International Journal of GEOMATE, Feb., 2023, Vol.24, Issue 102, pp.58-66
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2023.102.g12260
Geotechnique, Construction Materials and Environment

A COMPARISON BETWEEN PAVEMENT RESPONSES FROM THE FALLING WEIGHT DEFLECTOMETER AND THOSE FROM TRUCK LOADING BASED ON THE LAYERED ELASTIC ANALYSIS

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*Corresponding Author, Received: 21 June 2022, Revised: 07 Sep. 2022, Accepted: 26 Jan. 2023

ABSTRACT: Pavement responses e.g., surface deflections, tensile strains, and compressive strains etc. were determined from the multi-layered elastic analysis (LEA). The LEA has been widely accepted in most mechanistic design and performance analysis of the road pavements, where their structures were assumed to be homogenous, isotropic, linear-elastic, and finite thickness with modulus of elasticity and Poisson's ratio. The falling weight deflectometer (FWD) is a traditional tool for the structural condition evaluation of road pavements. In Thailand, a typical FWD loading stress of 700-800 kPa was practically adopted by the Department of Highways, while a tandem axle-dual wheel having a 690 kPa (100 psi) tire pressure and a 100 kN (10 metric tons) single axle load generated by the standard 10-wheel Thai truck (e.g., legal load permit of 25-ton gross weight) was considered in the pavement design and analysis. The objective of this paper is therefore to compare the pavement responses from the FWD and the standard Thai truck loads based on the LEA. Comparison results indicated that the average error was about 10% for 800-kPa FWD-standard Thai truck deflections, while 21% for 700-kPa FWD-standard Thai truck deflections. In case of tensile strain at the bottom of thin asphalt surface, the average error was respectively 2% and 14% for 800-kPa FWD-standard Thai truck and 700-kPa FWD-standard Thai truck. However, for thick asphalt surface, the average error was respectively 38% and 21% for 800-kPa FWD-standard Thai truck and 700-kPa FWD-standard Thai truck. In case of the compressive strain above the subgrade, the average error ranged from 7 to 11% for 800-kPa FWD-standard Thai truck and 8 to 12% for 700-kPa FWD-standard Thai truck.

Keywords: Pavement response, Layered elastic analysis, Falling weight deflectometer, Truck loading

1. INTRODUCTION

In recent years, road pavement design has evolved from a purely empirical approach to mechanistic-empirical methods, which require comprehensive knowledge of material behavior and their responses e.g., stress, strain, and deflection, under traffic loads [1]. The newly evolved mechanistic-empirical design method involved the physical relationship between causes (wheel loads, material properties) and effects (stress, strains, deflections) and developed mathematical models to relate these effects to failure modes [2]. The main structural response models used in pavement analysis and design are the finite element and layered elastic analysis (LEA).

KENLAYER computer program was originally developed by Professor Yang H. Huang at the University of Kentucky [3]. KENLAYER relied on the mathematical models to predict road pavement structural responses using the layered elastic theory. This theory is based on Burmister's [4] equations for the solutions of stresses, strains, and deflections in layered systems under traffic loads. Certain general assumptions and generalizations were incorporated into the layered elastic theory, including material isotropy and homogeneity. The KENLAYER considered the flexible pavements as elastic multi-layered system under circular loads and directly applied the superposition principle to multiple wheels in a linear system. The pavement analysis and design can be performed in a timely manner with high accuracy [5].

In Thailand, the Department of Highways (DOH) adopted both empirical and mechanistic (analytical) methods for the pavement analysis and design. A 10-wheel 25-ton truck was typically considered as the standard traffic load application in the design procedure. Recently, the deflection-based design approach has been comprehensively reviewed by the DOH for the possible adoption of local design standard and practice. One of the main reasons was that Thailand road authorities e.g., DOH and the Department of Rural Roads (DRR), consider the falling weight deflectometer (FWD) for the new construction and rehabilitation of road pavement. In addition, such the FWD has been globally accepted as the non-destructive test for deflection measurement and structural capacity evaluation [6]. Ultimately, the implication of FWD deflections for localized pavement analysis and design shall be developed and proposed to Thailand road authorities. Due to the aforementioned reasons, it was important that such a load magnitude of FWD shall be determined and verified with the 25-ton 10-wheel standard Thai truck. Therefore, this study presents the comparison of pavement responses from the FWD and those from the standard Thai truck based on the LEA.

