Taylor & Francis
Taylor & Francis Group

JOURNAL OF CIVIL ENGINEERING AND MANAGEMENT
ISSN 1392-3730 print/ISSN 1822-3605 online
2012 Volume 18(1): 5–13
doi.org/10.3846/13923730.2011.619328

CONSTRUCTION QUALITY CONTROL OF UNBOUND LAYERS BASED ON STIFFNESS MODULUS CRITERIA

Kamran Rafiei[1], **Amir Kavussi**[2], **Shahaboddin Yasrobi**[3]
Department of Civil Engineering, Tarbiat Modares University, Jalal Ale Ahmad Highway,
P.O. Box: 14115-111, Tehran, Iran
E-mail: [1]kamran_rafiee@yahoo.com (corresponding author)

Received 27 Nov. 2009; accepted 28 Nov. 2010

Abstract. NDT methods such as Portable Falling Weight Deflectometer (PFWD) provide measurements based on the engineering properties of materials (stiffness) instead of physical properties like field density and moisture content. However, PFWD testing method is not yet proven to be reliable enough for construction quality control. In this research, a laboratory testing unit box was prepared in which unbound materials were compacted at different compaction levels. The stiffness modulus of the compacted layers were then determined under PFWD Testing. The tests were repeated several days after construction when the materials moisture content was decreased to lower values. The results indicated that acceptable correlations exist between the stiffness modulus and both compaction percentage and moisture percentage. In addition, field testing was carried out on different unbound layers in several highway construction sites in Tehran and laboratory results were used in order to control in-situ conditions. With Comparing field and laboratory testing results, it was concluded that PFWD is an appropriate testing device for quality control and compaction monitoring of pavement layers during construction phases.

Keywords: PFWD, stiffness modulus, compaction, construction quality control.

1. Introduction

Current criteria of embankment compaction specifications utilize moisture content and maximum dry density measurements to ensure that in-situ materials have obtained required compaction. While a proper density may result in pavements to resist against settlement and deformation, however, this does not mean that proper bearing capacity has also been achieved. The measurement of unbound layers stiffness in terms of resilient modulus, allows a soil layer to be characterized by engineering properties. If the embankments and pavement unbound layers have sufficient stiffness, the strains induced in the pavement structure during service loading can be minimized. During recent years, research works have been performed to develop dynamic stiffness measuring devices such as Portable Falling Weight Deflectometer (PFWD) that can quickly measure the in-situ stiffness of unbound pavement layers (Peterson *et al.* 2006).

PFWD test method is a type of plate-bearing test. The load is a force pulse generated by a falling weight (mass) dropped on a buffer system that transmits the load pulse through a plate resting on the material to be tested (Fig. 1). The resulting deflections are measured at the center of the applied load. However deflections can also be measured at various distances from the loading point. The deflections measured can be used to determine the stiffness of unbound pavement surfaces upon performing back or forward calculation analysis techniques. Eq. (1) was used to forward calculation the pavement stiffness modulus (Egorov 1965):

$$E_0 = \frac{2(1-\upsilon^2)P}{\pi.a.D_0}, \tag{1}$$

where E_0 is composite modulus values (MPa), P is applied force at load plate (N), D_0 is deflection at the centre of loading point (mm), a is radius of loading plate (mm) and υ is Poisson's ratio.

Successful use of the PFWD for the compaction quality control was reported by George (2006) for in-situ embankment layers. In this study, a nonlinear regression model was developed between PFWD modulus with density ratio and field moisture. Laboratory testing results conducted by Nazzal (2003) showed that the influence depth of the PFWD ranged between 270 to 280 mm, depending on the stiffness of the tested materials. These results support the suggestion of using PFWD for QC/QA procedure during construction of pavement layers, since these layers are constructed usually in lifts with thickness ranging between 150 mm to 300 mm. However the results from some other researches indicated a rather poor correlation between PFWD modulus and percent compaction for pavement layers (James *et al.* 2007; Steinert *et al.* 2006).

The main objective of this study was to explore the feasibility of using a PFWD to control the compaction of unbound pavement layers. To achieve this objective, an

