Evaluating LFWD Testing for Characterizing Subgrade Layers Using Regression Analysis and Artificial Neural Network Model

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Abstract

The Light Falling Weight Deflectometer (LFWD) was developed to estimate the in-situ elastic modulus directly to the layers near the base as subgrade and subbase layers. The field tests were carried out on selected sections from landfill project within Anbar Province. Furthermore, Forty test sections have been constructed and tested at the Civil Engineering Department- University of Anbar. All sections were tested using the ZFG 3000 model - LFWD in companion with the Plate Load Test (PLT) which were used as reference measures. Regression analyzes were performed to determine the best correlation between the elastic modulus obtained from LFWD and PLT tests. ANN model was used to calculate E_{vd} and compare the regression statistical model. It was found that the ANN model showed a higher performance than regression analysis in predicting E_{vd}. Satisfactory correlations were obtained, which showed that LFWD could be a promising device for in-situ characterizing of subsurface and subgrade layers.

KEYWORDS: LFWD; PLT; dynamic modulus of deformation; static modulus; ANN

تقييم فحص LFWD لخصائص طبقات التربة باستخدام التحليل الاحصائي الانحداري ونموذج الشبكة العصبية الاصطناعية

د. احمد حازم عبدالكريم

الخلاصة

LFWD هو جهاز تم تطويره لايجاد معامل المرونة الحقلي مباشرتا للطبقات القريبة من سطح الارض كطبقات الاساس وتحت الاساس. اجريت الفحوص الحقلية مقاطع مختارة من مشروع مكب نفايات يقع في محافظة الانبار. تم اجراء الفحوصات الحقلية على 40 مقطع تم اختياره موقعيا من قبل المختبر الحلقي التابع لقسم الهندسة المدنية في جامعة الانبار. جميع المقاطع تم فحصها باستخدام جهاز (ZFG300). LFWD استخدم مع فحص تحمل الصفيحة (PLT) كمرجع للفحوصات الحقلية. اجري التحليل الاحصائي للانحدار لحساب افضل علاقة بين معاملات المرونة التي يمكن الحصول عليها من فحص LFWD و PLT. استخدم نموذج الشبكة العصبية لحساب Evd ومقارنة ادائه مع نموذج الحليل الاحصائي الانحداري. حيث اظهرت النتائج بأن نموذج الشبكة العصبية اداءه افضل من نموذج التحليل الاحصائي الانحداري في التنبؤ بقيمة Evd . العلاقات الاحصائية التي انجزت كانت مرضية والتي اظهرت بأن فحص LWFD يمكن ان يكون فحصا موقعيا يستخدم لايجاد الخصائص لطبقات الاساس وتحت الاساس بسهولة وسرعة ودقة.

الكلمات الافتتاحية : وزن السقوط الحر الانحرافي، معامل التشوه الدايناميكي، المعامل الاستاتيكي ، الشبكة العصبية الاصطناعية

1. Introduction

The different project in Iraq is used the Light Falling Weight Deflectometer (LFWD). In this study, The German device (ZFG 3000) from Zorn was used. The dynamic load bearing capacity of subgrade and subbase layers can be measured by this device.

It is limited to the use of these devices at the present time in places of secondary importance, which is difficult carry out the static plate load test [1].

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The possibility of using these dynamic devices on subgrade and embankment layers for landfill project, The study initially converted the measured dynamic modulus into static modulus.

The main purpose was to determine the accuracy of the use of LFWD device to find in-situ stiffness modulus of constructed road layers and embankment.

This was done using device LFWD along with standard in-situ test device PLT by conducting field tests on constructed layers. The other objective was to perform a regression analysis of all field test results that have been collected to obtain the best correlations between the PLT and LFWD modulus.

Otherwise a new quality assessment based on dynamic modulus might be able to substitute the exclusive usage of the slow and complicated static plate load test in the near future. With the help of these results, new dynamic design methods can be worked out and applied.

