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A Study of Piezoelectric as Electric Transducer on Asphalt Pavement

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Abstract: Electricity is a major source of necessity in human life nowadays. Renewable and clean energy resources have become a demanded research area due to the problems facing an energy shortage. Piezoelectricity is a type of technology used for electrical energy harvesting from mechanical pressure such as mechanical efforts of the vehicles. The objectives of this study are to determine the best type of piezoelectric, the instalment method of piezoelectric under the asphalt pavement and to observe the value of voltage produced. This study has been undertaken as a systematic literature review (SLR) to collect the data and results from the previous study. This study starts with the identification process to find out the related journals to the topic and continued with screening process. The last is the eligibility process which is important to achieve the objectives of this study. The results show that PZT5H is the best type of piezoelectric transducers because it can generate more energy and suitable for harvesting energy. The most depth used for the installation of this piezoelectric transducer is 40mm depth under the asphalt. This asphalt pavement can absorb higher energy from mechanical movement and 40mm depth is the best location to embed the piezoelectric transducer with vertical spacing 2.5m and horizontal spacing 1.875m to ensure the wheel fully acting on the piezoelectric transducer. The voltage value in this study is not the same as each previous study because different loads produced different voltage even use the same PZT and same depth.

Keywords: Piezoelectric, Asphalt Pavement

1. Introduction

Renewable and clean energy resources have become a demanded research area due to the problems facing energy shortage and environmental concerns using fossil fuel resources. The world electricity demand will increase by almost 80% from 2012 to 2040 in the International Energy Agency's (IEA) New Policies Scenario. Exploiting more energy sources has become the priority of the world nowadays

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because of the increasing and demanding energy needs. It will have an impact on economic growth and carbon dioxide (CO2) for a long term. A Previous study found that mechanical stress from vehicles may produce electricity, but the energies are dissipated as the wasted energy in the pavement. Hence, this makes the structure risky towards damage [1]. Zhao [1] also found that Energy Harvester (PEH) to overcome this situation.

Piezoelectricity is a type of technology used for electrical energy harvesting from mechanical pressure such as mechanical efforts of the vehicles [2]. Piezoelectric is a kind of electric charge that accumulates in certain solid materials in response to applying mechanical stress. This technology's component can be visualized from Figure 1 and 2 below.

Figure 1: Piezoelectric transducer

Figure 2: Installation of piezoelectric

Although the nature of energy harvesting makes it readily applicable to micro-power sources, it could be potentially used for macro-power sources by installing large scale harvester [3]. Piezoelectric energy has been applied in limited projects, opposed to the most widespread renewable energies resources [4]. Asphalt pavement during its life's cycle is frequented by millions of vehicles that receive strain, stress, and kinetic energy from the vehicle. By applying piezoelectricity, it reacts to stress and stores the electric charge in certain solid materials such as crystals, ceramics, and biological materials in response to stress. This method is used to replace the burning of fossil-fuels and coal in generating electricity. This burning process will emit carbon dioxide, sulphur dioxide and nitrous oxides which can contribute to global warming, acid precipitation or the depletion of the ozone layer [5].

Factors that affect in piezoelectric technology usage are output power per materials used, cost, number of stress in mechanical movement, distribution of high frequency road transport area and the method of utilizing this technology to get the optimal saving energy results that need the power to use as main power or as a sensor triggering to manage the small amount of power needed to locate users and direct a sufficient amount of power that meet their needs [6].

Some of the advantages of using piezoelectric are high output voltage can be achieved when pressure applied on the piezoelectric and high efficiency can also be achieved with small size and relatively simple structure of piezoelectric. Other than that, piezoelectric also a good consumer as it did not give a negative effect on the environment. For example, piezoelectric can replace the usage of fossil to produce electricity. The use of piezoelectric is the best solution because it was environmentally friendly. The modifications made to this piezoelectric system can be seen in terms of its operation and effectiveness in converting force from load into electricity.

