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Asphalt Elasticity Modulus Comparison Using Modified Laboratory LWD Against UMMATA Method

Lucky Caroles [1*]

[1] *Department of Infrastructure Engineering, Graduate School of Hasanuddin University, Makassar, Indonesia.*

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Abstract

Highway consultants need pavement structure strength to examine and design. With advances in computer, sensor, and microelectronic technologies, the light weight deflectometer (LWD) can measure granular and asphalt layers. This portable, easy-to-use tool is suggested. This article was designed to improve LWD Pusjatan's accuracy and distinguish it from other testing methods. This study compares the LWD Pusjatan and UMMATA (Universal Material Testing Apparatus) methods for measuring modulus of elasticity on different materials. Boussinesq elastic theory is used to compute the modulus of most LWDs. In a semi-elastic environment, modulus is the connection between pressure and displacement in a rigid or flexible basis. The deflection value is derived from the process of vibrations caused by a load delivered from a given height onto a test item, with the wave/vibration collected by an acceleration measuring instrument, such as a geophone or accelerometer. The modulus of elasticity provided by the AUDL (Laboratory Deflection Test Equipment) method is less than that produced by the UMMATA method. According to the test results, the average value of AC Base material is 7.52% less than that of AC Base. The average value of AC BC material is just over 0.3%. These results indicate that more testing is necessary when using the AUDL methodology to detect correlations that might serve as a basis for comparison. Thus, the AUDL test method may be used as a nondestructive testing technique. This kind of non-destructive technique should be used frequently so that simulations of field circumstances are more accurate.

Keywords: Asphalt; Elasticity Modulus; Light Weight Deflectometer (LWD); UMMATA.

1. Introduction

Highway consultants require the structural strength characteristics of a pavement structure for assessment and management planning. This structural strength criterion is expressed by the value of the California Bearing Ratio (CBR) for unpaved roads such as unpaved roads. The utilization of these methods takes a long time and requires numerous personnel. The Field CBR test, on the other hand, is inappropriate for any soil having particles with a longest dimension of more than 20 mm, since the plunger's sitting on a big stone might provide an inaccurate result. The sand test often yields substantially lower results than the laboratory testing upon which the design charts are based. Nondestructive testing (NDT) techniques may offer all of these characteristics and are particularly suited for use on pavements. Using NDT, many data sets may be collected at the same time, providing statistical dependability for the experimentally collected data. The basic purpose of a structural assessment procedure is to estimate the structural strength [1]. It may be described in terms of in situ layer elastic modulus, layer thickness, inter-layer bond conditions, and anomaly characterization for asphalt pavements. After excavating pits or removing pavement cores, which are disruptive processes, a layer's attributes may be estimated using a straightforward and basic visual assessment. Besides, it does not damage pavement and has a lower cost than destructive testing. It is also faster that from 50 to 60 tests can be done per

* Corresponding author: caroleslucky88@gmail.com

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hour. Furthermore, it is less disruptive to traffic than destructive testing. A dynamic cone penetrometer test, in comparison, may provide a qualitative (and to some degree, quantitative) estimate of layer thickness, despite its limitations in test-speed, inaccuracy, and subjectivity. However, the usage of Non-Destructive Test is still limited due to its lack of widespread recognition and use. Therefore, further references and references are required to promote the usage of NDT. One thing that must be done is to give a comparison to present conventional practices. It is also beneficial to increase the precision of testing utilizing NDT.

With advancements in computer, sensing, and microelectronic technology, a more practical instrument known as the Light Weight Deflectometer (LWD) has recently been created. A Light-Weight Deflectometer (LWD) is a device used to evaluate the rigidity of a road pavement structure. This instrument is recommended since it is portable and simple to use. Additionally, this instrument is reasonably priced. The LWD tool is now available for usage in both granular and asphalt layers. Presently, LWD is being designed for the scientific assessment of the structural strength of asphalt layers [1]. The LWD is effective and adaptable as a tool for field quality control and pavement study provided data users acknowledge the instrument's limitations. He indicated that the contact area of the plate surface is a crucial component in the case of LWD. Furthermore, regardless of the temperature of the buffer, the stiffness remained essentially constant. The only immediately obvious change was the duration of the load pulse, which increased from 18 to 20 milliseconds as the temperature of the buffer increased.

Subgrade as a component of the road pavement system is an essential component of the system. The necessity for a solid subgrade starts with the compaction process and its monitoring. Light Weight Deflectometer (LWD) Modification is an alternate instrument for quality control of compaction. It can be shown that employing this Modified LWD tool as a quality control tool has various benefits, including efficiency in terms of time, money, and the number of workers necessary [2]. The Binamarga (Indonesian Road Development Office) 2018 standard mandates the utilization of LWD in the inspection process for granular layer compaction in road building projects [3]. The Light Weight Deflectometer (LWD) is used to evaluate pavement structures and road subgrade. The primary goal of this LWD test is to ensure consistency of the tested coating. The Pusjatan LWD is a modified LWD tool developed via research and development at the Research Center for Roads and Bridges during the fiscal years of 2012 and 2014 [4].