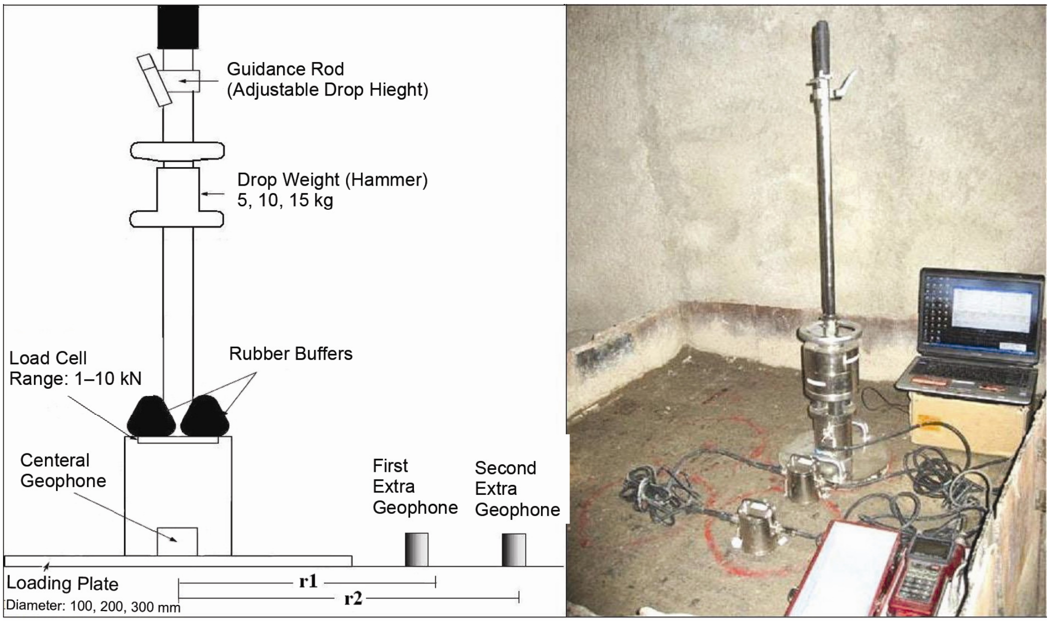

Fig. 1. A Schematic of a Portable Falling Weight Deflectometer (PFWD)

experimental program was performed in the laboratory that included testing different compacted layers which were composed of unbound materials. In addition, data from field projects were utilized to validate the laboratory methodology.

2. Experimental work

2.1. Test box

A large test box was built in the laboratory. This was rigid enough enabling to compact adequately unbound pavement layers. Previous research indicated that the minimum distance between the side of the PFWD loading plate and the wall of the box to be 150 mm (Seyman 2003; Nazzal 2003). But they have not presented theoretical reasons. This research utilized FLAC modeling of PFWD dynamic loading on a granular material. FLAC is a finite difference software and the solution scheme is explicit (FLAC 2000). The first step in solving a problem is to divide the problem zone into a suitable grid or mesh. Mesh generation in this study is shown in Fig. 2. The input parameters for FLAC analysis were drop weight (15 kg), drop height (500 mm), rubber buffer or damper diameter (100 mm), loading plate diameter (300 mm) and materials characteristics (sandy gravel with a depth of 650 mm). The solutions are reached through a process known as time-marching or time stepping, which is simply adjusting the values of each node in the mesh through a series of cycles or steps. These adjustments take place on the basis of the selected constitutive model and equation of motion. The adjustment continues until the error (e.g., unbalanced force in the system) becomes minimal.

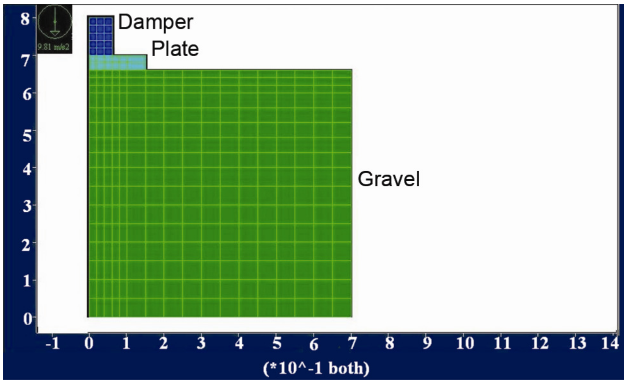

Fig. 2. Mesh generation for FLAC analysis

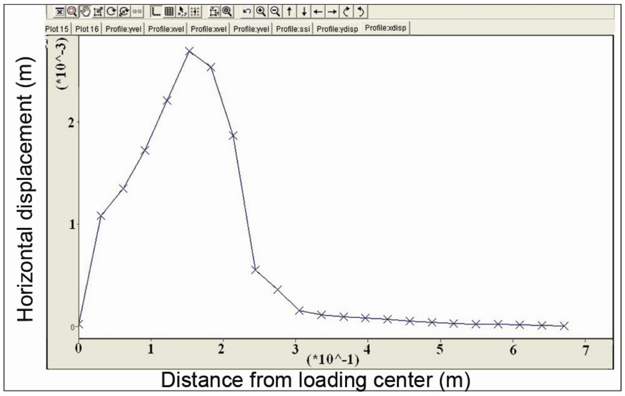

Fig. 3. Horizontal displacements of dynamic loading versus the distances from loading plate center (FLAC output)

Horizontal and vertical Displacements of dynamic loading versus distances from central loading point are plotted in Figs 3 and 4. These figures indicate that displacements beyond 550 mm distance from the loading plate center considerably decrease. Therefore, with respect to loading plate radius of 150 mm, the minimum distance between the side of the loading plate and the wall of the box will be 400 mm.

Based on FLAC results, the steel box sizes were determined 1400 mm × 1400 mm × 700 mm. The layout of PFWD and sand cone tests in the box is shown in Fig. 5.

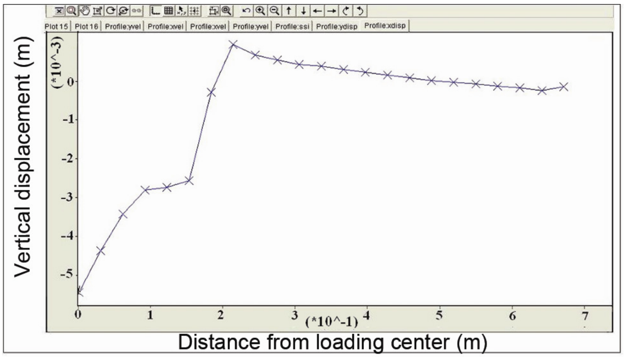

Fig. 4. Vertical displacements of dynamic loading versus the distances from loading plate center (FLAC output)