2. Light Falling Weight Deflectometer (LFWD)

LFWD may have contracted low weight deflectometer was formed this need to Germany as an optional in-site testing device to the load plate test. There are common types in the markets of LFWD. Generally, the LFWD c Consists of a loading device, a loading plate, and geophone sensor located in the center of the device used to measure the center surface deflection[2].

The ZFG 3000 LFWD starting with Zorn Instruments might have been utilized within this study. Fig.1 is a compaction control device, according to ASTM E2835-11 and ASTM E2583-07 (2011). Dynamic modulus of deformation E_{vd} is accurate and independent ways to find stiffness of compaction layers [3].

A 10 kg falling weight is dropped onto a 300 mm diameter plate from a height of 72 cm through guide rod; the vertical displacement of the plate (δ_c) is recorded by an accelerometer built in a steel case on the top of the plate. The drop weight, drop height and plate diameter are constants. The plate coefficient (c) and the Poisson's ratio (μ) are also set constant, therefore the dynamic subgrade modulus (E_{vd}) is calculated by a simplified Boussinesq equation [1]:

$$E_{vd} = 22.5/\delta_c \quad (1)$$

To estimate dynamic elastic modulus, E_{vd} for each test in this study, test 8 locations (nearly 45 degrees apart) surrounding the location of the static plate test were selected and dynamic plate load test were performed each test was repeated three times in each time 3 preconsolidation tests were conducted as shown in Fig. 1.

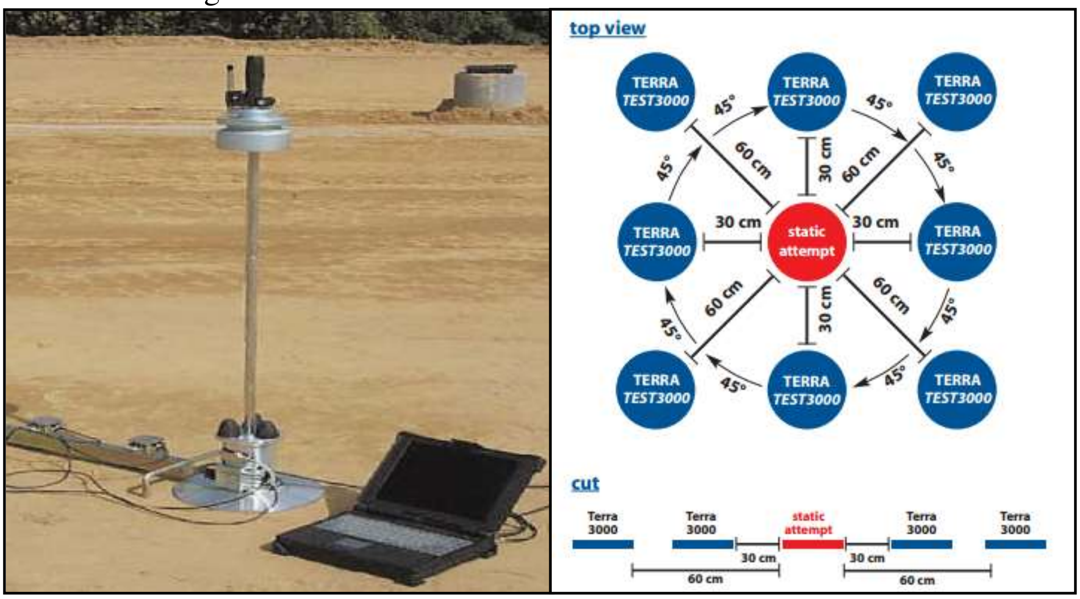

Fig. 1. Light Falling Weight Deflectometer (LFWD)and location of tests [3,6].

3. STATIC PLATE LOAD TEST (PLT)

PLT is a device that is widely used in soil investigations and it is highly efficient in finding the bearing capacity of soil layers as subgrade and subsoil layers .

The test was conducted by the procedure recommended by ASTM D1196-93 as shown in Fig.2. The test consists of a circular plate (450mm diameter according to the requirements of the employer) which is in contact with the layer to be measure the deflections under load increments. The load increments were applied via a hydraulic jack with a suitable load capacity. The load was applied in increments up to a final value of externally applied stress of 700kPa. The corresponding settlement was monitored and recorded by using three suitable dial gauges (120 degrees apart), for each increment until the settlement had ceased.