2. RESEARCH SIGNIFICANCE

This study was a part of the deflection-based approach for flexible pavement design concept. The road pavement engineering practitioners can adopt this new conceptual approach in their analysis and design for new construction and rehabilitation of the flexible pavement. This design concept would be practically beneficial for pavement engineering communities and those in the road transportation authorities and agencies.

3. LAYERED ELASTIC ANALYSIS

A flexible pavement has been considered an ideal elastic body due to its relatively ease of calculation of stresses, strains, and deflections. The elastic theory has been used extensively in the computation of stresses, strains, and deflections. This involved the stresses in a homogeneous, isotropic linearly elastic solid of semi-infinite extent when subjected to a load applied normally to the surface. The assumptions of homogeneity and isotropy specify that the elastic properties in any part of a material were identical in all directions, regardless of location within the material. In this context, elasticity referred to a relationship between stress and strain that had no relationship with time, loading path, or other factors. The linearly elastic solid was the most convenient to handle, and superposition can be employed [7].

Elastic solutions were developed from Boussinesq's [8] one-layer system to Burmister's two [9] and three-layer system [4] to multi-layered elastic theories [3], to finite element techniques for the pavement performance prediction based on material properties and traffic conditions. To accurately approximate the responses of flexible pavement, the elastic solution was extended to multiple layer systems. As a consequence, multi-layered elastic analysis (LEA) has been widely accepted in most mechanistic design and performance analysis of the road pavements due to its simplicity in pavement response calculation.

4. PAVEMENT RESPONSES

Pavement responses are results of the combined effects of loading, environment condition, subgrade, and pavement material characteristics. This study only focuses on the flexible pavement where their layer materials are linearly elastic under load application. With respect to flexible pavements, the current failure criteria are the tensile strain at the bottom of the asphalt surface and the compressive strain at the top of the subgrade [10]. Tensile strain at the bottom of asphalt surface is used to predict and control fatigue cracking of the asphalt surface [3]. The compressive strain at the top of the subgrade is used to predict and control the permanent deformation of the pavement structure due to shear deformation in the upper subgrade [3]. Surface deflection is an indicator of the strength and stiffness of the entire pavement structure, which can be also related to the pavement design life [11]. Figure 1 illustrates the positions of pavement responses for surface deflection, horizontal tensile strain at the bottom of asphalt surface and vertical compressive strain at the top of the subgrade.

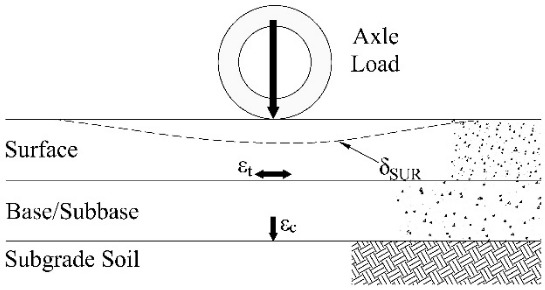

Fig.1 Positions of pavement responses

Sawangsuriya et al. [12] utilized three-dimensional (3-D) finite-element analysis (FEA) model and LEA to examine the structural responses of flexible pavement under different types of axle group loads, e.g., single axle-dual wheel, tandem axle-dual wheel, and tridem axle-dual wheel and compared with the field measurement data. The results indicated that both FEA and LEA were in good agreement with the field measurement results with some exceptions for strains under the asphalt surface. The structural responses in terms of vertical stresses, vertical strains, and horizontal strains from LEA were identical with the FEA results. Thus, both FEA and LEA approaches could be applied for estimating the pavement structural responses.