This study was prepared as part of the process of improving the LWD Pusjatan so that it may be more accurate and stand out above other comparable testing techniques. The results of reading the modulus of elasticity using the LWD Pusjatan technique and the UMMATA method on various kinds of materials will be compared in this research.

2. Literature Review

2.1. Performance Evaluation of Flexible Pavement

In essence, road pavement assessment is inextricably linked to road rehabilitation, with choices concerning the kind of rehabilitation being heavily influenced by information about road pavement evaluation findings [5]. Pavement assessment is separated into three actions in general [6]:

- Determine functioning qualities (ride quality and surface roughness);
- Conduct a condition and damage inspection;
- Perform pavement structural testing (destructive and non-destructive) [7].

There are two common types of pavement assessment, specifically structural evaluation and functional evaluation [8]. Road pavement performance assessment is a method that includes a review of the performance of the road pavement during the road's service life [9]; this is essential for maximizing the function and quality of the road pavement itself [10]. Evaluation operations are directly tied to a pavement's repair and maintenance programme, assessing the road's geometric and structural qualities [11]. If the state of the pavement is still deemed satisfactory from a service standpoint, then only little maintenance will be performed [12]; however, if there is a decline in road performance, many measures will be done that are tailored to the kind of pavement damage [13]. Functional evaluation serves to determine the impact felt by road users. Parameters related to functional conditions are [14]:

- International Roughness Index (IRI);
- Pavement Condition Index (PCI);
- Damage Type.

Assessment of the performance of the road pavement's structural functions, particularly in terms of the strength or deformation caused by traffic loads over the service life, is structural evaluation [15]. The form of the findings of this examination is a collection of data that offers information about the structural performance of the pavement, such as the existence or absence of cracks, potholes for road surface settling, etc. [16]. On the basis of the technique of application, the evaluation of the road pavement structure may be separated into two parts [17]:

(a) Destructive Test

This sort of test will have a harmful impact on the sample or test item, given its origin. In general, this examination may be conducted by:

1- Drilling for sampling;

2- Sampling by creating test holes [18].

(b) Nondestructive Evaluation

Non-destructive testing is the most popular option among practitioners, scholars, and players in the construction industry sector since it is not only less expensive, but also practical and non-destructive in nature [19].

Several variables influence the deflection value of this nondestructive test, including temperature, moisture content, kind of component of the pavement layer, operator abilities, and type of equipment [20]. Typically, the equipment used for this test consists of static or dynamic loads that are given to the road surface through a load plate [21], while other tests are conducted by directly measuring the amount of the deflection [22].

2.2. Light Weight Deflectometer (LWD)

LWD is a sort of readily transportable (portable) equipment designed for use in the field, based on its operating principle [23]. Its operating concept employs the wave principle to calculate the deflection value [24]. LWD was created by the Federal Highway Research Institute and made its debut in Germany in 1981 [25]. This instrument has been utilized as quality assurance for earthwork construction for over two decades. This tool was formerly used only for earthwork and just lately for asphalt [26]. In the United States, the findings of LWD tests, i.e. soil deflections or estimations of their dynamic soil modulus, have been used as relative and qualitative values due to the fact that the criteria rely on dry density and moisture content [27]. This field test kit may be used to quickly estimate the modulus of elasticity and input parameters for mechanical designs, offering an alternative to time-consuming field experiments (such as static load tests) and input parameters for mechanistic pavement designs. The LWD modulus of elasticity (ELWD) is computed using the half-elastic space theory, plate contact stress and deflection, and stress distribution assumptions [28]. Although the majority of devices have a similar function and approach, there are variations in the contact plate pressure. This results in a variation in the computed ELWD values. A typical LWD device has a loading plate with a diameter of 100 to 300 mm and a drop weight of 10 to 20 kg, an accelerometer or geophone to measure deflection, and a load cell or load limit calibrated to measure the plate contact stress [29].

The parts of an LWD based on Figure 1 are (1) Handrail, (2) Load locking latch, (3) Slide Rod, (4) Load, (5) Spring or rubber, (6) Load cell, (7) Load plate. Multiple nations, including Indonesia, have created LWD because it is extremely simple to use and the results gained may be delivered promptly [6]. Through study performed at the Road and Bridge Research Center, the following will describe numerous varieties of LWD, including those manufactured outside and those produced by Indonesians (*Puslitbang*).