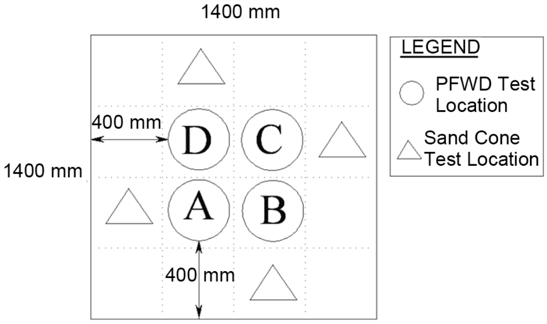

Fig. 5. Layout of the PFWD and sand cone tests in laboratory box

2.2. Materials

PFWD Laboratory tests were performed on a typical base material (i.e. type E base according to Iran highway specifications code). This material was composed of 67% gravel, 25% sand, and 8% silt. Grain size distribution curve of the material and its specification limits are shown in Fig. 6.

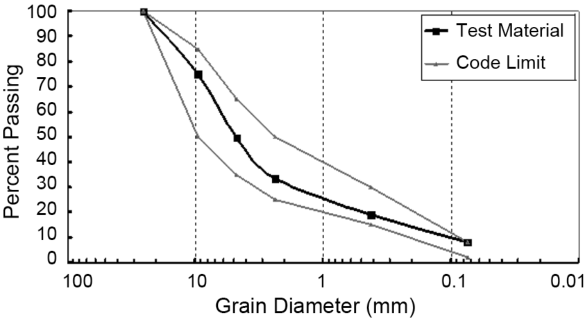

Fig. 6. Grain size distribution curve of the material and its code limits

Then aggregate were subjected to Modified Proctor test (AASTHO T 180) in order to determine optimum moisture and maximum density. Based on Proctor curve, a maximum dry density of 2.15 Mg/m^3 at an optimum water content of approximately 7.5% was determined.

2.3. Test layers preparation

A hand electric jackhammer with a modified flat plate attachment (350 × 350 mm) conducted the compaction of all layers inside the box. The layers were first compacted in four 150 mm thick lifts at optimum water content level. The time of compaction was 90 seconds at each testing point. Then layers were removed and four 130 mm thick lifts again were compacted at optimum water content. The compaction time was 100 seconds at each testing point. Finally, fourth layer was replaced twice. Once it was compacted in 55 seconds and again it was compacted in 40 seconds.

2.4. Testing program

PFWD testing was performed at four locations on all layers immediately after construction (as shown in Fig. 5). The tests were repeated several days after construction when the materials moisture content was decreased to lower values. PFWD modulus depends on loading drop weight and plate diameter (Kavussi *et al.* 2010; Lin *et al.* 2006). In this study, PFWD testing was performed with 15 kg falling weight, 300 mm loading plate diameter and six drops at each location. The first three drops were ignored as seating drops and the next three were then averaged and reported as stiffness modulus (Fleming *et al.* 2007; Thompson, White 2007; Kim *et al.* 2007). The sand cone method (AASHTO T 191) was used to measure density and moisture contents together with PFWD testing at locations as shown in Fig. 5. In addition, density and moisture content were measured in PFWD test locations in fourth layer. The average dry density, moisture content, and stiffness modulus of each layer in different times (days) are summarized in Table 1.

3. Field testing

Field testing was carried out on different unbound base and sub-base layers in five highway construction sites (twenty five testing location) in Tehran. The stiffness module of the compacted layers was determined under PFWD testing. In addition, the dry unit weight and moisture content were determined at each location. Table 2 reports the summary of the field testing results.

4. Laboratory testing results

4.1. The influence of moisture content on stiffness modulus

The stiffness modulus of the unbound layers was determined at several moisture contents below of optimum moisture content (w_{opt}) after compaction. Variations of the modulus and moisture content with time are shown in Fig. 7 for a typical location on different layers.

With reference to the results of the regression analysis (Fig. 7), there is a strong linear relationship between stiffness modulus and moisture content with time at each point. Also, the stiffness modulus of the materials tended to increase as the moisture content decreased due to evaporation.

However, regression coefficients tend to vary depending on testing location, rate of evaporation and the degree of saturation. Therefore, it was not possible to

Table 1. Summary of laboratory measurements

	First Test Inside the Box					Second Test Inside the Box				
Layer	Location	Dry Density (Mg/m^3)	Moisture Content (%)	Stiffness Modulus (Mpa)	Time (Day)	Location	Dry Density (Mg/m^3)	Moisture Content (%)	Stiffness Modulus (Mpa)	Time (Day)
1	Average A,B,C,D	2.15	8	13	1	Average A,B,C,D	2.11	7.6	12	1
			7.5	15	2			3.1	73	5
			4.9	26	4			–	–	–
			3.3	28	6			–	–	–
2	Average A,B,C,D	2.11	7.8	34	1	Average A,B,C,D	1.95	6.3	50	1
			6.1	52	3			2	91	3
			4.5	82	4			–	–	–
			3.8	102	5			–	–	–
3	Average A,B,C,D	2.11	7.4	65	1	Average A,B,C,D	2	6.1	73	1
			4.9	91	2			5.4	89	2
			4.8	114	3			4.7	98	3
			–	–	–			3.1	129	4
4	A	2.17	7.7	78	1	A	2.16	7.6	74	1
			6.3	102	3			5.4	81	2
			6.2	108	5			4.5	85	3
			6.1	122	6			4.1	118	6
	B	2.16	7.7	78	1	B	2.17	7.6	100	1
			6.3	73	3			5.4	101	2
			6.2	89	5			4.5	104	3
			6	108	6			4.1	125	6
	C	2.15	7.7	79	1	C	2.17	7.6	100	1
			6.3	93	3			5.4	102	2
			6.2	100	5			4.5	121	3
			5.8	106	6			4.1	152	6
	D	2.13	7.7	73	1	D	2.16	7.6	118	1
			6.3	90	3			5.4	125	2
			6.2	116	5			4.5	152	3
			5.8	129	6			4.1	123	6
4 (First Replacement)	A	2.05	7.3	67	1					
			6.2	81	2					
			5.9	99	3					
			4.8	106	5					
	B	1.97	7.3	69	1					
			6.2	72	2					
			5.9	88	3					
			5.2	105	5					
	C	2.07	7.3	72	1					
			6.2	76	2					
			5.9	84	3					
			5	99	5					
4 (Second Replacement)	A	2.02	7	64	1					
			6.6	72	2					
			5.8	93	3					
			5.2	96	4					
	C	2.03	7	68	1					
			6.6	81	2					
			5.8	94	3					
	D	2.01	7	71	1					
			6.6	82	2					
			5.8	101	3					
			5.0	107	4					

