Correlation of modulus elasticity of Falling Weight Deflectometer (FWD) towards Light Weight Deflectometer (LWD) laboratory

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Abstract. Develop a new laboratory LWD and this study aims to analyse the laboratory version of the LWD with the field version of the LWD currently developed by Bina Marga, Indonesia. Basically, the working principle of the developed laboratory LWD is same as the LWD equipment in the field, which is an instrument that can measure deflection value and modulus of elasticity through load impulses arising from a load with a specific weight dropped at a certain height on a plate surface with a particular area on a pavement surface that is will cause deflection that is measured using a displacement sensor. A series of studies were conducted to compiled an equation that provides a correlation between the laboratory LWD and the LWD used in the field.

1. Introduction
Several indicators are used to explain the behaviour of both unbound and bound materials used in pavement design and construction such as California Bearing Ratio (CBR), resilient modulus, dynamic penetration, strength, stresses and strains, deformations, etc. However, resilient modulus that is a stiffness property of the material has been considered as one of the prominent input parameters used in the several flexible pavement design methods. The level of compaction is evaluated through spot measurements of density and bearing capacity at some selected locations in the traditional testing procedure of pavement subgrade. Such tests can leave soft spots undetected and could result in the premature failure of the pavement. Predicting the pavement surfacing and the compacted soil by nondestructive equipment decreases material, time and a destructive spot in the measuring area. In recent times, Light Weight Deflectometer (LWD) equipment has been introduced and employed to investigate the stiffness or resilient modulus of compacted layers of the pavement structure directly, instead of testing the quality of those layers in term of field density. Several existing studies have provided detailed descriptions of LWD for investigating soil compaction in the field.

Recently, the nondestructive testing methods are gained acceptance and recommendation in road construction and evaluation practices for Indonesian highways as the rapid control of compacted soil bearing capacity.

2. Material and method
2.1. **Light Weight Deflectometer (LWD) Test**

The Light Weight Deflectometer (LWD) is a hand portable falling weight equipment originated from Germany that first developed in 1981, and has obtained acceptance in several countries such as the United States, as there is an increasing concern in the use of nondestructive tests such as LWD as in situ spot-testing equipment for quality control and quality assurance of earthwork compaction.

To provide suitable equipment as the rapid control of compaction of soil bearing capacity, Ministry of Public Works and Public Housing’s Institute of Road Engineering, Agency for Research and Development office of road and bridge (Pusjatan) has developed LWD device that used in this present study. The LWD measures the deflection of the test layer produced from drop weight, drop height weight, and load according to from the Indonesian National Standard (SNI) (Pd–03-2016-B, SE PUPR Minister No/19/SE/M/2016), “Standard Test Method for Measuring Deflections with a Light Weight Deflectometer.". Furthermore, the deflection value obtained from LWD is used to determine the elasticity modulus of $E_{LWD}$. Prediction of $E_{LWD}$ is based on the Boussinesq theory relating the static deflection of an elastic half-space subjected to an axisymmetric surface loading as given by Eq 1, in which is a stress distribution factor, $V$ is Poisson’s ratio of the soil, $w_0$ is the peak vertical deflection, $F_{pk}$ is the peak applied load, and $r_0$ is the radius of the load plate. Figure 1 had shown LWD test to measure the deflection at the prepared field. Table 4 shown properties of various lightweight deflectometer devices.

![Figure 1. LWD test to measure the deflection at the prepared field.](image)

**Table 1. Properties of Various Lightweight Deflectometer Devices.**

| Properties          | Zorn             |
|---------------------|------------------|
|                     | Plate style      | Solid           |
|                     | Plate diameter   | 150, 200, 300   |
|                     | (mm)             |                 |
|                     | Drop mass        | 10              |
|                     |                  |                 |


| Plate Style       | Plate Diameter (mm) | Drop Mass (kg) | Drop Height (m) | Damper       |
|-------------------|---------------------|----------------|-----------------|--------------|
| **Prima**         | 100, 200, 300       | 10,15,20       | Variable        | Steel spring |
| **TFT**           | 100, 150, 200, 300  | 10,15,20       | Variable        | Rubber       |
| **Dynamic test**  | 100, 150, 200, 300  | 10,15,20       | Variable        | Rubber       |
| **LWD PUSJATAN**  | 300                 | 12             | Variable        | LWD          |
| **LWD Laboratory (Research)** | 100              | 4              | Variable        | LWD          |