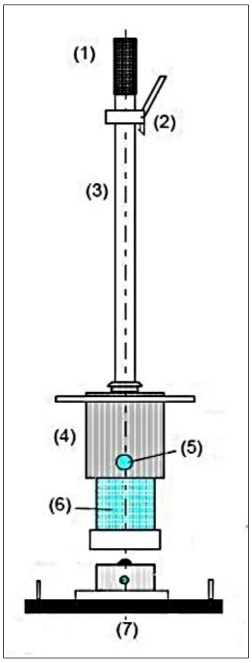

Figure 1. Lightweight Deflectometer

2.3. Modified Light Weight Deflectometer (LWD Pusjatan)

The Pusjatan LWD is the outcome of research [30] undertaken during the 2012 and 2013 budget years at the Research and Development Center for Roads and Bridges (Figures 2 and 3). West Java has used the Pusjatan LWD on various parts of dirt roads. The usage of LWD on paved roads is anticipated to mitigate the dearth of Falling Weight Deflectometer (FWD) in Indonesia while performing surveys to gather data for road management, particularly on paved roads with moderate to low traffic flow. Because the effective structural number (SN_{eff}) is strongly connected to the surface modulus value, it is possible to utilize the Pusjatan LWD to calculate the extra layer thickness by correlating the modulus values acquired from these two tools. The surface modulus is used to compare two structures. On the roadways around the Pusjatan Bandung campus, LWD research was conducted for cemented roads [6]. This Pusjatan LWD tool differs from ordinary LWD tools in the following ways [3]:

- The load capacity of the Pusjatan LWD differs from that of the Standard LWD. The LWD Pusjatan can carry a weight of 12 kg. This exceeds the load utilized for regular LWD. The primary objective is to employ a bigger load to generate a higher stress level so that this LWD Pusjatan instrument may also be used for testing roads with moderate traffic levels [31].
- LWD Pusjatan does not employ load cells. Because the load cell is a component that needs attentive maintenance, upkeep is much simplified.
- Three geophone sensors are used by LWD Pusjatan.
- At LWD Pusjatan does not employ load cells.
- There are five levels of load, ranging from zero to four. Each level generates a certain burden. This load's magnitude has been previously calibrated using a standard load cell.
- LWD has just one load type, which is 12 kg, and one plate size, with a diameter of 30 cm; it is suitable for subgrade to asphalt surfaces with medium to low average daily traffic volumes (500 vehicles).

Figure 2. Modified Lightweight Deflectometer (LWD Pusjatan)

Figure 3. Modulus Elasticity Determination using UMMATA Method

3. Methodology

3.1. Specification of Modified Light Weight Deflectometer (LWD Pusjatan)

Pusjatan LWD specifications are as follows:

- The circular bearing plate with a diameter of 100 to 300 mm is made of metal with a hole in the middle (annulus). The annulus diameter is 50 to 75 mm, while the plate thickness is 10±5 mm;
- The load cell is used to measure the magnitude of the load caused by the falling load. The accuracy of this load cell is a minimum of 0.1 kN. In performing calibration, this load cell must be calibrated in the range of 0-15 kN;
- Geophone to measure vertical deflection caused by falling loads. The accuracy of this geophone is ±2 micrometers. In performing the calibration, this geophone must be calibrated in the range of 0 to 2000 micrometers;
- Free-falling loads with a range of 10 to 20 kg that can be lifted at a certain height and when dropped will provide an impact load on the loading plate;
- Rubber buffer which aims to distribute the impact load to the loading plate in a time range (16 to 30) milliseconds;
- The processor is equipped with an Analog to Digital Converter (ADC) and a program to record wave data and process it into deflections. The program used gives the operator the flexibility to provide input data in the form of Poisson's ratio, temperature, plate stiffness, location, and type of pavement being tested;
- The processor must be able to record the deflection with an accuracy of ± 1 micrometers;
- Maximum load and deflection measurements must be recorded for a minimum period of 60 milliseconds;
- The processor must be capable of registering the maximum load with an accuracy of ±1 kN;
- Calibration;
  - Reference calibration for both load cells and geophones is carried out at least once a year.
  - For each new LWD appliance, factory calibration is valid for 1 year.
- Accuracy Coefficient of variation for single operator and equipment for GM/GC/GP soil type is 10-20%. Meanwhile, for soil type SW/SM/SP it is around 15-35%. For soil ML/CL is 20-40%.

3.2. Testing Procedure

The Testing Procedure is carried out with the following steps:

- Place the Light Weight Deflectometer tool on the test point. The surface slope of the coating that can be tested with LWD is a maximum of 4%. For granular coatings it is recommended to use a thin layer of sand at the test point. This is to obtain a uniform contact surface between the loading plate and the coating surface;
- Check once again the position of the loading plate and geophone sensor (Items 5 of 7 in Figure 1);
- Lift the load at a certain height until it reaches the desired stress level and then drop it so that it causes an impact load on the loading plate;
- Do the test at that point at least 2 times. If the difference in the results of tests 1 and 2 is greater than 3%, record this difference in the report. A third test is required when this occurs;
- For the test on the granular layer, it is also noted the amount of field moisture content.