Srikanth [13] conducted linear and nonlinear analysis for pavement layers using a finite element software tool named Michigan Flexible Pavement Design software (MFPDS) and KENLAYER computer program to evaluate the pavement response. Results obtained from both programs appeared to be equivalent for linear analysis, but there was a significant difference in tensile strain when the surface thickness was less than 75 mm. In case of nonlinear analysis, the results did not correspond well.

Based on the past studies, the LEA was suitable for analyzing pavement responses because it gave equivalent pavement responses to FEA, but less analysis time.

5. METHODOLOGY

5.1 Material Properties and Layer Thicknesses

Flexible pavement structure in this study were comprised of different layer materials, e.g., asphalt surface, crushed rock base, soil-aggregate subbase, selected material, above natural subgrade. According to AASHTO [14], a minimum thickness of the asphalt surface and aggregate base shall be 25.4 mm (1 inch) and 100 mm (4 inches), respectively. Thus, the minimum thicknesses of asphalt surface and aggregate base were considered to be 50 mm (2 inches) and 100 mm (4 inches), respectively.

A total of 625 pavement sections was selected in this study. Five asphalt surface thicknesses included 50, 100, 150, 200, and 250 mm. Five crushed rock base thicknesses included 100, 150, 200, 250, and 300 mm. Five soil-aggregate subbase thicknesses included 100, 200, 300, 400, and 500 mm. Four selected material thicknesses included 100, 200, 300, and 400 mm as it did not existed in some sections.

Elastic modulus is the stiffness of the materials that are related to the structural performance of the pavement layer and is one of the key parameters for pavement design and analysis. Poisson's ratio is typically obtained from the laboratory test and is defined as the ratio of radial to longitudinal strains. Table 1 summarized the elastic moduli and Poisson's ratio for pavement layer materials according to the DOH's pavement design practice [6].

Table 1 Pavement Material Properties

Pavement Materials	Elastic Modulus (MPa)	Poisson's Ratio
Asphalt Surface	2,500	0.35
Crushed Rock Base	350	0.35
Soil-aggregate Subbase	150	0.35
Selected Material	100	0.35
Subgrade	40	0.40

5.2 Load Applications

The study considered two load applications, FWD and standard Thai truck. The FWD was selected as the main load application. According to the FWD testing protocol by the DOH, a loading pressure ranging from 700 to 800 kPa was typically adopted along with a plate radius of 0.15 m. The standard 10-wheel 25-ton Thai truck was selected to represent the design traffic loads for reference and to compare with the FWD in this study. This standard Thai truck was adopted for Thailand pavement design and analysis. Having a tandem axle-dual wheel configuration, this standard Thai truck had a tire pressure of 690 kPa (100 psi) and a single axle load of 100 kN (10 metric tons). A tire contact radius of 0.11 m was determined by dividing a wheel load of 2.5 tons (approximately 25 kN) by a tire pressure of 690 kPa. Table 2 summarized the pressure and radius of contact for the FWD and the standard Thai truck.

Table 2 Pressure and Radius of Contact for the FWD and the Standard Thai Truck

Description	Pressure (kPa)	Radius of Contact (m)
FWD	700, 800	0.15
Truck	690	0.11

5.3 Allowable Number of Load Repetitions

Strains obtained from the KENLAYER computer program were used in the calculation of the allowable number of load repetitions to limit permanent deformation and fatigue failure. In this study, damage analysis was carried out for both fatigue cracking and permanent deformation by using Asphalt Institute equations. Equation (1) was the relationship between fatigue failure and tensile strain at the bottom of asphalt surface expressed by the number of load repetitions [3]. Equation (2) was the relationship between rutting (permanent deformation) failure and compressive strain above the subgrade expressed by the number of load repetitions [3]. The pavement section that gave the maximum value of N_f and N_d was considered to be the most suitable pavement section with respect to the pavement responses.

