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YOUNG'S MODULUS AND DEFLECTION ASSESSMENT ON PAVEMENT USING A LIGHTWEIGHT DEFLECTOMETER

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ABSTRACT: This research implemented direct assessment in the field on road structures using the Light Weight Deflectometer (LWD) method. This method is similar to the Falling Weight Deflectometer (FWD) method. The LWD method uses a lower loads compared to the FWD method. LWD method was chosen because the equipment is quite portable and straightforward allowing it to be used directly in the field, making inspection easier. The LWD method is more suitable for assessing the pavement conditions in which the volume of road use is not too high. This study aims to determine the value of the road structure conditions based on material properties. The location of the survey was Kupang City, East Nusa Tenggara, and Indonesia. The number of test points is 77 main points, with each point consisting of several tests. The test results obtained in this study are the value of deflection and modulus of elasticity at each test point. In addition, a radius of curvature analysis was carried out to determine the base of the pavement structure conditions. LWD testing by giving a load on the surface of the pavement was found to predict the base conditions of the road structure. This study also analyzes the EFWD conversion value from the ELWD test results and the correlation between these methods is presented.

Keywords: Young's Modulus, Deflection, Light Weight Deflectometer (LWD), Pavement Assessment, Indonesia.

1. INTRODUCTION

The performance of road or highway materials mainly depends on the strength and stiffness that can withstand the load of traffic. The assessment of road conditions has been conducted to obtain the remaining service life of the pavement [1]. Many methods can be used to check the performance of pavement structures. The methods available include destructive tests and non-destructive tests. However, testing using non-destructive test methods is more popular because it can accommodate parameters that are useful for optimizing material without damaging the existing structures [2, 3].

The assessment is carried out primarily to find out the service life of the structure. In the non-destructive tests, many previous researchers have used the pavement condition index method [4, 5], 2 such as Benkelman beam deflectometer [6] and falling weight deflectometer [7-10]. However, the falling weight deflectometer is not easy to use at construction sites because this device is not very portable. Thus, in recent years, researchers have developed test equipment using a portable falling weight deflectometer [11]

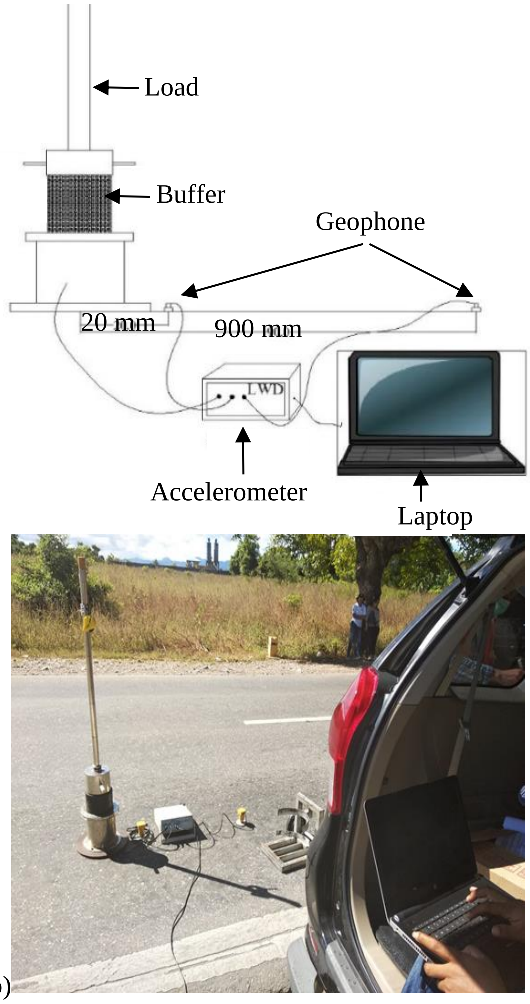
LWD was used to obtain deflection and stiffness data for materials form subgrade, embankment to surface pavement [12-15]. Several studies have also been carried out to find the correlation between the LWD test results and other deflection measurement equipment [16], such as between Portable Falling Weight Deflectometer (PFWD) and surface wave measurement [17], plate bearing load test [18]. Several other tests on the use of LWDs in pavement conditions have been carried out. Some of them aim to estimate the stiffness of the pavement [19, 20], as a reference for quality control [21], and as a model for predicting deflection [22].

