latif for providing his services.

Furthermore, we are very thankful to Dr. Usman for continuously guiding us regarding Piezo-electric material, its availability in Pakistan, its working principle and its efficiency.

We would also like to acknowledge lab incharge Zaeem Sheikh for his continuous guidance regarding the design of pavement.

At last we would like to thank School of Civil and Environmental Engineering, NUST, for supplying the resources and information required to achieve our goals and for successfully executing our project.

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CHAPTER 1

1. INTRODUCTION

1.1 PROBLEM STATEMENT

The average shortfall in the power sector is 4,000 MegaWatts, and nearly two billion cubic feet per day (BCFD) in the natural gas sector. The shortfall in the power sector can rise to around 7,000MW or 32pc of total demand for electricity. Chronic power shortage, in the form of load-shedding and power outages, costed the Pakistan economy Rs14 billion (7pc of GDP) last year. It has been estimated that about 140 million Pakistanis either have no access to electricity or they have to face severe load shedding of about 12 hours and over daily. Pakistanis who do not have access to the grid are often poorer than those on the grid. Meanwhile, household electricity consumption has grown at an average annual rate of 10pc yearly. Due to energy shortages in Pakistan about 500,000 households are unemployed as businesses have been forced to shut down in order to cater for energy shortages.(Source: Dawn News, 6 August 2016)

Fig.(1) shows the installed capacity and maximum electricity demand for Pakistan over the last few years.

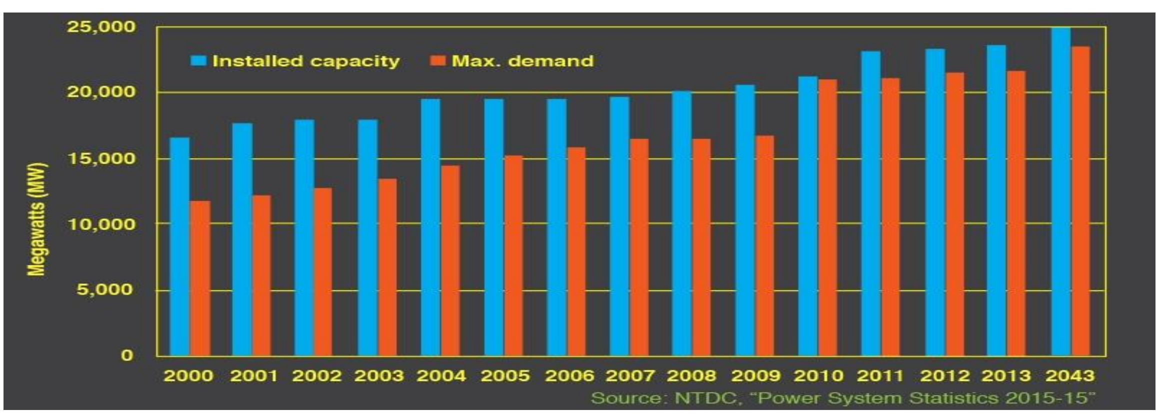


Figure 1-Energy Capacity and Demand

Because of the energy crises in Pakistan there is a need to carry out research on renewable energy sources. Thus, we decided to carry out research on this topic because our country is facing energy crisis, due to which the inclination is not much towards renewable energy resources. And the conventional resources are depleting as well as causing damage to the environment. Secondly, the population of country is increasing resulting in high energy demand. Therefore, creativity matters much in this situation as our traffic and its congestions is increasing day by day, due to an increase in the ownership of vehicles by the people, and thus we find a way to utilize the vehicular loads' energy that could be a great idea.

In this research, harvesting vehicular loads energy by converting it into electricity energy would be the main focus. Our aim is to implement this whole idea using NUST as a model, analyzing our results and further increasing its scope.

1.2 INSTALLED CAPACITY AND MAXIMUM DEMAND FOR ELECTRICITY

In the last five years, losses occurring due to inefficient transmission and distribution have taken a hit of Rs 145 billion per annum. Investment in the power sector has fallen to 0.7pc of the GDP in the last 10 years, from a high of 1.5pc during the 1980s and 1990s. Rs30 billion is the approximate expenditure by Pakistani households on UPS and battery chargers alone. To cater for energy shortages about 60pc of Pakistanis have some sort of energy backups for selected appliances during power cuts and shortages, UPS is the common one. Backup power sources are a stopgap solution, both wasteful and inefficient. 17% of total electricity used in Pakistan can be saved through conservation and efficiency measures. In spite of the fact that the administration is endeavoring to add ability to the network with a specific end goal to cure the determined power lack, these measure will set aside opportunity to become effective. A standout amongst other options is to move to sustainable types of vitality, for example, wind and sunlight. Another inexhaustible type of vitality is utilizing the mechanical vitality and heap of the autos to create power utilizing piezoelectric material which changes over the vehicular burdens into electrical vitality by conveyance of electrical charges. Thus, harvesting of energy is possible.

1.3 OBJECTIVE

There are two ways of generating energy from vehicular movement:

a) Traditional way of converting kinetic energy of vehicles into mechanical energy and then mechanical energy is further converted into electrical energy using shaft and generator system.
b) Second way is to convert kinetic energy of vehicles directly into electrical energy using PZT sensors.

The purpose of our study is to:

1. Harvest energy from vehicular movement using Piezoelectric Nano generators.
2. Design and propose a system for NUST H-12 campus.
3. Design and embed the system with current pavement design and situation.

Our emphasis is on second way of generating electricity as losses are minimum in this regard, because it does not involve any shaft system. We are using NUST as a model to test our study results and the material which we are going to use is known as “PZT”. Sole purpose is to convert maximum amount of kinetic energy into electrical energy using PZT material Fig.(2), in order to contribute to NUST energy reserves. The solution is supposed to be cost-effective and it must not affect the life span of asphalt pavements. Moreover, it must not add to the fatigue or effort of vehicles crossing it. We will also propose optimum position of placing PZT material after testing, by placing it at various locations in pavement design.

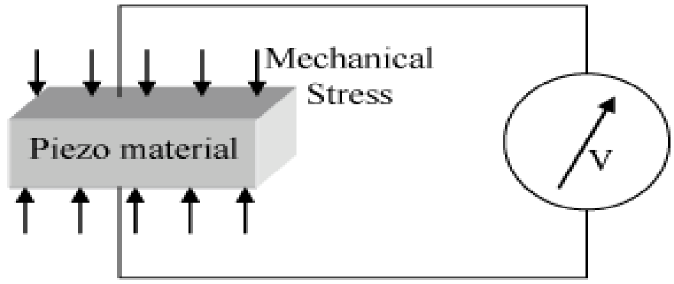


Figure 2-Piezoelectric Material

1.4 REASON FOR SELECTION OF TOPIC

In this age of technology the world is moving towards sustainability and new ways to suffice for the energy demands. Therefore, day by day new methods of energy production are being invented. Being a developing nation, we are in need of a method which utilizes minimum resources and produces maximum outcome. Thus, to strive for this purpose we are focusing towards energy harvesting by traffic loads using piezoelectric Nano-generators. Our aim is to preserve kinetic energy of vehicles which could otherwise be wasted.

After a couple of brainstorming sessions all of the group members proposed different ideas and the ingredients that remain common in proposals were energy efficiency and sustainability. We selected this topic because it was a feasible and doable work that contained both of the above stated parameters. And the project will contribute to energy reservoir without disturbing the current environment and is sustainable if applied well.

1.5 ADVANTAGES AND EDUCATIONAL BENEFITS

At NUST level, we are confident enough to contribute towards NUST energy reservoir without conceding any further consumption of natural resources. It will not only reduce its burden of electricity bill but it will also help in culminating the curse of load shedding.

We will become well aware of how to convert kinetic energy into electrical energy and how to sustain environment. Furthermore, we are not making our lives easy by consuming resources of our future generations; rather we are focusing on environmental, economic and social sustainability. As sustainability states "development that meets the needs of present without compromising the ability of future generations to meet their own needs"

1.6 AREA OF APPLICATION

In our project we are using NUST flexible pavements as a model. If the analysis along with the experimentation goes well, this will help in making the pavements with energy producing material keeping in view slight changes in the existing design. This will further evolve the pavement structure for efficient energy production on highways.

Our focus is neither to add to the fatigue life of vehicles nor to reduce the working life of pavement. We will recommend a design by keeping in mind the above mentioned constraints. Later on, we will not only implement our project with in NUST but we will also put forward the new design at National level, in order to contribute as a responsible citizen of Pakistan.

1.7 SCOPE OF STUDY

Due to advancements in university, it is growing day by day resulting in more expenses at all levels i.e : electricity. So, our focus is to contribute towards electricity generation and its conservation by possible means. By converting the loads of vehicles at NUST into electricity it is possible to lessen the burden of expenses, the university spends on electricity.

Energy that is wasted in pavement damage can be used to make electricity. This energy can also be amplified and boosted. Research shows that 1lane of 1km highway, with truck volume 600v/hr can generate about 150kW/hr. (Zhao, Tao, Niu, & Ling, 2014). Another research carried out concluded that power generation from roads had minimal LEF (levelised energy cost)

In comparison to solar one which is the main source of renewable energy 0.455AED/kW/hr. This system is cost effective and efficient as compared to other sources of renewable energy application. (Najini & Muthukumaraswamy, 2017).

1.8 MATERIAL INTRODUCTION

The piezoelectric effect was initially found by curie. The word ‘piezo’ on its own implies pressure which was derived from the Greek, while electric alludes to electricity or power. This form of electricity is produced when the precious stones such as the crystals with a piezoelectric nature are pressurized, an electric field is produced. Curie found that voltage can be seen when the crystals are squeezed, this is known as the piezoelectric effect. Piezoelectric materials are classified into two main types: the naturally occurring and the synthetic elements. Natural ones are namely quartz, tourmaline and Rochelle salt. While crystals, polymers and ceramics are artificially made. The man-made chemically obtained polycrystalline ferroelectric materials tend to produce more electricity.

Figure 3-PZT Sensor

Piezoelectric material Is polarized using strong electric field. Even after removal, there will be strong amounts of polarization. In order to maintain electric neutrality of the material, free charges will be absorbed on the polarization surface. When force is applied, material undergoes deformation, free charge is released to maintain neutrality, these charges can move in a route if connected and hence generate a current. Lead zirconate titanate PZT is the most popular material that has piezoelectric effects.

Because of moving vehicles every day, asphalt bears the heap of a huge number of vehicles in its service life. Because of the heap of vehicles stretch, strain, disfigurement and vibration happens in asphalt as shown in Fig.(4). In the meantime, the asphalt gets strain and kinetic energies from load of vehicle. Piezoelectric energy generation uses the strain caused by vehicles over pavement surface because of gravity and harnessing kinetic energy or vibrations with a specific end goal to catch and Harness such an energy, a piezoelectric transducer by nature is an ideal gadget as piezoelectric materials respond to 'Pressure' to deliver electrical yield.

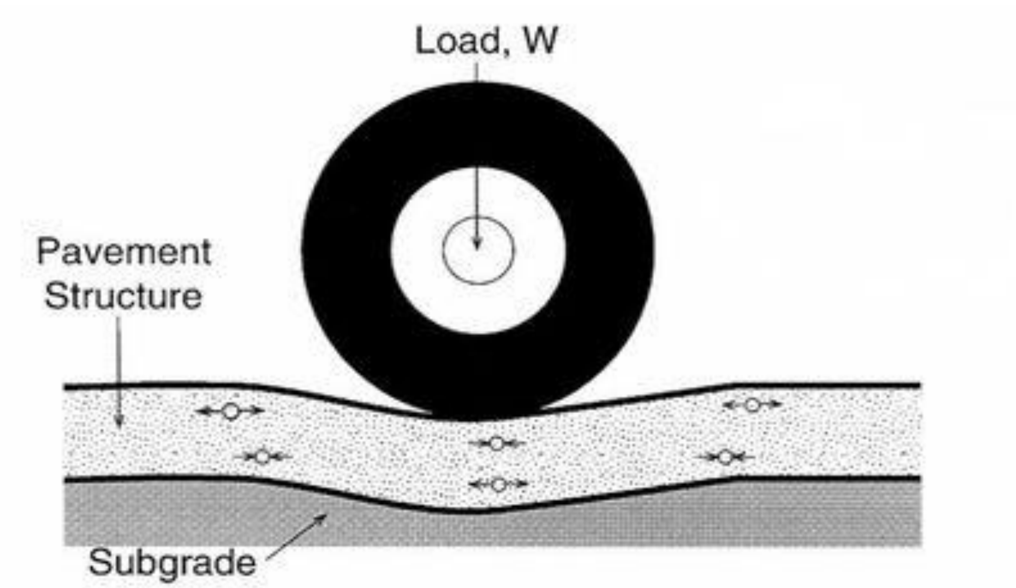


Figure 4-Pavement Behavior Under Loading

CHAPTER 2

2. LITERATURE REVIEW

It is possible to convert the mechanical energy of vehicles that is lost as heat and pavement damage to electricity. Piezoelectric technology is the most potential one because of its ability to convert stress into electricity.

The first time in 2009, a pilot project was constructed by Innowattech-an Israel based company. (Zhao et al., 2014)

There is a potential level of mechanical energy in asphalt pavements. A pavement generator with high converting efficiency is used to couple with pavements to serve the purpose; the amount of potential mechanical energy in the asphalt pavements equal to the work done by the vehicle tyres.

The amount of energy can be estimated by having a look at the vehicle loads and displacements. The contact stress between tyre and asphalt pavements equal .7MPa. Stress, strain and displacement can be analyzed by software's such as BISAR, OPEN PAVE, FINITE ELEMENT ANALYSIS.

It is deduced that 1lane of 1km highway, with truck volume 600v/hr can generate about 150KW/hr. this energy is disable for harvesting. The result of this paper conclude that PZT pile and multilayer have the highest k and ¥max (Zhao et al., 2014). This means that it has a higher compatibility with asphalt pavement and more ability to convert stress to electric energy. Also, it says that a structure is designed to magnify the stress as larger energy is the output of large stress.

2.1 SELECTING THE RIGHT MATERIAL

Asphalt road comprises of finer gravel and a structure almost similar to cement roads. PEG has to be highly sensitive and closer to impact in theory. When different piezoelectric material was compared, the most compatible was selected using finite element analysis.

Two main types of implementation of the PEG were considered:

1. The cantilever beam type implementation such as a bimorph with the tip mass. Fig.(5)

2. Piezoelectric transducers in pavements. Fig.(6)

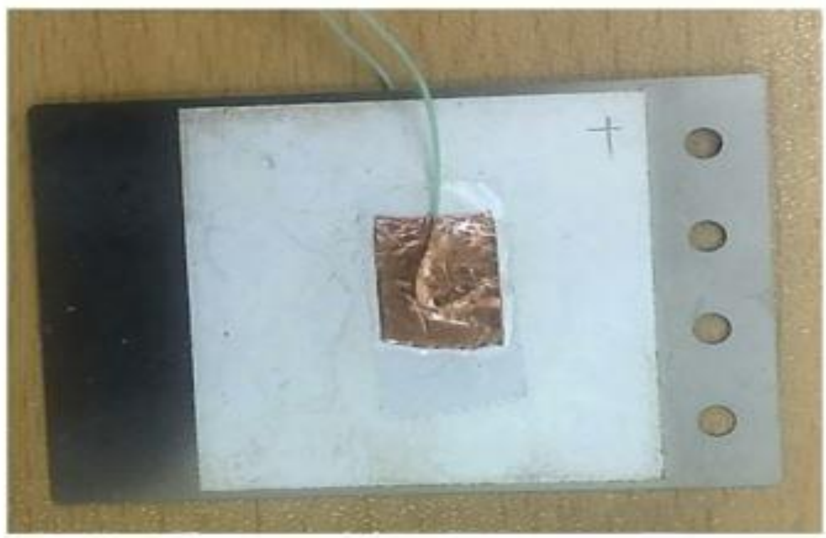


Figure 5-Piezoelectric Cantilever Beam

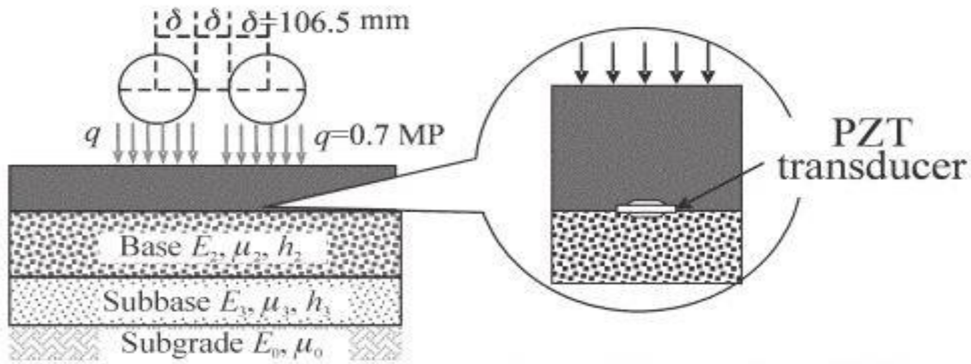


Figure 6-Concept of Embedding PZT Transducer in Pavement

PEGs have the advantage over the other means energy harvester system such as turbines that they don't have a complex system and it doesn't even require fuel or rotating shafts. According to this study, lead zirconate titanate is the best because it's the soundest synthetically produced crystal. Amongst all, PZT-5H exhibits the highest piezoelectric properties and its design could yield upto 150kw/hr depending upon the speed and flow of traffic. (Najini & Muthukumaraswamy, 2016).

Results stated that PZT piles and multilayer, concave plates of brasses that makes up the transducer to bridge the piles together has the potential of working under the asphalt environment for certain. Also, these generators can be improvised as sensors that are within the pavement to monitor the traffic, pavement stress and the temperature. In this study, it is stated that the vertical displacement of the PZT decreases with the increased strength of the road structure. (Zhao et al., 2014)

Also, it is stated that PZT transducers placed directly into the pavement produced less amount of energy as compared to PZTs placed at 5cm level below the road surface (difference being of more than 50kW/hr energy under heavy conditions). (Zhao et al., 2014)

The foundation structure of the pavement is altered so that it behaves like a plate; methodology being used is the classic plate theory, Fourier analysis, Cauchy's residue theorem and so on. Combining these and implementing these is better that the bimorph structure implementation as it provides a spring-like structure to maximize the output power generated by amplifying the impact signal. (Najini & Muthukumaraswamy, 2016).

2.2 WORKING

The first stage of designing used classic plate theory as a base structure to build up the formulation of the structure. Further research was done as to how to attain increased levels of kinetic energy absorption. Economic viability has been checked by establishing a Simulink model with real safety systems and then by using estimated energy production to estimate the cost of investment, ROI and interest-rate-of-return. Lastly brief levelised energy cost [LEC] computations were carried out to justify the relevance of proposed system to existing technology. The outcomes were then inspected to help accompanying conclusions.

This method of harvesting electricity is ideal for developed countries as the installation process requires revenue and the power generated has high voltage which requires proper transmission installation.

Piezoelectric generator➡ rectifier➡ DC-DC booster➡ inverter street lights, traffic signals and radar +grid Fig.(7)

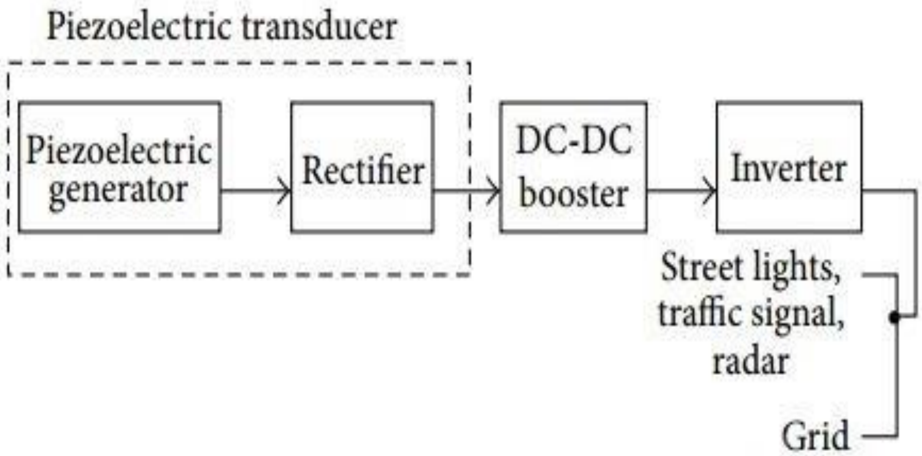


Figure 7-Process Flow Diagram

The generator converts mechanical input into electrical input. This power is rectified. This power is then ‘doubled’ in the next process. This power is then converted to AC before being supplied to grid for further transmission.

This invertor circuitry is also used to step up the AC voltage up to a frequency of that is feasible and standardized to the grid frequency range for further transmission.

This paper is based on the analysis done on the data of Dubai. It was concluded by the research that piezoelectric transducer was able to produce .137W from a four-wheeled vehicle with a travelling speed of 100kmph that is 30m/s. Similarly, the power generation was .085W and .204W when the speed of travel was 80kmph and 120kmph. The number of piezometer devices for 1km long road was 3280 as per Specified dimensions. (Najini & Muthukumaraswamy, 2016). Table.(1) has been attached containing all the required information including number of piezoelectric transducers, speed of vehicles, traffic rate per hour and total power generation.(Najini & Muthukumaraswamy, 2017)

Table 1- Power Estimation From One-Km Road

Power estimation from one-kilometer stretch road.

Number of piezoelectric transducers	3280
Traffic rate per hour	500
Speed of travel (kmph)	100
Load traffic rate	444.44
Traffic rate per minute	8.333
Power/piezo/vehicles/km	0.137
Total power/piezo/km/hr	57.083
Total power (Wmin)	3120.556
Total power (kWhr)	187.233

Table.(2) contains the power generation summary of the same research which has been conducted in DUBAI in 2016. Table shows the both peak time and peak-off time energy generation.(Najini & Muthukumaraswamy, 2017)

Table 2-Power Generation Summary

Total power generation summary.

Duration	Traffic rate/hr	Speed of travel (kmph)	Energy generated (kWhr)
Peak time	500	60	73.55
		80	136.8
		100	254.2
		120	469.04
	300	60	60.81
		80	105.78
		100	183.024
		120	281.424
Off-peak time	100	60	20.81
		80	35.26
		100	61.01
		120	93.81
	50	60	10.4
		80	17.63
		100	30.51
		120	46.91
Peak time	400	60	76.782
		80	136.83
		100	244.03
		120	375.23
	200	60	40.76
		80	70.52
		100	122.02
		120	187.62
Off-peak time	25	100	15.252
		80	8.825
		120	23.452
	100	60	20.81
		80	35.26
		100	61.01
		120	93.81

Once the power analysis was conducted, its findings stated that power losses occurred due to the different components of the system. And not all kinetic energy produced is transformed into useful electrical energy.