Table 2. Summary of field testing results

Point	Project	Layer type	Average PFWD Modulus (MPa)	Field Moisture Percent	Optimum Moisture Percent	Percent Compaction
1	Kahrizak	Clay subgarde	57	5.4	10.5	84
2		Clay subgarde	34	6.1	10.5	89
3		Clay subgarde	28	5.7	11.7	90
4	Kalij	subbase	105	3.0	8.5	93
5		subbase	101	4.0	7.0	97
6	Azadegan	base	124	3.0	5.5	100
7		subbase	96	3.5	6.5	99
8	Amam Ali	subbase	108	2.6	7.5	99
9		subbase	105	3.3	7.5	100
10	Yadegar	subbase	117	4.1	8.5	98
11		subbase	152	3.9	8.5	99
12		subbase	182	4.2	8.5	99
13		subbase	196	4.1	8.5	99
14		subbase	89	3.8	8.5	94
15		subbase	82	4.0	8.5	94
16		subbase	92	4.0	8.5	94
17		subbase	214	3.9	9.0	100
18		subbase	168	4.2	9.0	100
19		subbase	174	4.1	9.0	100
20		subbase	161	4.1	9.0	100
21		base	122	5.2	7.0	99
22		base	94	5.0	7.0	99
23		base	106	5.3	7.0	99
24		base	131	5.3	7.0	99
25		base	87	5.1	7.0	95

determine a single moisture-modulus curve for a typical material. It should be noted that at least 9 points are required to fit a regression line to the required confidence level. However, in this research due to laboratory limitations and timing, few moisture contents were measured.

4.2. The influence of compaction level on stiffness modulus

First, the stiffness modules and percent compaction values of a certain layer (fourth layer with two replacements) were considered to ignore the effect of underlying layers stiffness in the analysis. However, moisture content was an important parameter in developing a correlation model. Hence, a multiple linear regression analysis was conducted in order to develop a model that can predict PFWD modulus from the percent compaction and moisture content. A linear regression model is given in Eq. (2) based on thirty seven tests:

$$E_{\mathrm{PFWD}} = -74.7 + 2.81\mathrm{Comp} - 16.9w, \qquad (2)$$

$$R^2 = 0.73;\ F = 47.64;\ N = 37,$$

where E_{PFWD} is PFWD stiffness modulus (MPa); Comp is percent compaction (%) and w is moisture content (%). R^2 value of 0.74 and the calculated value of F = 47.64 being larger than the tabulated F (95, 1, 34) = 4.13 indicate that there is a reasonable correlation between stiffness modulus and both percent compaction and moisture content. In addition, the calculated t of coefficient of percent compaction (t = 6.02) and moisture content (t = 8.62) are more than the tabulated t (95, 34) = 2.73, indicating significance of these coefficients.

A sensitivity study showed that a 10% change of density ratio brings about 28% changes in EPFWD. On the other hand, a 10% change of moisture results in only 11% change of E_{PFWD}. Clearly, the compaction has more effect on stiffness modulus than moisture content.

The results from the developed model are consistent with the previous laboratory study conducted by Steinert (2006) who performed several tests on five unbound materials inside a box. He developed Eq. (3) to investigate the combined role of percent compaction and water content on PFWD modulus:

$$E_{\mathrm{PFWD}} = -77.99 + 1.81\mathrm{Comp} - 7.3(\mathrm{RWC}), \qquad (3)$$

$$R^2 = 0.33;\ N = 145,$$

where EPFWD is PFWD stiffness modulus (MPa), Comp is percent compaction (%) and RWC is water content relative to optimum.