This study analyzes the results of the assessment testing using LWD on the low traffic volume road segment in East Nusa Tenggara Province, Indonesia. Through the results of this assessment, Young's modulus and deflection data will be displayed. The results of this test will later be converted to FWD results, which can often be used to overlay the pavement.

2. METHODOLOGY

A lightweight deflectometer is known as a portable falling weight deflectometer. It is one of the tools used to test the quality of material with non-destructive methods.

(a)



(b)

Fig.1 (a) LWD equipment installation; (b) LWD installation in field measurement

This equipment uses falling mass as the source of vibration and bearing plate with the attached buffer assumed to simulate the vehicle load. The drop-down load produces a vibration that is seized by the geophone installed along with the equipment with distance of 0 mm, 20 mm, and 900 mm. The minimum distance between the centre of geophone and other receivers should be at least one half of the wavelength to get the sufficient phase velocity [23].

Figure 1 (a) is an installation of a lightweight deflectometer (LWD). This tool consists of a load with a small size, then dropped on a buffer, and a plate. Then, the geophone will record the data transferred to the accelerometer so that the data can be transferred into the digital file. Meanwhile, Figure 1 (b) is a picture of the form of installation using LWD in the field assessment.

This research was conducted for the National Segment road as the government program to find out the quality of the infrastructure service life in Indonesia. Assessment using LWD has been used by several provinces in Indonesia, especially for roads that have low levels of traffic volume. This research was carried out on Flores Island, East Nusa Tenggara Province. Flores Island is one of the very famous tourist destinations in Indonesia because it is close to Komodo Island and Bali.

Thus, infrastructure is an integral part of factors supporting economic sustainability. Figure 2 shows the location of the inspection conducted in June 2019. The national road being assessed was the Labuan Baji – Malwatar route with Morom ID 44.00. The total length of the road being tested was 60 km, with the test point taken every 100 m. For every test point, the data are taken for 2 to 3 times.