2. Methodology

This study has been undertaken as a systematic literature review (SLR) to collect the data and results from the previous study. It will declare and explain about the preferred reporting items used. This guideline shown that three phases will be comprised such as identification, screening, and eligibility process. The Flow diagram in Figure 3 below was set-up consisting of all the steps taken.

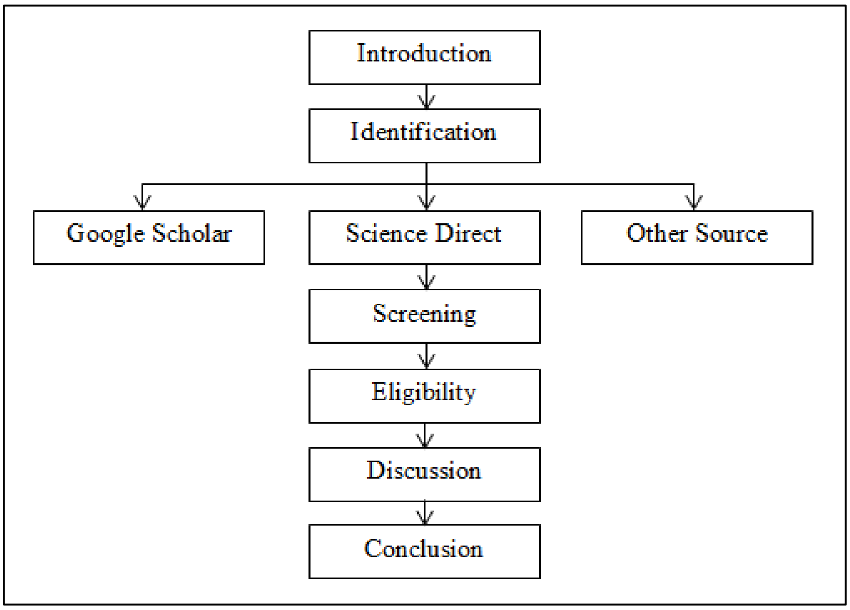

Figure 3: Flowchart

2.1 Resources

This study used several platforms to find out the information and answering the objectives. The platform used to find journals and conferences was Google Scholar, Science Direct and other sources. Google Scholar was a great platform to find journal for references in making systematic literature review. Science Direct also a great platform because it was user friendly and accessible. Other sources were also used to seek out additional backup information for this study.

2.2 Research Question

To achieve the objectives in this study, researched questions have been addressed. Few questions will help to collect all the information needed in this study. The research questions addressed by this study were:

Q1 - What type of PZT that suitable and reached the objectives of this study?
Q2 - How was PZT installed under asphalt pavement?
Q3 - What was the allowable load and quantity used to seek out the data?
Q4 - Does PZT performance affected when asphalt pavement replaced with others?
Q5 - What kind of model used to install PZT under road pavement?

With respect, Q1 used to know the best type of piezoelectric while Q2 was about how PZT will be embedded under asphalt pavement with variety of ways. These questions allowed us to identify either asphalt was the best pavement combining with PZT or if any rigid or flexural pavement used, it will affect the output from PZT or not. To address, Q3 help this SLR to know the suitable load applied to produce the voltage output. Other than that, for Q4 to Q5 focused on the evaluation characteristics of PZT and finding results. Besides, Q5 will let this SLR identified on what kind of model was produced to place the PZT under pavement thus did not affect both.

2.3 Search Process

The Search process was the manual method used to determine the results in this SLR. In this part, there were three steps taken to finalize the best and specific research needed. The steps were identification, screening, and eligibility.

2.3.1 Identification

The search process started with identifying the journal related to the main topic which was Piezoelectric Transducer in Harvesting Energy. The selected journals and conferences were shown in Table 1. The selected journals potentially relevant to piezoelectric.