The governing formula:

$$Load\ Intensity = \frac{Mass\ of\ vehicle * coefficient\ of\ rolling\ friction * Contact\ tires}{Area\ of\ contact * Speed\ of\ travel}$$

When the economic analysis was Carried out, its findings declared that the propose rate of return was 90% when the speed of travel was 80kmph and 100% for 120kmph. At both times, AED 550000 loan was taken at an interest rate of 7%. Also, it was found out that power generation from the proposed system has minimal LEC (levelised energy cost); is cost effective and efficient in comparison to solar and other renewable resources.(Najini & Muthukumaraswamy, 2016)

Table 3-Research Paper's Summary

Sr. No.	Paper Author	Paper Year	Paper Title	Summary
1.	ZHAO Hongduo, TAO Yuji and others	2014-Korea	Harvesting energy from Asphalt pavement by Piezoelectric generator	• A study has been conducted in which PZT sensors are used as Cantilever Beam. • Frequency analysis has been performed in order to match the natural frequency of material with the vibration of pavement.
2.	Yeoung Saung, Chan Ho yong , Seong Kwang Hong and others	2016-Dubai	Road energy harvester designed as a macro-power source using the piezoelectric effect.	• A study has been conducted and results were simulated. • No practical work has been done. • PZT transducers have been used. • Power generation summary shows that it has ability to generate 187 kW/h/km of electricity.
3.	Amir H. Alavu, Hassene Hasni, Nizar Lajnef, Karim Chatti	2016-Michigan State University USA	Continuous health Monitoring of pavement system using smart sensing technology	• Method to use PZT sensors for pavement health monitoring. • How to encapsulate sensors. • Continuous health monitoring. • Possibility of damage and its severity via sensors.
4.	Hiba Najini, Senthil Arumugam Muthukumarasamwamy	2017-Dubai	Piezoelectric Energy Generation from vehicle Traffic with Techno economic Analysis	• Generation of energy from Vehicular loads using PZT. • Practicability and feasibility of material. • Power generation results. • Cost-Benefit analysis and Pay-back period analysis.

CHAPTER 3

3. RESEARCH METHODOLGY

3.1 GENERAL

A brief Research methodology was used in the process which was initiated with identifying the critical locations of heavy traffic flow in NUST premises such as entrances at Gate 1 and 10 and common junctions such as Zainab Chowk and Iqbal square. Then traffic data count of these locations were measured and tabulated in the forms.

We have studied previous research papers and studied their practicality and applications in Pakistan. We will study behavior using different parameters of typical pavement structure under different loading conditions. We will study stress, strain analysis of PZT material based on various loading conditions. Then we will propose the best possible view of laying out Piezoelectric Energy Harvester and seeing the results it gives depending on which further methodology will prevail. After that we will identify optimum position of PZT material in Asphalt pavement and effect of laying it in the pavement design. Later on, we will see comparison of peak time and peak off time data and perform analysis on that which would help us further identifying the position and placement of the material and its benefits in harvesting of the energy. Furthermore, we will study frequency analysis and its equation and thus calculating the Payback period. And in the end we will also perform cost-benefit (economic) analysis which would tell us whether it’s feasible to install the material in NUST with the cost it, the material, comes and the benefit it give or not!

Flowchart of our research methodology is attached below.

3.2 FLOWCHART

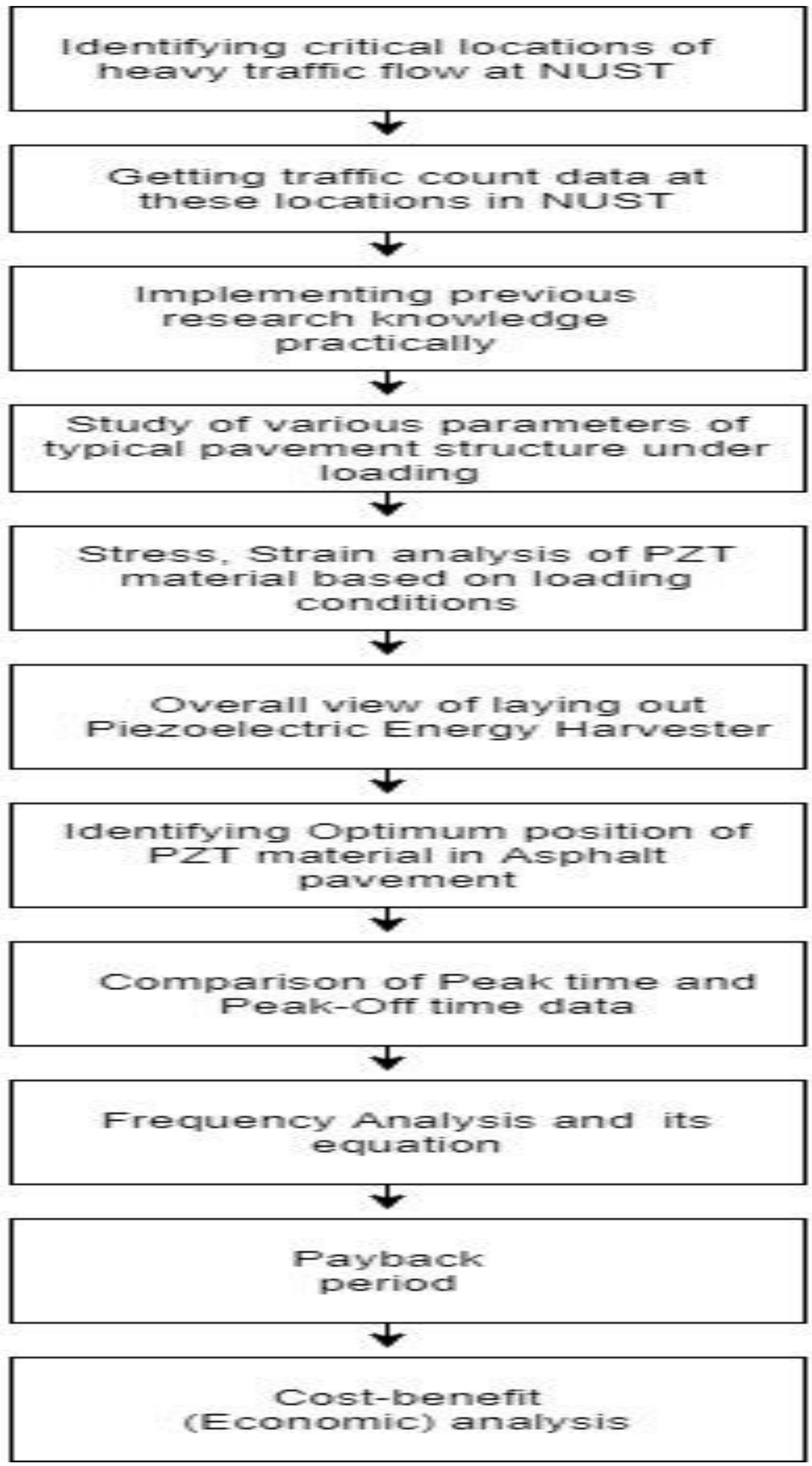


Figure 8-Flow Chart Of Methodology

3.2.1 IDENTIFYING CRITICAL LOCATIONS OF HEAVY TRAFFIC AT NUST

In this section, we have highlighted the critical locations with respect to traffic in NUST. By critical we mean the locations' having maximum traffic flow. Following locations have been identified as critical.

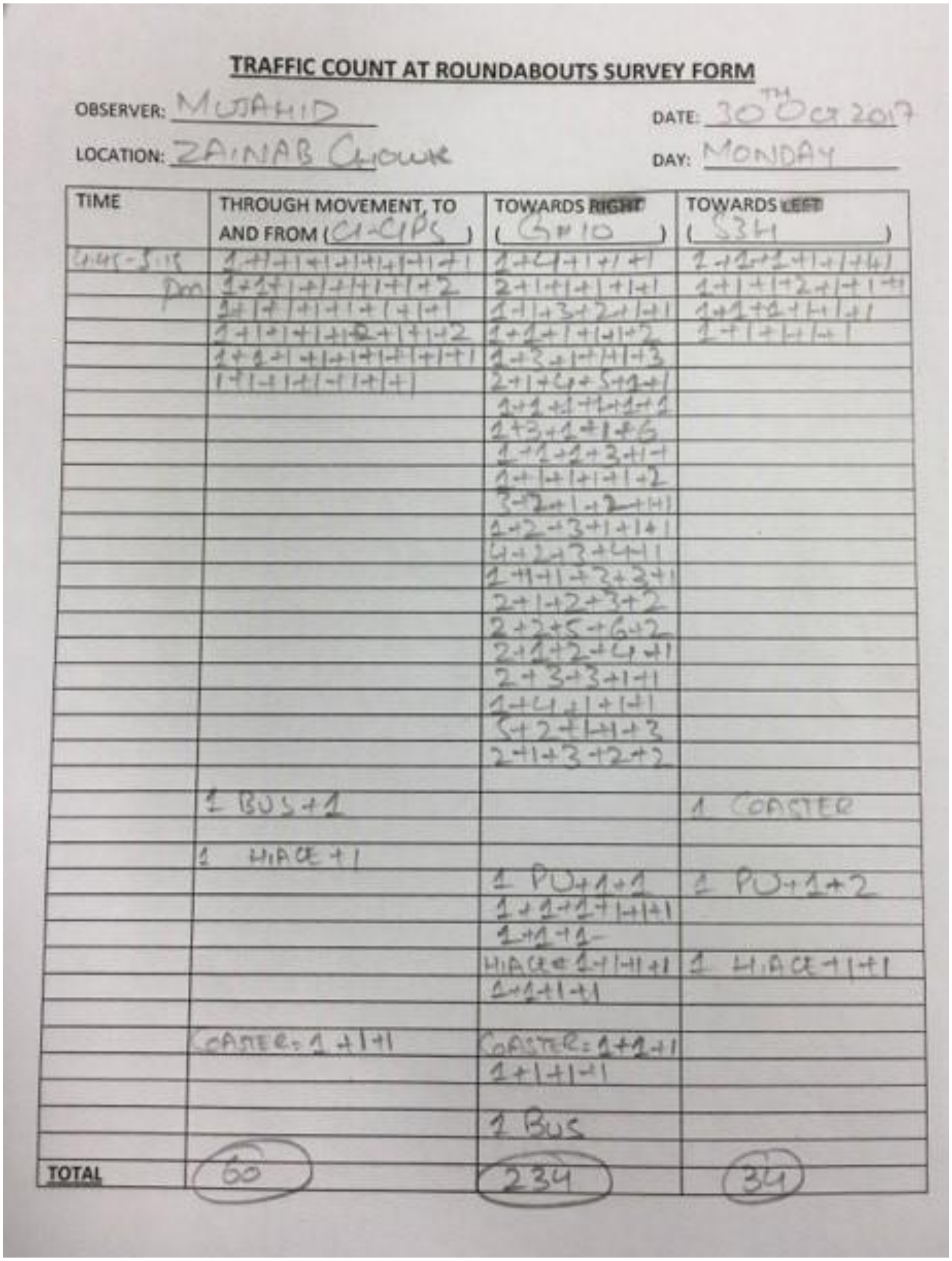
- Gate 1
- Gate 10
- Zainab Chowk
- Iqbal Square

With the difference in location, different times have been identified as critical. For gates Morning and Evening time have been identified as critical. For Zainab roundabout 4:45 pm to 5:15 pm is recognized as critical while for Nice roundabout 12:45 pm to 1:45 pm is critical. The difference in critical time is due to the difference of traffic flow.

3.2.2 GETTING TRAFFIC COUNT DATA AT THESE LOCATIONS IN NUST

After recognizing critical locations, we have performed a traffic count survey at these locations. Different times have been marked as critical for various locations, despite the fact, office open and closing hours are critical. Later on, the data gathered by conducting surveys have been converted into tabular form and graphs.

Traffic count data form has been attached for both round about Fig.(9) and Gates Fig.(10)



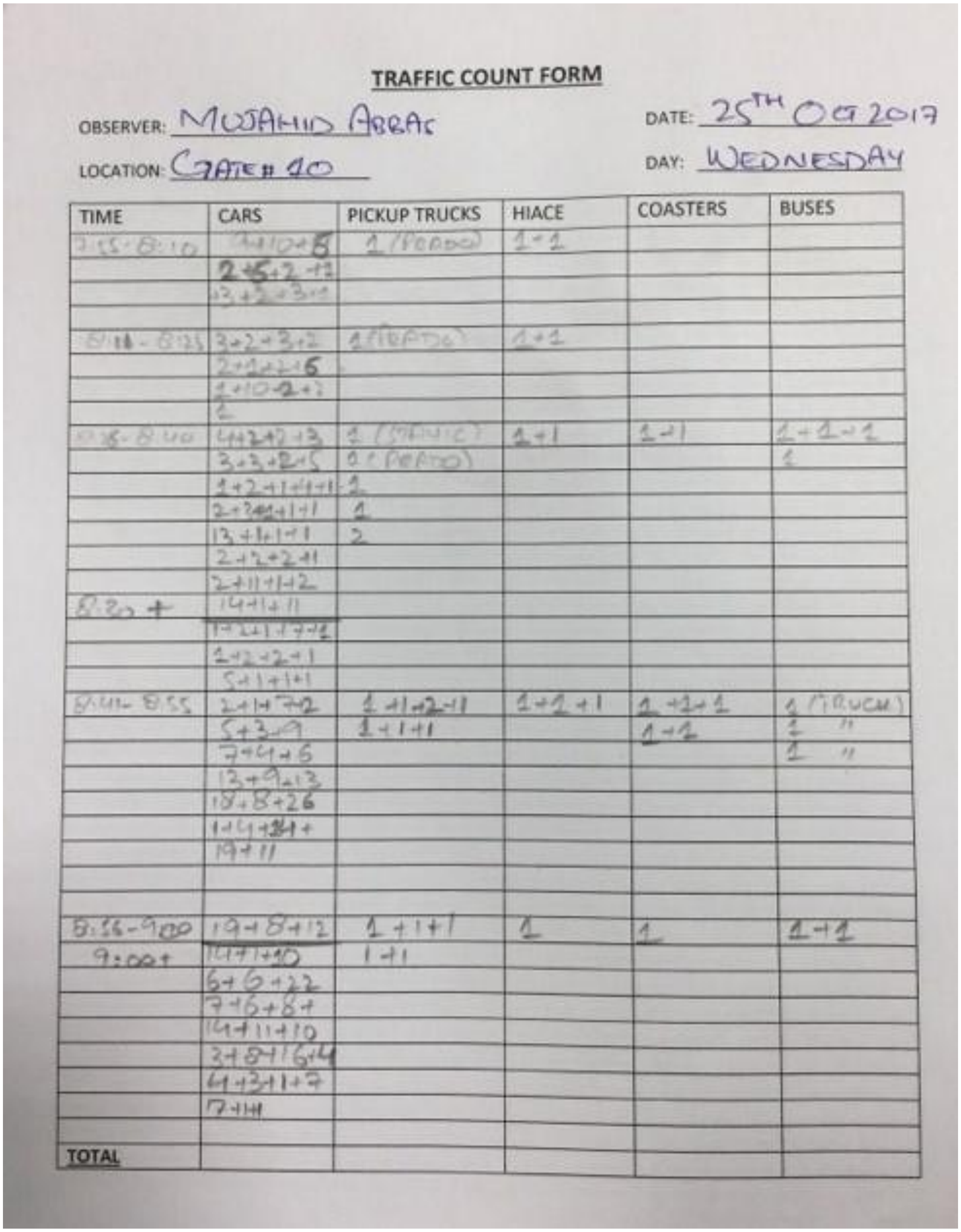
TRAFFIC COUNT AT ROUNDABOUTS SURVEY FORM

OBSERVER: MUJAHID DATE: 30TH OCT 2017

LOCATION: ZAINAB CHOWK DAY: MONDAY

TIME	THROUGH MOVEMENT, TO AND FROM (G-6 IPS)	TOWARDS RIGHT (G#10)	TOWARDS LEFT (S3H)
4:45-5:15	1+1+1+1+1+1+1+1+1+1	1+4+1+1+1	1+1+1+1+1+1+1
pm	1+1+1+1+1+1+1+1+2	2+1+1+1+1+1	1+1+1+2+1+1+1
	1+1+1+1+1+1+1+1	1+1+3+2+1+1	1+1+1+1+1+1
	1+1+1+1+1+2+1+1+2	1+1+1+1+1+2	1+1+1+1+1
	1+1+1+1+1+1+1+1+1+1	1+3+1+1+1+3	
	1+1+1+1+1+1+1	2+1+4+5+1+1	
		1+1+1+1+1+1	
		1+3+1+1+6	
		1+1+1+3+1+1	
		1+1+1+1+1+2	
		3+2+1+2+1+1	
		1+2+3+1+1+1	
		4+2+3+4+1	
		1+1+1+2+3+1	
		2+1+2+3+2	
		2+2+5+6+2	
		2+1+2+4+1	
		2+3+3+1+1	
		1+4+1+1+1	
		5+2+1+1+3	
		2+1+3+2+2	
	1 BUS+1		1 COASTER
	1 HIACE+1		
		1 PU+1+1	1 PU+1+2
		1+1+1+1+1+1	
		1+1+1	
		HIACE 1+1+1+1	1 HIACE+1+1
		1+1+1+1	
	COASTER: 1+1+1	COASTER: 1+1+1	
		1+1+1+1	
		1 BUS	
TOTAL	60	234	34

Figure 9- Traffic Count Form at Zainab Chowk



TRAFFIC COUNT FORM

OBSERVER: MUJAHID ABBAS

LOCATION: GATE # 10

DATE: 25TH OCT 2017

DAY: WEDNESDAY

TIME	CARS	PICKUP TRUCKS	HIACE	COASTERS	BUSES
7:55-8:10	[illegible]+10+8	1 (PEDRO)	1+1		
	2+5+2+1				
	+3+2+3+1				
8:11-8:25	3+2+3+2	1 (PEDRO)	1+1		
	2+1+2+6				
	1+10+2+3				
	2				
8:26-8:40	4+3+2+3	1 (SHAHZORE)	1+1	1+1	1+1+1
	3+3+2+5	0 (PEDRO)			1
	1+2+1+1+1+1	1			
	2+3+1+1+1	1			
	13+1+1+1	2			
	2+2+2+1				
	2+11+1+2				
8:20+	14+1+11				
	1+2+1+7+1				
	1+2+2+1				
	5+1+1+1				
8:41-8:55	2+1+7+2	1+1+2+1	1+1+1	1+1+1	1 (TRUCK)
	5+3+9	1+1+1		1+1	1 "
	7+4+6				1 "
	13+9+13				
	18+8+26				
	1+4+21+				
	19+11				
8:56-9:00	19+8+12	1+1+1	1	1	1+1
9:00+	14+1+10	1+1			
	6+6+22				
	7+6+8+				
	14+11+10				
	3+8+16+4				
	4+3+1+7				
	7+1+1				
TOTAL					

Figure 10-Traffic Count Form At Gate 10

Graphs of morning and evening traffic count conducted at Gate 1 is attached in Fig.(11) and Fig.(12)

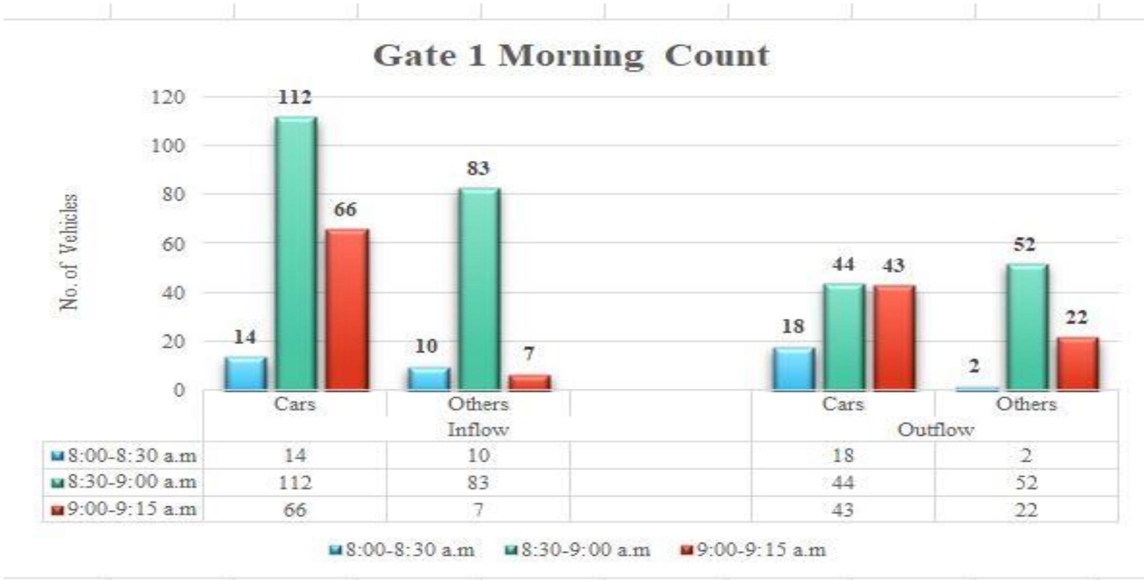


Figure 11- Gate 1 Morning Count

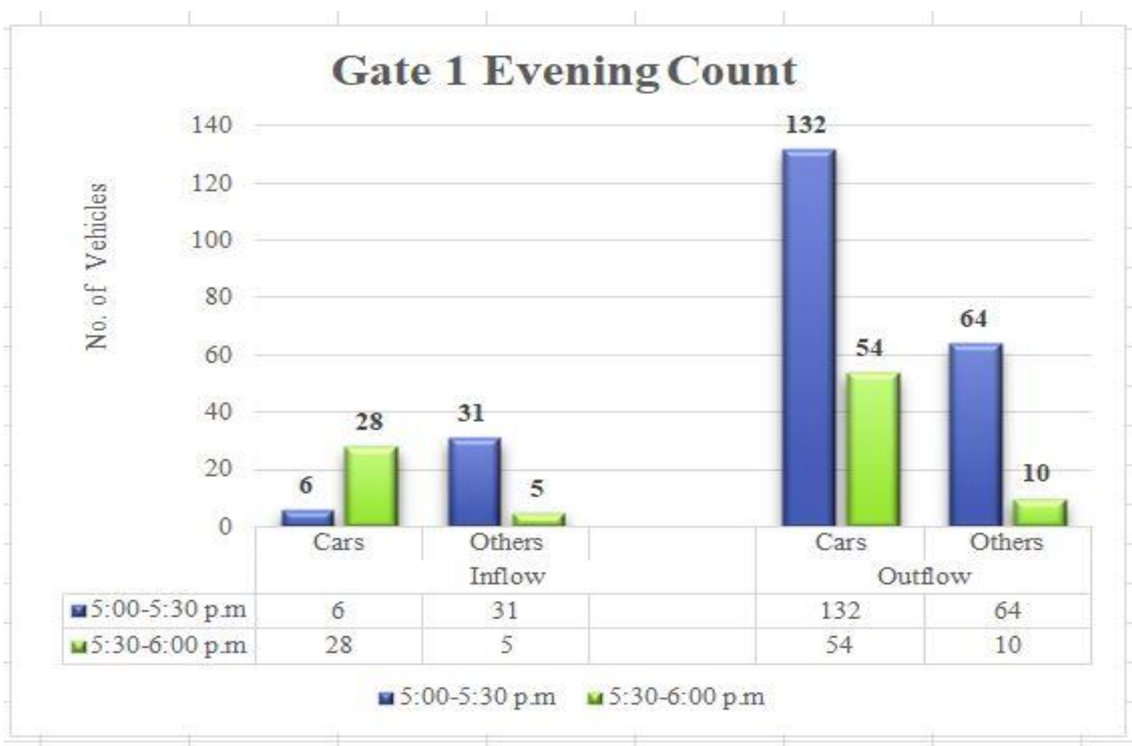


Figure 12-Gate 1 Evening Count

Graphs of morning and evening traffic count conducted at Gate 10 is attached in Fig.(13) and Fig.(14)