3.3. Laboratory Deflection Measuring Device (AUDL)/Laboratory LWD

This tool is the result of Hasanuddin University doctoral research [32] assisted by researchers working at the Bandung Road and Bridge Research Center (*Pusjatan*) [4] from 2018 to 2020, and until now, development and improvement are still being carried out. The research was inspired to make a deflection/modulus test device on a laboratory scale using the working principle of a field LWD device. From the physical form and working principle used, this Laboratory Deflection Measuring Tool is a miniature of the LWD Pusjatan, but there are some basic differences with the LWD Pusjatan, namely:

- Load weight: 4 kg;
- Drop height: 49.5 cm;
- The diameter of the load plate is 10 cm (according to the diameter of the asphalt core/bitumen briquette);
- Intended for laboratory tests, especially for asphalt core samples and briquette samples;
- Not using a geophone but using an accelerometer to read the vibration acceleration.

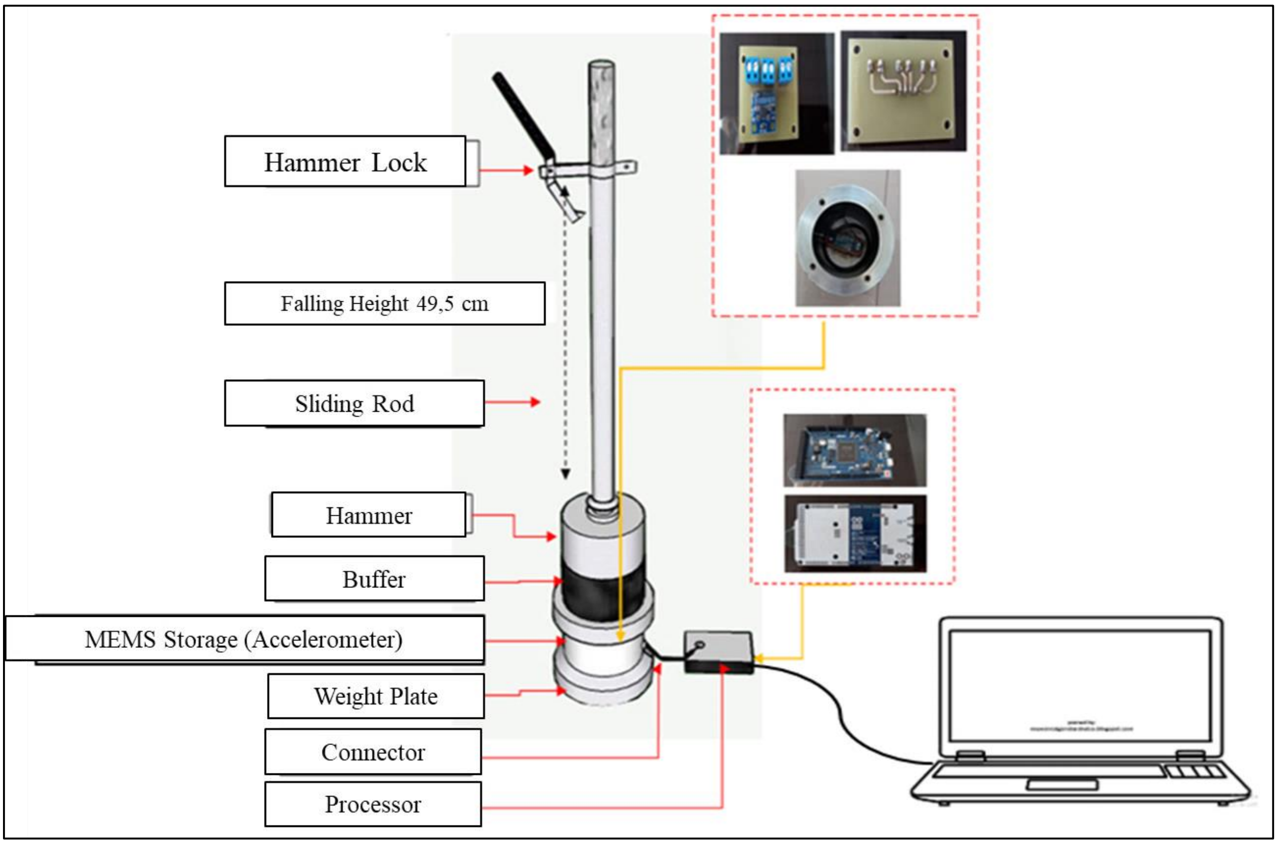

Figure 4. Configuration of Modified LWD

In addition to the above, the advantages of using this tool are:

- The direction of the deflection measurement is in the direction of the load and is the same as the deflection measurement principle in the field. While the current tool (UMATTA) reads the deflection not in the direction of the load, where in UMATTA the deflection reading is considered the sum of the two-way horizontal strain due to the working cyclic load. So it is possible that the correct deflection direction is closer to the AUDL approach.
- Has a cheaper production cost than current laboratory test equipment (If AUDL is acceptable).
- It is portable so it can be carried/moved easily to any location.
- Does not use electricity in the operation of the tool so that it can be used in road laboratories in remote areas where electricity is difficult.
- Only requires 2 people to operate the tool.
- Simple operation, fast and relatively low maintenance costs.

