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## **CORRELATION OF MARSHALL TEST BASED WITH LIGHT WEIGHT DEFLECTOMETER (LWD) LABORATORY BASED ELASTICITY MODULUS OF ASPHALT MIXTURE**

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### **ABSTRACT**

*Currently in Indonesia, one of the most rapid concentrations of development is the construction of roads, especially national road infrastructure network. Stress conditions that occur due to wheel load on the pavement layer can be tested in the laboratory under simplified factors. In actual conditions, pressure or load is applied in three dimensions. Therefore, a number of simplified tests were introduced to be able to test certain aspects of in-situ behavior. This study aims to find the correlation of the modulus of elasticity obtained by the Marshall test with the modulus of elasticity obtained by the laboratory version of the LWD. This research is conducted with of experimental tests in the laboratory. The study design was applied to the HRS-WC mixture by testing the Marshall test and LWD laboratory version at an optimum asphalt level of 8.0%. The results showed that there was a strong correlation between the modulus of elasticity produced by the laboratory LWD and the Marshall quotient value produced by the Marshall instrument and the modulus produced by UMATTA, namely laboratory ELWD = 1.073 E<sub>Marshall</sub> quotient and laboratory ELWD = 1.068 E<sub>UMATTA</sub>. Laboratory LWD tools can be used as instruments in determining deflection and modulus values in laboratory scale asphalt pavement.*

**Keywords:** LWD, Marshall Test, Modulus elasticity, HRS-WC, UMATTA

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## 1. INTRODUCTION

In Indonesia, recently works have been carried out through Survey of Road and Bridge Slopes with the intention of obtaining real data and used as a data base as a reference in making long-term and short-term work programs. One of the goal is to provide data on the condition of real roads that are on the status of national roads and national strategic roads. Retrieval of data needed is, surface conditions (unevenness using Raughness meter), inventory survey (using manual method or also with Garuda eye camera), pavement condition index survey or road condition survey (can use camera and manual equipment) and deflection survey remaining pavement age using a Bankleman Beam or Falling Weight Deflectometer (FWD) tool or it can also be with a Light Weight Deflectometer (LWD) tool. Specifically regarding the retrieval of the remaining pavement data, the three pieces of equipment can be used as long as they are in accordance with the terms and conditions of the survey area. The working principle of the three tools is almost the same, such as how to put pressure on the pavement surface and is expected to get results in the form of deflection and modulus on the surface to the subgrade.

Stress conditions that occur due to wheel load on the pavement layer can be tested in the laboratory but with many simplified factors. In actual conditions pressure or load is applied in three dimensions. Therefore, a number of simplified tests were introduced to be able to test certain aspects of in-situ behavior. The test was divided into three groups. The first group of tests is the basic test of a triaxial repeated load test, static compressive test for unconfined static uniaxial creep compression test, repeated load indirect tensile test, dynamic stiffness and fatigue test (stiffness and fatigue tests). The second group of tests is laboratory simulation (simulative): Wheel-tracking test (wheel-tracking test) and the third group is empirical testing with Marshall test (Marshall tests), (Shell Bitumen Handbook, 2013) [1].

Various previous studies have been carried out using LWD tools to calculate the modulus of the pavement. Mazari et al., 2017 [2] introduced the Intelligent Compaction (IC) technology that has emerged over the past decade to evaluate the rigidity of compacted pavement layers. The application of IC technology to condense uncoated geomaterial layers has been combined with nondestructive testing (NDT) devices to better provide the characteristics of the stiffness parameters. The identified area is not well connected in conducting the NDT spot test.

Rahman et al., 2007 [3] discussed the subgrade rigidity obtained from a new compaction device called the Roller Intelligent Compaction (IC) on the highway embankment project in Kansas. The three test sections on the two routes are compacted using Bomag Variocontrol (BVC) single-sided smooth steel roller compacting and at the same time measuring the value of compacted soil stiffness. Traditional compaction control measurement such as density testing, in-situ water content, measurement of soil stiffness using Geogage, surface deflection tests using Light Falling Weight Deflectometer (LFWD) and Falling Weight Deflectometer (FWD) and penetration tests using Dynamic Cone Penetrometer (DCP). The results showed that the IC roller was able to identify the location of the lower soil stiffness in the spatial

direction. In general, the stiffness of the IC roller shows that it is sensitive to the level of humidity in the field.