Fig.2a Location of the field measurement of East Nusa Tenggara Province

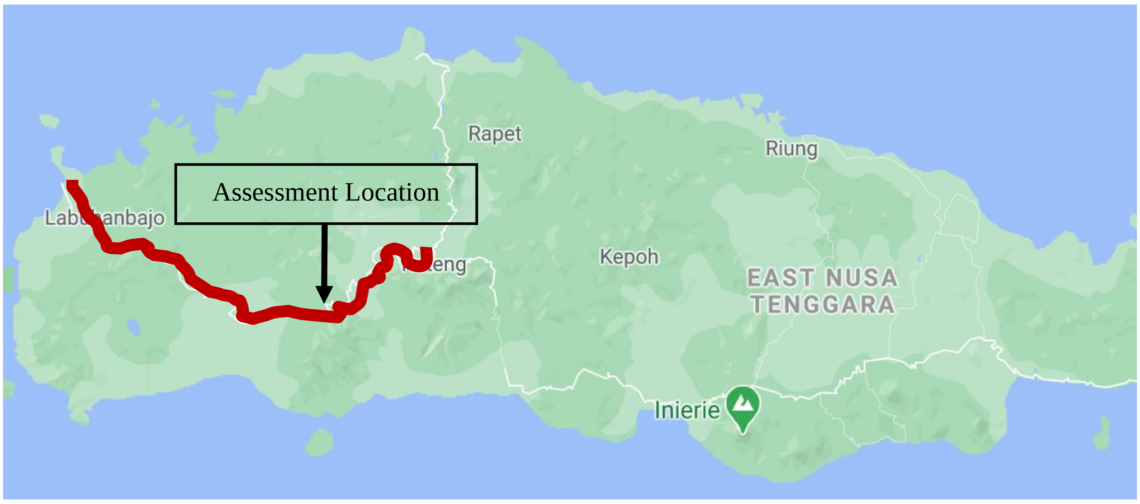


Fig.2b Assesment location of the field measurement a

As for low traffic volume, traffic analysis was described using road traffic counting (RTC survey) from 2018 on the same road to get the traffic volume. Road traffic volume was conducted within 7 x 24 hours and got the peak hour volume to analyze the peak hour flow. As seen in Table 1, the volume per capacity of 0.4 indicates the low traffic volume for the road segment. The types of vehicles that pass are also dominated by light vehicles such as motorbikes and cars. In Table 1, it appears that the volume of vehicles crossing this road is 914.2 PCU/Hour.

This test will produce several values, namely d0, d_1, and d_2, which are the results of deflection results that occur on geophone sensors at a distance of 0 mm, 200 mm, and 900 mm, respectively. Besides, this test will also measure the temperature of the pavement surface by plugging the thermometer into a particular layer. Meanwhile, Equation 1 can be used to calculate the modulus of elasticity in this test.

Table 1 Peak hour analysis

Vehicle	Normal	Opposite	Normal	Opposite
	(Veh/Hour)		(PCU/Hour)	
MC	629	964	251.6	385.6
LV	105	107	105	107
HV	22	28	28.6	36.4
	Total		385.2	529
		Volume (Qv)	914.2	PCU/Hour
		Capacity	2401.2	PCU/Hour
	Degree of Saturation		0.4	

Note: MC: Motocycle; LV: Light Vehicle;
HV: Heavy Vehicle
PCU: Passenger Car Unit

$$E_{LWD} = \frac{(1-v^2)K.P.r}{d} \quad (1)$$

The definition of the equation is that v is Poisson’s ratio; and it usually was 0.35 used for flexible pavement. K is for plate rigidity factor, 2 is for the flexible plate, and π/2 is for the rigid plate. Meanwhile, P is for applied stress, r is for plate radius, and d is for deflection. The use of LWD as a result of the development of the Indonesian Government's National Road Center with the FWD tool has been carried out by several previous researchers in different locations. The use of this LWD tool can also be converted into a young’s modulus value from FWD, which is one of the testing methods that represent the real results in the field. This test is done to prove that the LWD tool can be used as a substitute for FWD [24]. In this study, there will be a convergence of several calculation methods that have been done before.

$$E_{FWD} = 1.059\ E_{LWD} \quad (2)$$

Meanwhile, another method in this study to calculate the EFWD value from the conversion result of ELWD value is the use of Fremming [3] and Nazzal formula [20]. In previous studies, Equations 2, 3, and 4 used linear regression to determine the conversion value from ELWD to EFWD. Merely, the use of conversions is quite varied, ranging from 0.97 to 1.095.

$$E_{FWD} = 1.032\ E_{LWD} \quad (3)$$

$$E_{FWD} = 0.97\ E_{LWD} \quad (4)$$

This study shows the correlation between the results of EFWD conversion using the Siegfried equation and the Fremming and Nazzal equations. Siegfried equation is the result of the equation obtained through testing in Indonesia. Meanwhile, other equations are not done in Indonesia.

3. RESULTS AND DISCUSSION

The test was conducted on a flexible pavement along 60 km, but this research only shows results along the 6 km. These results have already illustrated the overall results of the data obtained. Through field assessment results using LWD, the results of deflection and Young's modulus were obtained. Figures 3 to 5 are deflection results obtained at locations D0, D1 and D2. Figure 3 is the result at D0 location in which it is the closest location to the test location, while D2 is the location of the test location. The results show that the farther the test location with the LWD tool, the smaller the deflection value will be.