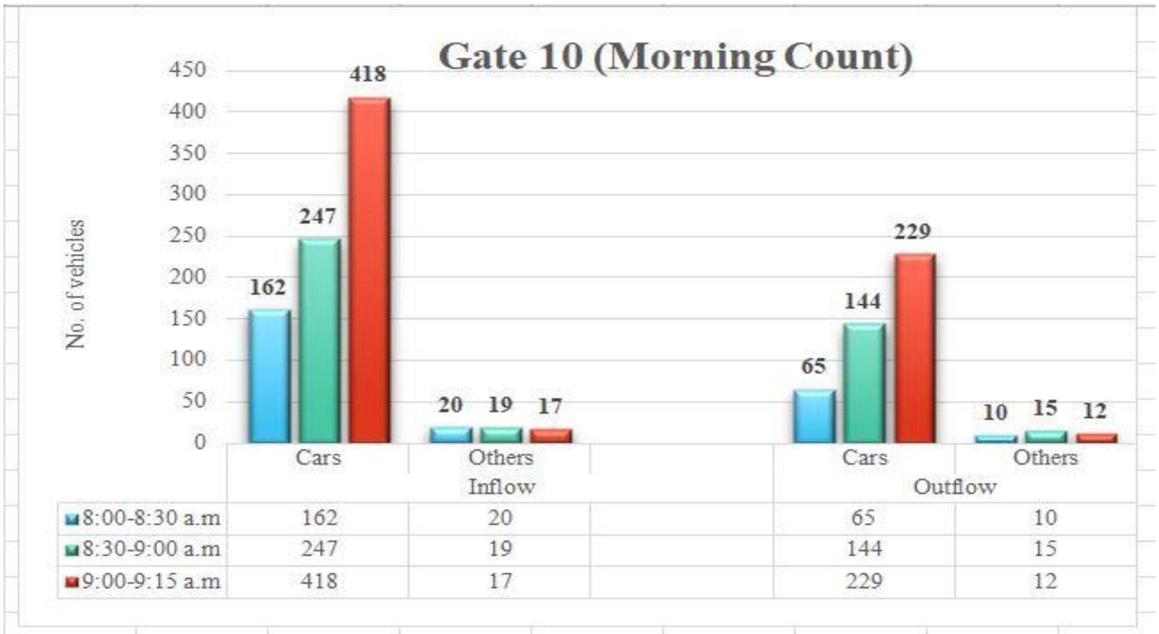


Figure 13-Gate 10 Morning Count

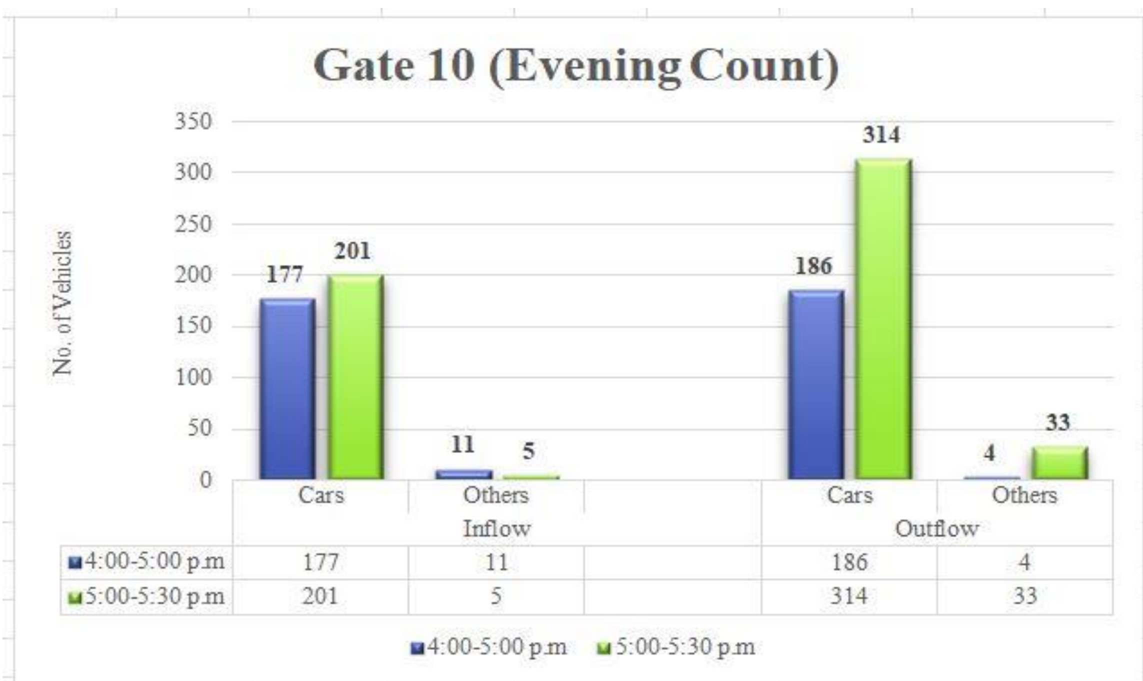


Figure 14-Gate 10 Evening Count

Zainab Chowk traffic count data and its pie-chart in both directions is attached in Fig.(15) and Fig.(16)

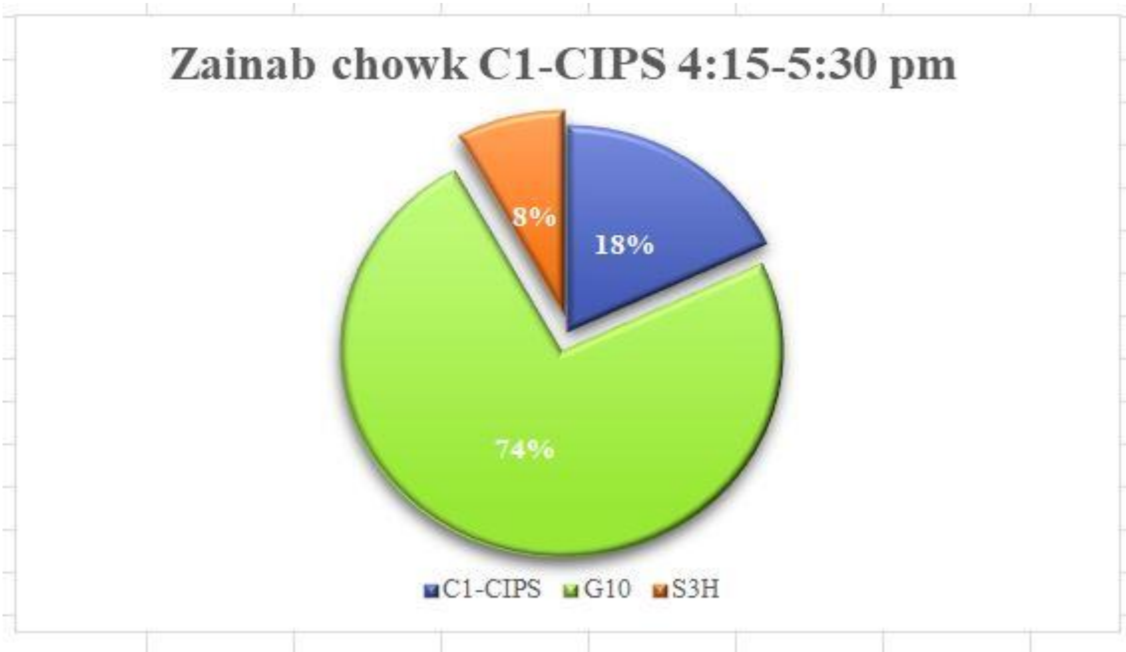


Figure 15-Zainab Chowk C1-CIPS

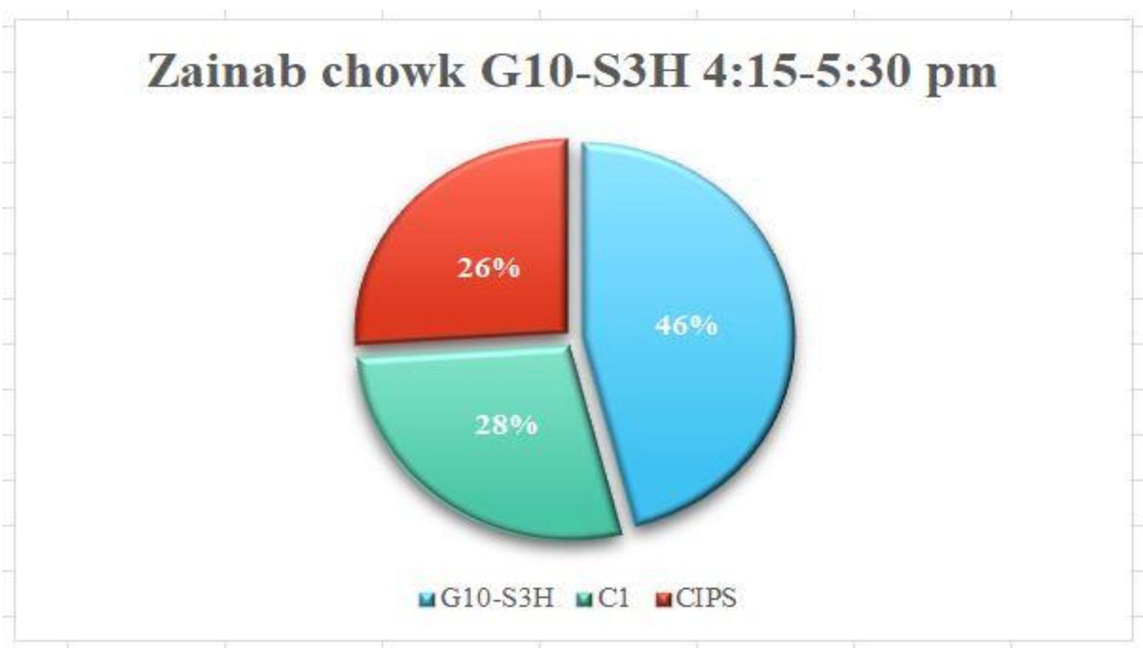


Figure 16-Zainab Chowk G10-S3H

NICE Chowk traffic count data and its pie-chart in both directions is attached in Fig.(17) and Fig.(18)

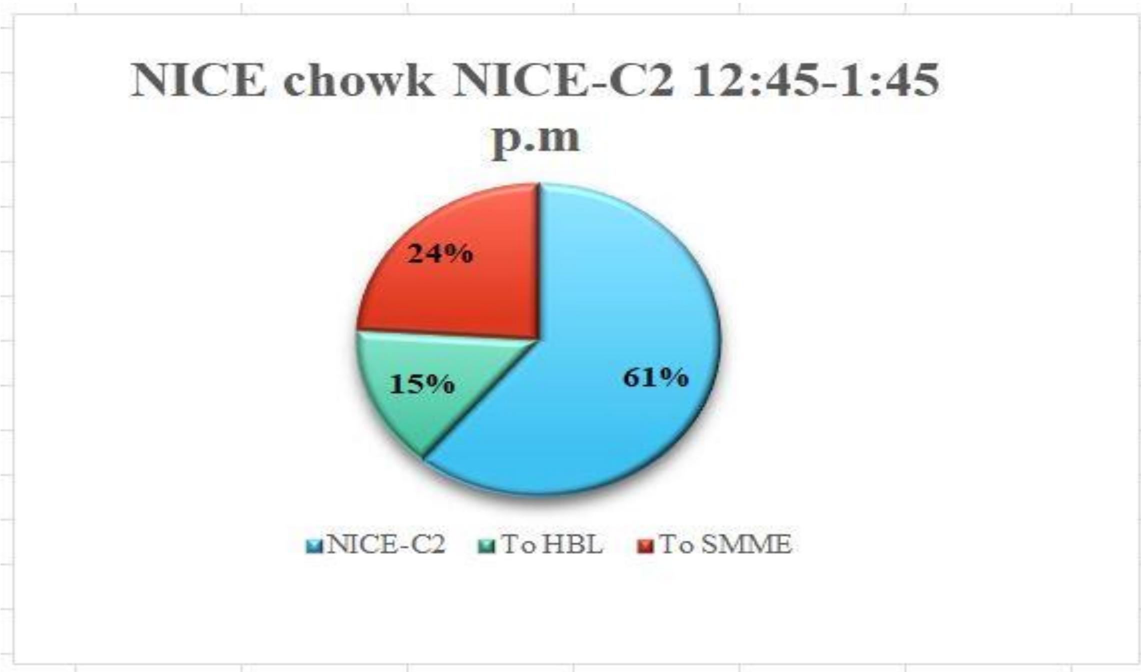


Figure 17-NICE Chowk NICE-C2

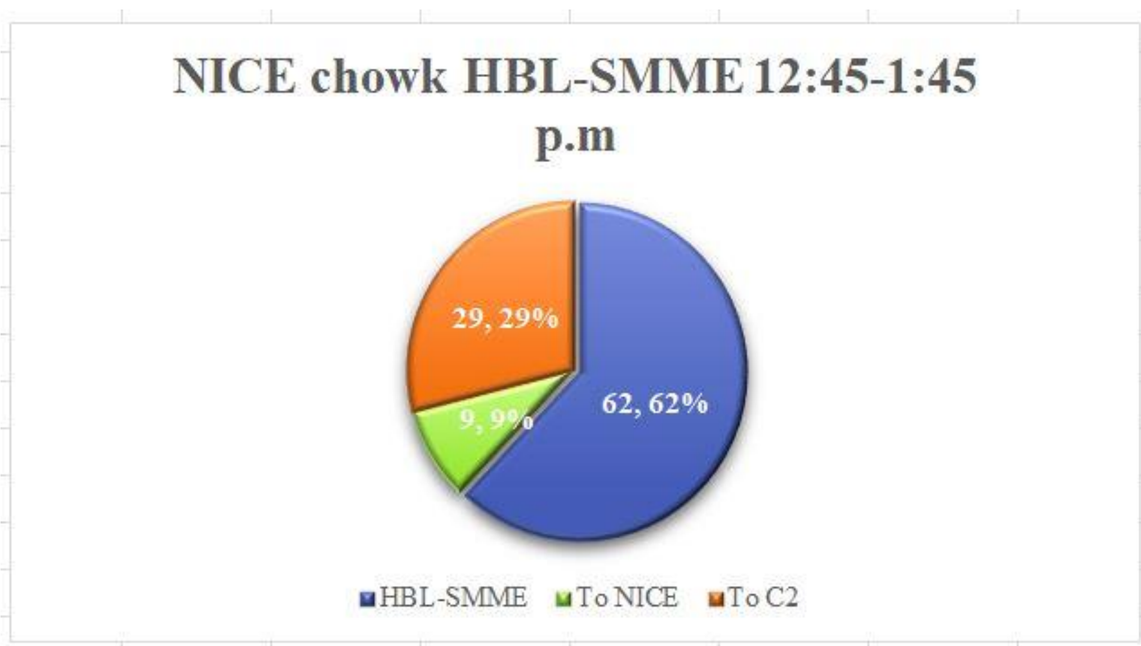


Figure 18-NICE Chowk HBL-SMME

3.2.3 IMPLEMENTING PREVIOUS RESEARCH KNOWLEDGE PRACTICALYY AND ITS APPLICATION IN PAKISTAN

By reading and analyzing the previous knowledge regarding this concept, we have selected the new design of pavement which is suggested under CPEC. By going through the documents issued by respective departments, we concluded some parameters as basic.

3.2.4 BEHAVIOUR OF VARIOUS PARAMETERS OF TYPICAL PAVEMENT STRUCTURE UNDER LOADING

As far as design of pavement with in NUST is concerned, we have got the structural and architectural drawings of pavement from PMO NUST. Later on, we will perform various experiments on different layers of pavement, in order to study its behavior under loading, which includes the following:

- Surface layer
- Binder layer
- Base
- Sub-base
- Sub-grade

3.2.5 STRESS, STRAIN ANALYSIS OF PZT MATERIAL BASED ON VARIOUS LOADING CONDITIONS

In order to place PZT in pavement, it is necessary to get a detailed assessment of its some basic parameters i.e: stress, strain and displacement. For this purpose, we will use “NICE STRUCTURE LAB UTM Machine” and then we will conclude the testing result.

3.2.6 OVERALL VIEW OF LAYING OUT PIEZOELECTRIC ENERGY HARVESTER

After performing the above mentioned testing and getting the test result, we will then propose a system of laying out Piezoelectric in pavement.

3.2.7 IDENTIFYING OPTIMUM POSITION OF PZT MATERIAL IN ASPHALT PAVEMENT

Once we propose an overall view of laying piezoelectric in pavement, we will then perform various experiments on enhancing its efficiency. This is done either by changing its location of placement in pavement or just by adding some material with it. Our sole purpose is to capture maximum kinetic energy of vehicular movement and then converting it into electrical energy with minimum losses.

3.2.8 COMPARISON OF PEAK TIME AND PEAK OFF TIME DATA

A table will be made at end indicating the difference of electrical energy production between peak time and peak off time. As a result, we will be able to determine the total electrical energy production at NUST with respect to data gathered in the year 2017.

3.2.9 FREQUENCY ANALYSIS AND ITS EQUATION

We will conduct a survey in which we will collect the data considering the speed of vehicle and road vibration frequency. We will do that by using the following equation.

$$f = 0.1867v - 1.2127$$

Where f is exerted road vibrational frequency in hertz and v is speed of the vehicle in kilometers per hour.

We will conduct our study considering the NUST model observing the vehicle speed of 30-50 kilometers per hour and calculating the respective frequency and matching it with a natural frequency. That will give us a good idea of harvesting of the energy.

3.2.10 PAYBACK PERIOD

Studies showed that the payback period of PZT energy harvester is quite good in short as well as in the long run. We will also conduct the same type of analysis on project and will calculate its payback period.

3.2.11 COST-BENEFIT(ECONOMIC) ANALYSIS

We will conduct a study on how much we are spending on the project including the material cost and the changes in the design and how much we will get benefit out of it in how much time that will give us a brief idea of the feasibility of the project.

CHAPTER 4

4. DATA ANALYSIS AND RESULTS

4.1 BACKGROUND

Background contains steps which we are going to follow in order to carry out the analysis and results as a whole are as follows:

- Hourly Traffic To ADT (Graphs)(K factor)(Peak and peak-off)
- ADT TO ESALS (Equation)
- ESALS to Deflection and road dimensions (Graph esals vs deflection + road cross-section)
- Deflections causing stress at the top of base (graph deflection vs stress)
- Stress causing strain (Graph)
- Strain producing electricity (Graph strain vs electricity production)
- Identification of potential points at Map of NUST H-12
- Looking Forward 'Where to use this electricity' (Energy harvesting / Road Health Monitoring)

4.1.1 INTRODUCTION

Introduction covers the work flow which is carried while doing project. Every project is completed under some specific steps. This project has some steps which were adopted while carrying the project. The steps are listed below.

4.1.2 SELECTION OF TOPIC

Our topic was "harvesting energy from pavement under stress due to vehicular load for road health monitoring"

Our main purpose was to harvest electricity from the strain caused on the pavement by the vehicular loading. The scope to use this generated electricity has two choices:

- For electricity generation if sufficient amount is produced
- For pavement health monitoring at remote areas where traditional pole and wire system is costly.

4.1.3 LITERATURE REVIEW

You can see with the passing time, the demand for vehicles and how the rush on the roads and volume of traffic is on a rise. The rapid increase in vehicles and the devastating volumes of traffic cause strain on the road pavement that they travel on. This strain ultimately leads to the failure of the road and has an adverse effect on the pavement. Moreover it affects its PSI (Pavement serviceability index) , it’s very important to monitor the condition of the pavement so that timely repair can be done which will save us from the hassle of complete structural or functional failure of the road. In this research of ours we have basically used the strains (deformations caused on the pavement) in order to generate electricity that can be used to operate sensors installed inside the pavement for road health monitoring.

4.1.4 SITE SELECTION

We selected NUST H12’s different locations for our research. We already knew about these points that they were the critical points in Nust regarding traffic and that the traffic count on these points were maximum. This information was provided to us by our project advisor.

4.1.5 DATA COLLECTION POINTS

We went to those points that we already knew were critical points. Also, it was provided that which hours are peak hours (hours having maximum flow during the time of the day). We went there during that time frame and took traffic counts.

Those points were as follows

- Gate1
- Gate10
- Nice chowk

- Khatija chowk

After gathering the traffic count at these points we have performed analysis on the traffic count using software “KENPAVE”, in order to identify the quantity of deflection, stress and strain at these points.

4.2 GENERAL INFORMATION OF TRANSPORTATION FACTORS

The software used for our project was KENPAVE. KENLAYER Computer Program has been used for determining the damage ratio using distress models. This software is used for analysis and design of pavements. We analyzed our pavement using this software. Using the traffic counts at the estimated peak hours and estimating the traffic flow at off peak hours, the ADT was calculated, the ADT was then used to calculate ESALs (equivalent single axle loads).

4.2.1 HOURLY TRAFFIC TO ADT CONVERSION

After obtaining the data on the specified locations, we had to find the ADT. ADT stands for average daily traffic.

For converting a 1 hour counting result to an ADT-value, you need to know the variation patterns of the traffic volume on the road in question. That means that you have to know the seasonal variations, weekday variations and the hourly variations. The question is of course, where you can get these patterns, if there has not been continuous counting’s on the road in question. Usually the road administrations and city transportation offices have information of typical variation patterns collected from different types of roads in different areas.

Further on, it is also important to choose the 1 hour counting period carefully. Choose a time of day with a representative volume (not too small, but not necessarily the peak hour either). In general the accuracy of the estimation increases with volume, but it is possible, that certain daytime hours between peak times are more stable than the peak volumes. Choose also a normal weekday (no special events or other irregularities in flow). If possible, repeat your count some other day.

To get the ADT form one hour traffic, you first have to count the daily estimate from your one hour value by the knowledge of the share of this hour from the whole day in your reference location. After that, you convert the value to correspond an average weekday based on the weekday variations and finally you convert your average weekday to yearly average.

In a nutshell, what you need is a reference location for each of your counting sites and based on the variation patterns of the reference locations, you can estimate the ADTs for your counting points.

4.2.2 DESIGN HOUR VOLUME

The DHV is a two-way traffic volume that is determined by multiplying the ADT by a percentage called the K-factor. Values for K typically range from 8 to 12% for urban facilities and 12 to 18% for rural facilities. Neither the AADT nor the ADT indicate the variations in traffic volumes that occur on an hourly basis during the day, specifically high traffic volumes that occur during the peak hour of travel. The traffic engineer has to balance the desire to provide an adequate level of service (LOS) for the peak hour traffic volume with proposing a design in which the highway capacity would only be utilized for a few hours of the year. This is where the design hour volume (DHV) comes in.

4.2.3 DIRECTIONAL DESIGN HOUR VOLUME

The directional design hour volume (DDHV) is the one-way volume in the predominant direction of travel in the design hour, expressed as a percentage of the two-way DHV. For rural and suburban roads, the directional distribution factor (D) ranges from 55 to 80 percent. A factor of approximately 50 percent is used for urban highways. Keep in mind that the directional distribution can change during the day. For example, traffic volume heading into the central business district is usually higher than outbound traffic in the morning, but the reverse is true during the afternoon peak hour. In summary, DDHV = ADT (or AADT)*K*D.

4.2.4 ADT TO ESALS

After we found out the value of ADT, we had to calculate ESALS using that value.

What is ESAL?

ESAL stands for Equivalent Single Axle Load. ESAL is developed from data that has been collected by American Association of State Highway Officials known as AASHTO Road Test to establish a standard damage relationship for varying axles carrying different loads.

The reference axle load is an 18,000-lb. single axle with dual tires.

What is design ESALs?

Design ESALs is used for the design of pavement. It is a cumulative traffic load summary which shows the mixed stream of traffic of different axle loads and different axle configurations over the design period and then converting that cumulative traffic into an equivalent number of 18,000-lb single axle loads summed over that entire period.