Senseney et al., 2012 [4] presents a LWD recalculation scheme to determine the layer parameters, including the thickness of the top layer, from a two-layer earthwork system. The approach can be solved by using a dynamic finite element model (FE) for the calculation of LWD deflection data, and implementing a genetic algorithm (GA) as a solver. The objective function is formulated as a measure of data mismatch between predicted and observed data, normalized by peak deflection, and includes 180 data points from a dynamic deflection time history.

Tehrani & Meehan, 2010 [5] explored the sensitivity of modulus-based in-situ test results measured against the effect of compaction water content, a field study was conducted in the State of Delaware in the summer of 2008. Two LWD tools were used in this study. For measuring compacted soil modulus values, one with a contact plate diameter of 300 mm and one with a plate diameter of 200 mm. The filler tested during this research was sand rated poorly by silt (SP-SM).

Tirado et al., 2015 [6] evaluated the performance of LWD under various loading conditions, different plate sizes, and various geomaterial properties. The depth of influence is analyzed using stress and strain criteria. The parameters of the nonlinear constitutive model appear to have significant effect on the measured depth of influence of the two devices used. However, the different functional properties of each device were found to be a source of variation in results.

Buechler et al., 2012 [7] used the element-discrete (DEM) method to investigate the relationship between soil properties and mechanical responses to plates (LWD simulation) and drum-roller loading. Simulations of pure granular soil without cohesion are shown to show much different stresses and strain fields compared to cohesive soil simulations.

Kessler, 2009 [8] outlines the origins of DCP for soil testing and their respective applications for various DCP configurations. The various types of LWD and the results obtained are explained, the ongoing efforts in the use of this instrument and the standards for QC/QA (quality control/quality assurance) for subgrade and aggregate basis for roads.

Kongkitkul et al., 2014 [9] conducted a study of lateritic soils namely the Proctor compaction test which was modified to determine the optimal water content (opt w) and the appropriate maximum dry density), California Bearing Ratio (CBR) test on specimens prepared in opt w, sand cone tests to find field density and hence compaction levels (c D); and LWD test to find surface stiffness (LWD k). While gradually increasing compaction efforts in the test pit, sand cones and LWD tests are carried out on compacted soil. It was found that there was a relevant correlation between cD and % CBR and LWD k.

Elhakim et al., 2013 [10] conducted a study namely first, the index of soil properties of the tested soil including grain size distribution; maximum and minimum voids ratio and specific gravity are obtained. Petrographic analysis of the tested sand was also carried out to determine the mineralogical composition. A 1 m<sup>2</sup> room is built to do LWD testing in the laboratory. The study was conducted for the relative densities of 20%, 40%, 60% and 80% to represent the behavior of very loose, loose, dense and dense sand.

Hari Prasad et al., 2016 [11] used the Light Weight Deflectometer (LWD) as a quality control device to assess the quality of compacted pavement layers. As part of this research, an extensive LWD field testing program was carried out on the freeway along the Outer Ring Road (ORR) located in Hyderabad, India, to determine the modulus of deformation (ELWD) of the base layer and pavement surface. The compacted surface and surface ELWD range from 37.6 to 58.6 MPa respectively, and 89.3 to 125.7 MPa, respectively.

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As explained above that at this time taking the value of deflection and modulus of elasticity in laboratories especially road pavement laboratories are very limited in the type of tool and also certainly not cheap so from this problem an idea arises how we make a tool that can be another alternative in determining deflection values and elastic modulus which is certainly faster, and cheaper and reliable. Based on the background and previous research that has been presented, this study was conducted to develop the LWD tool but for the laboratory version. With the conditions in the laboratory this tool is made of course following the rules or parameters in the field. Therefore, this study aims to find the correlation between the modulus of elasticity produced by the Marshall Test and the UMATTA tool to the modulus of elasticity produced by the laboratory version of the LWD.