Deflection values at Do locations ranged from 61.6 µm to 464.5 µm, while D1 areas produced deflection values from 51.3 µm to 291.6 µm. Smaller deflection values were produced at D2 location, ranging from 4.3 µm to 92.3 µm. The level of data distribution or standard deviation produced quite varied at D0 location. It produced a standard deviation of 68.5%, 41.3% and 12%.9% at D0, D1 and D2 locations consecutively.

Through the displacement test results, it can be concluded that the closer to the location of loading, the higher the resulting displacement value. The average value obtained along the 6 km at D0 location produced a deflection value of 186.8 µm, while at D1 location the deflection value decreased to 126.0 µm and at D2 location, it produced an average deflection value of 37.8 µm. These statistical results can be seen in Table 2.

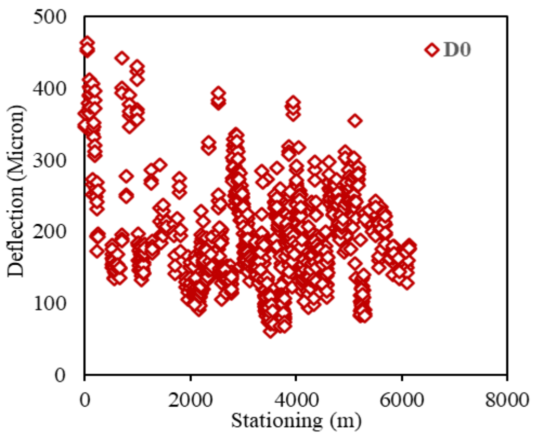


Fig.3 Displacement D0

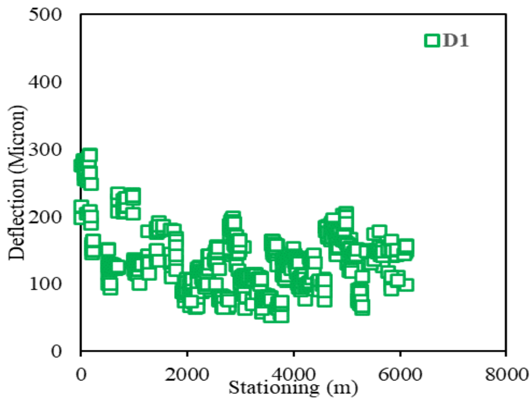


Fig.4 Displacement D1

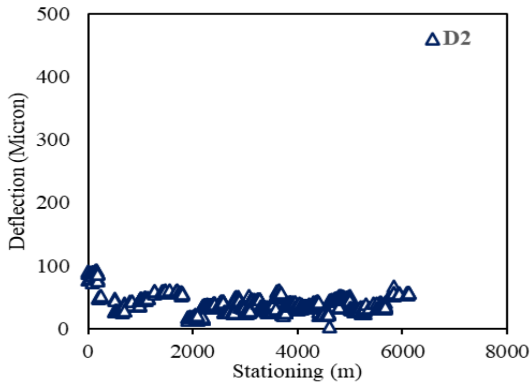


Fig.5 Displacement D2

After producing the deflection value, the Young's modulus LWD value can be calculated using Equation 1. And the results can be seen in Figure 6 and Figure 7. Figure 6 is the result of the Young's modulus value at D0 location, while Figure 7 is that of at D1 location. The value of Young's modulus at D0 location ranged from 85 MPa to 1734 MPa, while at D2 it was between 68 MPa to 1573 MPa. In the testing at D1 location, there were some data which were quite high beyond 100 MPa, but in Figure 7, it is seen that most of the modulus data are not more than 600 MPa.

Through the results of this test, it can be concluded that higher Young's modulus values were generated at D0 location compared to D1 location. In Table 2, it is seen that the average Young's modulus value at D0 location is 471.4 MPa, whereas at D1 location, the Young's modulus value is 187.6 MPa. From Table 2, the temperature values obtained from the LWD device are obtained where the temperature produced consists of the temperature on the road surface, on the asphalt and in the air. The results of the average temperature value on asphalt was 33.08 °C while on the surface was 38.18 °C.