However, the previous equation can be written as Eq. (4) (where the R^2 improved):

$$E_{\mathrm{PFWD}} = 39.1 + 1.6\mathrm{Comp} - 10.6w, \qquad (4)$$

$$R^2 = 0.53.$$

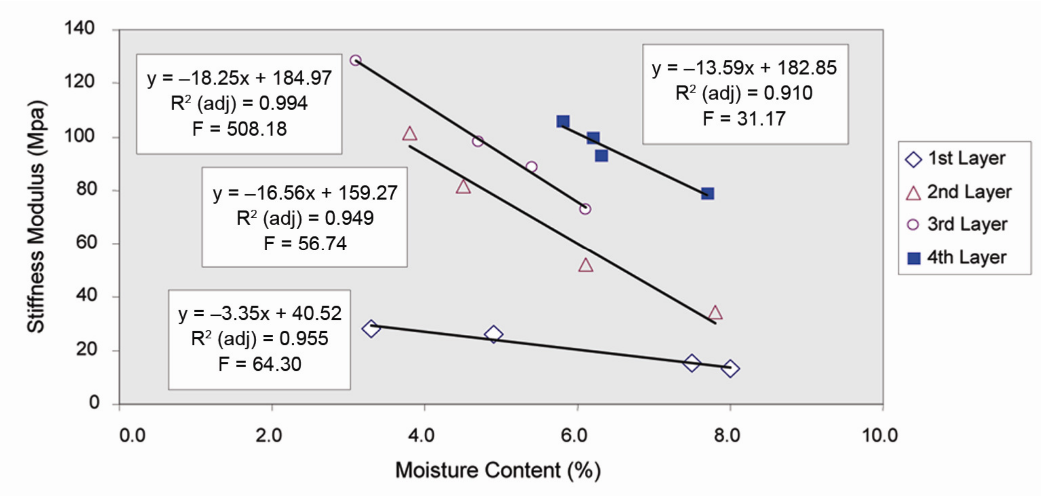

Fig. 7. Variation of stiffness modulus versus moisture content in different layers

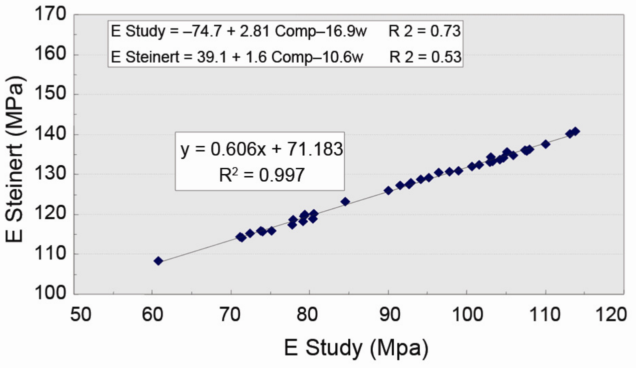

Fig. 8. Comparison between current study model to Steinert (2006)

Fig. 8 presents a comparison between the proposed regression model (Eq. 2) and the one suggested by Steinert (2006) (Eq. 4).

It can be seen that the stiffness modulus predicted by Steinert ($E_{Steinert}$) absolutely correlates with the stiffness modulus predicted in this study (E Study). Thus the proposed model is compatible with Steinert (2006) model. It is worth mentioning, that the model in Eq. (2) was only proposed for a typical material (37 tests). However, five unbound materials were investigated in Steinert study (145 tests). PFWD measurements were taken utilizing a 20 kg drop weight in Steinert study, whereas the tests were performed with 15 kg drop weight in this research, thus resulting in higher moduli in Steinert study.

As noted earlier, stiffness modulus was increased as the moisture content decrease with time. However, dry density (percent compaction) is not dependent to moisture content after compaction. Hence, it is possible to achieve a direct correlation between percent compaction and stiffness modulus upon determining stiffness modulus at certain moisture content (e.g. optimum moisture). In this study, the moisture-modulus curves were determined for all the testing points and stiffness moduli were predicated at optimum moisture content. The following linear regression model was obtained between percent compaction (Comp) and predicted PFWD modulus at optimum moisture (E_{opt}):

$$E_{opt} = 2.61\text{Comp} - 182.38 \quad \text{for Comp} > 89\%, \qquad (5)$$

$$R^2 = 0.86;\ F = 47.23.$$

The high coefficient of determination (0.86) indicates that there is a good correlation between percent compaction and stiffness modulus for the tested conditions.

4.3. The influence of underlying layers

As mentioned above, all layers were compacted on the box with defined compaction energy. Hence, it was expected that density of upper layer would become progressively greater (for any level of compaction energy) as the thickness of underlying layers is increased. However, this was not found through in all cases. Fig. 9 shows the relationship between dry density of the upper layer and the thickness of underlying layers. This shows that the density data dose not follow a well-defined pattern with increasing underlying layers. The minimum dry density was resulted when the thickness of underlying layers was about 150 to 250 mm. Also, where no underlying layer was placed (i.e. the first layer), the density achieved in the upper layer was equal to that achieved on 400 mm underlying layer.

The relationship between PFWD stiffness modulus of the upper layer and the thickness of underlying layers is shown in Fig. 10. This indicates that there is a consistent pattern of improvement in stiffness with both underlying layers and compaction energy increasing. This is in contrast with the density changes. Hence, it can be resulted that there is no correlation between the density achieved and stiffness of the upper layer. This finding is consistent with a full-scale field research results in UK for capping layers (Rogers *et al.* 2000). However, the stiffness modulus and dry density of the upper layers can be correlated together when the thickness of underlying layers is greater than 300 mm.