$$N_{f,fatigue} = 0.0796\ (\mathcal{E}_t)^{-3.291}(E)^{-0.854} \tag{1}$$

$$N_{f,rutting} = 1.365\ x\ 10^{-9}\ (\mathcal{E}_c)^{-4.477} \tag{2}$$

$N_{f,fatigue}$ = allowable number of load repetitions to limit fatigue cracking
$N_{f,rutting}$ = allowable number of load repetitions to limit rutting
E = elastic modulus of asphalt layer (psi)

ε_t = tensile strain at the bottom of asphalt surface (microstrain)
ε_c = compressive strain above the subgrade (microstrain)

5.3.1 Allowable number of load repetitions based on normalized deflections

This study adopted a normalized deflection ($d_o/d_{o,\ DOH}$) in order to overcome the actual FWD measurement constraints (e.g., load magnitude, drop height, load configuration etc.). Such normalized deflection was determined by dividing the maximum surface deflection (d_o) by the maximum surface deflection determined from typical DOH pavement section ($d_{o,\ DOH}$). According to Thailand DOH, a typical pavement section consisted of 100 mm asphalt surface, 200 mm crushed rock base, 200 mm soil-aggregate subbase, and 200 mm selected material. The normalized deflections and the allowable number of load repetitions to fatigue cracking and permanent deformation were plotted in order to determine the most conservative allowable number of load repetitions based on the most desirable load magnitude of FWD with the standard Thai truck.

6. KENLAYER ANALYSIS

LEA by KENLAYER computer program was used to determine the pavement responses under FWD and standard Thai truck load applications. A layered elastic model required a minimum number of inputs to adequately characterize a pavement structure and its response to loading. The essential input parameters were the material properties for each layer (e.g., elastic modulus and Poisson's ratio), layer thicknesses, load configurations, numbers of load groups, x, y, and z coordinates for loads and responses.

6.1 Stress Response Point Positions

Pavement responses under the FWD load application was determined right at the center of loading plate, while the pavement responses under the standard Thai truck were determined at four positions, e.g., under the wheel load, between the dual-wheel load, between the tandem-axle load, and between the dual-wheel and tandem-axle load etc. The standard Thai truck had a center-to-center spacing of 1,300 mm between the axles and 330 mm between the wheels. Figure 2 illustrates the location of four pavement responses as well as axle and wheel configurations of standard Thai truck. The outputs from KENLAYER computer program were surface deflection, tensile strain at the bottom of the asphalt surface, and compressive strain at the top of the subgrade.

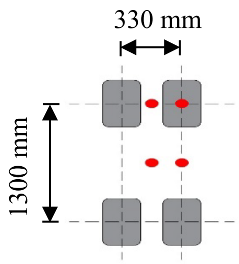

Fig.2 Positions of pavement responses and axle/wheel load configurations of standard Thai truck

6.2 Vertical Distances of Each Response Points

In this study, three vertical distances were analyzed to compute the pavement responses in KENLAYER computer program. Vertical distances were started from the surface layer and went down to the subgrade layer. To compute the surface deflection, vertical distance 0.001 was used. To compute the horizontal tensile strains at the bottom of the asphalt surface, the response point was located exactly at the interface between asphalt layer and crushed rock base layer. To compute the vertical compressive strain above the subgrade, a slightly larger vertical distance, say 0.001 larger, was used. Vertical distances of each response point for both FWD and Truck are shown in Fig. 3 and 4 respectively.