Table 1: Selected journals and conferences proceedings

Source	Acronyms	Quartile
International Journal of Hydrogen Energy		Q1
Journal of Renewable and Sustainable Energy		Q3
International Journal of Power Electronics and Drive Systems	IJPEDS	Q2
World Journal of Engineering and Technology		Q1
Journal of Intelligent Material Systems and Structures		Q1
International Journal of Pavement Research and Technology		Q1
Journal Wuhan University of Technology, Materials Science Edition		Q3
Journal of Physics		Q2
Journal of the Ceramic Society of Japan		Q2
International Research Journal of Engineering and Technology	IRJET	Q1
International Journal of Engineering and Technology		Q1
Journal Material Civil Engineering		Q1
International Journal of Transportation Science and Technology		Q1

The keyword used to retrieve the journals and articles was ‘piezoelectric’ because of the main tools to get the voltage reading when installed under the asphalt pavement. Other keywords used such as ‘piezoelectric – asphalt pavement’ and ‘piezoelectric - highway’ also used because the relationship between piezoelectric with asphalt pavement was needed in this study.

The identification was made by reading the abstracts in each journal. If the journal was relevant, it was moved into Mendeley for the next step which was screening phase. All the selected journals were published from 2005 until 2020.

2.3.2 Screening

The Screening phase was the selected criteria used to find suitable journals in the Systematic Literature Review. All the journals found during the search process were evaluated based on their review title and abstract. Then, the journal was reviewed again and divided into a few points that related to this study and answering the research questions as shown in Appendix A. The total journals selected in this phase were 37 journals. After that, screening phase continued focused on the objectives of this study as in Table 2.

Table 2: Journal related to the objectives

References	Type of PZT	Instalment of PZT	Voltage Produced
Finite element analysis of cymbal piezoelectric transducer for harvesting energy from asphalt pavement [7].	/	/	/
Designing Piezoelectric Harvesting Unit from Road Vibration [8].	/	/	/
Piezoelectric energy harvester for public roadway: On-site installation and evaluation [9].	/	/	/
Feasibility study of embedded piezoelectric generator system on a highway for street lights electrification [10].	/	/	/
Finite Element Analysis of Vehicle Load effect on Harvesting Energy Properties of a Piezoelectric Unit [11].	/	/	/
Effect of Traffic Flow on Characteristics of Piezoelectric Harvesting Unit [12].	/	/	/
Feasible integration in asphalt of piezoelectric cymbals for vibration energy harvesting [13].	/	/	/
Piezoelectric Roads [14].	/	/	/
Piezoelectric Effect: Smart roads in green energy harvesting [15].		/	/
A preliminary study on the highway piezoelectric power supply system [16].	/	/	
Piezoelectric polymer based roadway energy harvesting via displacement amplification module [17].	/	/	/
Energy harvesting from roadways [18].	/	/	/
Road energy harvester designed as a macro-power source using the piezoelectric effect [3].		/	
Development in Stacked-Array-Type Piezoelectric Energy Harvester in Asphalt Pavement (Yang et al., 2017).	/	/	/
Harvesting Energy from Asphalt Pavement by Piezoelectric Generator [20].	/	/	/
Degradation of piezoelectric device as an energy harvester under equivalent traffic stress condition [21].	/		
A New Method for Accurately Estimating the Weight of Moving Vehicles Using Piezoelectric Sensors and Adaptive-footprint Tire Model [22].	/		/
Parameters optimization for piezoelectric harvesting energy from pavement based on Taguchi's orthogonal experiment design [23].	/	/	
Application of piezoelectric transducer in energy harvesting in pavement [24].	/		/
Modelling on piezoelectric energy harvesting from pavements under traffic loads [25].	/		
Synergistic performance of piezoelectric transducers and asphalt pavement [26].	/	/	
Energy Harvesting Assessment Using PZT Sensors and Roadway Materials [27].	/	/	
Potentials of piezoelectric and thermoelectric technologies for harvesting energy from pavements [28].	/	/	