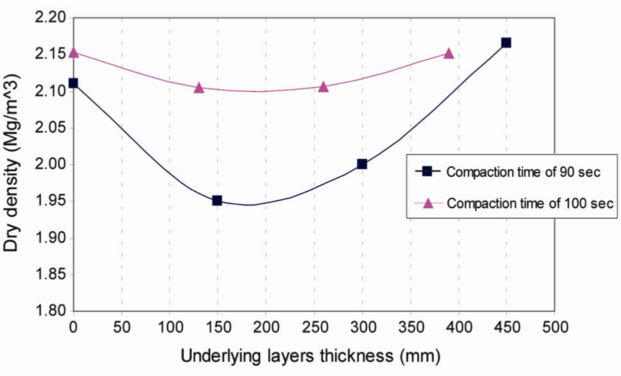

Fig. 9. Relationship between dry density of the upper layer and the thickness of underlying layers

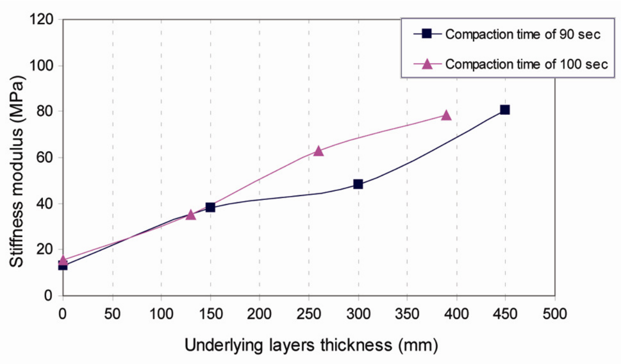

Fig. 10. Relationship between PFWD stiffness modulus of the upper layer and the thickness of underlying layers

5. Field results

The PFWD modules are compared with compaction achieved and moisture contents in the above mentioned projects. The field results indicated that the stiffness modulus is influenced by degree of compaction. However, the stiffness modulus was independent of moisture content because of the small range of the moisture contents in field conditions.

The following exponential regression model was obtained between percent compaction (Comp) and PFWD modulus (E_{PFWD}):

$$E_{PFWD} = 0.0005e^{0.1262*Comp}, \quad (6)$$

$$R^2 = 0.72; F = 53.35.$$

R^2 of 0.72 indicates that there is a reasonable correlation between stiffness modulus and percent compaction for different unbound pavement layers.

6. Applicability of laboratory results in the field conditions

If stiffness modulus is considered as quality acceptance criterion for unbound layers construction, it is necessary to select critical modulus for defining of pass/fail regions. The relationship between PFWD stiffness modulus with percent compaction and moisture content for laboratory conditions was provided in Eq. (2). If critical percent compaction is defined, the target stiffness modulus can be calculated at different moisture contents, based on Eq. (2). For example, if a percent compaction of 95% is assumed as construction quality control criterion, the target stiffness modulus (E_{Target}) will be calculated based on the moisture content (w) by following equation:

$$E_{Target} = 192.25 - 16.9w. \quad (7)$$

Eq. (7) can be used for field conditions. The values of the measured and target modulus and percent compaction in field conditions are shown in Fig. 11. This figure indicates that the quality control procedure in according to the percent compaction criterion is different from the stiffness modulus criterion in 32% of locations.

This error is considerable due to the inherent differences between laboratory and field conditions. Due to the differences above, the target modules calculated for the field locations should be corrected. As shown in Fig. 12, the best corrective coefficient in this work was determined to be 0.76.

Fig. 13 shows the quality control procedure based on stiffness modulus criterion and performing corrective coefficient. As shown in this figure, the error decreased to 8% (two locations). It should be noted that the presented model in this research has been determined from testing on single material, but the model was used on different materials in field projects. Hence the above error can be considered acceptable and PFWD stiffness modulus can be reliably used for construction quality control of unbound pavement layers.

7. Conclusions

This paper presents the results of laboratory and field tests conducted to assess PFWD stiffness modulus as a construction quality control criterion of unbound layers. Based on the results of this study, the following conclusions can be made:

- Based on FLAC software results, it was found that the 400 mm can be considered as the minimum distance required between PFWD loading plate and the side walls of the test box.
- PFWD stiffness modulus of the unbound materials tended to increase linearly as the moisture content decreased due to evaporation.
- Acceptable correlation was achieved between PFWD stiffness modulus and both compaction percentage and moisture content of the tested unbound material ($R^2 = 0.73$).
- A sensitivity analysis showed that compaction level had more effect on PFWD modulus than moisture content.