Use the following calculations to determine design ESALs:

Σ ESALs= Tf TGDL(365) Y

Where:

Tf = truck factor

Use the following calculation to determine Tf

$\mathrm{Tf} = \sum_{i=1}^{m}(Pi\ Fi)$A Where:

pi = percentage of total repetitions for the ith load group

Fi = equivalent axle load factor for the ith load group

A = average number of axles per truck.

T = percentage of trucks in average daily traffic (ADT)

G = growth factor

Use the following calculation to determine G=$\frac{(1+g)^n-1}{g}$

Where:

g = annual growth rate

n = analysis period in years

D = directional distribution factor

L = lane distribution factor

Y = design period in years

4.2.5 LANE DISTRIBUTION FACTOR

Lane distribution factor is used to estimate the cumulative ESALs in one-direction thus by reducing the estimated ESALs count that have three or more lanes in one direction. For these sections, truck movement will tend to utilize the internal paths more frequently than the two-path situation, in this manner decreasing the aggregation of burdens on any one path. The following distribution factors can be used as a multiplier to the one-direction cumulative ESALs to establish the design traffic:

- 3 lanes 0.7
- 4 or more lanes 0.6

However. We found an online application to convert ADT to ESAL and that's what we used in our calculations. You can see in the picture attached below that it has used the same factors. Using of this application saved us from the hassle of calculations and the problems associated with human error.

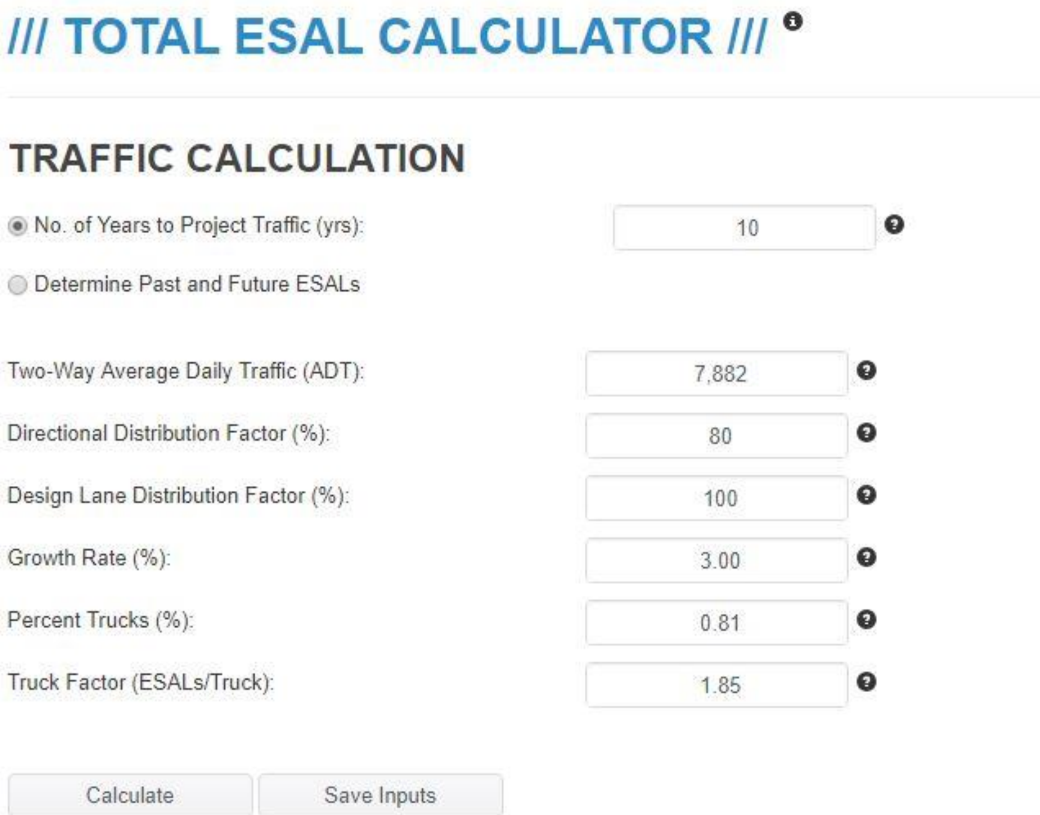


Figure 19- ESAL Calculator

4.2.6 PERCENT TRUCKS

Instead of using the percent trucks we have allocated this percentage to buses/hiaces/vans as our site selection does not include any trucks.

4.2.7 ESALS TO DEFLECTION AND ROAD DIMESIONS

We used the ESALS to calculate the deflection, stresses and strains at the top of base and subgrade. This required 'Mr' and thickness that we obtained through testing in the NICE and NIT laboratories. Those stresses in turn produced strain. We monitored all this In the software KENPAVE. By the help of the strain produced we were able to analyze the amount of electricity that could be generated. Now the magnitude of this electricity will tell us as to where it can be used and how beneficial it is going to be.

4.3 NHA REPORT AND INPUT PARAMETERS

NHA report was taken in which an analysis has been performed of a road and many factors which were eventually going to be used in the KENPAVE software were listed which included:

- CBR value
- Moduli
- Layer thicknesses
- Contact Pressure (CP)
- Contact Radius (CR)
- Resilient Modulus (M_R)
- Number of load repetitions NR
- Poisson's ratio

The values of thicknesses were extracted from the report. (NHA, n.d.)

The ESAL was then used as an input parameter inside KENPAVE along with other factors to calculate the stress, strain, deflection and design life. The parameters that have been used are defined below.

4.3.1 CBR

CBR stands for the California bearing ratio. The California bearing ratio (**CBR**) is a penetration test for evaluation of the mechanical strength of natural ground, subgrades. The soil in NUST was found out to be hard brown Clay CBR of was assumed to be 8%. The report stated soft clay and had a CBR value of 13% .this value of CBR is then used to find out the resilient modulus of the subgrade.

Using the CBR we calculated (M_R) which came out to be 8059.

4.3.2 MODULI (Psi)

These values were also taken from a report by NHA:

- Asphalt wearing layer (AWC) 450000
- Asphalt base course (ABC) 350000
- Base course (BC) 42000
- Subbase (SB) 22000
- Sub grade (SG) 8059

4.3.3 THICKNESS (inches)

There were 5 layers. The thicknesses of each layer were also taken from an NHA report. (NHA, n.d.)

- Asphalt wearing layer 2”
- Asphalt base course 7”
- Base course 6”
- Subbase 8”
- Sub grade infinite

4.3.4 CONTACT PRESSURE (Psi)

Contact pressure was assumed to be 80 because either it is taken as 80 or 120 as the traffic was mainly of cars, we took it 80.

4.3.5 CONTACT RADIUS (Inches)

Contact radius was 5” because we used single axle single tire vehicles.

4.3.6 NUMBER OF LOAD REPITITIONS (NR)

Number of load repetitions was selected to be 1. This value can be taken from 1-25. We took it as 1 because we only needed value right under the midpoint of the contact area.

4.3.7 POISSONS RATIO

Poisson’s ratio was assumed to be 0.5 for every layer.

After all the data input, analysis were done on KENLAYER. Kenlayer is an option in KENPAVE.

An L graph was obtained. The file saved/created was a word pad life which contained all the summary and damage analysis was obtained for each particular ESAL input.

4.4 WORKING ON KENPAVE

4.4.1 OPENING THE SOFTWARE

When you open up the software following window will pop up in front of you. Main screen will have the options of performing analysis either on flexible pavement or either on rigid pavement. We have performed our analysis on flexible pavement.

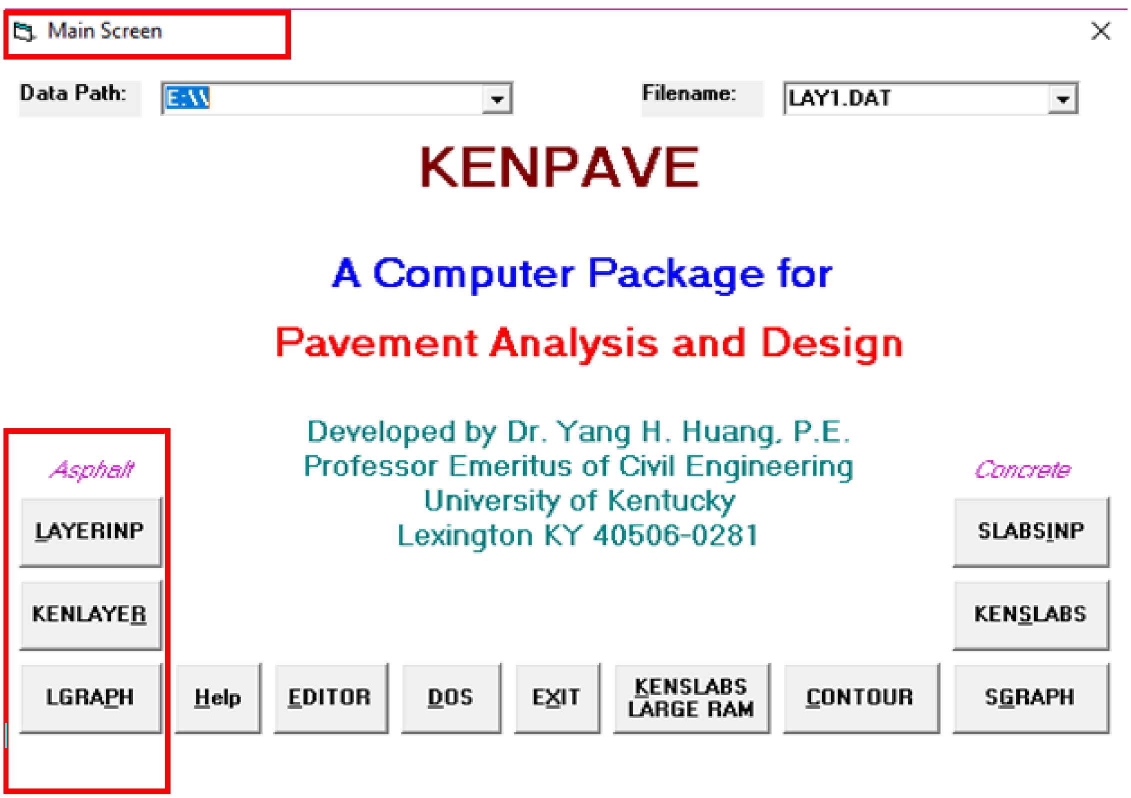


Figure 20-KENPAVE Main Screen

Here in the red box there are three options. Click 'layer input' will open up into main menu.

4.4.2 MAIN MENU LAYOUT

Main menu layout of KENPAVE contains all the factors that are necessary in order to perform analysis. Starting from the general information KENPAVE allows you to edit layer thicknesses, modulus of elasticity of different layers, Poisson ratio of each layer, contact pressure of tires, contact radius of tires, number of times your load is going to repeat and much more. In short, KENPAVE is a key to perform your analysis as per your own requirements.

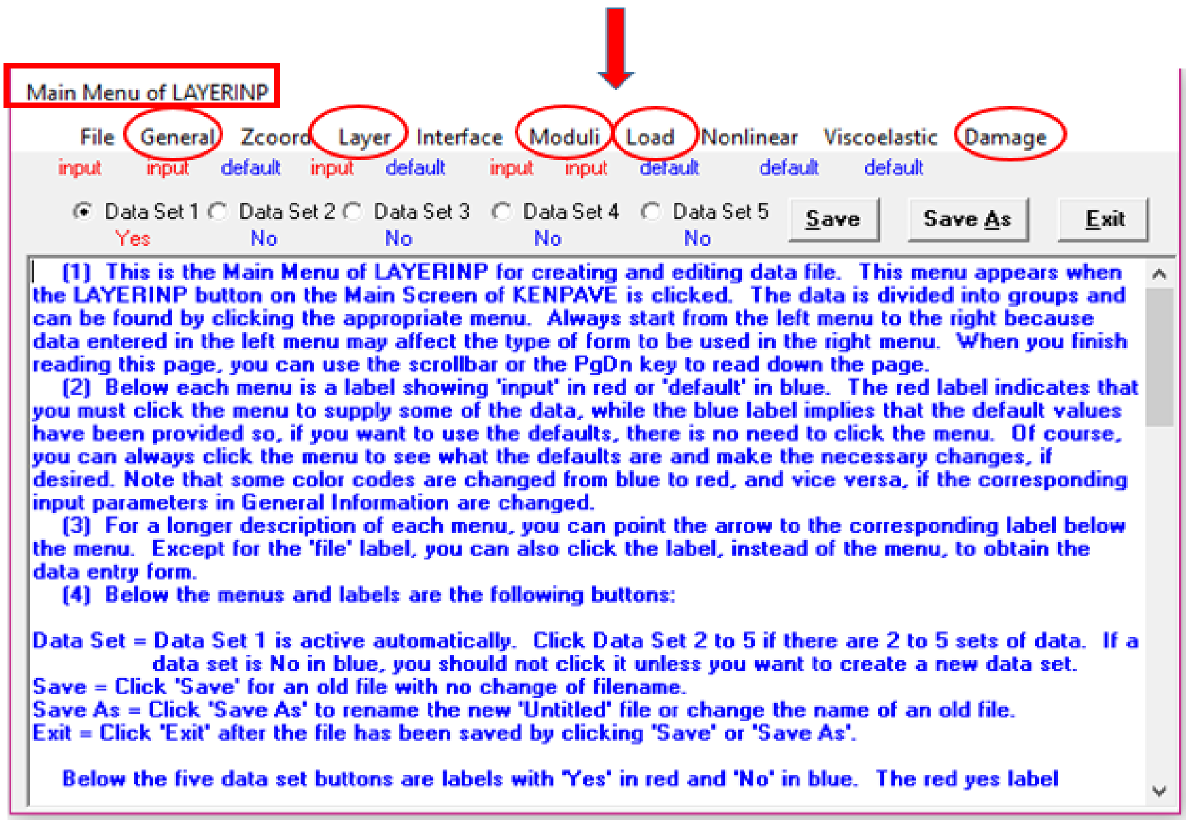


Figure 21-KENPAVE Main Menu

There are 5 main options of input. Go to 'General' first as this will allow you to generate analysis results of your own choice by changing the number of layers, output result variation with graph or without graph.

4.4.3 GENERAL LAYOUT

General layout contains some of the general parameters that are used to perform analysis on pavement. These parameters have been shown below.

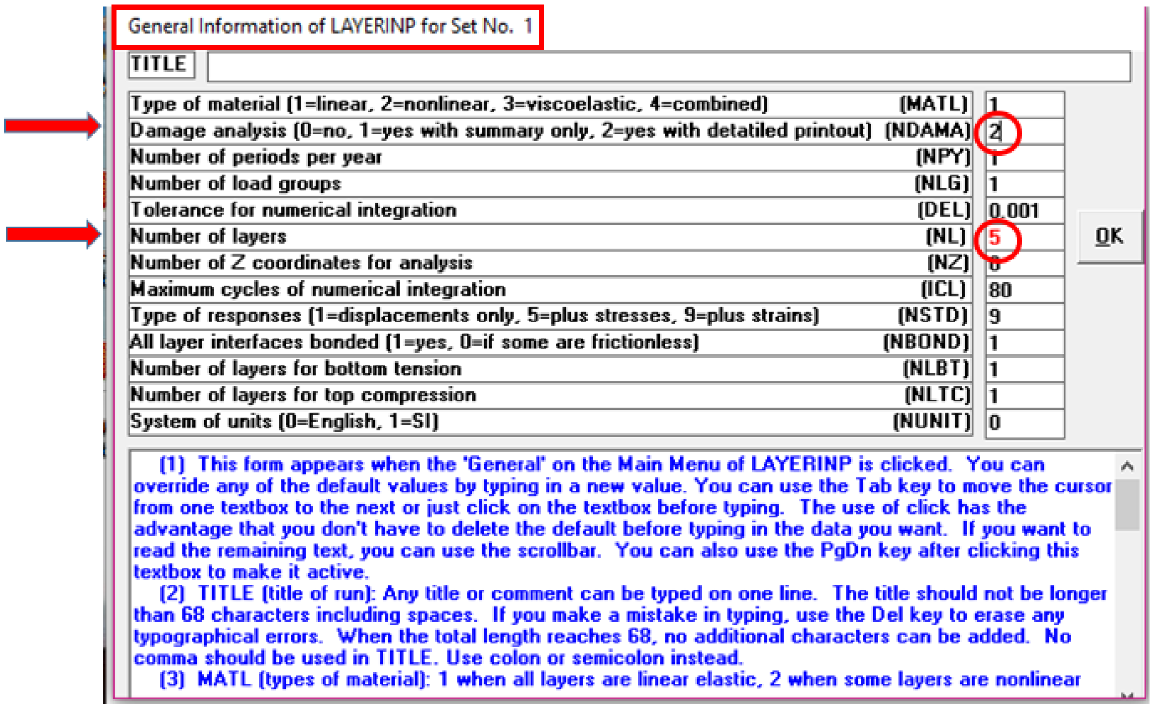


Figure 22-KENPAVE General Layout

We let remained other options as they were and only changed the damage analysis to 2 and number of layers to 5. (RED MARKINGS). Click ok

4.4.4 OPEN LAYER MENU

How you can enter the layer thickness and Poisson ratio. KENPAVE provides you with the option to amend both the parameters as per your choice. 'Unit column' shows you the layer number starting from the top layer. Layer 5 thickness is shown as 'xxxxx' as this is subgrade with infinite thickness. 'TH' indicates thickness of layer whereas 'PR' shows Poisson Ratio.

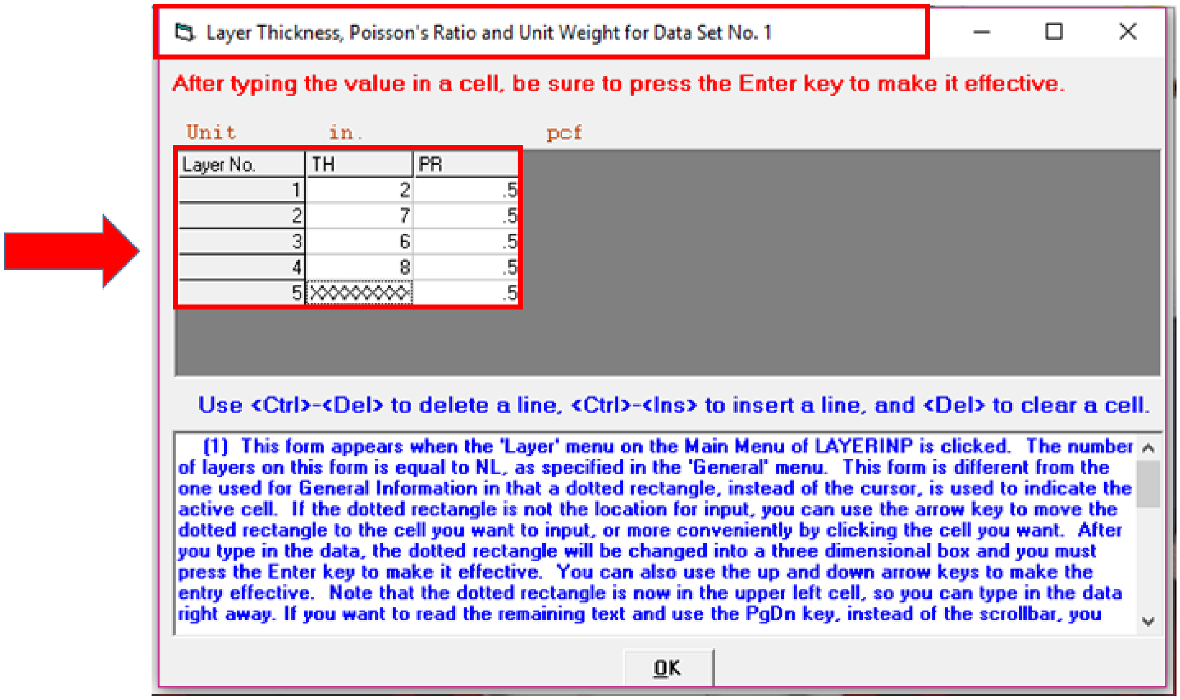


Figure 23-KENPAVE Open Layer Menu

This gives us the option to edit thickness of the layers and also the Poisson's ratio editing. Insert the values and click ok.

4.4.5 LOAD INPUT

In order of how to input load parameters following image has been attached.

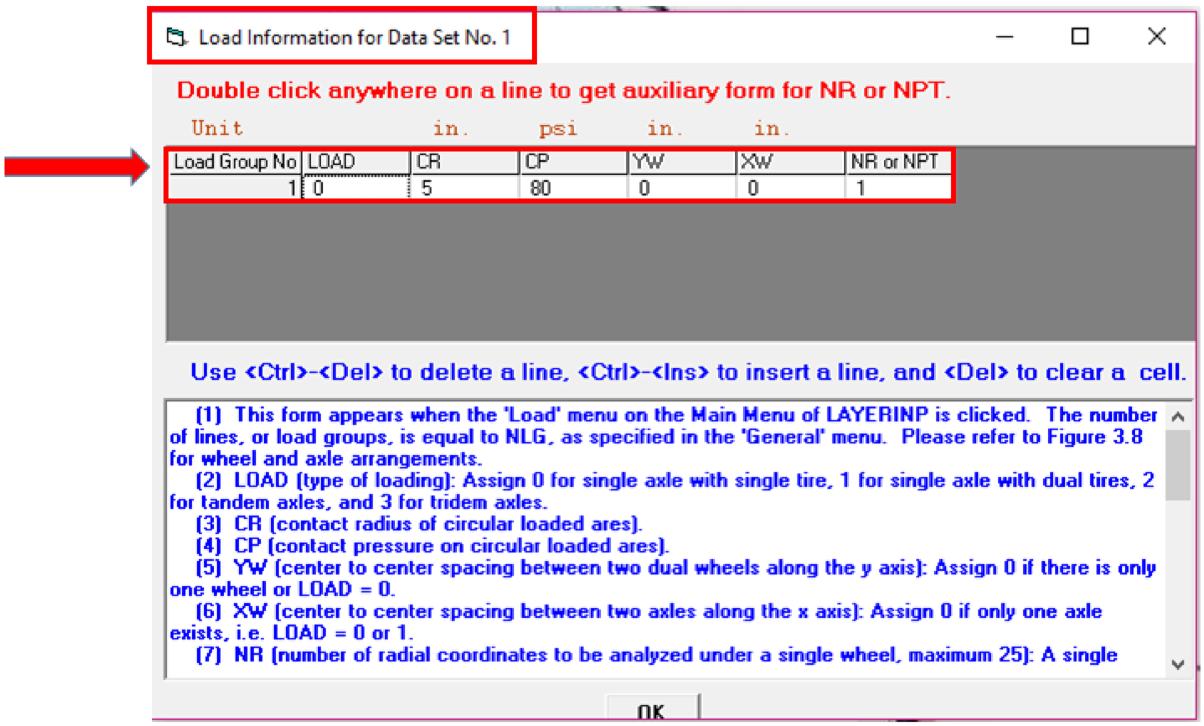


Figure 24-KENPAVE Load Parameters

In this option there are multiple inputs .we used LOAD to remain as we used only single axle single tire

- CR was 5 inches
- CP was 80 psi
- NR was taken as 1.

Clicking NR open a new tab which shows number of reputations points as we input 1 so we will have only 1 point. We let it remained 0.