Piezoelectric Energy Harvesting System Assessment for Highway Sustainability [29].	/	/
Experimental Analysis for Piezoelectric Transducers Applications into Roads Pavements [30].	/	/
Test and Analysis of Bridge Transducers for Harvesting Energy from Asphalt Pavement [31].	/	
Studies on Mechanical and Electrical Characteristics of PZT5H patch [32].	/	

2.3.3 Eligibility

In this phase, all the selected data will be reviewed to fulfil the required objectives. From the screening phase, any journals that did not meet the criteria were excluded. Each publication will be reviewed based on these objectives which were, to determine suitable pavement used towards piezoelectric, the best type of piezoelectric in generating energy and estimated voltage produced when different types of piezoelectric transducer and loads applied. All the data was reviewed in the Appendix.

3. Results

This chapter performed all the achieved objectives once this SLR took few months to fully identify, extract and analyses. The selected results were classified into three major points which were to determine the best type of piezoelectric transducers used, to identify the instalment of piezoelectric transducer under the asphalt pavement and the voltage collected once different loads and piezoelectric transducer applied.

3.1 Type of piezoelectric transducer

Table 3 shows the types of piezoelectric transducer used from the previous study.

Table 3: Types of piezoelectric transducer used

Type of Piezoelectric	PZT5H	PZT5A	PZ Ceramics	PZ Generator	Other PZT
Number of Previous Study Used	10	3	3	2	8

From Figure 4, Piezoelectric Transducer type 5H mostly used by the researcher from the previous study compared to the Piezoelectric Transducers type 5A and Piezoelectric Transducers Ceramics to harvest energy by mechanical movement. Hongduo et al. [20] and Xu et al. [24] stated in their journal, PZT5H was used because it can generate more energy and suitable for harvesting energy while [7] choose PZT5H because of it is high with d.g value. PZT5H also has high piezoelectric strain constant tensor and relative dielectric constant [26]. It could be concluded that PZT5H was the best type of piezoelectric transducers that can be used in future.

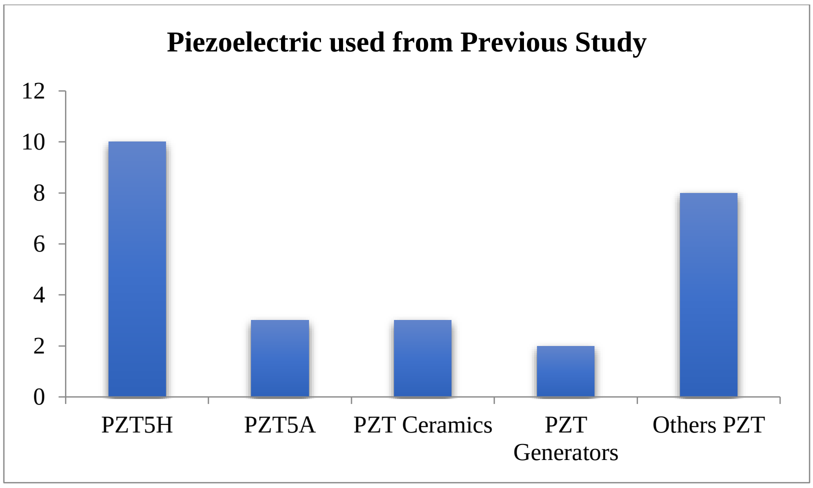

Figure 4: Piezoelectric used from previous study

3.2 Instalment of Piezoelectric Transducers

This part shows the result of the installation process of piezoelectric transducer. These results were classified into two parts which were the types of pavement used and the installation method of the piezoelectric transducer to produce higher voltage energy. From the previous study, it showed that piezoelectric transducer was embedded under the asphalt pavement at various depths. Asphalt pavement could absorb higher energy from vehicles. Figure 5 shows the percentage of different depth used in the previous study. Most of the previous studies used 40mm for embedded the piezoelectric with 31.25% comparedthe depth of the others. For a better comprehensive results, the Piezoelectric Harvester Unit (PHU) must be embedded under 40mm under the bottom of the top asphalt layer [23].