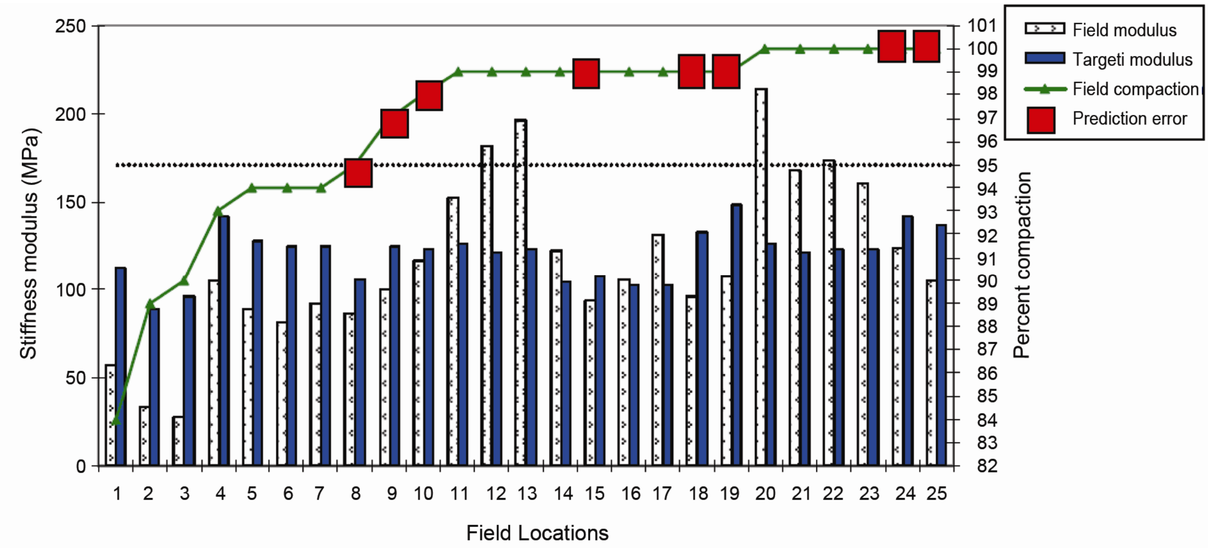

Fig. 11. Applicability of laboratory model in filed locations

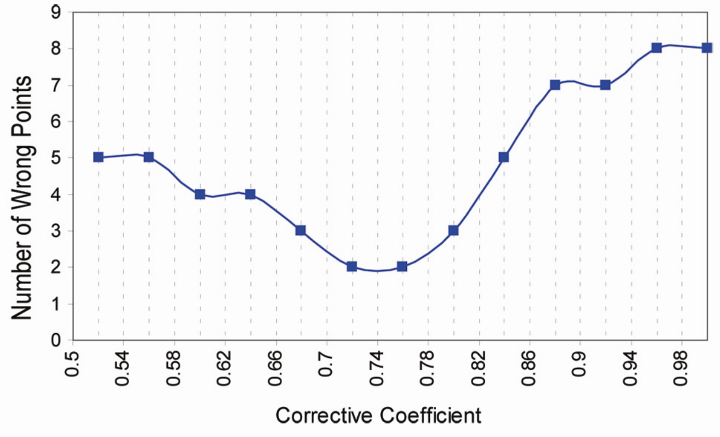

Fig. 12. The influence of different corrective coefficients on number of wrong points

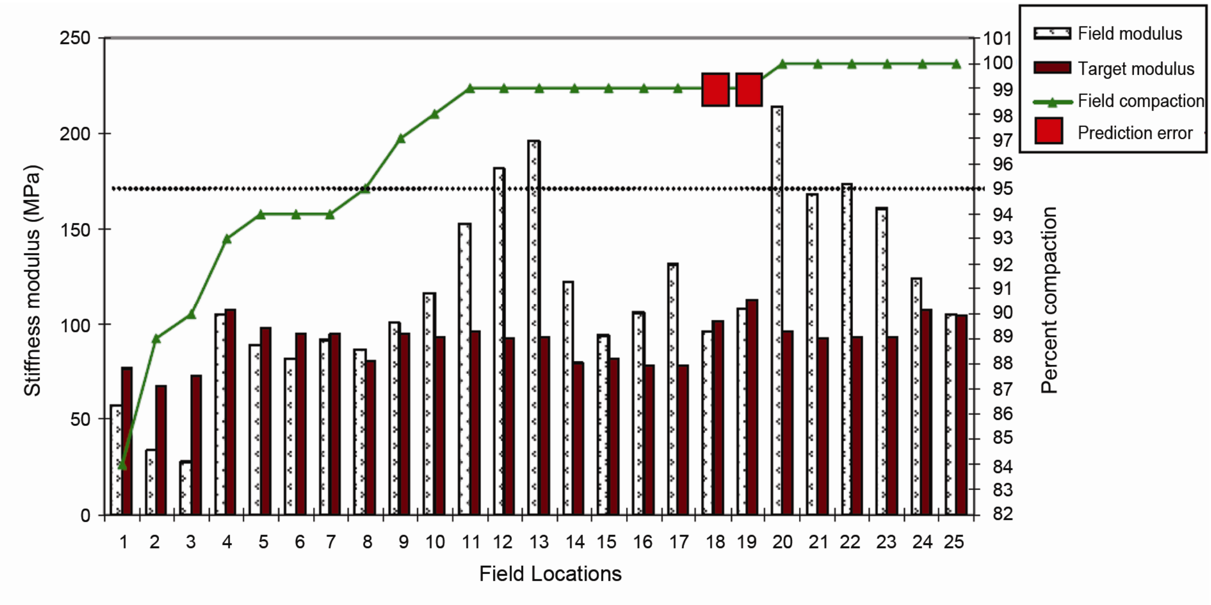

Fig. 13. Relationship between PFWD modulus and FWD modulus

- There was a consistent pattern of improvement in stiffness of upper layer with underlying layers increasing. But, the density of upper layer did not follow a well-defined pattern and the minimum dry density was resulted when the thickness of underlying layers was about 150 to 250 mm.
- PFWD stiffness modulus can be reliably used for construction quality control purposes of unbound pavement layers.

References

Egorov, K. E. 1965. Calculation of Bed for Foundation with Ring Footing, in *Proc. of the 6th International Conference of Soil Mechanics and Foundation Engineering*, Montreal, 8–15 September, 1965 2: 41–45.

FLAC. 2000. *Fast Lagrangian Analysis of Continua, User's Manuals, Version 4.0.* ITASCA Consulting Group Inc. Minneapolis., Minnesota, USA. 3 p.

Fleming, P. R.; Frost, M. W.; Lambert, J. 2007. A review of the Light Weight Deflectometer (LWD) for routine insitu assessment of pavement material stiffness, *Transportation Research Board Meeting*. [CD–ROM]. National Research Council, Washington DC, USA.