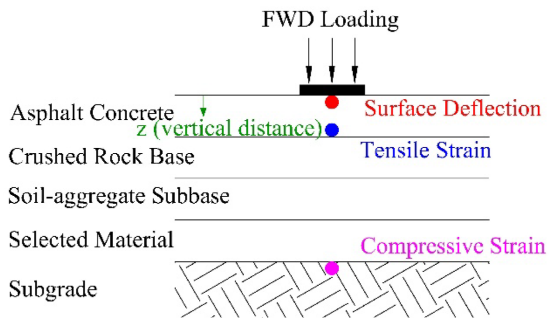

Fig.3 Vertical distances of three response points (FWD)

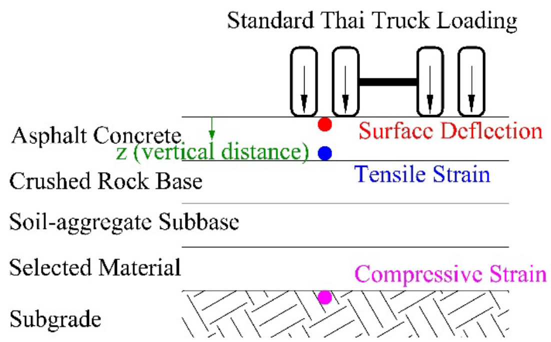

Fig.4 Vertical distances of three response points (Standard Thai Truck)

7. RESULTS AND DISCUSSION

Pavement responses e.g., surface deflections, tensile strains, and compressive strains of flexible pavement under 700-kPa FWD, 800-kPa FWD, and 690-kPa standard Thai truck loads were presented herein. Only responses under the applied loading pressure were reported for the FWD, while the maximum responses were reported for the standard Thai truck. Additionally, the allowable number of load repetitions to fatigue cracking and permanent deformation based on normalized FWD deflections were plotted herein.

6.1 Comparison between FWD and Standard Thai Truck

6.1.1 Deflections

Comparison between the FWD and the standard Thai truck deflections is shown in Fig. 5. Based on the comparison, 800-kPa FWD-standard Thai truck deflections yielded smaller error than 700-kPa FWD-standard Thai truck deflections. An average error of 10% was obtained for 800-kPa FWD-standard Thai truck deflections, whereas an average error of 21% was obtained for 700-kPa FWD-standard Thai truck deflections. As a consequence, 800-kPa FWD deflection was closer to 690-kPa standard Thai truck deflection than 700-kPa FWD deflection.

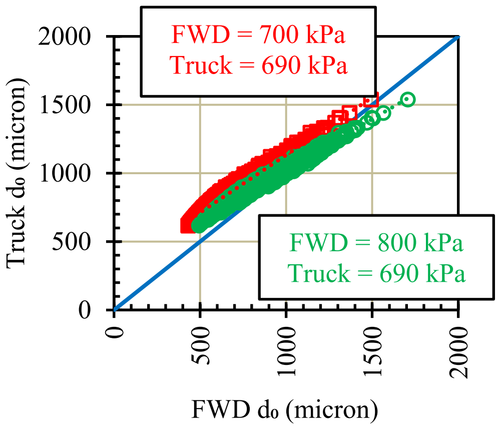

Fig.5 Comparison between FWD and standard Thai truck deflections

Additionally, a paired samples t-test [15] was used to compare the means of two deflection samples between the FWD and the standard Thai truck at significance level 0.05 as each observation in one deflection sample can be paired with an observation in other deflection sample. The null hypothesis was the two-deflection means were equal. The result showed that there were significant differences between 700-800-kPa FWD deflections and 690-kPa standard Thai truck deflection. A 800-kPa deflection mean (811 microns) was significantly closer to 690-kPa deflection mean (888 microns) than 700-kPa deflection mean (709 microns). Therefore, it was significant that 800-kPa FWD deflection was closer to 690-kPa standard Thai truck deflection than 700-kPa FWD deflection.

6.1.2 Tensile Strains at the bottom of Asphalt Surface

Comparison between the FWD and the standard Thai truck tensile strain at the bottom of asphalt surface is shown in Fig. 6. In cases of thin asphalt surfaces with thickness less than 100 mm, 800-kPa FWD-standard Thai truck tensile strains yielded smaller error than 700-kPa FWD-standard Thai truck tensile strains. An average error of 2% was obtained for 800-kPa FWD-standard Thai truck tensile strains, whereas an average error of 14% was obtained for 700-kPa FWD-standard Thai truck tensile strains. As a consequence, for thin asphalt surface with thickness less than 100 mm, 800-kPa FWD tensile strain was closer to 690-kPa standard Thai truck tensile strain than 700-kPa FWD tensile strain.