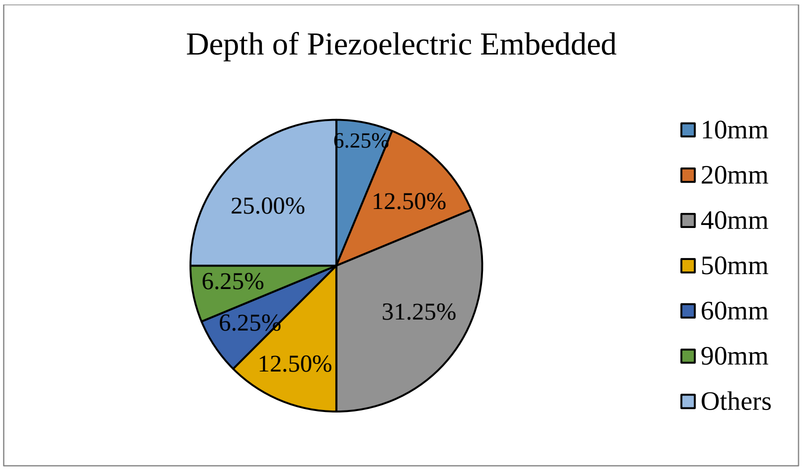

Figure 5: Different depth for embedded piezoelectric

Besides, piezoelectric transducer was arrayed in a series and parallel connection with vertical spacing 2.5m and horizontal spacing 1.875m. Chunhua et al. [23] and Hailu et al. [16] placed the PZT model design to be arrayed under the pavement with vertical spacing is 2.5m and horizontal spacing is 1.875m between the PZT models.

To conclude, piezoelectric transducer could be arrayed in a series and parallel connection with vertical spacing 2.5m and horizontal spacing 1.875m. While the depth used was 40mm from the top of asphalt pavement.

3.3 Voltage Value

Piezoelectric transducer type 5H was determined as the best type of PZT and the best depth of embedded the piezoelectric transducer was 40mm from the top of asphalt pavement. In addition, the voltage produced could be optimum by considering load passed by the pavement.

Hongduo et al. [20] used load as one rear axle with 6 tires in total (1 + 1 type) and with two rear axles with 10 tires in total (1 + 2 type). The volume of the truck is 600 vehicle/hour. The potential energy in each lane produced by the trucks reaches up to 150kW in one hour. Chunhua et al. [23] used load as one tyre truck and bus where 25kN and the contact stress are 0.7Mpa. The voltage produced from this load is 97.33V. This also produced 1.2mW of electric energy when 20Hz vehicle load pass through the piezoelectric transducer embedded under the asphalt pavement. It could be concluded that different load affected the voltage produced by piezoelectric.

4. Discussion

The collected result from the previous study was discussed more in details at this chapter.

4.1 Type of piezoelectric transducers

Piezoelectric transducer that produced high voltage was significant to consume more electrical energy thus reducing the used of burning of fossil-fuels and coal. Based on the result obtained, PZT5H was the best piezoelectric transducer and commonly used in previous study. According to [20], PZT5H was used in their research because it could obtain more energy. The study was produced 150kW/h per lane per kilometre. Xu et al. [24] also conducted a study on the use of different types of piezoelectric and the output showed that PZT5H was ideal to apply in pavement because it could produce higher voltage under the same load.

4.2 Instalment of method of piezoelectric transducer

This part discussed about the instalment method of piezoelectric transducer which was the piezoelectric transducer arrayed in a series and parallel connection with vertical spacing 2.5m and horizontal spacing 1.875m. The depth for the piezoelectric installation was 40mm from the top of asphalt pavement.