### 2. METHOD OF DEFLECTION TEST USING LWD LABORATORY

LWD tools are used depending on the model and testing procedure. In this case the procedure used is to calculate the force applied based on the magnitude of the fall. The modulus testing process using a laboratory LWD begins with the loading of the research sample which will be read as deflection on the MEMS Accelerometer which is passed on to the processor and read  $D_0$  (deflection) on software on the computer. Surface modulus (surface layer modulus) is calculated from surface deflection using the Boussinesq equation 1 and 2:

$$E_0(0) = 2(1 - \mu_2) \sigma_0 a/D(0) \quad (1)$$

$$E_0(r) = (1 - \mu_2) \sigma_0 a^2/(r D(r)) \quad (2)$$

In the case of Zorn LWDs, the force applied from the falling mass is measured in the laboratory and used for all surface modulus calculations for the LWD tool. Equation 3 can be used to estimate the load applied to Zorn LWDs.

$$F_z = \sqrt{2 \times m \times g \times h \times k} \quad (3)$$

Where:

$F_z$  = Estimated magnitude of force (N)

$m$  = Load weight of the LWD (kg)

$g$  = Magnitude of gravitational acceleration (9.81 m/s<sup>2</sup>)

$h$  = Height of load drop from LWD tool (m)

$k$  = buffer rubber constant (N/m)

While the peak voltage is calculated by equation 4 and equation 5.

$$\sigma = \frac{F}{1000\pi r_p^2} \quad (4)$$

$$ELWD = 2r_p \sigma (1 - \nu_2) \frac{(1 - 10^6)R}{\Delta} \quad (5)$$

Where:

$ELWD$  = Modulus of elasticity (MPa)

$r_p$  = Plate radius (m)

$\sigma$  = peak voltage applied to the surface (MPa)

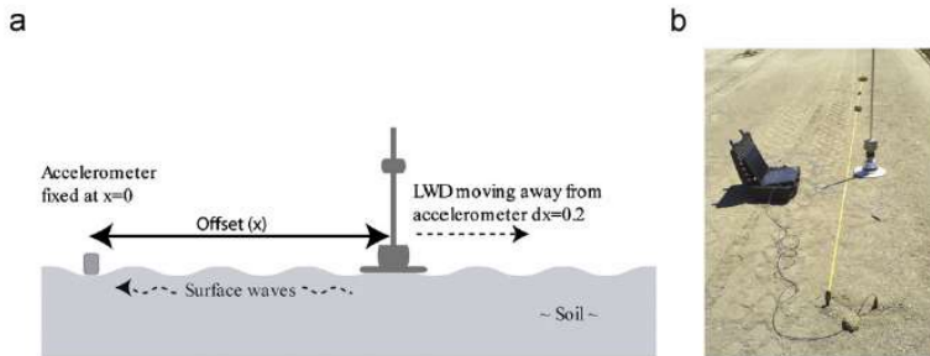
$\nu$  = Poisson bitumen ratio

$R$  = Test object rigidity (0.79 for rigid and 1.0 for flexible)

$\Delta$  = Deflection ( $\mu\text{m}$ )

$F$  = Maximum load (kN)

The calculation used is based on the basic theories of seismology and soil mechanics, especially the Boussinesq theory to produce the modulus of elasticity. The basic theory of seismology is used in wave analysis to obtain the resulting deflection value. Whereas Boussinesq's theory is to calculate the modulus of elasticity of the soil layer by considering deflection values. These two theories in LWD testing are juxtaposed to obtain parameters from the soil that are so important in the form of deflection values and modulus of elasticity. Fig 1 shows the LWD tool testing scheme. The use of this LWD tool involves measuring deflection of the surface of the layer due to the impact load being dropped. Apart from deflection at the point of loading, deflection must also be measured at a certain distance from the point of loading. The deflection obtained can be used for designing pavement thickness.