Although currently AUDL is still in the development stage and is still a prototype, it is hoped that this tool will later become a worthy alternative for laboratory testing.

3.4. Modulus and Deflection Calculation

In general, the modulus value for almost all types of LWD is calculated based on the Boussinesq elastic theory, namely the relationship between pressure and displacement applied in the soil for the case of a rigid or flexible base located in a semi-elastic space, with the formula [6, 32].

$$E_{LWD} = 2r_p\sigma(1-\nu^2)\frac{(1\times10^6)R}{\Delta} \quad (1)$$

$$\sigma = \frac{F}{1000\pi r_p^2} \quad (2)$$

where, E_{LWD} is Elasticity Modulus (MPa), r_P is Loading Plate Radius (m), σ is Peak Stress to the ground (MPa), v is Poisson's ratio, R is Plate Stiffness (0.79 for rigid plate, and 1.0 for flexible plate), Δ is Peak deflection (µm), and F is Maximum force to the ground (kN).

Because LWD and AUDL use the same working concept, the deflection value is derived from the process of vibrations caused by a load delivered from a given height onto a test item, with the wave/vibration collected by an acceleration measuring instrument, such as a geophone or accelerometer. Then, a computer software will translate it into a value of deflection or deflection by using the laws of vibration and soil dynamics. If utilize a geophone as a speed transducer, it will often use a one-time integral method to calculate the deflection value, however by using an accelerometer, a two-integral system is used [4].

4. Results and Discussions

In this research, numerous types of asphalt mixture materials are evaluated. Several kinds of materials were then evaluated for deflection and modulus of elasticity using the AUDL/Modified LWD approach and compared with the UMMATA method. Several kinds of materials were tested using the AUDL/Modified LWD approach, and the results are illustrated in Figures 5 to 8.