The bottom of the top layer of the pavement was the best location to set the piezoelectric transducer which was 40mm depth according to the practical pavement and axisymmetric characteristics as shown in Figure 6 [7] [8]. At the same time, the surface displacements of pavement were analyzed to examine the coupling effects between piezoelectric transducer and the pavement. Besides, if the study use 50mm and above for the depth, the collected result was not optimum. The voltage produced was low because piezoelectric transducer was embedded too deep under the asphalt pavement.

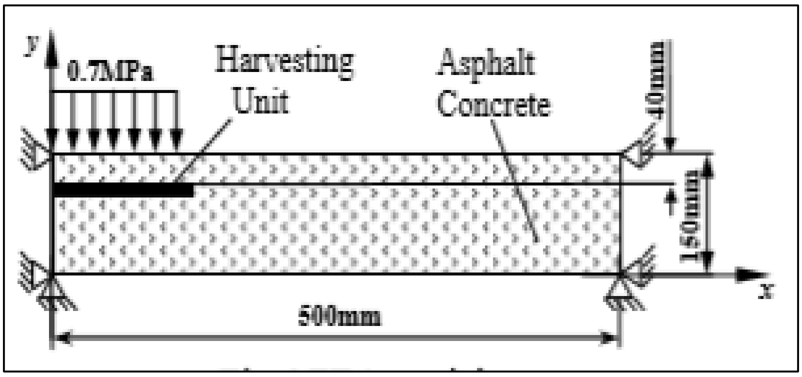

Figure 6: Piezoelectric transducer embedded under 40mm depth

Vertical spacing was 2.5m between two harvester and horizontal spacing with 1.875m which was consistent with the axle structure of load. The distance was used in previous study to reduce damage from road construction [16]. If the distance was not suitable forthe load, the wheel might not be fully acting on the piezoelectric transducer, thus the output voltage was low [19]. Vertical spacing with 2.5m and horizontal spacing with 1.875m according to the distance of wheel to ensure it acted on the piezoelectric transducer to produce a higher voltage.

4.3 Voltage Value

By choosing PZT5H as the best type of PZT used among the others and the depth of PZT embedded under the asphalt pavement was 40mm, the voltage value was highly produced. But, based on the previous studies, the voltage produced also affected by another factor which was the used of different load passed by the asphalt pavement. There were several types of load used such as small car and large truck. Both vehicles carried different weight and large impact on the voltage produced.

Hongduo et al. [20] used load as one rear axle with 6 tires in total (1 + 1 type) and with two rear axles with 10 tires in total (1 + 2 type). The volume of the truck was 600 vehicle/hour. The potential energy produced by the trucks reaches up to 150kW in one hour. While, [11] used load as one tyre truck and bus where 25kN and the contact stress were 0.7Mpa. The voltage produced from this load was 97.33V. Both results obtained from the previous study showed the highest potential voltage produced by PZT when large vehicle was used. Large vehicle had higher compressive strength on PZT over the small one thus increases the ability of PZT in generating energy. To summarize, by combining those 3 factors which were, type of piezoelectric transducer used was PZT5H, depth to embed the PZT5H under asphalt was 40mm and large weight of load passed by the pavement, the optimum voltage value could be reached.

5. Conclusion

This study had reviewed the journals and all the objectives were successfully achieved. For the first objective, PZT5H was found as the best type of piezoelectric transducer to generate more electrical energy. Other than that, Piezoelectric transducer worked more effectively in generating energy when embedded 40mm under asphalt pavement and arrayed in series and parallel connection with vertical spacing 2.5m and horizontal spacing 1.875m. Lastly, the electrical energy could rise much higher by using large load to pass on piezoelectric transducer. As a conclusion, piezoelectric transducer was the best technology in harvesting electrical energy on asphalt pavement.