To evaluate the modulus of subgrade reaction (k), Plate loading tests were used. This test is performed by subjecting the subgrade soil to stress at a predetermined speed rate. The following equation calculates modulus of subgrade reaction, k [4]:

$$k = Q/\delta \tag{2}$$

Where, Q is the loading plate (kN) and δ is the plate deflection (mm)

The value of Young's modulus was obtained from the well-known relationship that correlates the young's modulus to the modulus of subgrade reaction[5]:

$$E_s = k\,B\,(1-\mu^2) \tag{3}$$

Where B in this case represents the diameter of the testing plate and μ is the Poisson's ratio and its value can be 0.5 for the assumption of flexible base plate.

Fig. 2. Static Plate Load Test (PLT).

4. EXISTING RELATIONSHIPS

The Institute for Transport Sciences (KTI) launched a research program in 1995 aiming to convert the dynamic modulus obtained by that device (E_{vd}) into the well-known static plate load test modulus (E_2) obtained by conventional measurements [6]. After collecting 64 measurement results performed on different subgrade and subsoil materials, a general conversion formula was suggested as following :

$$E_{vd} = 0.52 \cdot E_2 + 9.1 \tag{4}$$

Several correlation results between E_2 and E_{vd} are available in the international literature. The most relevant results are summarized in Fig. 2.

Fig. 3 shows that the value of the static plate load test modulus clearly exceeds at least two times that of the E_{vd} modulus. Some of the results show even higher ratios. Only two publications give a ratio less than two, but both of them are based on modulus values measured only at few points and within small intervals [1].

Nazzal (2003) studied the relationship between PLT and LFWD on different types of soils. The correlation for modulus (surface modulus for LFWD) is thus developed as follows [7]:

$$E_{PLT} = -20.9 + 0.69(E_{LFWD}) \quad (R^2=0.94) \tag{5}$$

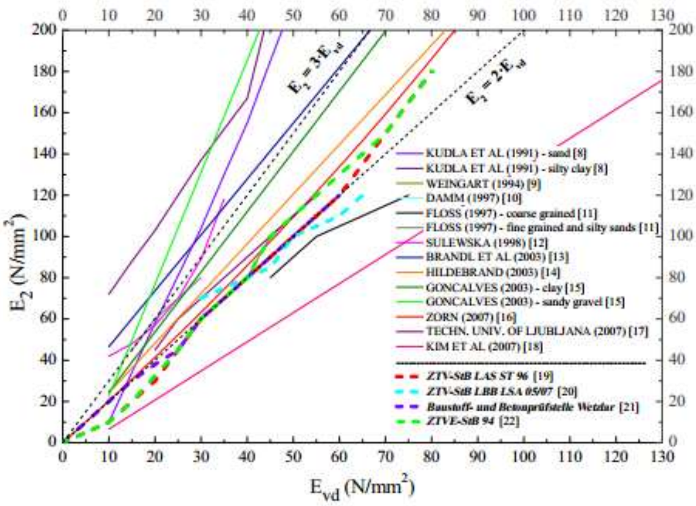

Fig. 3. Correlation results between E2 and Evd found in the international literature[1].

5. ANALYSIS OF RESULTS

5.1 Linear Regression Model

In this study, 40 measurement results were collected for plate load test (PLT) performed on subgrade crushed limestone material by the field laboratory for civil engineering department at University of Anbar. After the division of project area as strips and establish the location of each point by mark. The performance of LFWD test is in Fig.4.

In order to distinguish the difference from E_{vd} used as an independent value and descriptive statistics were calculated using SPSS version 20 (2012) package. Table 1 shows the values of independent statistics.

In this study, simple regression analysis was performed. The relations between the measured E_{vd} moduli values with conventional static E_s moduli values were analyzed.