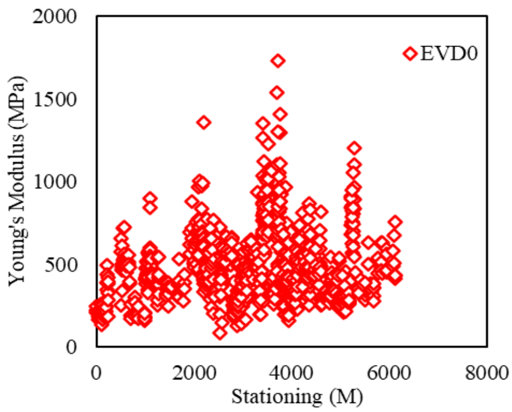


Fig.6 Young’s Modulus D0 (LWD)

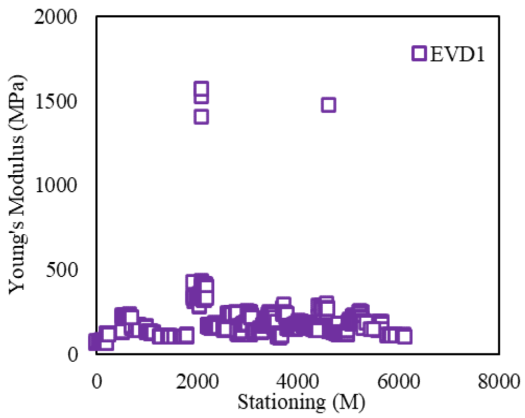


Fig.7 Young’s Modulus D1 (LWD)

The results of the Young’s modulus LWD test would be converted into the Young’s Modulus FWD value. This conversion calculation uses three empirical methods from the results of previous studies. Figure 8 is the result of the value of the Young’s modulus FWD using the conversion equation commonly used in Indonesia.

Meanwhile, figures 9 and 10 contains the value of the Young’s modulus FWD from the results of previous studies which are still rarely used in Indonesia. The results obtained from the Young’s modulus FWD show the value that is not too different between the methods used. This shows that each method can be used to convert the value of Young’s modulus LWD to FWD.

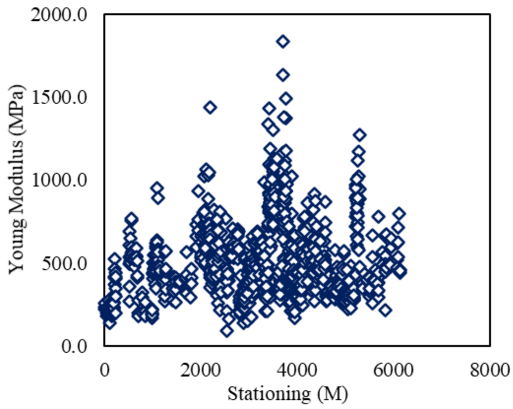


Fig.8 Young’s Modulus FWD using Siegfried Equation

The Young’s modulus value converted in this study is only at D0 location because it has a higher value compared to that of D1 and D2 locations. Young’s modulus value produced by Siegfried method is higher than that of the Flemming and Nazzal methods. The results of testing on this national road obtained a value of Young’s modulus FWD that was not greater than 2000 MPa. Meanwhile, Figure 11 to Figure 13 represents the correlation of the value of the Young’s modulus LWD and the value of the Young’s modulus FWD.

Figure 11 is the correlation between the value of the young modulus LWD and FWD using the Siegfried method. The results show a linear equation where the value of Young’s modulus FDW is 1,059 greater than the value of Young’s modulus LWD. This is consistent with the euation used in Equation 2. Meanwhile, Figure 12 is the correlation between the value of the Young’s modulus LWD and FWD Flemming method, and the results show that the value of the Young’s modulus FWD is 1,032 greater than that of LWD. The same thing is also seen in Figure 13.