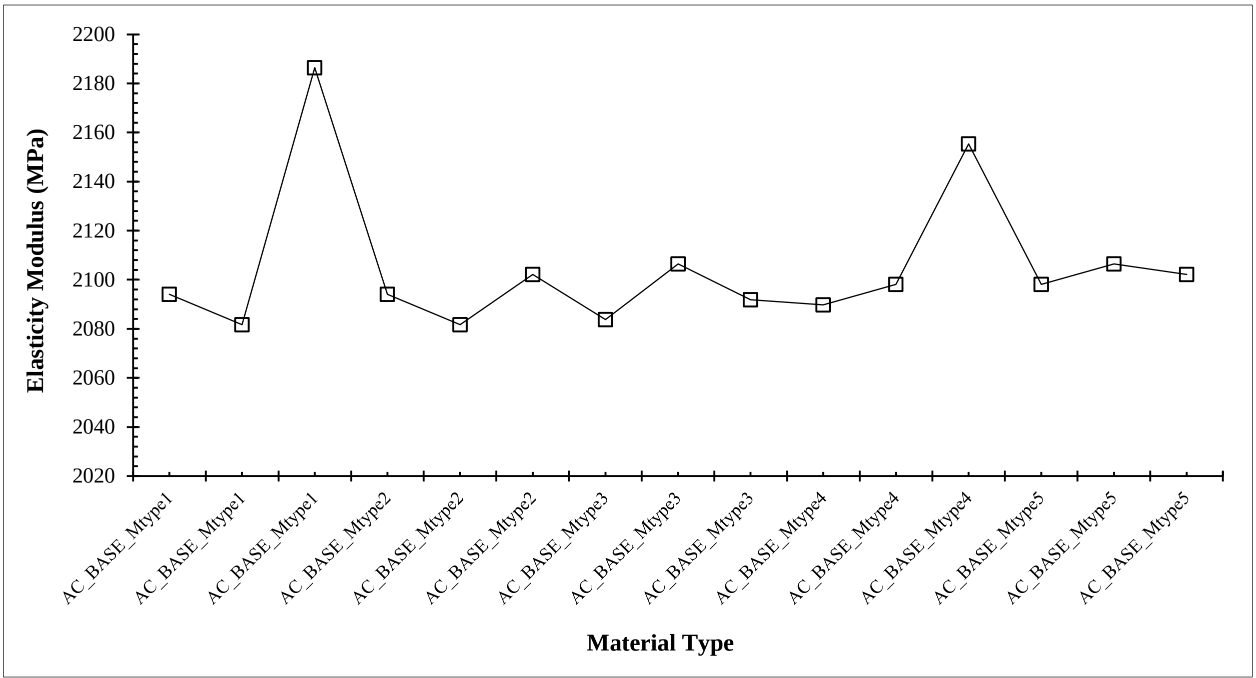

Figure 5. Modulus Elasticity of AC_Base type material using AUDL

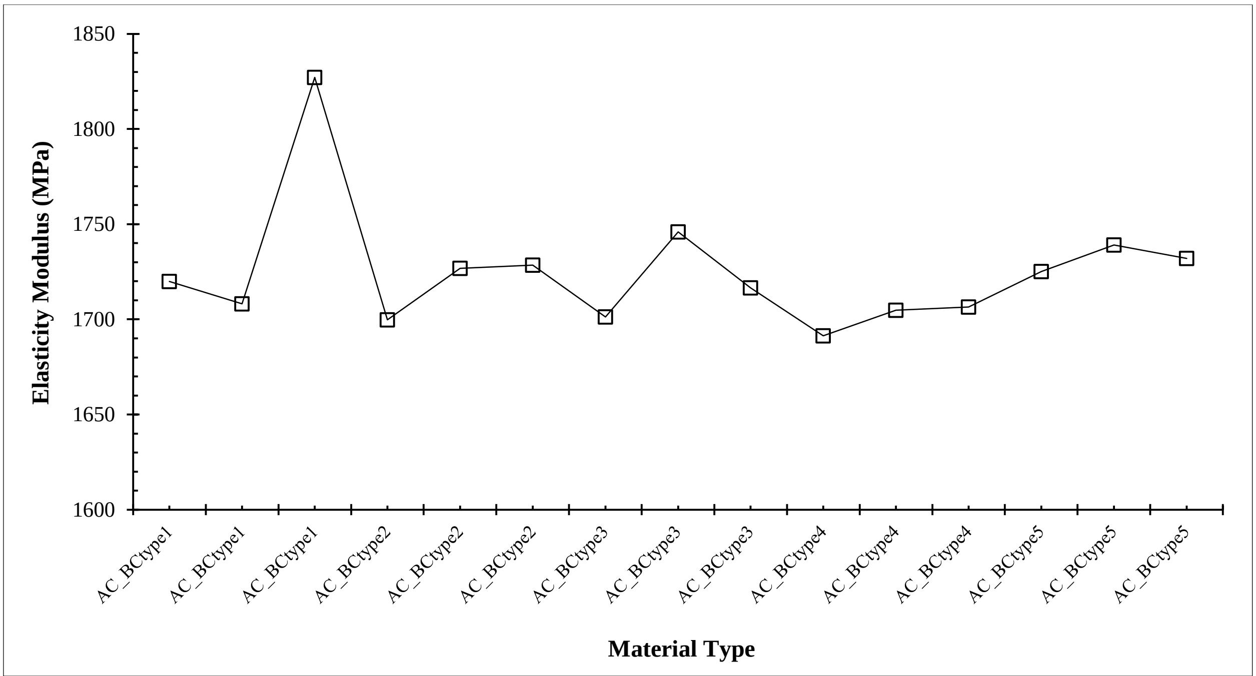

Figure 6. Modulus Elasticity of AC_BC type material using AUDL

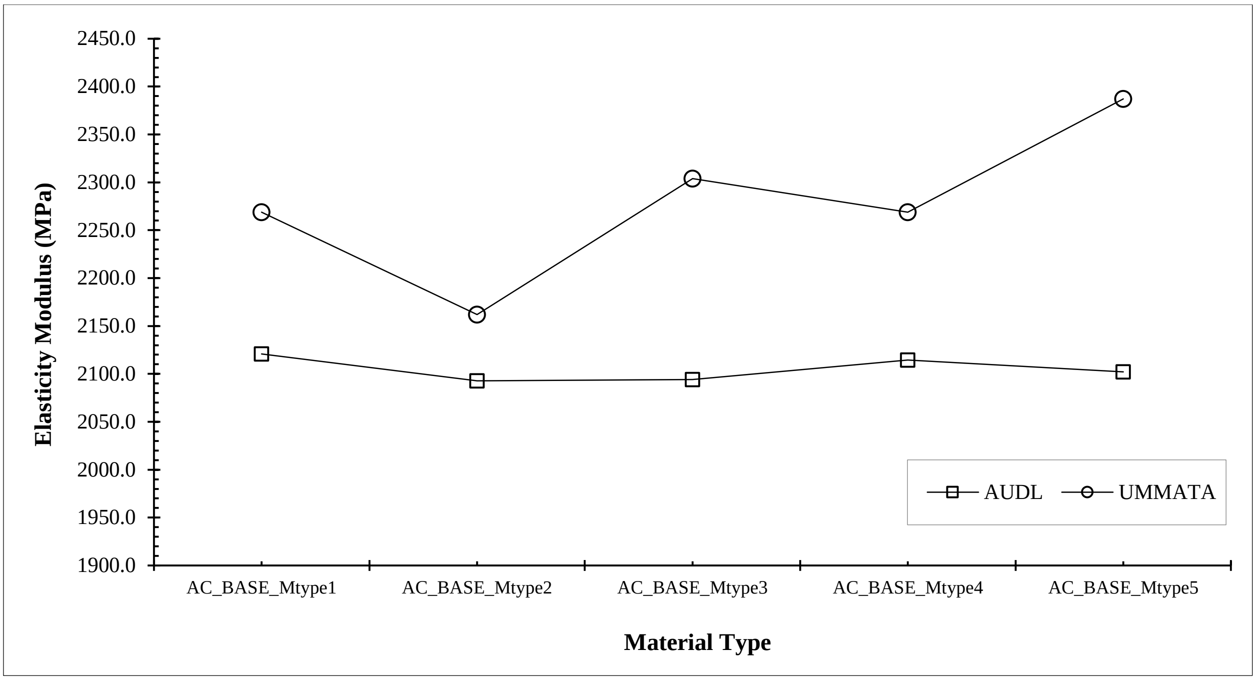

Figure 7. Comparison of Average Elasticity Modulus of AC_Base Type Material using AUDL and UMMATA Method