Acknowledgment

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Appendix A

References	Load	Type of Piezoelectric	Design of Model	Type of Pavement	Installation
[7]	One tyre of truck and bus with 25kN (0.7Mpa).	PZT5H with 32 mm diameter.	Cymbal model is surrounded by asphalt concrete (direct contact).	Asphalt pavement.	Embedded 40 mm from the top.
[8]	One tyre larger car 0.7MPa.	PZT5A.	Box with 280 x 280 x 20mm and contain 64 piezoelectric.	Asphalt pavement.	Embedded 40mm under the top layer.
[9]	Truck weight with 4000 truck per day pass through it with 49km/h.	PZT Ceramics.	Length and Width of the packaging box is 30cm × 27cm. Six packaging box consist with PZT piezoceramic disks and sealed in a protective package made from insulating material.	Install in pavement at weight station.	NA
[10]	Average vehicle weight = 1650kg with 300,000 vehicles per day with 25km/h.	Piezoelectric generator.	NA	Asphalt pavement.at plaza toll gate.	Embedded at the area before and after each lane carriageways entrance along the wheel path of vehicle.
[11]	Vehicle Load	PZT5A with diameter 30 mm	Box size = 280 × 280 x 280mm and have 16 unit of piezoelectric	Asphalt pavement.	Embedded 40mm from the surface.
[12]	0.85MPa tire contact pressure.	PZT5A.	Box size = 280 x 280 x 20mm.	Asphalt pavement on Transverse and Longitudinal Section.	NA
[13]	Heavy vehicle wheel.	Piezoelectric cymbal with 29 mm diameter.	Using 30000 cymbals.	Asphalt Pavement at Highway at Madrid with high vehicle densities.	Along 100 m road at Madrid.
[14]	Different types of vehicles such as bus, truck, car, and motorcycle were tested at a speed of 45 mph and 65 mph.	Piezoelectric generators.	Thin box around the piezoelectric material.	Asphalt Pavement.	Embedded underneath the asphalt layer.

[15]	5 tons truck and assuming 600 vehicles in an hour.	Piezoelectric Generator.	Generator size = 1 Square feet (3280 generator needed for 1km of road).	Asphalt roads (Tar road) with 8 lane road of 158km stretch	6cm under the road level and at a distance of 30cm apart.
[16]	Toyota Highlinder SUV. Wheel speed at 20km/h, 40km/h, 60km/h and 80km/h. Weight of vehicle 1.8 tons. The axle load is 4.5Kn. Tire pressure is 0.7MPa.	PZT5H with unit size is diameter 20mm × 23.2mm	Rectangular (F2) : Piezoelectric harvester was designed to be 30cm wide, 30cm long and 8cm height considering contact area of tires with 12 units piezoelectric. Circular (Y10) : Piezoelectric harvester was fabricated with diameter 30cm and a height of 8cm with 12 units of piezoelectric.	Asphalt pavement at Located at K90 + 700 of Ma-Zhou Highway near Zhaotang City, Yunnan Province. Trial pavement section about 50m with two directions with six line highway.	Surface layer of the pavement test is 9cm to 10cm. Installed 10 rectangular and 10 circular with spacing 2.5m between two piezoelectric harvester and horizontal spacing is 1.875m.
[17]	Midsized vehicle speed with driver side and passenger side	Piezoelectric polymers fabricated with Bimorph.	Contains 80 unit energy harvester. To comprise the 30 ×.30 × 10cm modules, two 15 ×.30 ×12cm modules are inserted next to each other in the housing unit sized 34 × 40 × 11cm and the model surface is gently covered with a thin layer of polyurethane.	Road excavation was performed with Bobcat S770 Skid-Steer Loader located at North 37.2040, East 127.6086 at Local Highway in Korea.	NA
[18]	Wheel load at three levels were applied which are 50lbs, 100lbs and 200lbs by assuming traffic level 0f 600 vehicles/hour at a speed of 45mph.	PZT5H.	NA	Asphalt pavement at Georgia Southern University..	NA
[3]	600 vehicles passing the harvester per hour. Assuming a constant rate of 600 vehicles on the	NA	15 × 15 × 10cm contains 48 units piezoelectric.	Asphalt Pavement at Korean Highway.	The road is paved with 15cm of asphalt. Construct harvester with a depth 10cm and designed