Table 2 Peak Hour Analysis

Statistical Analysis	Deflection (µm)			Modulus (MPa)		Temperature (°C)		
	d0	d1	d2	Evd0	Evd1	Surface	Asphalt	Air
Mean Value	186.8	126.0	37.8	471.4	187.6	38.18	33.08	34.42
Max. Value	464.5	291.6	92.3	1734.0	1573.0	38.9	40.0	40.0
Min. Value	61.6	51.3	4.3	85.0	68.0	36.9	26.0	26.0
St dev	68.5	41.3	12.9	202.0	103.5	0.5	4.1	3.9

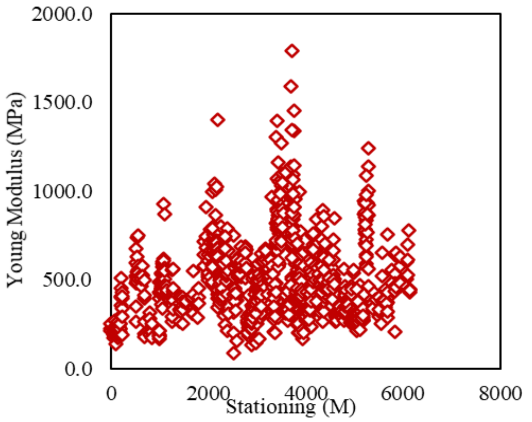


Fig.9 Young's Modulus FWD using Flemming Equation

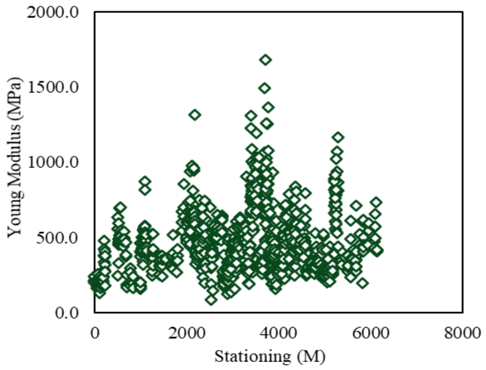


Fig.10 FWD Young's Modulus using Nazzal Equation

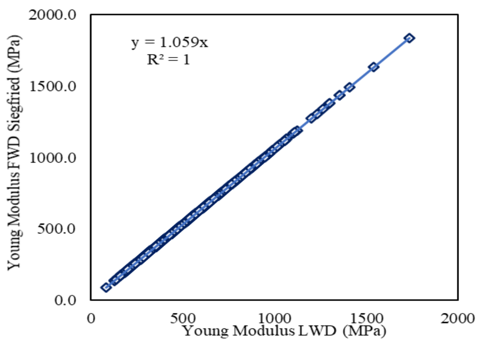


Fig.11 Young's Modulus relationship between LWD and FWD Siegfried

However, Figure 13 presents that the results of the Nazzal method show that the value of the Young's modulus FWD is 97% of the value of the Young's modulus LWD. This shows that the Nazzal method will produce a smaller value of the Young's modulus FWD than that of LWD. So, this shows that the Nazzal method will always produce the value of the Young's modulus FWD smaller than ELWD while other methods always produce the value of the young modulus FED higher than ELWD. All equations analyzed produce Linear equations.