**Figure 1** Testing scheme using LWD (Ryden and Mooney, 2009) [12]

The modelling of laboratory LWD tools is based on the concept of a field LWD tool that is simplified so that it can be used in the laboratory and the results obtained are the same and correlate with the field LWD tool. By using deflection data obtained from the LWD reading then calculating the modulus value. The data obtained is then calculated using computer programs and the results are evaluated with a simple statistical analysis. Giving load to the research sample which will be read as deflection on the MEMS Accelerometer which is forwarded to the processor and read as D0 (deflection) in software on the computer.

### 3. TESTING AND ANALYSIS

#### 3.1. Research Instruments

Basically, the working principle of the laboratory LWD is the same as the LWD in the field, which is an instrument that can measure deflection and modulus of elasticity through load impulses arising from a load with a certain weight dropped at a certain height on a plate surface with a certain area on a pavement surface that will cause deflection that is measured using a displacement sensor. The difference lies in the sensor used. In the field LWD, the sensor used is geophone while in the LWD the laboratory uses an accelerometer type MEMS Accelerometer. To evaluate the LWD tool produced then the Marshall Test specimens are made using an HRS-WC mixture.

#### 3.2. Data Analysis Method

The method of testing the asphalt mixture with Marshall Tools refers to SNI 06-2489-1991 about the method of testing asphalt mixtures with Marshall Tools. The quotient of stability (flow) and flow (plastic discharge) whose magnitude is an indicator of potential flexibility to

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cracks is called Marshall Quotient. The Marshall Quotient value can be calculated using equation 6.

$$MQ = \frac{S}{F} \quad (6)$$

Where:

$MQ$  = Marshall Quotient (kg/mm)

$S$  = Stability (kg)

$F$  = Flow value (mm)

Data analysis using laboratory LWD tools is the same principle as analyzing data using field LWD tools, namely computerized systems. Based on Bousinesq elastic, the relationship between pressure and displacement applied in the soil for the case of rigid or flexible bases located in a semi-elastic space can be derived as in equation 7.

$$E = \frac{(1 - \nu^2) \times \sigma_0 \times a}{d_0} \times f \quad (7)$$

Where:

$E$  = modulus of elasticity (MPa)

$d_0$  = measured decrease (mm)

$\nu$  = Poisson ratio

$\sigma_0$  = applied voltage (MPa)

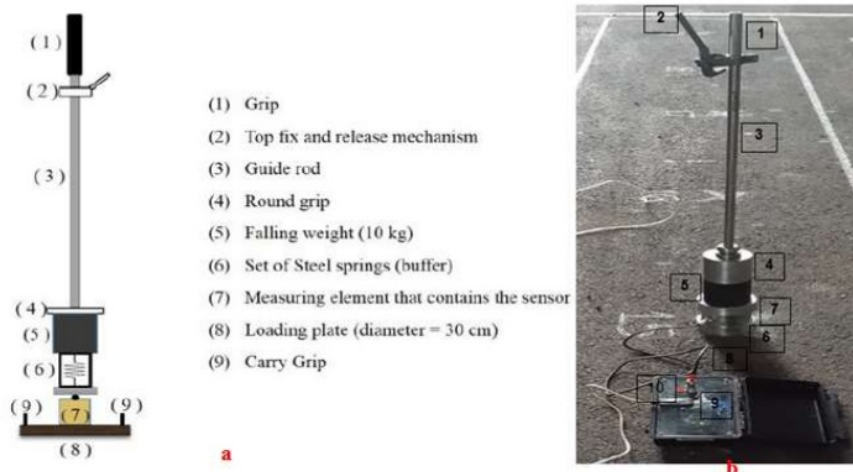
$a$  = plate radius (mm)

$f$  = form factor depends on the stress distribution

## 4. RESULTS AND DISCUSSION

### 4.1. Working Principle of Laboratory LWD Equipment

The working principle of the laboratory LWD tool is the same as the field LWD tool where this tool will produce deflection value (D0) from the impact load. Fig 2 shows the components of a laboratory LWD tool.