Determining the parameters in the lower square error models, that used to predict the E_{vd} from E_s modules with the corresponding coefficient, R^2 was the aim of this regression analysis. In the linear regression models, the dependent variable is assumed to be a linear function of one or more independent variables plus an error as follow[8]:

$$Y_i = \beta_o + \beta_1 x_{i1} + \ldots\ldots \beta_k x_{ik} \tag{6}$$

Where

Yi = the dependent variable,

x_{i1}, ..., x_{ik} = the independent variables, and

βo= error term.

The coefficient of selection, R^2, represents the variance ratio of the dependent variable, which is calculated by the regression model.

The elastic modulus obtained from LFWD, E_{vd}, has been linked to the traditional static of PLT. The regression models obtained were as follows:

$$E_{vd} = 7.384 + 0.527\ E_s \tag{7}$$

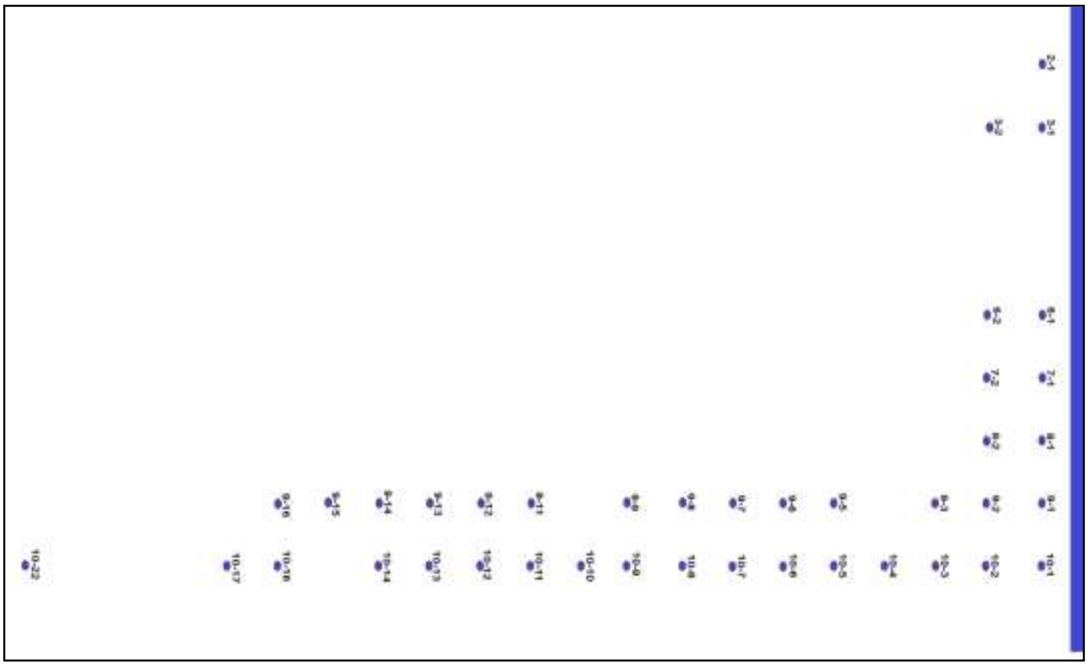

Fig. 4. Profile of the study area.

Table 1. Descriptive statistics for Evd value.

N	40
Range	187.7
Minimum	21.3
Maximum	209
Mean	49.87
Std. error of mean	4.7394
Mode	27.61
Median	46.28
Std. deviation	29.97452
Skewness	3.957
Std. error of skewness	0.374
Kurtosis	20.714
Std. error of kurtosis	0.733
Variance	898.472
Sum	1994.91

With R^2= 0.801, and standard error = 13.56. Fig. 5 illustrates this regression model. Fig. 6 shows the relationship between measured and predicted values of E_{vd} which is a good agreement with R^2=0.81.