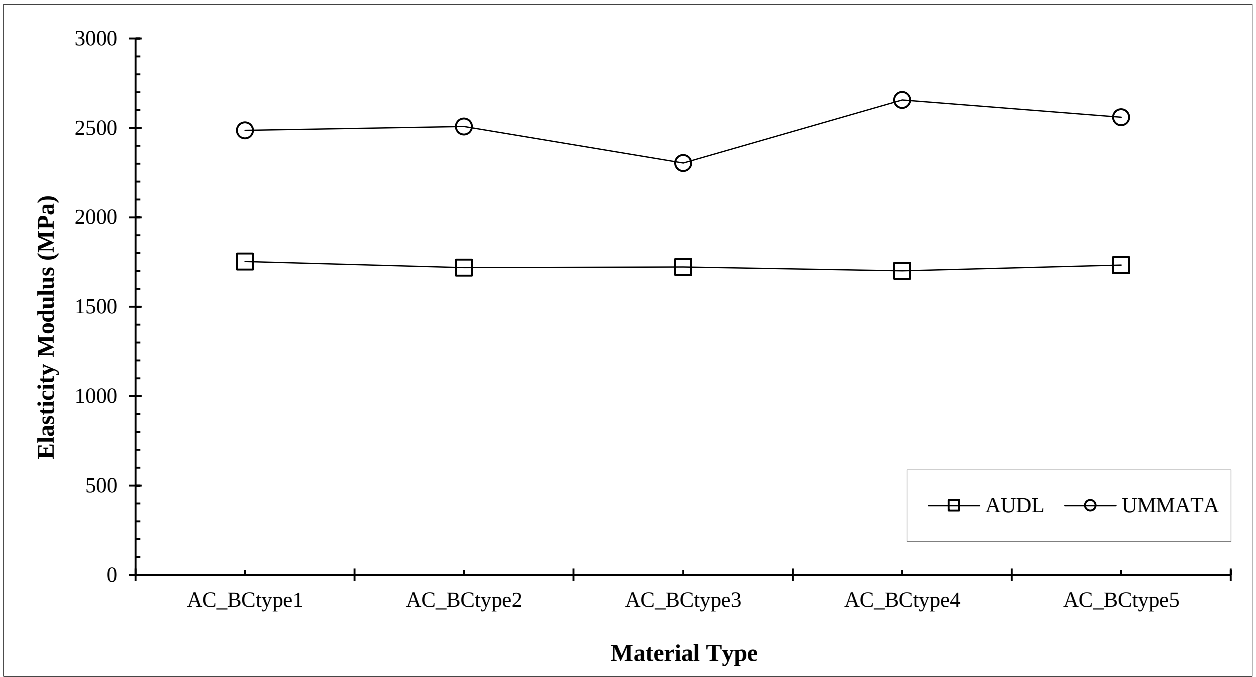

Figure 8. Comparison of Average Elasticity Modulus of AC_BC Material Type using AUDL and UMMATA Method

According to a comparison of the AUDL and UMMATA testing methods, the modulus of elasticity obtained by the two procedures differs. The modulus of elasticity determined using the AUDL approach tends to be lower than the UMMATA method. Figure 6 demonstrates that for the AC-Base material type, the AUDL test method produced a difference between 3 and 11% less than value produced using the UMMATA method. Compared to Figure 8, the difference is bigger between 25 and 35%. The comparison of the modulus of elasticity between material types is shown in Table 1.

The difference in test results based on the Table 1 and figure above forms a pattern. This pattern needs to be analyzed further to find the equations that can be used to produce a smaller margin of error. From the test results, it can be noted that the difference in the value of the modulus of elasticity shows different patterns for different types of materials. This means that correlation does not only need to be carried out on the test method but also requires improvements that include parameters related to the material being tested.

Table 1. Modulus Elasticity values using AUDL and UMMATA method

Material Type	AUDL Modulus Elasticity (MPa)	UMMATA Modulus Elasticity (MPa)	Differences (MPa)	Difference Rate (%)
AC_BASE_Mtype1	2120.7	2269	148.30	6.54
AC_BASE_Mtype2	2092.6	2162	69.37	3.21
AC_BASE_Mtype3	2094.0	2304	210.00	9.11
AC_BASE_Mtype4	2114.4	2269	154.57	6.81
AC_BASE_Mtype5	2102.2	2387	284.77	11.93
AC_BCtype1	1751.7	2487	735.30	29.57
AC_BCtype2	1718.3	2507	788.67	31.46
AC_BCtype3	1721.3	2304	582.73	25.29
AC_BCtype4	1700.8	2657	956.17	35.99
AC_BCtype5	1732.0	2560	827.97	32.34

From these results, as shown, for the AC Base Modified material, the difference rate between the UMMATA and AUDL methods is around 7%, while for AC BC the difference rate is around 30%. This value is very critical if it cannot be converted and correlated, because the value generated through these two tests is the main parameter in planning and designing road pavement.