However, in cases of thick asphalt surfaces with thickness greater than or equal to 100 mm, 700-kPa FWD-standard Thai truck tensile strains yielded smaller error than 800-kPa FWD-standard Thai truck tensile strains. An average error of 21% was obtained for 700-kPa FWD-standard Thai truck tensile strains, whereas an average error of 38% was obtained for 800-kPa FWD-standard Thai truck tensile strains. As a consequence, for thick asphalt surfaces with thickness greater than or equal to 100 mm, 700-kPa FWD tensile strain was closer to 690-kPa standard Thai truck tensile strain than 800-kPa FWD tensile strain.

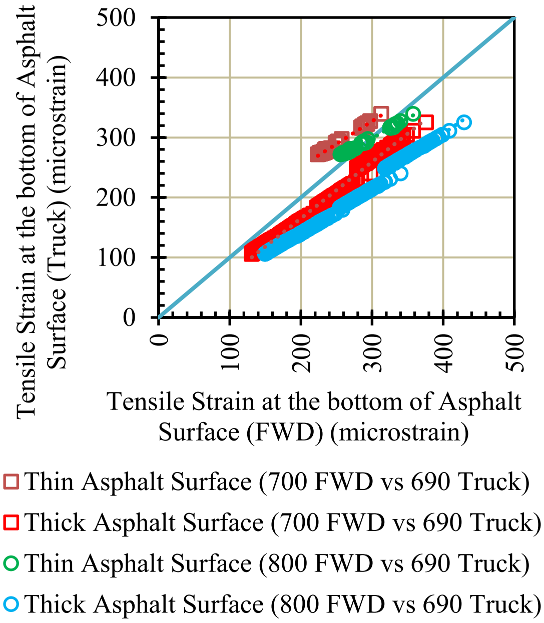

Fig.6 Comparison between FWD and standard Thai truck tensile strain at the bottom of asphalt surface

Additionally, a paired samples t-test [15] was used to compare the means of two tensile strain samples between the FWD and the standard Thai truck at significance level 0.05 as each observation in one tensile strain simple can be paired with an observation in other tensile strain sample. The null hypothesis was the two tensile strain means were equal. The result showed that there were significant differences between 700-800-kPa FWD tensile strains and 690-kPa standard Thai truck tensile strain. In cases of thin asphalt surfaces with thickness less than 100 mm, 800-kPa tensile strain mean (284 microstrains) was significantly closer to 690-kPa tensile strain mean (288 microstrains) than 700-kPa tensile strain mean (249 microstrains). Therefore, it was significant that 800-kPa FWD tensile strain was closer to 690-kPa standard Thai truck tensile strain than 700-kPa FWD tensile strain.

In case of thick asphalt surfaces with thickness greater than or equal to 100 mm, 700-kPa tensile strain mean (218 microstrains) was significantly closer to 690-kPa tensile strain mean (182 microstrains) than 800-kPa mean tensile strain value (249 microstrains). Therefore, it was significant that 700-kPa FWD tensile strain was closer to 690-kPa standard Thai truck tensile strain than 800-kPa FWD tensile strain.

6.1.3 Compressive Strains above the Subgrade

Comparison between the FWD and the standard Thai truck compressive strain above the subgrade is shown in Fig. 7. In cases of compressive strains less than 400 microstrains, 800-kPa FWD-standard truck compressive strains yielded smaller error than 700-kPa FWD-standard Thai truck compressive strains. An average error of 7% was obtained for 800-kPa FWD-standard Thai truck compressive strains, whereas an average error of 12% was obtained for 700-kPa FWD-standard Thai truck compressive strains. As a consequence, for small compressive strains less than 400 microstrains, 800-kPa FWD compressive strain was closer to 690-kPa standard Thai truck compressive strain than 700-kPa FWD compressive strain.