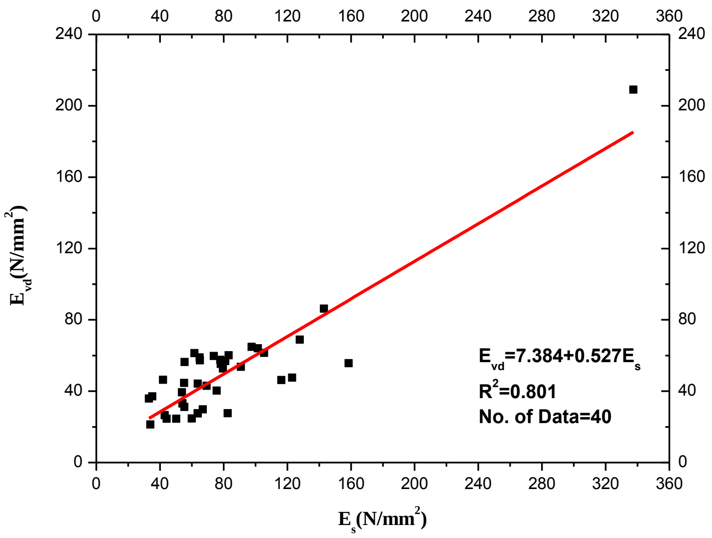

Fig. 5. Relationship between Evd and Es.

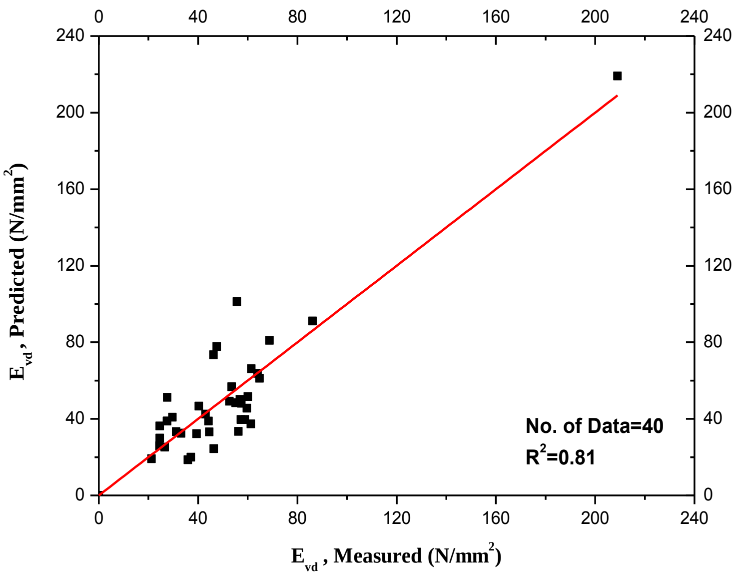

Fig. 6. Relationship of predicted and measured values of Evd.

5.2 Multiple Regression Model

In this study, 13 test results were selected from 40 sites as shown in Fig.4. These sites have been tested by PLT and LFWD and have conducted field density test by sand cone method according to ASTM D1556-00. The modified proctor compaction test according to ASTM D1557-12. Tables 2 is presented the results for this section.

Table 2. The result tests for crushed limestone layer.

Strips	E_{vd} MPa	E_s MPa	MC (field) %	γ_{dry} (field) kN/m^3	$D_{pr,\ Modified}$ %
6-2	37.08	35.21	7.59	16.99	96.56
8-1	59.63	73.93	13.57	17.27	98.12
9-5	21.3	34.01	16.2	16.25	92.36
10-8	44.2	63.84	14.08	16.54	93.96
9-1	68.8	127.90	15.6	16.42	93.30
10-3	24.53	50.30	15.7	16.23	92.20
10-4	46.33	41.91	13.08	16.72	94.99
10-5	26.55	43.05	13.8	16.13	91.64
10-6	52.63	79.56	14.08	16.89	95.95
10-7	47.53	123.00	13.8	16.74	95.12
9-2	64	101.57	16.11	16.22	92.18
9-6	24.6	59.97	15.32	16.23	92.21
9-7	86.2	143.12	16.2	16.92	96.14

Three parameters, namely, static modulus (E_s) , moisture content (MC) and degree of compaction (D_{pr}), a multiple regression analysis was performed to find E_{vd} value as in Table 3. The predict E_{vd} is given:

$$E_{vd} = 0.375(E_s) + 0.754(MC\%) + 3.75(D_{pr}\%) - 345.76 \quad (8)$$

The indicator is good for the predictive performance of the model for the correlation coefficient value (R^2 = 0.804). Figure 7 shows the relationships of predicted and measured E_{vd} values obtained from the multiple regression model.