Based on the comparison in Figure 9, the modulus value produced by the AUDL method has a lower value than the UMMATA approach. The average value in the AC Base material is 7.52 percent lower. In contrast, the average value of the AC BC material is just 30.93%. These findings show that more trials are required when utilizing the AUDL method to identify correlations that might serve as a foundation for comparison. The AUDL test method may thus be used as a nondestructive testing approach. This kind of non-destructive technology should be extensively used in order to provide more realistic simulations of field conditions.

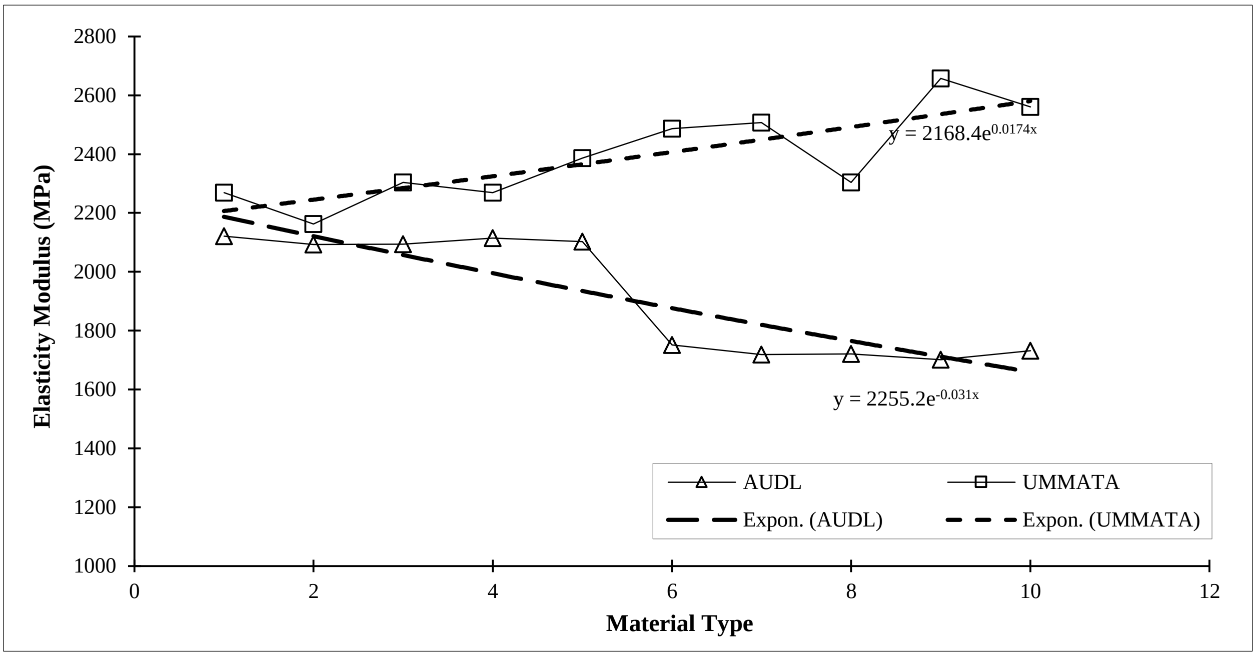

Figure 9. Comparison of Average Elasticity Modulus using AUDL Method and UMMATA

5. Conclusion

Compared to the AUDL and UMMATA testing methodologies, it is revealed that the obtained modulus of elasticity varies between the two methods. The modulus of elasticity generated using the AUDL method tends to be less than the UMMATA method. For the AC-Base material type, the difference between the AUDL and UMMATA methods is between 3 and 11 percent less. In comparison to the AC BC material type, the difference is between 25 and 35% bigger. The average value of AC Base material is 7.52 percent less than AC Base. The average value of AC BC material is just 30.93%. From here, it shows that the UMMATA and AUDL methods are sharing a mutual trend. This means that future research could obtain comparative correlations between similar methods and use them to calibrate the AUDL, improving its accuracy. These results indicate that further trials are necessary when using the AUDL methodology to detect correlations that might serve as a fundamental comparison for calculation. Furthermore, a comparative study is necessary to provide other possible correlations between AUDL and other methods. Thus, the AUDL test method may be used as a nondestructive testing method that is reliable and accurate. This kind of non-destructive method should be used frequently so that simulations of field circumstances are more accurate.

6. Declarations

6.1. Data Availability Statement

The data presented in this study are available in the article.

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6.4. Conflicts of Interest

The author declare no conflict of interest.

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