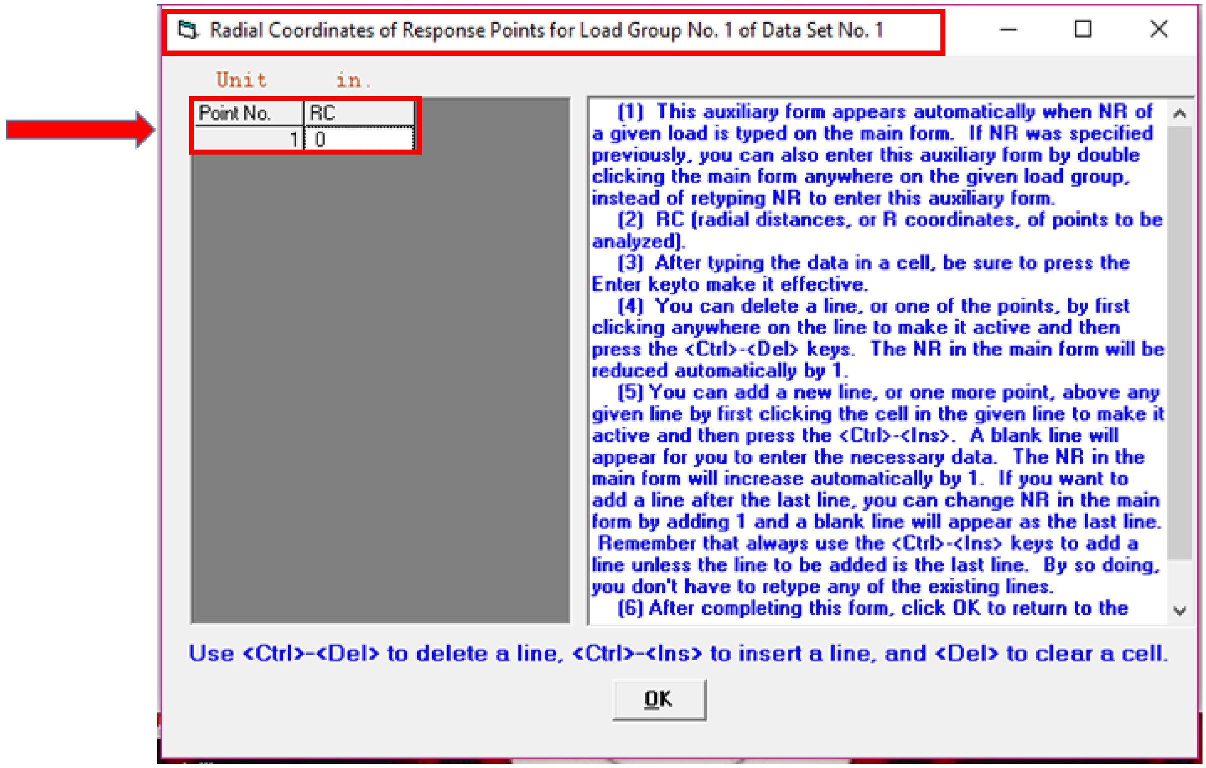


Figure 25-KENPAVE Raidal Coordinate Input

After amending this tab as per your own requirement click ok.

4.4.6: MODULI INPUT

In this tab there shows input allowance of the moduli of the layers. We entered the values as shown which has been taken from NHA Report.

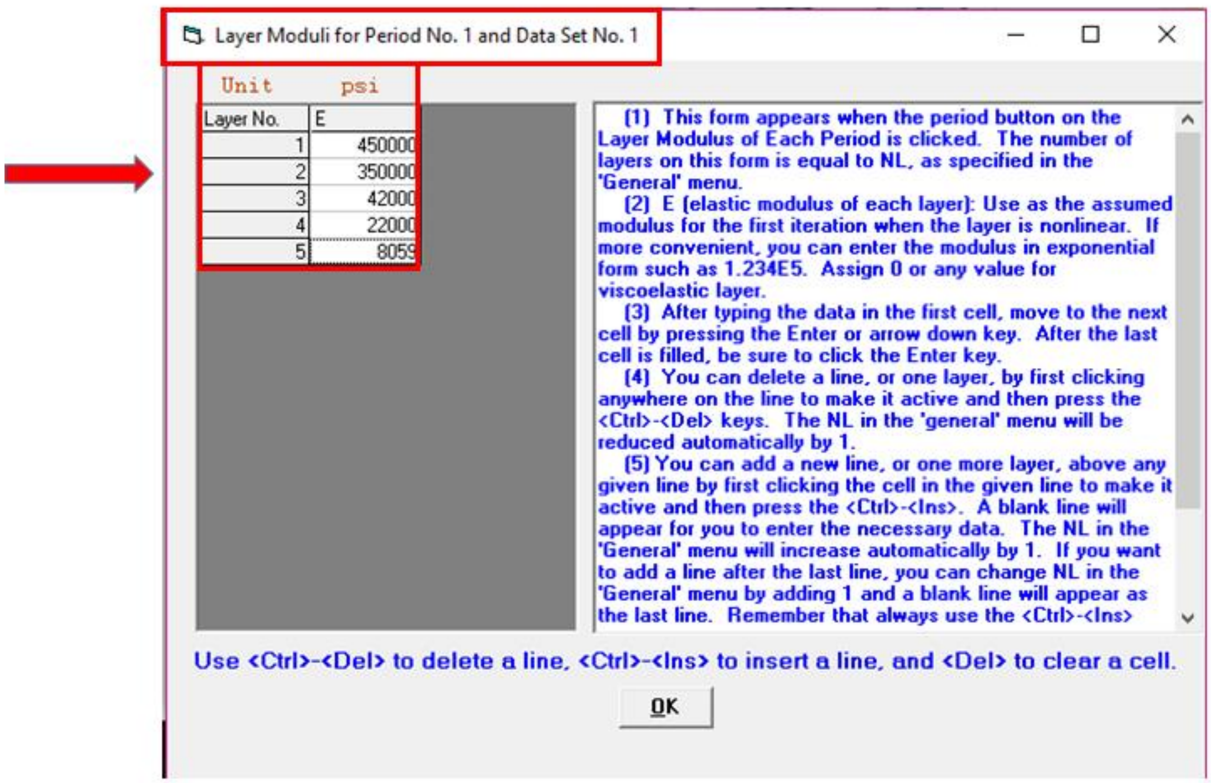


Figure 26-KENPAVE Layer Moduli

Click ok.

4.4.7 DAMAGE ANALYSIS PARAMETERS

Click on the damage tab and this will open a menu like this:

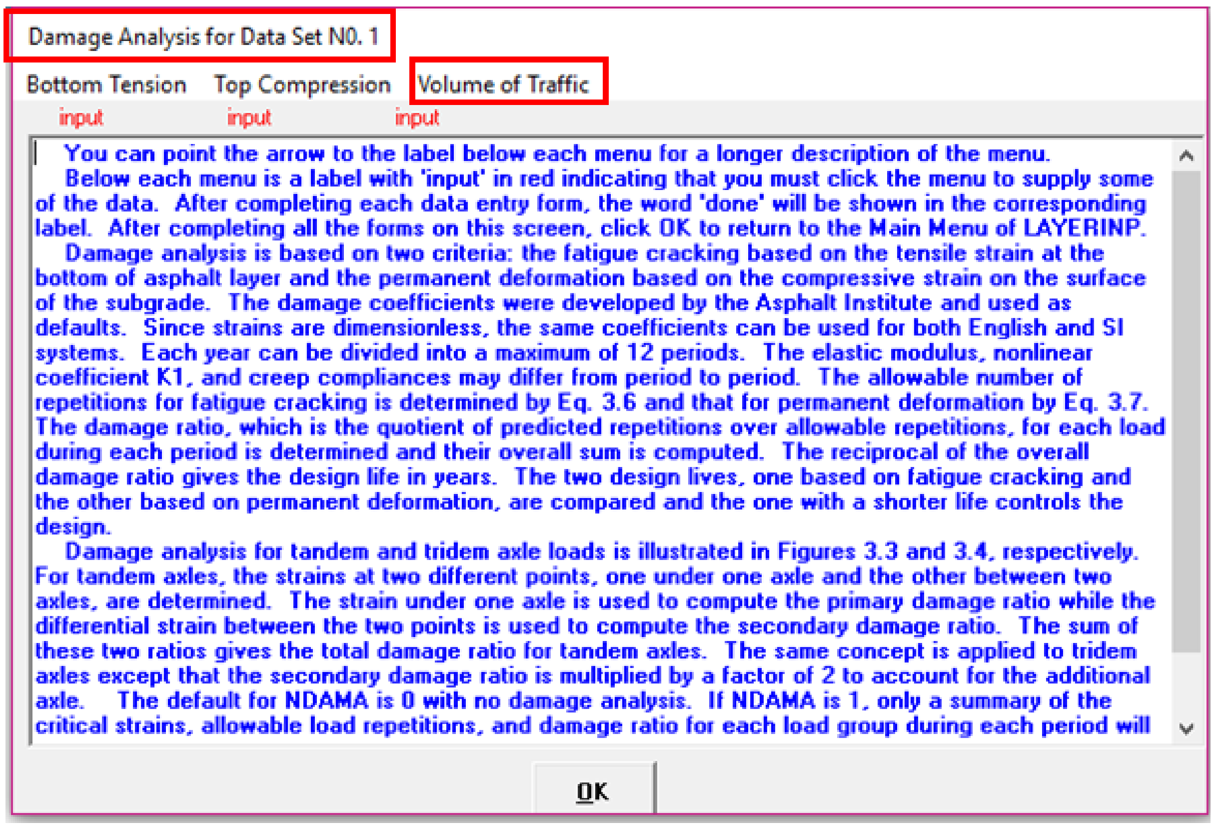


Figure 27-KENPAVE Damage Analysis Parameters

Click on the volume of traffic and you will get a new tab like this:

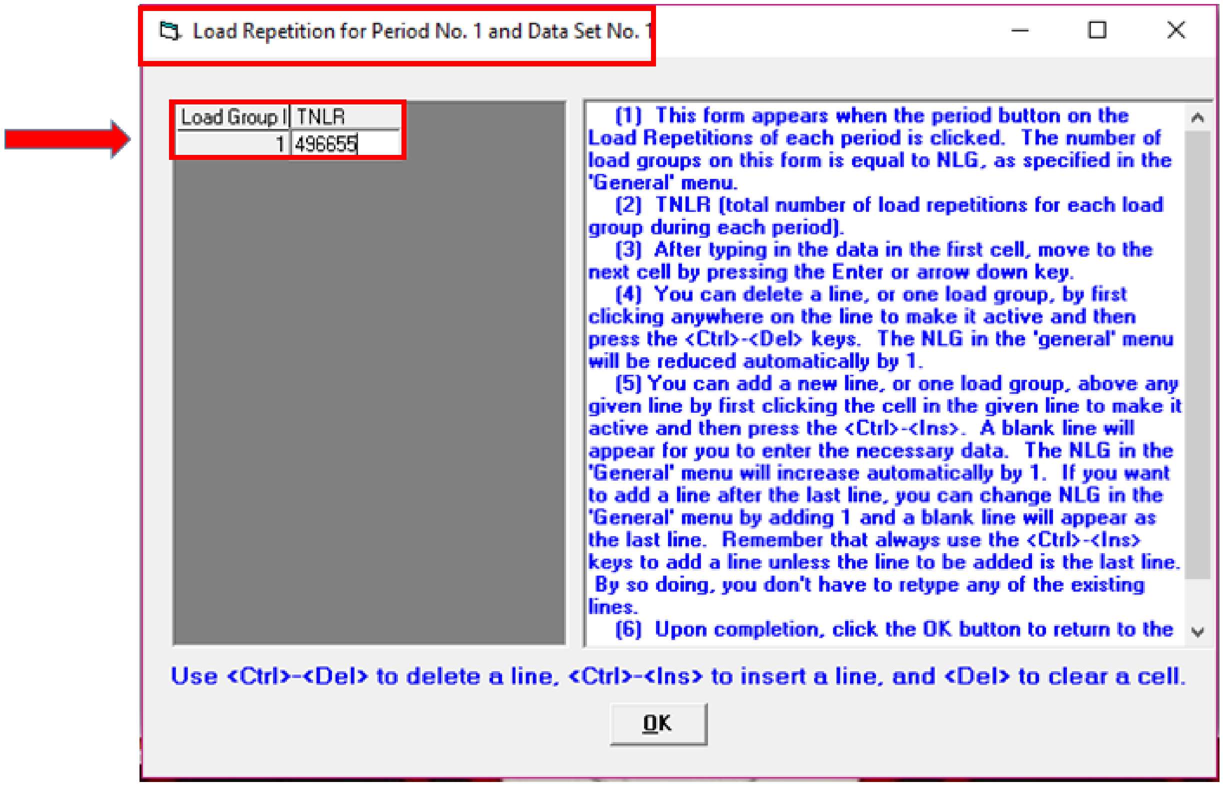


Figure 28-KENPAVE Load Repitition Input

Here TNLR means total number of load repetitions i.e. ESALS. Enter the required ESALs and click ok.

4.4.8 ANALYSIS

Now save the file as required and exit.

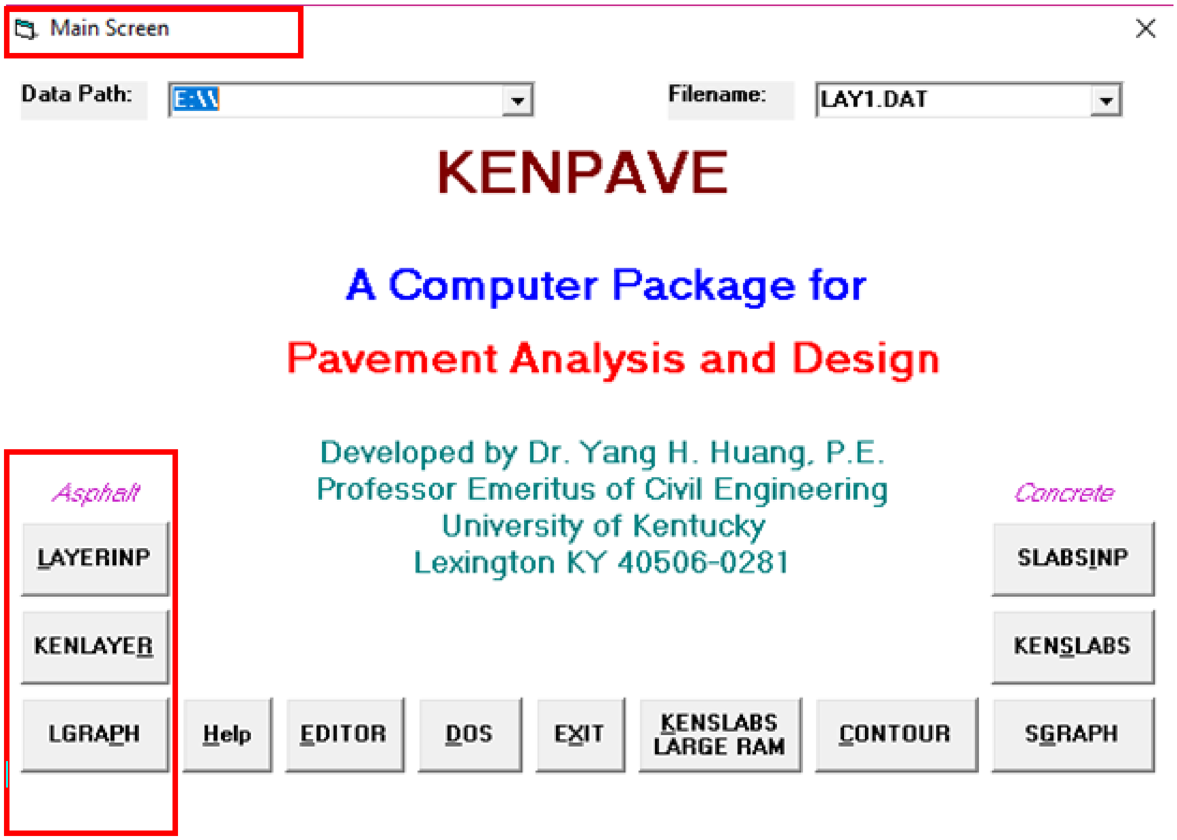


Figure 29-KENPAVE Main Screen

Click KENLAYER and your file summary will be saved in a notepad. That will show like this:

esall - Notepad

File Edit Format View Help

```
NUMBER OF PERIODS PER YEAR (NPY) =  1
NUMBER OF LOAD GROUPS (NLG) =  1
TOLERANCE FOR INTEGRATION (DEL) -- =  0.001
NUMBER OF LAYERS (NL)------------- =  5
NUMBER OF Z COORDINATES (NZ)------ =  0
LIMIT OF INTEGRATION CYCLES (ICL)- =  80
COMPUTING CODE (NSTD)------------- =  9
SYSTEM OF UNITS (NUNIT)------------=  0

Length and displacement in in., stress and modulus in psi
unit weight in pcf, and temperature in F

THICKNESSES OF LAYERS (TH) ARE : 2  7  6  8
POISSON'S RATIOS OF LAYERS (PR) ARE : 0.5  0.5  0.5  0.5  0.5
ALL INTERFACES ARE FULLY BONDED

FOR PERIOD NO. 1 LAYER NO. AND MODULUS ARE :    1  4.500E+05   2  3.500E+05
   3  4.200E+04   4  2.200E+04   5  8.059E+03

LOAD GROUP NO. 1 HAS 1 CONTACT AREA
CONTACT RADIUS (CR)--------------- =  5
CONTACT PRESSURE (CP)------------- =  80
RADIAL COORDINATES OF  1  POINT(S) (RC) ARE :  0

NUMBER OF LAYERS FOR BOTTOM TENSION (NLBT)---- =  1
NUMBER OF LAYERS FOR TOP COMPRESSION (NLTC)--- =  1
LAYER NO. FOR BOTTOM TENSION (LNBT) ARE: 2
LAYER NO. FOR TOP COMPRESSION (LNTC) ARE: 5

LOAD REPETITIONS (TNLR) IN PERIOD 1  FOR EACH LOAD GROUP ARE : 496655

DAMAGE COEF.'S (FT) FOR BOTTOM TENSION OF LAYER 2  ARE: 0.414  3.291  0.854

DAMAGE COEFICIENTS (FT) FOR TOP COMPRESSION OF LAYER 5  ARE:  1.365E-09 4.477

DAMAGE ANALYSIS OF PERIOD NO.  1  LOAD GROUP NO.  1

   RADIAL      VERTICAL      VERTICAL     VERTICAL     RADIAL   TANGENTIAL    SHEAR
 COORDINATE   COORDINATE   DISPLACEMENT   STRESS       STRESS      STRESS      STRESS
                                          (STRAIN)    (STRAIN)    (STRAIN)    (STRAIN)
   0.00000      9.00000      0.01067       7.935      -67.521     -67.521      0.000
  (STRAIN)                               2.156E-04 -1.078E-04 -1.078E-04  .000E+00
   0.00000     23.00010      0.00832       1.490       0.175       0.175       0.000
  (STRAIN)                               1.632E-04 -8.158E-05 -8.158E-05  .000E+00
```

Figure 30-KENPAVE Notepad Output File

All the data that your required in an analysis is stated here and you can easily comprehend the data. Stress, Strains, Deflections are mentioned in the data.

Now click L graph on main KENPAVE window and a graphical representation of your design will be shown.

4.5 ANALYSIS OF DATA

Traffic count data has been converted to ADT first and then to ESALS later on using online available software. Link has been attached (http://apps.acpa.org/applibrary/ESAL/). After getting the required ESALs analysis has been performed using KENPAVE. Purpose is to get the stress, strain and deflection data at our specified points, which will be later on used to calculate the estimated amount of electricity produced.

4.5.1 CONVERSION FROM ADT TO ESALS

The first thing is conversion of traffic count into ESALs as KENPAVE analysis is performed using ESALs.

Two images have been attached for both the locations. First image shows the factors that act as 'input parameters' and second image shows the estimated number of ESALs over the next 10 years, as our analysis is based on next 10 years.