**Figure 2** Schematic of Light Weight Deflectometer (LWD). (a) Field LWD; (b) Laboratory LWD

Based on Fig 2, it can be seen that the functions of each component of the laboratory LWD are:

1. A top fix and release mechanism which holds the falling weight at a constant height. This mechanism is released to allow the falling weight to freely drop and transmit the load pulse through the plate resting on the material to be tested.
2. A guide rod that allows the falling weight to drop freely at a set distance of about 720 mm. The guide rod and falling weight together weigh approximately 15 kg.
3. A falling weight grip which provides a grip for the operator to raise the falling weight to the top fix and release mechanism.
4. A falling weight which typically varies between 10 and 20 kg. This weight is capable of being raised to the bottom of the grip predetermined height. The weight is guided by a low resistance rod when dropped to impart a controlled force on the loading plate.
5. A lock pin which has two positions (locked and unlocked) to release the falling weight for use.
6. A damping system which provides a controlled transient pulse length to the impact force, typically in the range of 16 to 30 ms. The spring element is typically a series of rubber cones/buffers, or cylindrical pad system.
7. An anti-tipping fixture that prevents the guide rod and falling weight from tipping when these parts are placed and standing freely on the load center ball/loading plate. A load center ball serves as a connector between the anti-tipping fixture and the loading plate. It also allows for disassembly which reduces the size of the instrument for transport.
8. A cup with sensor that connects to an electronic device and is installed in the middle of the plate. It records the movements of the plate even while the test is being carried out.
9. Carry grips to assist the operator with carrying the loading plate.
10. A loading plate which provides an approximate uniform distribution of the impulse load on the surface. The diameter typically varies from 100 to 300 mm and the loading plate weighs about 5 kg.
11. A cable is used to connect the loading plate sensor to the data processing and storage systems. Each measurement can immediately be allocated to the relevant position using GPS. All data can be displayed on the printout electronic device without problems.
12. A printout electronic device which is suitable for self-supervision and documentation of measurements. A data capture system is required with software to display the impact test results and store them. Additionally, the relevant site and position details can be logged along with the captured data.

#### **4.2. Marshall Test Specimens Modulus Value Using UMATTA Tools**

The modulus value of Marshall test specimens using UMATTA instrument where the Marshall specimens are in KAO conditions. Fig 3 shows the pulse (impact load) based on the time of the UMATTA test results. It appears that the value of the impact load is getting bigger along with the 5th pulse given to the test object followed by an increasing time. Table 1 shows the resilient modulus values of Marshall test specimens under KAO conditions. The results of Marshall Deflection test at optimum asphalt content (KAO) using laboratory LWD are shown in Table 2.

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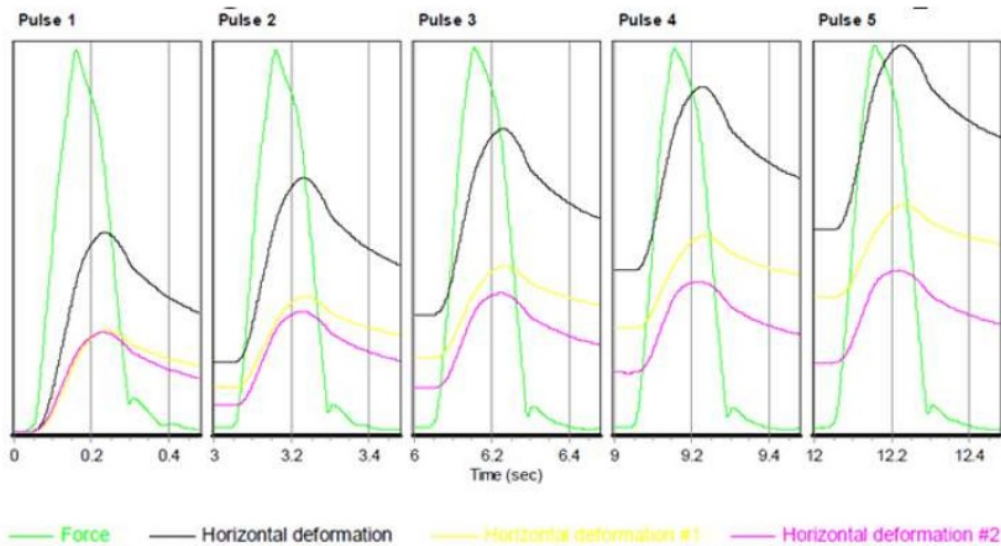
**Table 1** Marshall Modulus using laboratory LWD under KAO conditions (8.0%)

No.	Deflection ( $\mu\text{m}$ )	Fz (N)	$\sigma$ (N)	ELWD (MPa)
1	120,50	4609,13	0,587	461,93
2	133,60			
3	107,90			
4	84,150			
$\bar{x}$	111,54			

Seen in Table 1 deflection values at asphalt content of 8.0% are 111.54  $\mu\text{m}$  respectively while the modulus produced is 461.93 MPa.