	road per hour with range speed 60-80km/h			Could install harvesters along a 1km road along two straight lines	for implementation under 5cm-thick asphalt. The asphalt and the harvester will have a total height of 15cm,
[19]	Sport utility vehicle (SUV) with weight was 1.8. The average load of a single wheel was 4.41kN.	Multilayer stacked array piezoelectric.	NA	Asphalt pavement located at No. G85 highway, Zhaotong City, Yunnan Province, China..	Embedded under the asphalt pavement.
[20]	One rear axle and 6 tires in total (1+1 type) and with two rear axles and 10 tires in total (1+2 type) The truck volume is 600v/h.	PZT5H	8-16 PZT piles are recommended for $0.04m^2$.	Asphalt pavement. Considering 1 lane of 1km highway.	NA
[21]	Stress compaction machine	PZT Ceramics	20 × 20 × 2mm.	NA	NA
[22]	3 vehicles of known weight ranging from 1,400kg to 28,040kg. Speeds ranging from 30kph to 100kph.	Piezoelectric sensor signal.	2 piezoelectric sensors signal.	Asphalt Pavement at Highway in Korea.	NA
[23]	Vehicle Load with diameter of tire load area is 213mm and the contact stress is 0.7MPa.	PZT5H.	NA	Asphalt Pavement.	Height of pavement set to be 150mm. Different depth used which is 20mm, 30mm, 40mm and 50mm.
[24]	300N, 500N and 1000N.	PZT5H. with inner diameter 15mm, external diameter 45mm, thickness 5mm	Stacking boxes and cantilever package box features, box external size of the piezoelectric transducer is 300 × 300 × 100mm	NA	NA
[25]	Single-wheel load and four-wheel load.	PZT-5H	NA	NA	NA
[26]	Tire pressure (25kN for one tire)	PZT-5H	Arch array, composed of four transducers.	Asphalt pavement with 1.875m of width.	Embedded in the asphalt with a depth of 2cm.and 2.60m of total depth.

[27]	Loaded Wheel Test.	PZT5H	¾ in plywood 14” × 15” for the bottom of the formwork needed. The plywood was wrapped in 4 mil plastic to prevent the concrete from sticking. Next, the research team cut 2 1 × 4’s 14in long for one side of the formwork and 2 1 × 4’s 16 ½” for the other two sides.	Asphalt Pavement.	Piezoelectric element was 2in from the top.
[28]	Vehicle load at heavy traffic.	PZT system.	PZT should have the proper size of 280×280×20mm.	Asphalt Road pavement.	Embedded at a depth of 40mm in the pavement.
[29]	600 vehicles per hour at 45mp with 50lbs, 100lbs, and 150lbs.	PZT5H	Specimen is 6in diameter and 3in in thickness	Asphalt pavement and concrete pavement.	Contact area of load wheel is approximately $6in^2$ and depth of piezoelectric elements is 2in from the top.
[30]	Traffic load. Tandem axel of 1200N traveling	Piezoelectric transducers with size 80mm × 80mm × 30mm,	FEM PZT.	Asphalt pavement. FEM and laboratory test were conducted for 3 layers of hot mix asphalt.	Positioned at the interface between friction and binder.
[31]	Tire pressure is between 0.2 – 0.25MPa for small cars (with four tires) and between 0.5–1.0MPa for large cars (trucks and buses)	Bridge transducer	“V” flextensional device The metal caps are designed geometries	Asphalt pavement always includes 2 – 3 layers, and the stiffness of each layer varies from 1000 to 4000MPa.	NA

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