George, K. P. 2006. *Portable FWD (PRIMA 100) for in-situ subgrade evaluation. Final Report*. Mississippi Department of Transportation, FHWA/MS-DOT-RD-06-179, USA. 114 p.

James, S.; Stefan, A.; Mbaki, O.; Mustaque, H. 2007. Evaluation of Prima Light Falling-Weight Deflectometer as quality control tool for compaction of fine grained soils, *Transportation Research Board Meeting*. [CD–ROM]. National Research Council, Washington DC, USA.

Kavussi, A.; Rafiei, K.; Yasrobi, S. 2010. Evaluation of PFWD as potential quality control tool of pavement layers, *Journal of Civil Engineering and Management* 16(1): 123–129. doi:10.3846/jcem.2010.11

Kim, J. R.; Kang, H. B.; Kim, D.; Park, D. S.; Kim, W. J. 2007. Evaluation of In Situ Modulus of Compacted Subgrades Using Portable Falling Weight Deflectometer and Plate-Bearing Load Test, *Journal of Materials in Civil Engineering* ASCE 19(6): 492–499. doi:10.1061/(ASCE)0899-1561(2007)19:6(492)

Lin, D.-F.; Liau, C.-C.; Lin, J.-D. 2006. Factors affecting portable falling weight deflectometer measurements, *Journal of Geotechnical and Geoenvironmental Engineering* ASCE 132(6): 804–808. doi:10.1061/(ASCE)1090-0241(2006)132:6(804)

Nazzal, M. 2003. *Field evaluation of In-situ test technology for QC/QA during construction of pavement layers and embankments*. PhD Thesis, Louisiana State University, Louisiana, USA. 114 p.

Peterson, D. L.; Siekmeier, J.; Nelson, C. R.; Peterson, R. L. 2006. Intelligent soil compaction–technology: results and a roadmap toward widespread use, *Transportation Research Board meeting*. [CD–ROM]. National Research Council, Washington DC, USA.

Rogers, C.; Fleming P. R, Frost, M. 2000. Stiffness behaviour of trial road foundations, in *Proc. of the fifth International Symposium on Unbound Aggregates in Roads, UNBAR 5*, Nottingham, United Kingdom, 231–238.

Seyman, E. 2003. *Laboratory evaluation of in-situ tests as potential quality control/ quality assurance tools*. MSc Thesis, Louisiana State University, USA. 178 p.

Steinert, B. C.; Humphrey, D. N.; Kestler, M. A. 2006. Portable falling weight deflectometers for tracking seasonal stiffness variations in asphalt surfaced roads, *Transportation Research Board Meeting*. [CD–ROM]. National Research Council, Washington DC, USA.

Thompson, M. J.; White, D. J. 2007. Field Calibration and Spatial Analysis of Compaction Monitoring Technology Measurements, *Transportation Research Board meeting*. [CD–ROM]. National Research Council, Washington DC, USA.

NESUJUNGTŲ SLUOKSNIŲ KONSTRUKCIJŲ KOKYBĖS KONTROLĖ, ĮVERTINANT STANDUMO MODULIO KRITERIJŲ

K. Rafiei, A. Kavussi, S. Yasrobi

Santrauka

NDT metodai, kaip krintančio svorio deflektometrai (PFWD), leidžia matuoti technologines ir fizikines medžiagų savybes (standumą, tankį ir įmirkį). Tačiau PFWD bandymų metodas ir dabar dar nėra patvirtintas kaip patikimas konstrukcijų kokybei kontroliuoti. Šiame darbe atlikti laboratoriniai ir natūriniai bandymai, kuriuose buvo tirtos skirtingais lygiais sutankintų tarpusavyje nesujungtų sluoksnių konstrukcijos. Tiriamų medžiagų sluoksnių standumo moduliai buvo nustatyti PFWD metodu. Bandymas buvo pakartotas išlaikius konstrukciją keletą dienų, kai drėgmės kiekis medžiagose sumažėjo. Rezultatai parodė, kad yra reikšminė koreliacija tarp standumo modulio ir abiejų sluoksnių sutankinimo lygio bei drėgmės kiekio. Vėliau Teherano vietovėse buvo atlikti natūriniai konstrukcijų su skirtingais nesujungtais sluoksniais bandymai. Išanalizavus natūrinių ir laboratorinių bandymų tyrimų rezultatus, buvo nustatyta, kad PFWD yra tinkamas bandymo metodas konstrukcijų kokybei kontroliuoti ir tinkamam dangos sluoksnių tankinimui parinkti.

Reikšminiai žodžiai: PFWD, standumo modulis, tankinimas, konstrukcijų kokybės kontrolė.

Kamran RAFIEI. PhD graduted of the Department of Civil Engineering, Tarbiat Modares University. He is member of Pavement Maintenance Research Center (PMRC) in Iran. His research is focused on NDT methods for pavement evaluating and pavement management.

Amir KAVUSSI. Associate professor in the Department of Civil Engineering, Tarbiat Modares University, Tehran, Iran. He is also presently the head of Pavement Engineering Association of Iran. His research interests include properties of bituminous mixes, evaluation of warm mix asphalt, recycling of bituminous mixes, pavement evaluation, maintenance and rehabilitation.

Shahaboddin YASROBI. Associate professor of Geotechnical Engineering in Tarbiat Modares University. He is member of International Society for Soil Mechanics and Geotechnical Engineering. His research is focused on Advanced Site investigation and laboratory tests.