5.3 Target Values for Dynamic Models

Direct conversion between dynamic, static models and degree of compaction is not frequently used in practice. Generally target values are given for different embankment and subgrade layers, more often depending on the required degree of compaction of the tested layer. E_{vd} modulus target values are fixed in Germany, and some other countries[1].

Based on the results above, a table of target values can be introduced. Different E_s and degree of compaction values are given for required E_{vd} values in Table 4. Interpolation between given values is acceptable.

Table 3. Model summaries of multiple regressions for prediction of Evd.

Independent variables	Coefficient	Std. error	t-Value	Sig. level
Constant	-345.76	193.484	-1.787	0.108
E_s, MPa	0.375	0.1	3.733	0.005
MC, %	0.754	1.855	0.406	0.694
D_{pr}, %	3.75	1.902	1.971	0.08

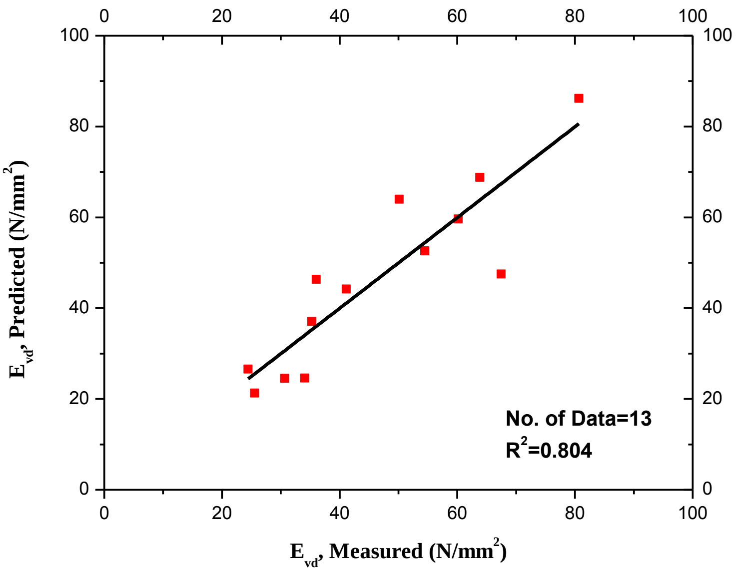

Fig. 7. Predicted and measured Evd values relationship by Multiple regression model.

Table 4. Target values for crushed limestone subgrade layers.

E_s MPa	E_{vd} MPa	D_{pr} % Modified	E_s/E_{vd} ratio
	Crushed Limestone Subgrade layers		
180	100	≥100	2
150	85	≥99	2
120	70	≥98	2
100	60	≥98	2
80	50	≥97	2
60	35	≥95	2
45	30	≥95	2
20	15	≥94	1.5

5.4 Artificial Neural Network(ANN) Modelling of Overview

At those materials are natural, there is dependably a questionable matter sourced starting with those nature of the materials. This might a chance to be those fundamental motivation behind the reason delicate registering methodologies for example, such that artificial neural networks, Fuzzy systems, genetic algorithms bring been created in later a long time. These systems draw in an ever increasing amount consideration over a few look into fields on they endure an extensive variety for vulnerability [9].

Typical multi-layer feed-forward neural networks is shown in Fig. 8. This kind of neural network comprises of an input layer, one or more hidden layer(s) and an output layer. Layers need aid completely joined toward arrows, also contain a number about transforming units, those supposed nodes or neurons. The quality about associations between neurons is spoken to toward numerical values known as weights. Every neuron need an actuation worth that is a capacity of the aggregate of inputs gained starting with other neurons through those weighted associations [10]. The problem specific is the optimum number of hidden layers and the number of neurons in each hidden layer. Therefore, experimentation ought to make conveyed out to pick a sufficient amount from hidden layers and the number of neurons in each hidden layer.