FOR GATE 1

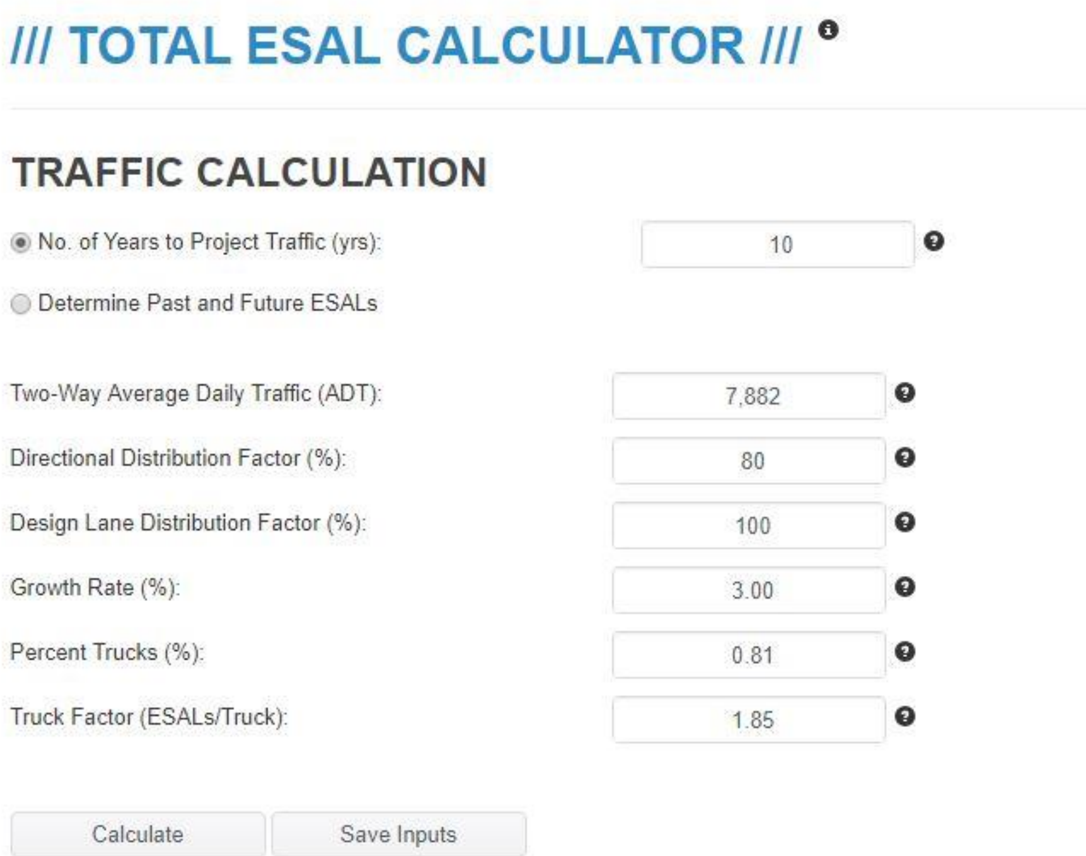


Figure 31-Gate 1 ESAL Input

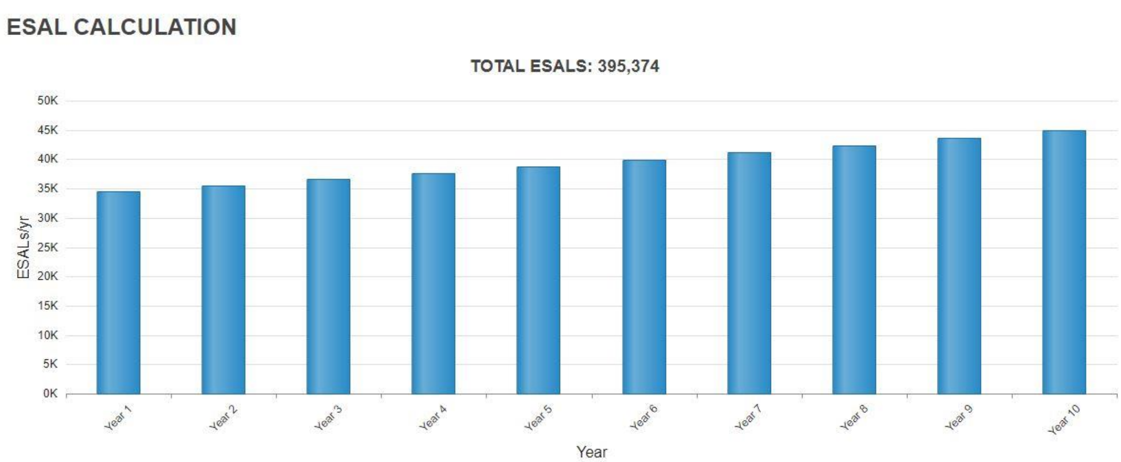


Figure 32-Gate 1 ESAL Calculation For Next 10 Years

FOR GATE 10

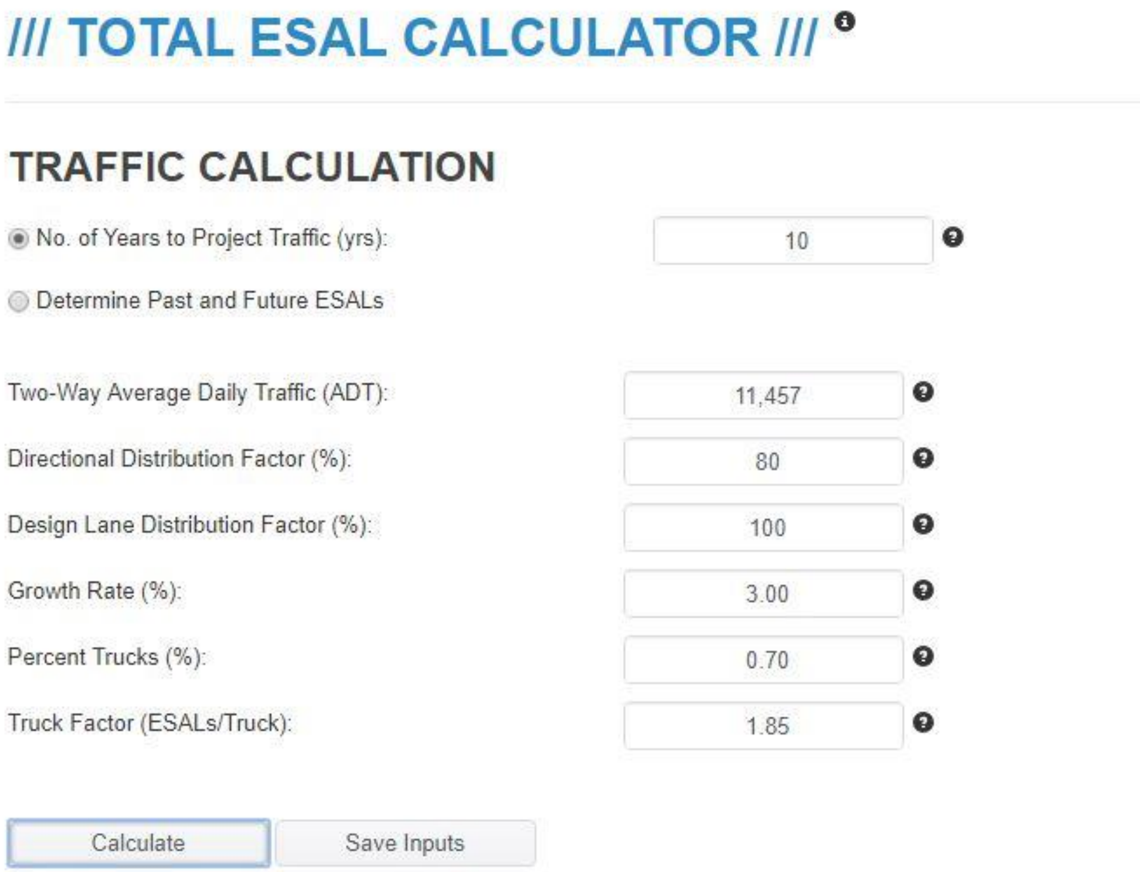


Figure 33-Gate 10 ESAL Input

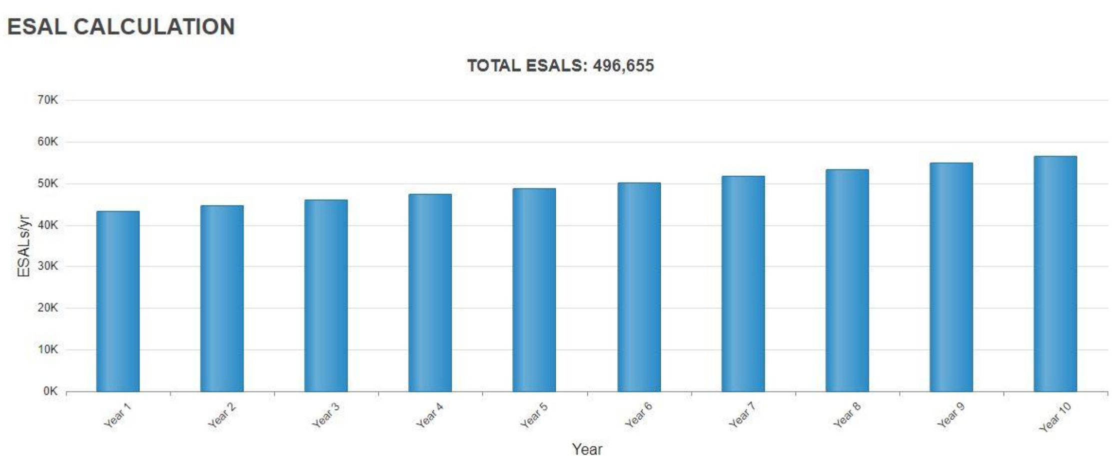


Figure 34-Gate 10 ESAL Calculation For Next 10 Years

FOR ZAINAB CHOWK

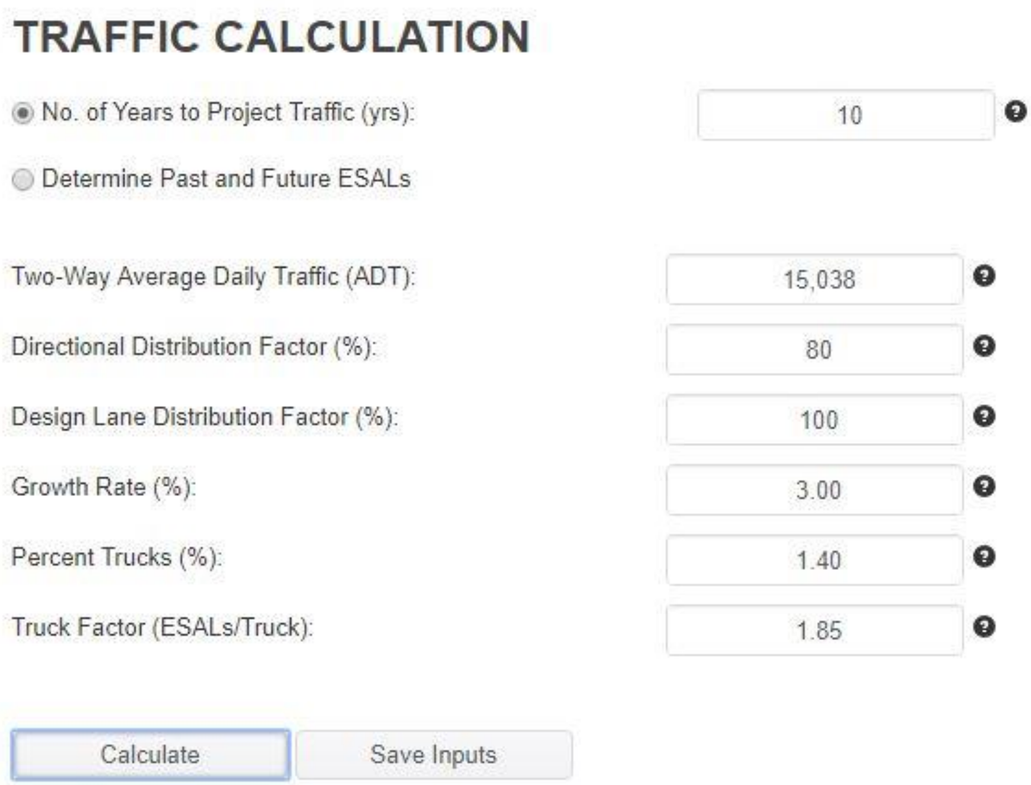


Figure 35-Zainab Chowk ESAL Input

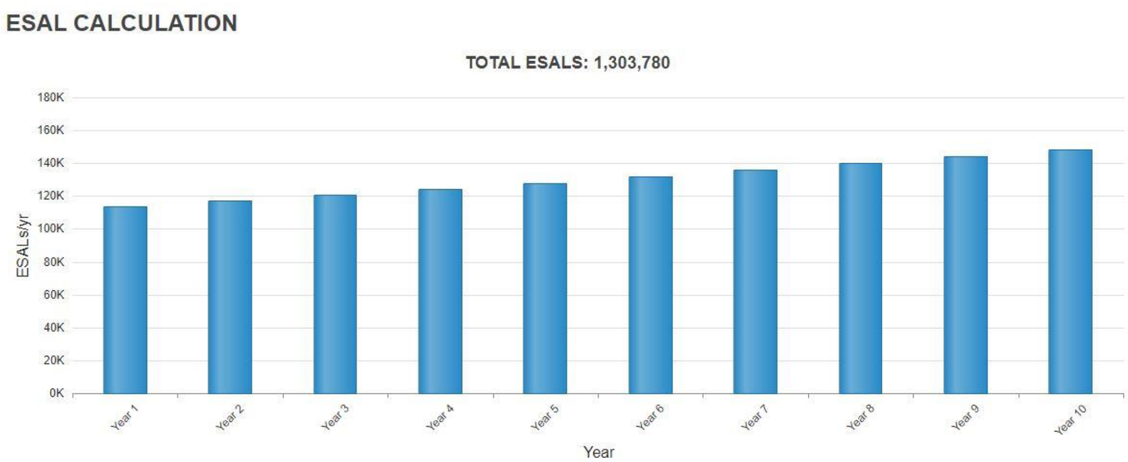


Figure 36-Zainab Chowk ESAL Calculation For Next 10 Years

FOR NICE CHOWK

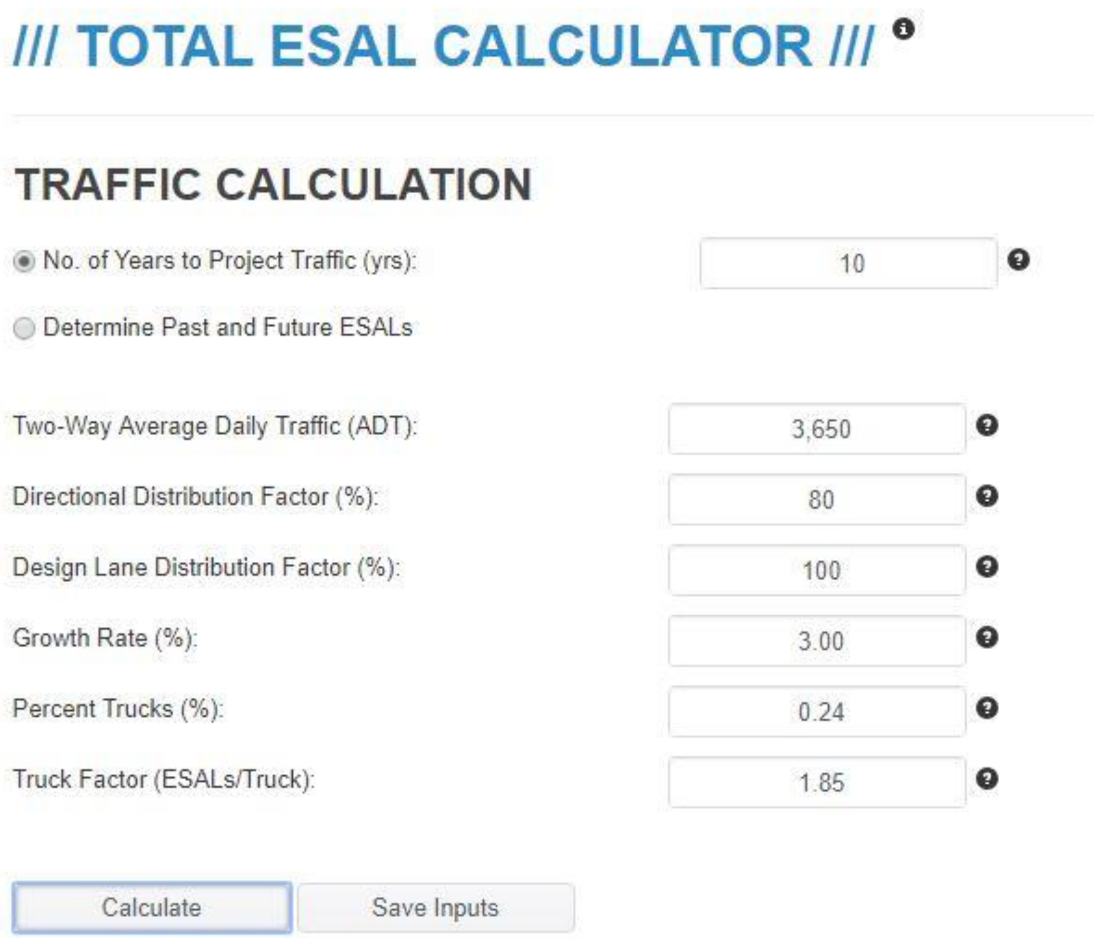


Figure 37-NICE Chowk ESAL Input

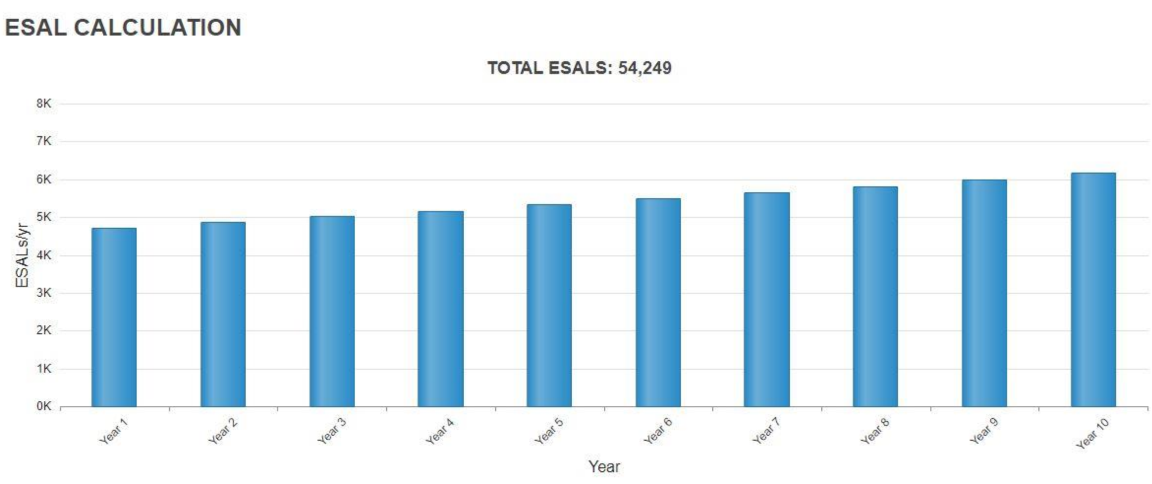


Figure 38-NICE Chowk ESAL Calculation For Next 10 Years

4.5.2 STRESS Vs STRAIN GRAPHS

After getting the ESALs count at our specified location, analysis has been performed using KENPAVE. Stress strain graphs for each location have been obtained which are attached below.