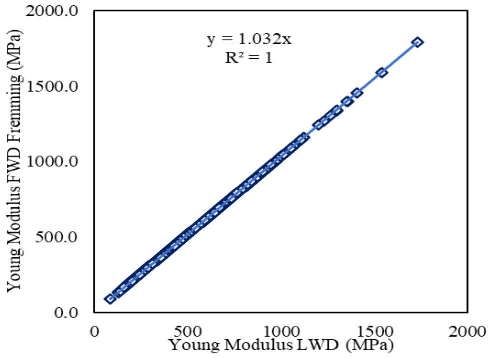


Fig.12 Young's Modulus correlation between LWD and FWD Flemming

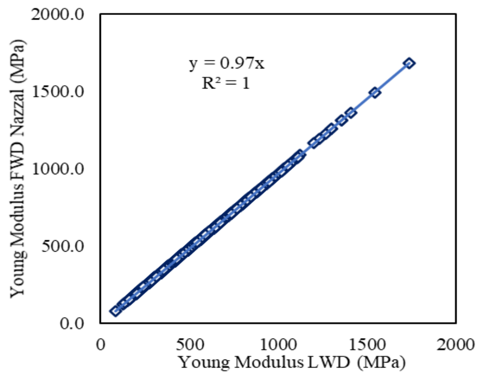


Fig.13 Young's Modulus correlation between LWD and FWD Nazzal

The next discussion is the correlation among the three methods that have been used to convert Young's modulus values from LWD to FWD. Figure 14 is a correlation between the value of the Young's modulus FWD Siegfried method and the Flemming method, where the result is a linear correlation. EFWD Flemming method obtained is 97.45% of the value of the Young's modulus FWD Siegfried method. Meanwhile, Figure 15 shows the EFWD correlation between the Siegfried method and Nazzal, where the value of the Young's modulus of the Nazzal method is only 91.6% of that of Siegfried method.

Overall, it can be concluded that converting the value of Young's modulus from ELWD to FWD results in a linear correlation between the two. In addition, the correlation between each method used also produces a linear and straightforward. So, all of these methods can be used to produce the value of the Young's modulus FWD through the LWD test results. Thus, this LWD test will be more useful because the results can be converted to the Young's modulus of the FWD to carry out an FWD assessment that requires fairly large equipment and is more difficult to carry out for field inspection.

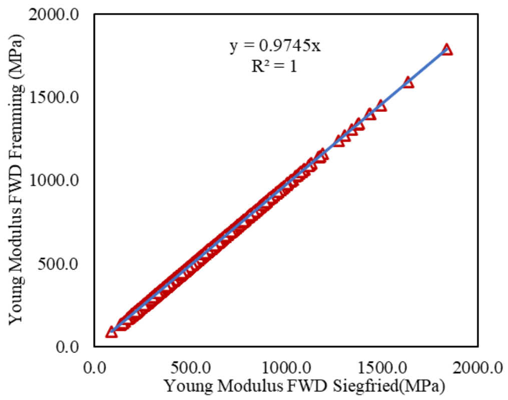


Fig.14 FWD Young's Modulus Relationship between Siegfried and Flemming equation

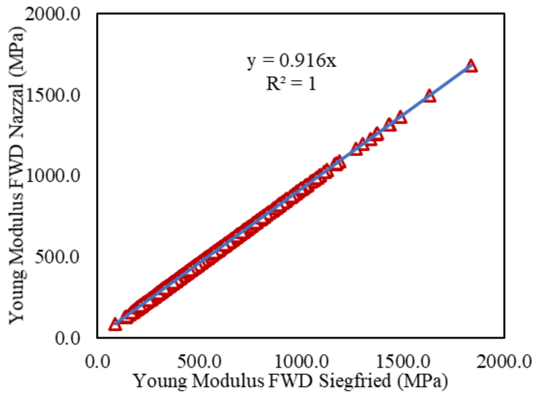


Fig.15 FWD Young's Modulus Relationship between Siegfried and Nazzal equation

4. CONCLUSION

Through the results and discussion above, it can be concluded that the deflection value is depend on the measurement positions. D0 location always produce a higher deflection than that of D1 and D2. Young's modulus test results on ELWD at D0 location are higher than locations of D1 and D2. It is with young modulus results obtaining an average of 471.4 MPa.

The results of the conversion show that the Siegfried and Flemming methods always produce EFWD values higher than that of ELWD, while the Nazzal method produces EFWD values smaller than ELWD. All conversion results obtained have a linear correlation between the ELWD and the Young's modulus from FWD.

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