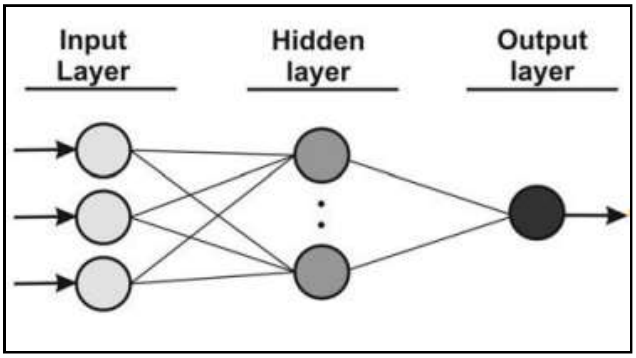

Fig. 8. Structure of Multi-layered feed-forward network[11].

The input may be propagated starting with those input layer through those hidden layers of the output layer in this method. The network input may be associated with each neuron in the first hidden layer while each network output is associated with every neuron in the last hidden layer. In this case, this might call full association ANN. During the network training phase, the network weights are initially determined according to the irregular and new values. The neurons output is determined using[12]:

$$O_i = F(\sum_j I_j \times W_{ij} + b_i) \quad (10)$$

Where

O_i = The neuron output i, I_j are the input of j neurons of the previous layer,

Wij = The neuron weights, b_i is the bias for the modeling, and

F = The activation function.

The activation function will be the part of the neural system where all the computing is performed. The activation function maps the input domain (infinite) will an output domain (finite). The extend on which The greater part activation functions map their yield may be possibly in the the interval [0, 1] or the the interval [-1, 1].

The network error may be back propagated from the output layer of the input layer to which the connection weights are balanced. This process is repeated until the error may be minimized with an inclination level. The error incurred during the learning can be expressed as Mean Squared Error and is calculate using[12]:

$$MSE = \frac{1}{nm}\sum_{i=1}^{n}\sum_{j=1}^{m}(t_{ij} - y_{ij})^2 \quad (11)$$

Where : t = the target value, and

y = the output value.

5.5. ANN Model for Prediction of E_{vd}

The use of ANN provides an alternative way to estimate dynamic modulus of deformation, E_{vd}. In this work a multi-layered feed-forward neural network with a back-propagation algorithm was adopted. MATLAB 7.1(2005)[13] software was used in neural network analyses having a three-layer feed-forward network[14]. Forty cases of actual measured were extracted from experimental tests used in this study. The databases is randomly divided into three sets such as; training (70% of all data), test (15% of all data), and verification (15% of all data). The model has one input parameter and one output parameter. The model has two hidden layers with nine nodes each (MATLAB software uses for determining the optimal number of hidden nodes rather than assuming a fixed number of hidden nodes in advance) , and output layer with one node giving dynamic modulus of deformation, E_{vd}. The learning parameter of analyses network, momentum parameters and networks training function, which is an activation (transfer) function for all layers, have typical values of 0.01, 0.9, trainLm (training Levenberg-Marquardt function) and tansig (transfer function) respectively. The use of models and parameters in order to reach the minimum Mean Square Error (MSE) values and as in many other networking training methods

coefficient for determination between the measured and predicted values may be a significant indicator of the actual implementation weight of the expectations of the model. The relationship between the measured and predicted values obtained from the models for E_{vd} is shown in Fig. 9.

In this study, difference represent VAF (Eq. 12) and root mean square error (RMSE) (Eq. 13 utilized by Alvarez and Babuska (1999) [14]:

$$VAF = \left[1 - \frac{var(y - y')}{var(y)}\right] \times 100 \qquad (12)$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(y - y')^2} \qquad (13)$$

Where

y = The measured values, and , y' = The predicted values.

The obtained values of VAF and RMSE presented in Table 5 which shown a high prediction performance.