The equation (Eq. 1) based on the theory of elasticity is used to calculate the deformation modulus of compacted material.

$$E_{LWD} = \frac{qr (1 - \nu^2)}{w} f_r$$  \hspace{1cm} (1)
Where, $ELWD$ is the modulus of deformation of pavement layer; $fR$ is the rigid plate factor (taken as $\pi/2$ for a rigid plate); $q$ is the maximum contact pressure; $r$ is the radius of the bearing plate; $\nu$ is the Poisson’s ratio of the soil; and $w$ is the settlement of the bearing plate measured at the centre. However, in this study, the inbuilt data processor directly shows the central average of deformation and the average modulus deformation of pavement layer considering three blows of impulse load. The LWD device consists of the following elements, which are illustrated in figure 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 free drop and transmit the load pulse through the plate resting on the material to be tested.
- A guide rod that allows the falling weight to drop free at a set distance of about 720 mm. The guide rod and falling weight together weigh approximately 15 kg.
- A falling weight grip which provides a grip for the operator to raise the falling weight to the top fix and release mechanism.
- A falling weight which typically varies between 10 and 20 kg. This weight is capable of being raised to the bottom of the predetermined grip height. The weight is guided by a low resistance rod when dropped to impart a controlled force on the loading plate.
- A lock pin which has two positions (locked and unlocked) to release the falling weight for use.
- 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.
- 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 centre ball/loading plate. A load centre 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.
- A cup with a 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.
- Carry grips to assist the operator with carrying the loading plate.
- 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.
- 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 electronic printout device without problems.
- An electronic printout 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.

3. Results and discussion

Figure 2 shows the relationship point of experiment with the modulus (falling weight laboratory and laboratory LWD). Between the FWD and laboratory LWD fields, it can be seen that the graph pattern formed is similar to the modulus value of 570 MPa, but the LWD modulus value of the laboratory is greater than the modulus value of the laboratory field. This is due to the falling weight of the smaller LWD field, which is 8 kg compared to the laboratory LWD, which is 10 kg. However, the modulus of the LWD field and laboratory can be justified and provides a correlation based on the derivative of the Boussinesq equation.

Figure 3 shows the relationship point of experiment with deflection (D0). It can be seen that the deflection value of the FWD is greater than the value of the LWD laboratory. Also visible is the graphic pattern formed equally between the FWD and laboratory LWD. The resulting deflection value in the LWD filed ranges from 350 - 450 microns while in the laboratory LWD ranges from 100 - 200
microns. In addition, the two parameters of stiffness, modulus and deflection, have proven Boussinesq theory.

Figure 2. Relationship point of experiment with modulus.

Figure 3. Relationship point of experiment with deflection.

From the experimental results held at the Road and Bridge Research Center Hall of Refinement (PUSJATAN) Ministry of PUPR Bandung, the data obtained with the following:
- Comparison between the average deflection (D0) value produced between FWD and laboratory LWD was 3.474, which means:
FWD D0 = 3.474 D0 laboratory LWD (2)

- Comparison between the average surface modulus (E) value generated between FWD and laboratory LWD was 0.888, which means:

\[ E_{\text{FWD}} = 0.888 \times E_{\text{laboratory LWD}} \] (3)

- Comparison between the average voltage (\(\tau\)) produced between FWD and laboratory LWD against 1.588, which means:

\[ \tau_{\text{Field LWD}} = 1.588 \times \tau_{\text{laboratory LWD}} \] (4)

Where the surface impact load comparison, the FWD gas a measured load (using a load cell) of ± 4000 kg while the laboratory LWD has a measured load on the surface of 470 kg. If you want to compare impact loads, then:

\[ F_{\text{FWD}} = 8.511 \times F_{\text{laboratory LWD}} \] (5)

4. Conclusion
At present, one of the most rapid concentrations of physical development in infrastructure is the construction of roads, especially roads with national road status. Recently, the nondestructive testing methods are gained acceptance and recommendation in road construction and evaluation practices for Indonesian highways as the rapid control of compacted soil bearing capacity.

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