GATE-1

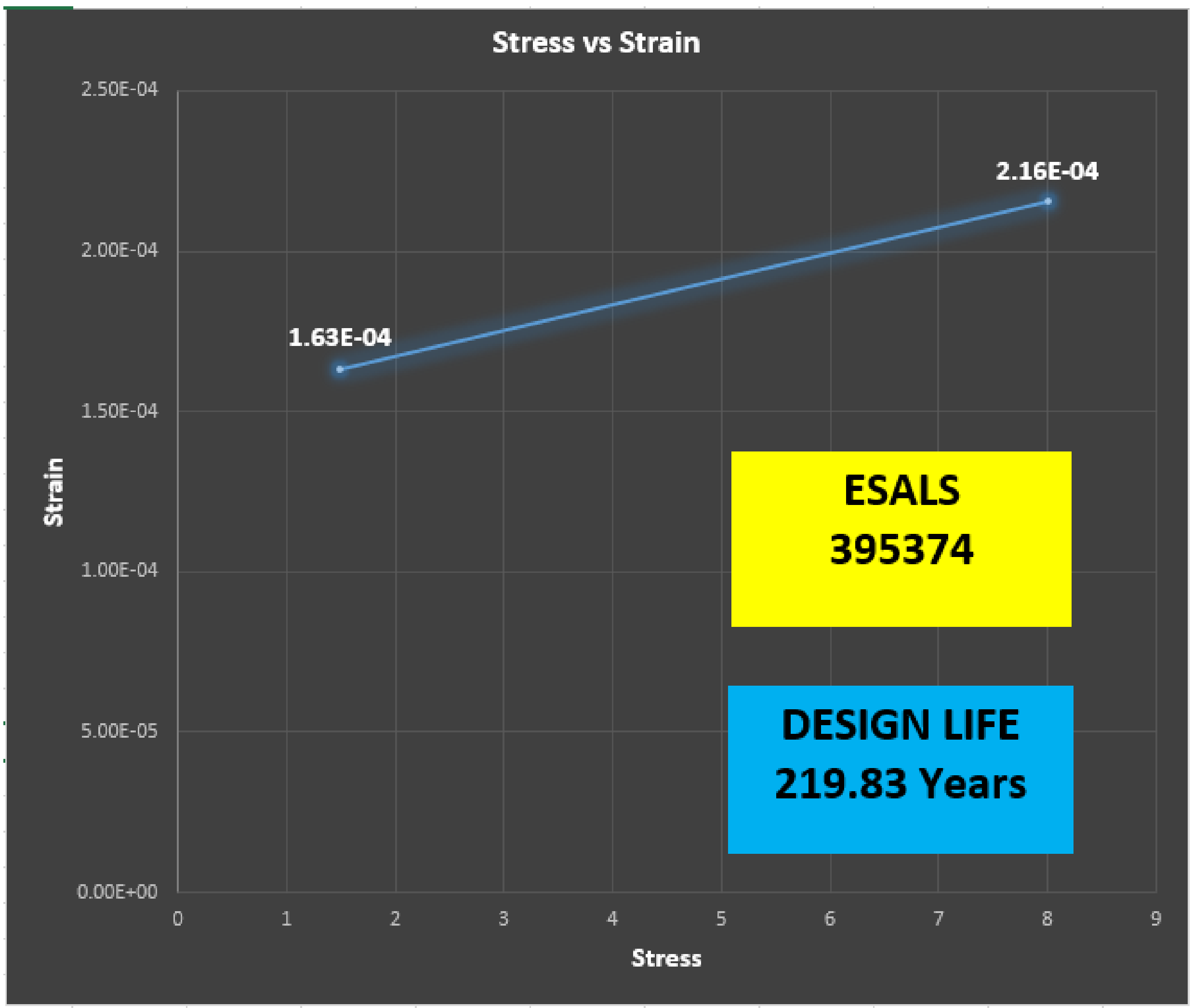


Figure 39-Stress Strain Graph Gate-1

GATE-10

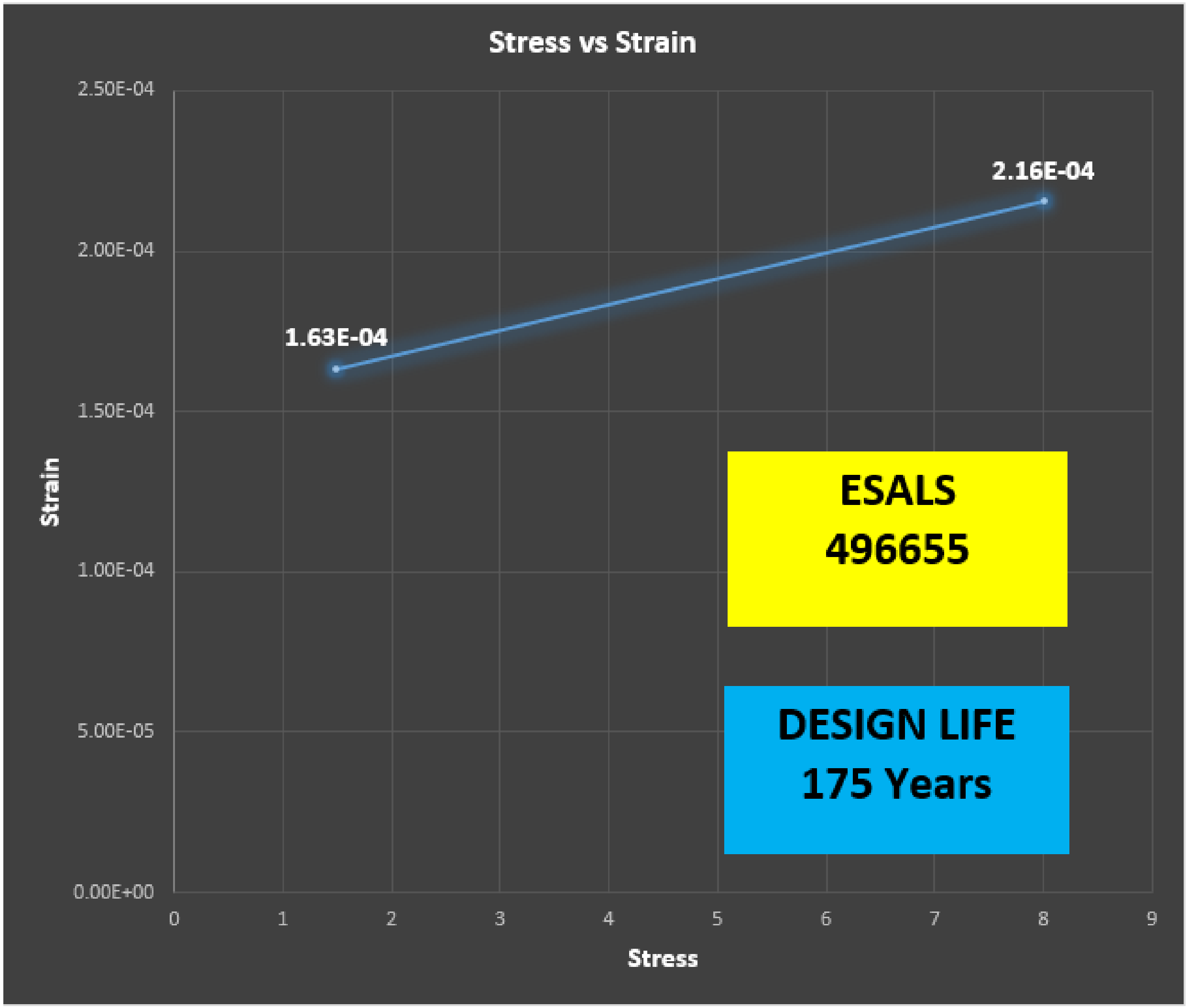


Figure 40-Stress Strain Graph Gate-10

ZAINAB CHOWK

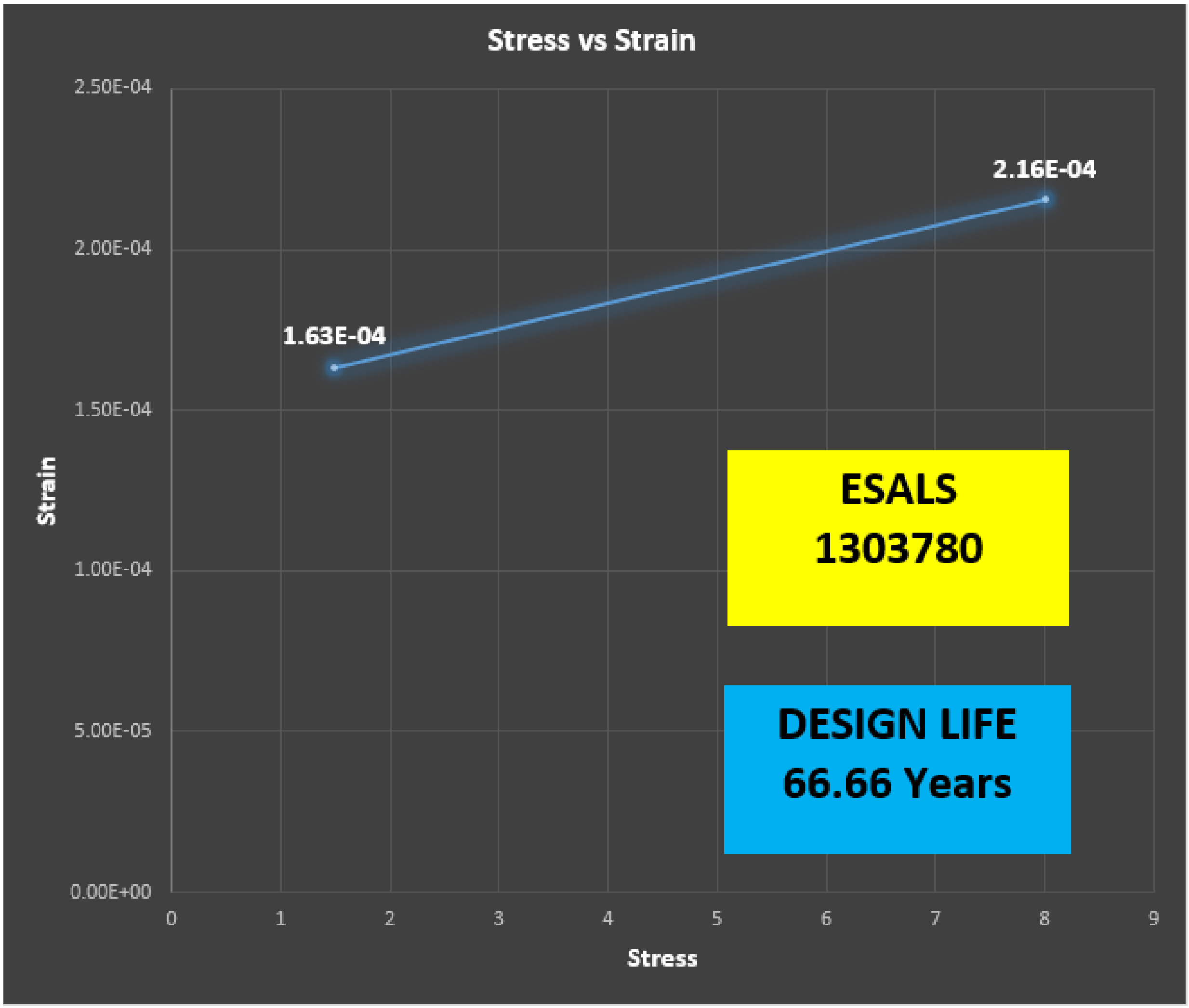


Figure 41-Stress Strain Graph Zainab Chowk

NICE CHOWK

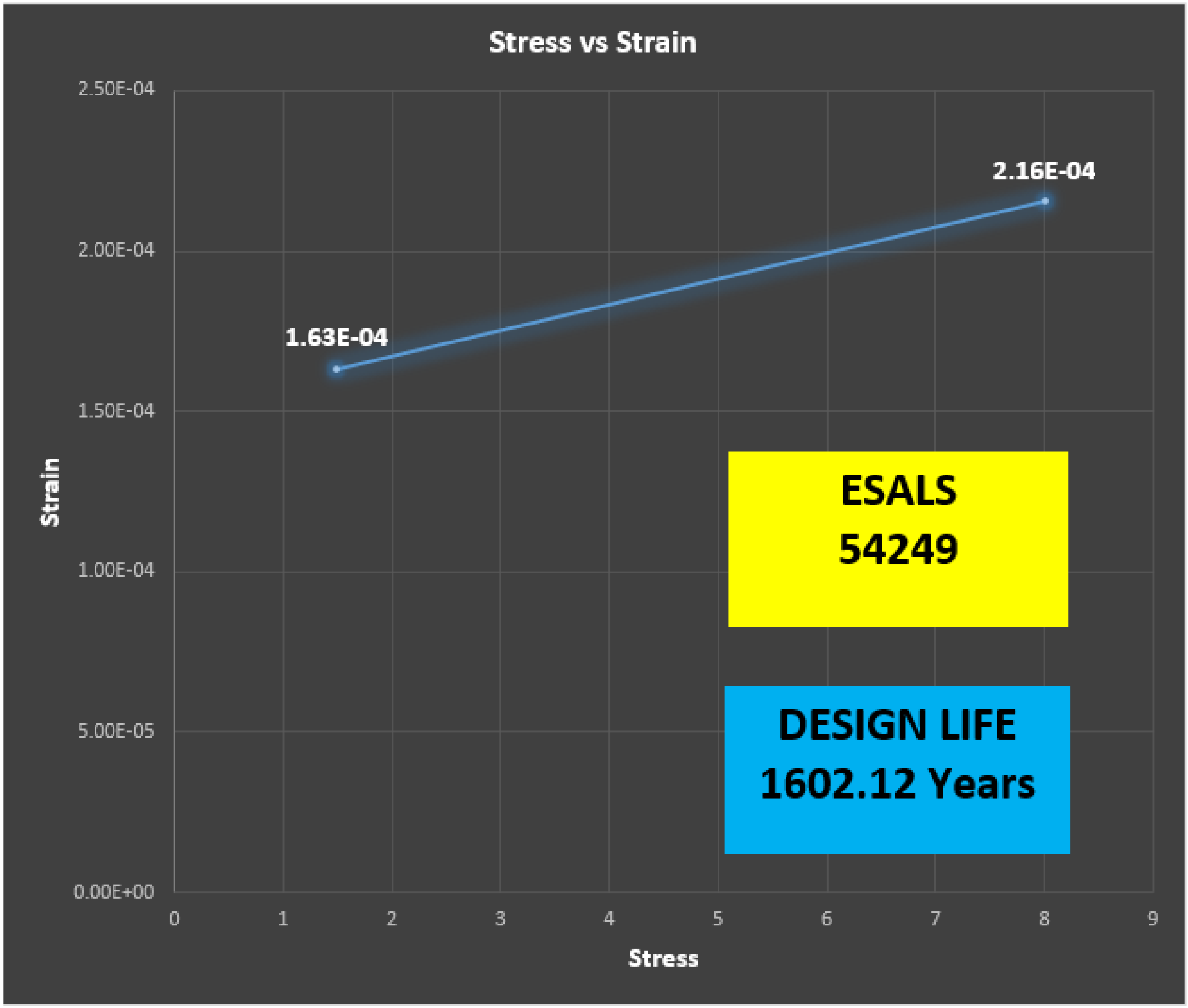


Figure 42-Stress Strain Graph Nice Chowk

Stress strain graphs shows the same values as our road dimensions are same for each point. Based on variation in traffic count and ESALs the only difference lies in "design life" for each point. In a nut shell, having less number of ESALs means greater design life and vice versa for less number of ESALs.

It is clearly evident from the graphs shown above that maximum life of pavement in our case is of Nice Chowk due to lowest number of ADT whereas Zainab Chowk has minimum life due to highest number of ADT.

4.5.3 STRESS Vs DEFLECTION GRAPHS

The same procedure has been adopted for calculation of deflections at specified points. Graphs for each point deflection have been attached below.

GATE-1

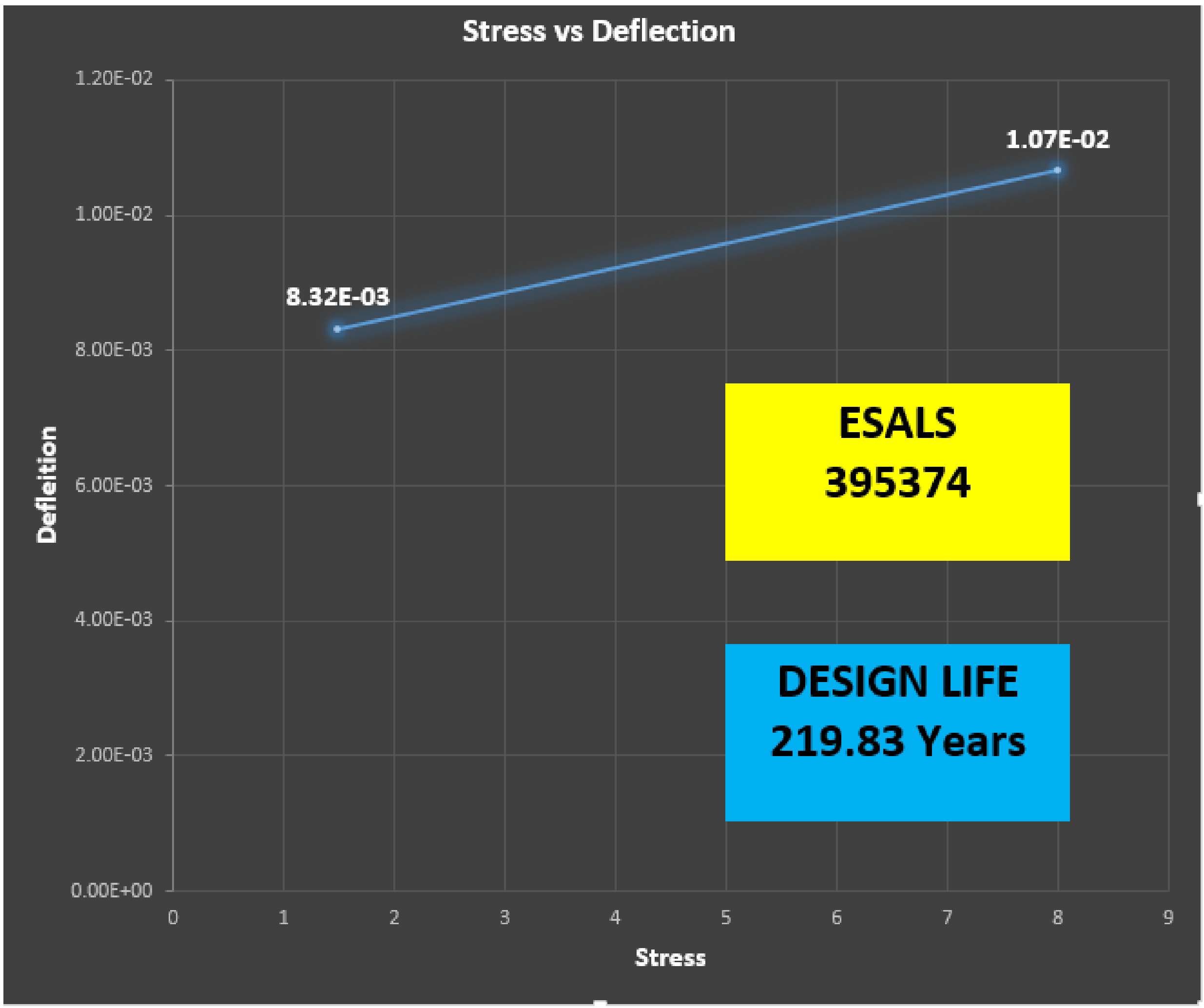


Figure 43-Stress Deflection Graph Gate-1

GATE-10

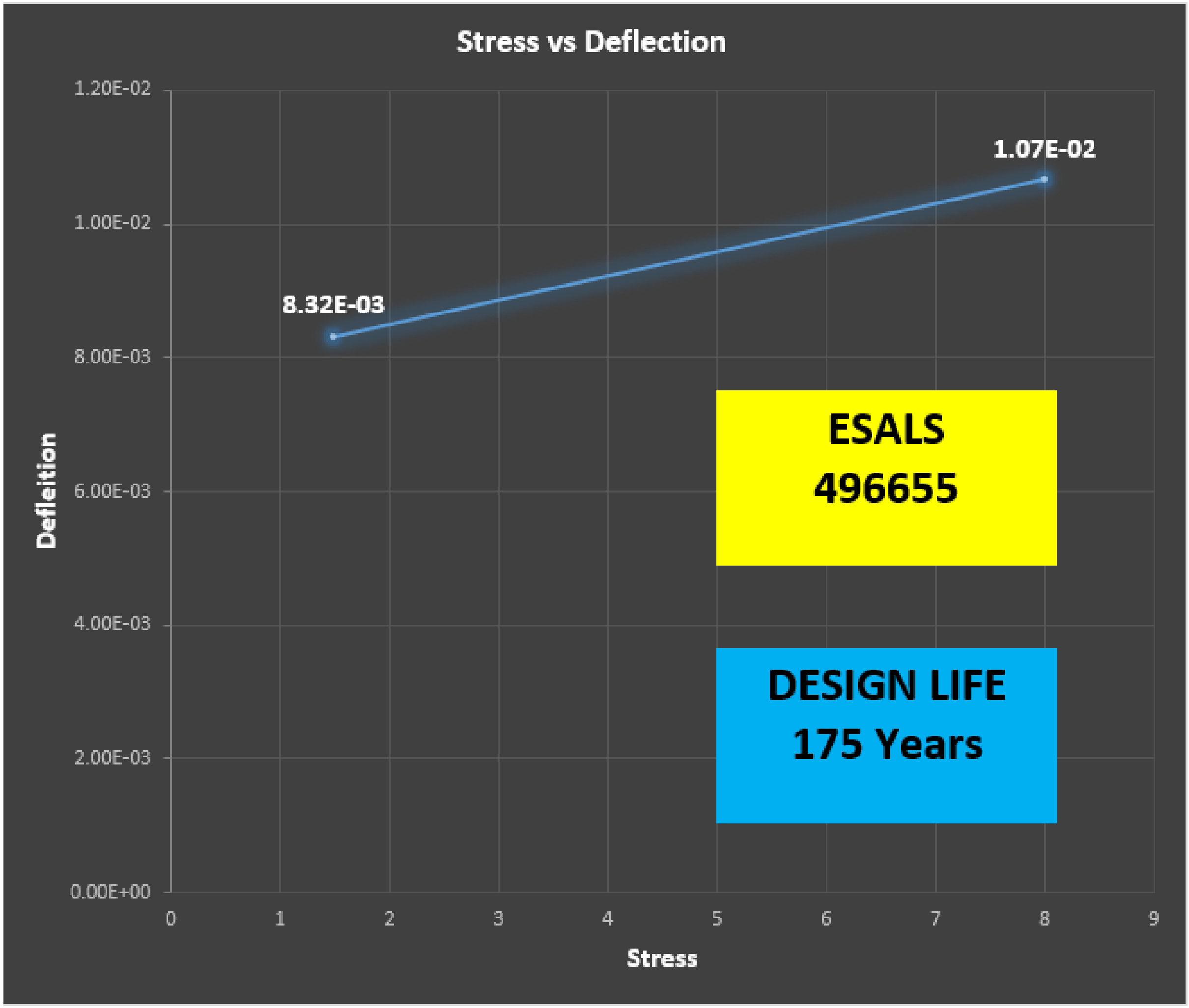


Figure 44-Stress Deflection Graph Gate-10

ZAINAB CHOWK

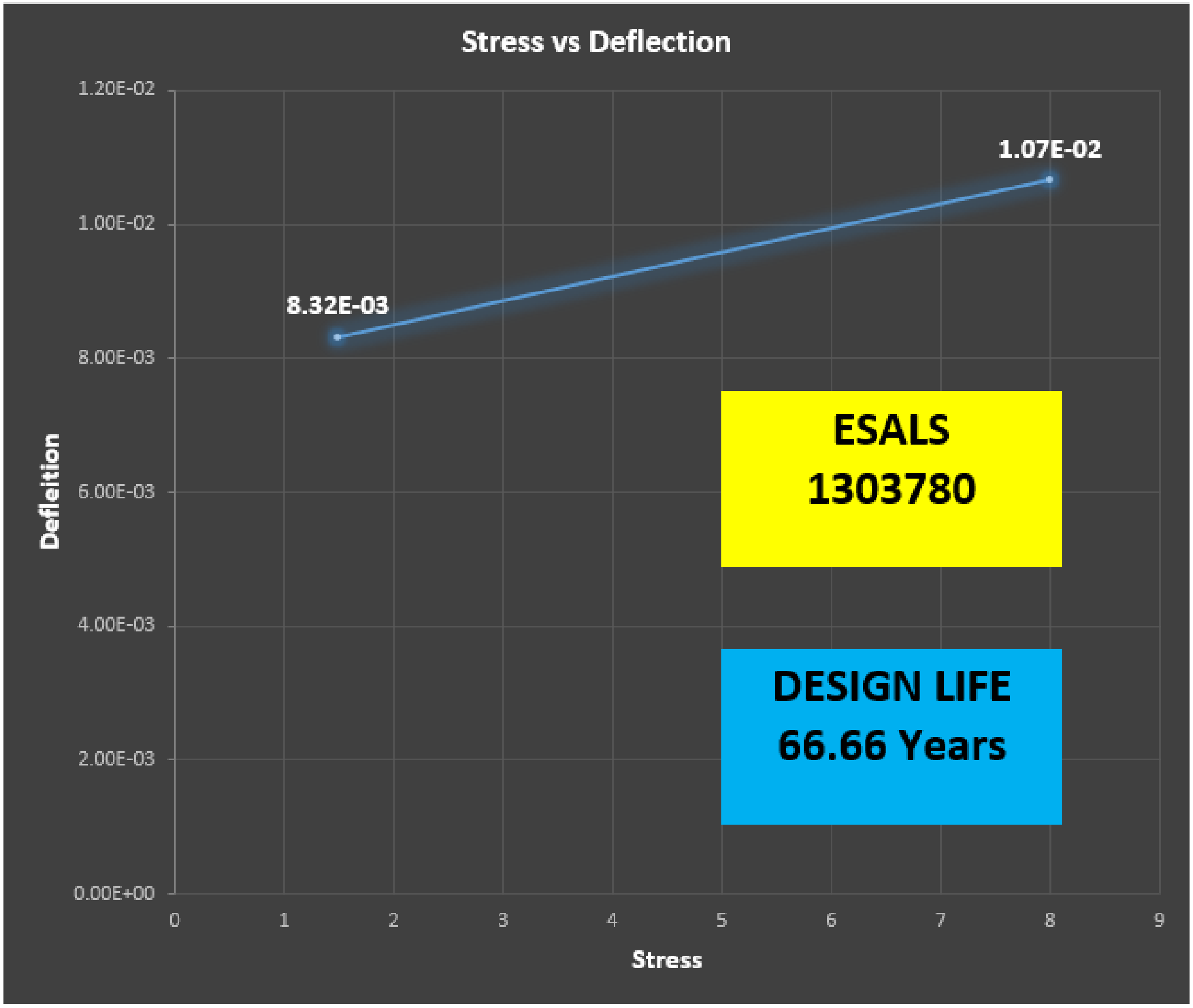


Figure 45-Stress Deflection Graph Zainab Chowk

NICE CHOWK

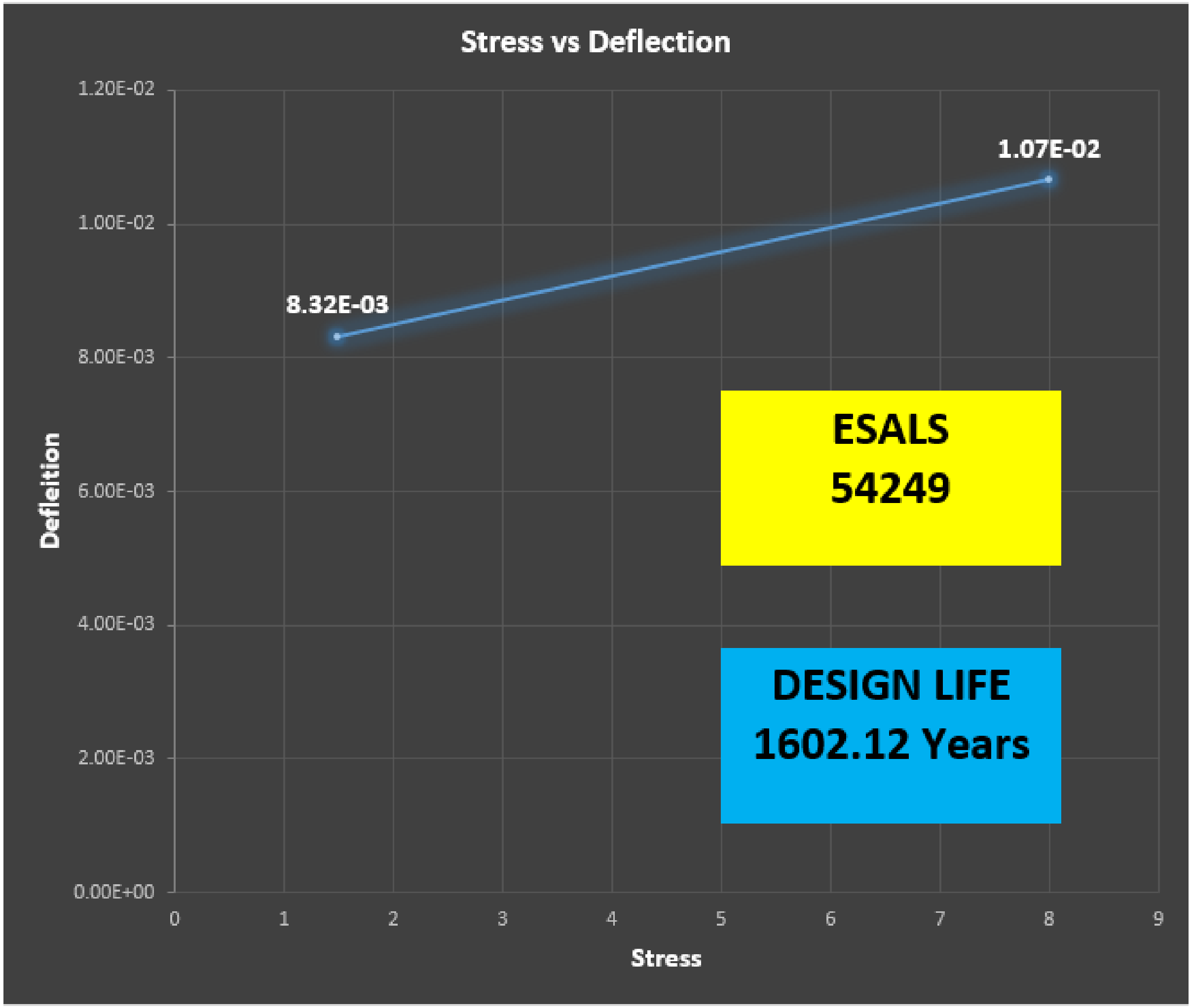


Figure 46-Stress Deflection Graph Nice Chowk

4.6 RESULTS

4.6.1 ANALYSIS PERFORMED AT TWO POINTS

Analysis has been performed at two points in order to check the best place for the placement of PZT sensors. Purpose is to ensure maximum energy output with minimum loss to the sensors and pavement.