**4.3. Marshall Test Specimens Modulus Value Based on Marshall Test**

Testing with each variation of oil asphalt



**Figure 3** Pulse (impact load) based on the time of the UMATTA test results

**Table 2** Resilient modulus of Marshall Specimens under KAO conditions (8.0%)

No.	Resilient modulus/Pulse (MPa)					$\bar{x}$
	1	2	3	4	5	
1	493	461	449	442	442	458
2	495	468	447	440	440	458
3	441	427	433	422	417	428
4	414	385	381	376	373	386
$\bar{x}$	460,75	435,25	427,50	420,00	418,00	432,50

Visible modulus values with 5 pulses generated on specimens 1, 2, 3 and 4 are 458 MPa, 458 MPa, 428 MPa and 386 MPa respectively. The average modulus value generated based on the results of the UMATTA test was 432.50 MPa. The estimated Poisson ratio value used is 0.4 with a maximum force of 1500 N.

#### 4.4. Marshall Test Specimens Modulus Value Based on LWD Laboratory

Content using Marshall Compactors with a collision of 75 times for each field. The parameters obtained are stability and flexibility or flow (flow) which shows the size of the resistance of a test object in receiving the load obtained from the results of the analysis of the Marshall test. From the results of the stability and flow testing the Marshall value is obtained. Table 3 shows the modulus values of Marshall Test specimens using the Marshall Test.

**Table 3** Marshall Modulus using Marshall Test under KAO conditions (8.0%)

No.	Stability (kg)	Flow (mm)	MQ (kg/mm)
1	1326,00	3,50	418,00

#### 4.5. Correlation between Modulus of LWD in Laboratory Using Marshall and UMATTA

Correlation between modulus values using laboratory LWD tools with Marshall Tools and UMATTA tools and calculated at the optimum asphalt content that is equal to 8.0%.

- a) The Relationship Between Modulus Value of Laboratory LWD Equipment and Marshall Tools

The relationship between the modulus value of the laboratory LWD tool and the Marshall tool is shown in equation 8. The value of this relationship is obtained from the comparison of the modulus value generated by the laboratory LWD tool that is equal to the modulus value generated by the Marshall tool at the optimum asphalt content of 8.0%.

$$ELWD \text{ laboratories} = 1,073 \text{ EMarshall quotient} \quad (8)$$

- b) The Relationship Between Modulus Value of Laboratory LWD Equipment and UMATTA Tools

The relationship between the modulus value of the laboratory LWD tool and the UMATTA tool is shown in equation 9. The value of this relationship is obtained from the comparison between the modulus values generated by the laboratory LWD tool that is equal to the modulus value produced by the UMATTA tool at the optimum asphalt content of 8.0%.

$$ELWD \text{ laboratories} = 1,068 \text{ EUMATTA} \quad (9)$$

Based on equations 8 and 9, it can be seen that the relationship between the modulus value of laboratory LWD tools and the Marshall Modulus value is the same as the UMATTA instrument modulus value. This gives an understanding that laboratory LWD tools can be used as instruments in determining deflection and modulus values in laboratory scale asphalt pavement.

### 5. CONCLUSION

There is a obvious correlation between the modulus of elasticity produced by the laboratory LWD with the Marshall quotient value produced by the Marshall instrument and the modulus produced by UMATTA. It is found that elastic modulus of laboratory LWD is 1.068 obtained from UMATTA, while obtain based on laboratory LWD is 1.073 that from by Marshall quotient.

Laboratory LWD equipment can be used as an instrument in determining deflection and modulus values in laboratory scale asphalt pavement

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