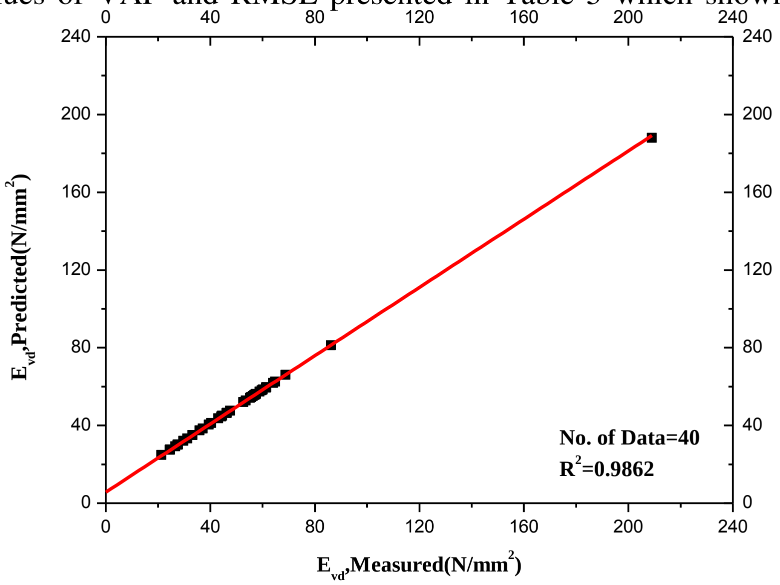

Fig. 8. Relationship of predicted and measured values of E_{vd} for ANN Model.

Table 5. RMSE, VAF and R2 values used to predict E_{vd} .

Model	Predictive Model	RMSE	VAF%	(R^2)
LRM	E_{vd} = 7.384 + 0.527 E_s	9.25	75.09	0.81
ANN		2.57	98.31	0.98

6.UMMARY AND CONCLUSIONS

The LFWD demonstrated will be An genuinely light weight FWD and may be Exceedingly transportable. It is altogether not difficult will work and progressions starting with the 10kg of the 20kg drop weights or loading plates (200mm Furthermore 300mm) would quick and easy should do. The essential data given by LFWD noticeably demonstrated with a chance to be very useful for construction quality control and assurance purposes.

The objective of this study will be to assess the possibility utilization of non-destructive testing device with measure the stiffness/strength parameters about roadway materials and embankment soils during and after construction for landfill project. The field testing project included leading tests utilizing the investigated devices, in addition to standard tests, which included the static Plate load test (PLT), field density test by the sand cone method, and modified proctor compaction test.

The effects of the statistical analysis show that a great relationship between the device under evaluation LFWD and the standard tests PLT, and degree compaction depending on standard tests. The relations obtained from analysis of statistical, were linear regression to model and multiple regression for another. The sum regression models required a adjusted, R^2 greater than 0.8.

A multi-layered feed-forward neural network with a back-propagation algorithm was used to demonstrate the feasibility of ANNs to predict the dynamic modulus of deformation, E_{vd}. Forty cases of actual field measurements were used for model development and verification. The predicted E_{vd} obtained by utilising ANNs were compared with the measured E_{vd}. The results indicate that ANN model have the capability of predicting E_{vd} with a high degree of accuracy. From *VAF*, *RMSE* indicators and correlation coefficient (R^2) results, it can be seen that the ANN model is more accurately than regression analysis to predict E_{vd} as in Table 5.

LFWD is reliably used to predict the modules obtained from PLT and the degree of compaction values, thus it can be used to evaluate the parameters stiffness / strength of the subsoil layers as a results of this study.

Targeted values for a new dynamic devices can open the opportunity for quality control and evaluation of the strengths of the tested layers and thus less reliance on the plate load test, which takes time, effort and accuracy

The widespread use of mentioned dynamic devices referred to above, may facilitate for contractors, laboratories and engineers in the highway and railway construction industry to perform quick and continuous quality control of embankments, subgrade and subsoil layers and backfills.

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