Result of analysis has been concluded by getting the required stress, strain and deflection values at these two points. Point 1 is referred as the top of the base and Point 2 is set as top of subgrade.

```
LOAD REPETITIONS (TNLR) IN PERIOD 1  FOR EACH LOAD GROUP ARE : 496655

DAMAGE COEF.'S (FT) FOR BOTTOM TENSION OF LAYER 2  ARE: 0.414  3.291  0.854

DAMAGE COEFICIENTS (FT) FOR TOP COMPRESSION OF LAYER 5  ARE:  1.365E-09 4.477

DAMAGE ANALYSIS OF PERIOD NO.  1  LOAD GROUP NO.  1

   RADIAL     VERTICAL     VERTICAL    VERTICAL    RADIAL   TANGENTIAL   SHEAR
 COORDINATE  COORDINATE  DISPLACEMENT   STRESS     STRESS     STRESS     STRESS
                                       (STRAIN)   (STRAIN)   (STRAIN)   (STRAIN)
   0.00000     9.00000     0.01067      7.935    -67.521    -67.521     0.000
  (STRAIN)                           2.156E-04 -1.078E-04 -1.078E-04 .000E+00
   0.00000    23.00010     0.00832      1.490      0.175      0.175     0.000
  (STRAIN)                           1.632E-04 -8.158E-05 -8.158E-05 .000E+00

AT BOTTOM OF LAYER  2   TENSILE STRAIN =  -1.078E-04
ALLOWABLE LOAD REPETITIONS =   8.691E+07  DAMAGE RATIO =   5.714E-03

AT TOP OF LAYER  5   COMPRESSIVE STRAIN =   1.632E-04
ALLOWABLE LOAD REPETITIONS =   1.234E+08  DAMAGE RATIO =   4.025E-03

******************************
* SUMMARY OF DAMAGE ANALYSIS *
******************************
AT BOTTOM OF LAYER  2     SUM OF DAMAGE RATIO = 5.714E-03
AT TOP OF LAYER  5        SUM OF DAMAGE RATIO = 4.025E-03

MAXIMUM DAMAGE RATO =   5.714E-03   DESIGN LIFE IN YEARS = 175.
```

Figure 47-Stress Strain Value For Layer 2 and Layer 5

It is clearly evident form the picture above that the value of stress, strain and deflection is more at the top of base (Layer 2) as compared to subgrade (Layer 5). Thus, more value of electricity production can be achieved in case of Layer 2.

4.6.2 TOP OF BASE

From the analysis performed above and results obtained in KENPAVE clearly depicts the location of PZT sensors at the top of base. For the safety of material as a whole epoxy material is used.

The important issue lies in the selection of the epoxy that would encapsulate the material and protect it so for that the spherical casing must be made up of that material. The issue was created because the material selected should be compatible with the hot mixed asphalt layer to prevent the damage. Conathane TU-981 epoxy was selected to be used as the resin. It's an already tested material and it gave good results. Its elastic modulus is 258.8 MPa.

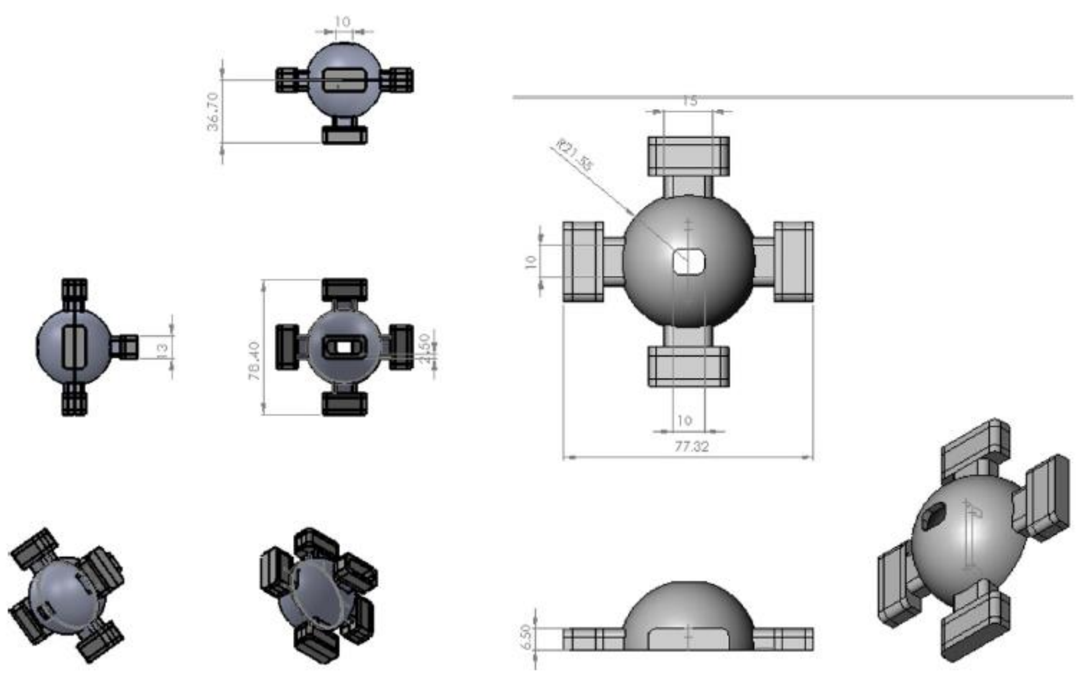


Figure 48-Epoxy TU-981

4.6.3 ESALS VS DESIGN LIFE BAR CHART

As it is clearly evident from the graphs shown above that with the increase in number of ESALs, design life of pavement reduces. In our case maximum numbers of ESALs are in case of Zainab Chowk due to which it has minimum design life.

ESALs and design life for different points are as follows:

Table 4- ESALs And Design Life

S. No	Point Name	ESALs	Design Life
1.	Gate 1	395374	219.83
2.	Gate 10	496655	175
3.	Zainab Chowk	1303780	66.66
4.	Nice Chowk	54249	1602.12

Figure 49-ESALs Vs Design Life

4.6.4 ESTIMATED ELECTRICITY PRODUCTION

The estimated values for power output have been shown below. It is taken from the user manual of Piezo-electric material. (Manual, n.d.)

Energy Harvesting Data for Middle Clamp Location									
Acceleration Amplitude (g)	Frequency (Hz)	Tip Mass (gram)	RMS Power (mW)	RMS Voltage (V)	RMS Current (mA)	Resistance (kΩ)	RMS Open Circuit	Peak to Peak Displacement (mm)	Peak to Peak Displacement (in)
0.25	413.0	0.0	0.0	0.6	0.1	9.0	1.2	0.3	0.01
0.50	410.0	0.0	0.1	1.3	0.1	13.6	2.2	0.5	0.02
1.00	404.0	0.0	0.4	2.0	0.2	11.1	3.3	0.7	0.03
2.00	400.0	0.0	1.1	3.2	0.4	8.9	5.7	0.8	0.03
0.25	60.0	15.1	1.2	10.8	0.1	95.7	14.4	2.4	0.09
0.50	60.0	15.1	3.7	13.9	0.3	52.1	25.8	3.3	0.13
1.00	60.0	14.9	9.8	19.5	0.5	38.8	30.5	4.0	0.15
2.00	60.0	14.9	25.9	27.3	0.9	28.8	36.1	5.0	0.19
0.25	47.0	25.3	2.0	14.1	0.1	100.0	17.0	3.1	0.12
0.50	46.0	25.3	4.8	17.2	0.3	61.9	24.8	4.6	0.18

Figure 50-Power Output

CHAPTER 5

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 BACKGROUND

This chapter summarizes the entire thesis. This chapter informs reader about the limitations of current study and provides guidelines for future study of the same subject. The introduction of thesis has been presented in chapter 1, which describes the general preface, need and objectives of thesis in detail. Why this study is important in current scenario and why there is need to do research on such material is necessary has been discussed in chapter 2. The adopted research methodology has been discussed in chapter 3. The analysis of data has been done in chapter 4. There is a need to transform theoretical knowledge, which was gained through literature review, into proper research. In this chapter achieved objectives will be discussed and the issues with them and their significance will be discussed.

This chapter highlights the limitation of study and future work of study. Suggestions and guidelines provided for the future work may result in development of an effective system to generate more electricity using PZT sensors.

5.2 CONCLUSION

The conclusions that we reached after our study are enlisted and explained below.

5.2.1 FUTURE LIMITATIONS OF PROJECT

Due to the lack of time and resources project findings were not executed practically and only theoretical study was performed. The availability of the material is another issue due to the fact that its manufacturing in Pakistan is not done and respectively the cost is very high.

Another major concern was the sensitivity of the material and the fact that it was going to be used on a high level practical project related to pavement, a lot of encapsulation and protection must be provided by an epoxy which demands serious testing before its implementation.

Pakistan being a developing country has lack of resources (budget) to produce energy in order to meet its own demands, let go of the new methods specifically that require much more new type of resources to produce electricity.

5.2.2 RESEARCH FINDINGS

By doing the project on PZT sensors, we were able to uncover the facts regarding new material, its working principle, its feasibility and its production capability.

We have learnt the use of material on different domains such as in multiple ways. i.e : Pavement Health Monitoring, Structural Health Monitoring and Bridge Health Monitoring.

Pavement analysis has been performed using KENPAVE which is software for analyzing and designing rigid as well as flexible pavements. Thus, by going through the whole project we have learnt how to use this software which is an effective tool for the analysis of pavement.

5.2.3 LOCATION LIMITATIONS

Our project is based on keeping NUST as a model for our study. This helped us in getting the traffic count early and to complete our research in a quick way but on the other hand, the site has low number of traffic count which did not allow us to get more desired results.

We are much hopeful that if this study is performed at large scale, we will be able to achieve much optimistic results like in case study of Dubai. i.e. Dubai research study 2017 (Najini & Muthukumaraswamy, 2017)

5.3 RECOMMENDATIONS AND SUGGESTIONS

After performing the detailed analysis on flexible pavement using KENPAVE and in the light of conclusions that we have made above, we have devised a set of recommendations and suggestions, which are explained below.

5.3.1 METHOD TO BE ADOPTED IN FUTURE

As far as the adaptation of this method is concerned this method is quite useful and sustainable in multiple ways. i.e : Pavement Health Monitoring, Structural Health Monitoring and Bridge Health Monitoring . Using the little electricity they produce they can be self-sustainable wireless tools that can be effectively used in the above mentioned domains.

5.3.2 TRAFFIC ON RISE IN PAKISTAN DUE TO CPEC AND MOTORWAYS DEVELOPMENT

Keeping in view the continuous increase in traffic due to CPEC and other infrastructure development programs in Pakistan, this method has much potential even to generate large amount of electricity if implemented under proper supervision and regulation. Even though that its payback period is quite long enough to meet the cost of its installation.

Considering NUST as a model we are able to generate low amount of electricity due to low traffic count with in the university premises.

5.3.3 PRODUCED ELECTRICITY WHERE TO BE USED

The project at its end enabled us to determine the amount of electricity produced. Our main objective is to produce large amount of electricity so that we could contribute the generated amount of electricity to NUST electric reservoir.

But after going through the analysis and detailed insight of project, working principle of PZT, its generated capacity and its efficiency we are able to know the exact amount of electricity produced, which is very less as compared to the amount we imagined. The generated amount is thus then to be used for

Pavement Health Monitoring, specifically in areas where traditional means of wires and poles is expensive.

5.3.4 PAVEMENT HEALTH MONITORING

5.3.4.1 INTRODUCTION

Self-powered seniors are proposed for pavement health monitoring.

A new spherical packaging system made up of resin was designed initially and then tested. From experiments and results it was noted that damage progression can be sensed and located with these sensors. Also, the experiments suggest that the method is efficient also. Furthermore, localizing the damage and quantifying the damage and its severity was investigated.

Damage detection algorithms are vital in the SHM systems. The three major phases of this system:

(1) Structural simulation with finite element method (FEM)

(2) Generation of data and feature extraction based on the outputs of the SWS memory cells, and

(3) Finding a rational relationship between the probability density function parameters attained from strain distribution, and damage progression. Initially, a damage scenario was defined for a given pavement structure through the Finite Element simulations. Afterword, sensors are used to determine the timely occurrence at points that have been identified as predetermined and preselected strain levels. The strain distribution in each sensor was used for defining damage indicators. Also, another challenge is the application of wireless sensors which is a local phenomenon and it results from the damage in structures. Thus, the influence on the sensors that are close to the damaged site is more and is less for sensors remote to the damage site. By to densely distributing the sensors throughout the structure the effective measurements cab be taken.

Radio Frequency Identification (RFID) technology is used to create the communication between the sensor and a service vehicle. The sensor can be read using an RFID scanner from a distance of 16 in. The thickness of the asphalt layer affects the accuracy of the transmitted and recovered signal due to its viscoelastic properties of asphalt. In this scenario, at least 12 in distance is required to communicate with RFID scanner. The amount of electricity produced is typically less than 1W. By given strain levels observed in pavements, it is assumed that the available harvestable energy is also around 1W. Novel analog signal processing circuits that require less than 1W of power are used in the system.

5.3.4.2 GEOMETRY

The model has a dimensions of 6200x4170 mm2. 6200 mm or (244 in.) along the direction of traffic and 4170 mm or (164 in.) along the transverse direction (the width of one lane).

5.3.4.3 MESH

The model was idealized with linear hexahedral element of type (C3D8R). The mesh dimensions were considered about 12.7 mm (0.5 in.) in the loading area and 25.4 mm far from the contact zone. In total 615,076 elements of type C3D8R were used. A supercomputer was used to run the Abaqus simulations for both the intact and damaged models due to the high number of degrees of freedom of the model. The available servers with high performance computing were used for this aim. A server with 384 GB RAM and 72 logical RAM, the simulation time for the intact configuration took around 42 hours.

5.3.4.4 LOCATION OF SENSORS AND DAMAGE ZONE

The sensors were situated at a separation of 50.8 mm (2 in.) from the base of the asphalt layer. The figure underneath outlines the design of sensors inside the asphalt, 304.8 mm (12 in.) is the separation between two back to back sensors. The separation of Sensors 1 and 9 from vertical limits was equivalent to 74 in. In this examination, A sum of 55 sensors were utilized to gauge both longitudinal and transversal strains.

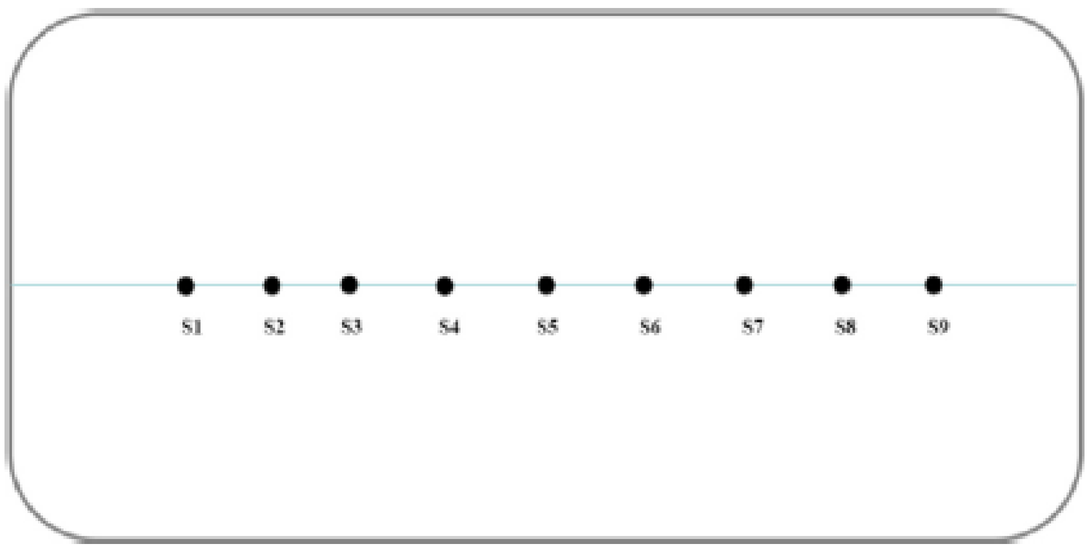


Figure 51-Array of Sensors In Laboratory Testing

As per the FE simulations, the strain esteems for detecting hubs a long way from the loading way is low. Therefore, it isn't useful for the sensors to recognize the change. Just those sensors which could quantify strains higher than 20 le were kept for the investigation. These are Sensors 1 to 9 situated under loading way. The tire loading engrave region was begun from the area of Sensor 1 and wrapped up by Sensor 9, just the outcomes for Sensors 3 and 7, situated at an appropriate separation from loading focuses, were incorporated into the analysis. From that point forward, at the base of the asphalt layer another FE show was produced with a harm zone. The aggregate length of the split zone was 0.5 in. from the base of the asphalt layer. The location of the sensors is the same as the intact model. Sensor 5 is over the harmed zone.

5.3.4.5 EPOXY

The important issue lies in the selection of the epoxy that would encapsulate the material and protect it so for that the spherical casing must be made up of that material. The issue was created because the material selected should be compatible with the hot mixed asphalt layer to prevent the damage. Conathane TU-981 epoxy was selected to be used as the resin. It's an already tested material and it gave good results. Its elastic modulus is 258.8 MPa.

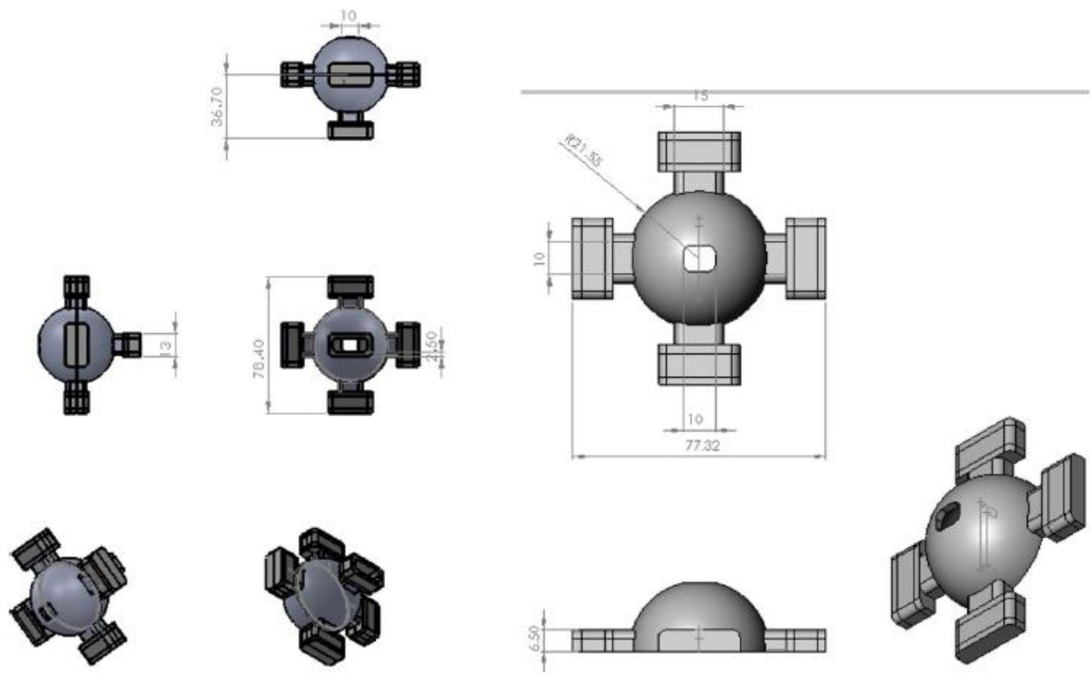


Figure 52-EPOXY TU-981 Coating

The capsules were located at a distance of approximately 2 in. apart from the bottom of the layer. The primary PZT was placed at middle and the remaining ones were located at a distance of 3 in. from the middle PZT. Subsequently applying load caused the voltage generation and, the PZT output voltage was read on NI 9220 data acquisition system (with 1 GX impedance) in parallel with a resistor with an impedance similar to the self-powered wireless sensors (50 MΩ).

5.3.4.6 DAMAGE DETECTION: FE MODEL

A series of sensing nodes was measured at the bottom of the asphalt layer to sense the damage progression. Excessive tensile stress at the bottom of the asphalt layer causes fatigue cracking. As the tensile strain measures the fatigue cracking it was considered very important and subsequently used for the analysis. Sensors 3 and 7 were located at a good and reasonable distances so the results of these sensors were included. A smart pebble wireless sensor has a series of memory cells (gates). Now these gates store the duration of strains at a prescribed preselected level. In general, the number of gates is dependent on the nature of the problem and the material. In FE simulations the strain values are extracted. There were 10 strain levels that were designed to cover upper and lower limits of these. The min. level of strains to be captured by PZT transducers was approx. 20.00 le. Oppositely, the max. value was aprrox. 97 le. As a for 10 strain levels for the gates, the difference between each of the strain levels is 8.56 le.

5.3.4.7. DISCUSSION

Providing a power source for the detection sensors is a problem in order to deal with this problem. In order to deal with this matter an energy less method was devised to monitor pavement structures. Sensors are the damage indicators and it have been shown in the results. The PDF obtained from the cumulative time histograms change with the damage changes. It is a sign of damage amount that the growth of PDFs and their shift to left side. Changes of r seem to be a good indicator of damage changes. Similarly, the designed mini sensor packaging endures temperature and pressure during compaction, the experimental study verified. Such small size system can be used and installed in large-scale sensor networks by State highway agencies.

5.3.4.8 CONCLUSION

This method is very good at the detection of fatigue cracking as shown by the FE simulations. The same conclusions were extracted from the laboratory testing. The sensors could detect multiple damage states including a crack propagation phase, it was found that damage progression can be considered as a function of PDF parameters (l and r) gotten from the strain distribution. l and r were extracted by curve fitting of the sensor output distribution collected from the whole memory cells of the sensor. The important remark from the individual sensor analysis was that the PDFs shift to left (l decreases) and their width grows (r increases) due to the damage progression. Resultantly, variations of r can be regarded as a better indicator of damage.

Study of the effect of group of sensors for the numerical simulations with a number of active sensors was done. Similarly, it was shown that there is a good and relationship between the STD of l and r of group of sensors with the damage progression. Resultantly, with the progression of damage this parameter increases.

Another observation was the likelihood of localization of the damage and measuring its severity through the analysis of the PDF shifts was another obs. For the localization of the damage the variations of both l and r could be taken.

5.3.5 FUTURE THREADS

Cost-benefit analysis and payback period analysis have not been performed due to lack of time. Work in pavement health monitoring section is commendable.

REFERENCES

Alavi, A. H., Hasni, H., Lajnef, N., & Chatti, K. (2016). Continuous health monitoring of pavement systems using smart sensing technology.

Construction and Building Materials, *114*, 719–736. https://doi.org/10.1016/j.conbuildmat.2016.03.128

Manual, U. (n.d.). Ppa products.

Najini, H., & Muthukumaraswamy, S. A. (2016). Investigation on the Selection of Piezoelectric Materials for the Design of an Energy Harvester System to Generate Energy from Traffic. *International Journal of Engineering and Applied Sciences (IJEAS)*, *3*(2), 43–49.

Najini, H., & Muthukumaraswamy, S. A. (2017). Piezoelectric Energy Generation from Vehicle Traffic with Technoeconomic Analysis. *Hindawi Journal of Renewable Energy*, *2017*, 16.

NHA. (n.d.). Pavement Design Report(E-35).pdf.

Zhao, H., Tao, Y., Niu, Y., & Ling, J. (2014). Harvesting energy from asphalt pavement by piezoelectric generator. *Journal Wuhan University of Technology, Materials Science Edition*, *29*(5), 933–937. https://doi.org/10.1007/s11595-014-1023-3