However, in cases of compressive strains between 400 and 2,900 microstrains, 700-kPa FWD-standard Thai truck compressive strains yielded smaller error than 800-kPa FWD-standard Thai truck compressive strains. An average error of 8% was obtained for 700-kPa FWD-standard Thai truck compressive strains, whereas an average error of 11% was obtained for 800-kPa FWD-standard Thai truck compressive strains. As a consequence, for the compressive strains between 400 and 2,900 microstrains, 700-kPa FWD compressive strain was closer to 690-kPa standard Thai truck compressive strain than 800-kPa FWD compressive strain.

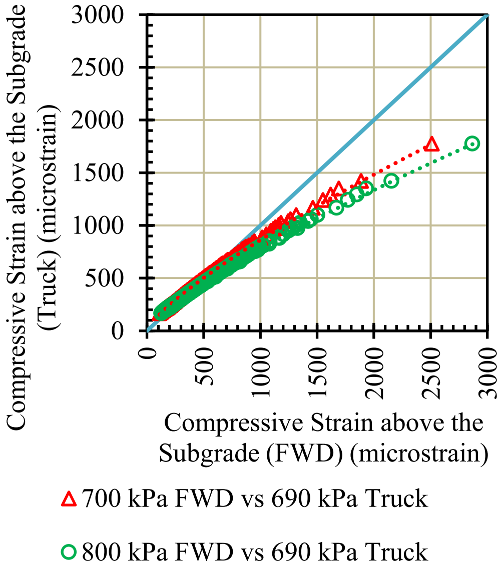

Fig.7 Comparison between FWD and standard Thai truck compressive strain above subgrade

Additionally, a paired samples t-test [15] was used to compare the means of two compressive strain samples between the FWD and the standard Thai truck at significance level 0.05 as each observation in one compressive strain sample can be paired with an observation in other compressive strain sample. The null hypothesis was the two compressive strain means were equal. The result showed that there was a significant difference between 700-kPa FWD compressive strain and 690-kPa standard Thai truck compressive strain and there was no statistically significant difference between 800-kPa compressive strain and 690-kPa standard Thai truck compressive strain.

In case of compressive strains less than 400 microstrains, 800-kPa compressive strain mean (294 microstrains) was significantly closer to 690-kPa compressive strain mean (295 microstrains) than 700-kPa compressive strain mean (257 microstrains). Therefore, for compressive strains less than 400 microstrains, it was significant that 800-kPa FWD compressive strain was more similar to 690-kPa standard Thai truck compressive strain than 700-kPa FWD compressive strain.

In case of compressive strains between 400 and 2,900 microstrains, 700-kPa compressive strain mean (633 microstrains) was significantly closer to 690-kPa compressive strain mean (599 microstrains) than 800-kPa compressive strain mean (723 microstrains). Therefore, for compressive strains between 400 and 2,900 microstrains, it was significant that 700-kPa FWD compressive strain was closer to 690-kPa standard Thai truck compressive strain than 800-kPa FWD compressive strain.

6.2 Allowable Number of Load Repetitions to Fatigue Cracking based on Normalized Deflections

The horizontal tensile strains at the bottom of asphalt surfaces obtained from multi-layered elastic analysis by KENLAYER computer program were used to determine the allowable number of load repetitions to fatigue cracking. According to the comparison results from Sections 6.1.1 and 6.1.2, the tensile strains induced by the 800-kPa FWD were selected for determining allowable number of load repetitions to fatigue cracking based on the normalized deflections.

Figs. 8 and 9 show the allowable number of load repetitions to fatigue cracking as a function of the normalized deflections for thick and thin asphalt surfaces, respectively. As expected, smaller normalized deflections would result in higher allowable number of load repetitions to fatigue cracking, while larger normalized deflections would result in lower allowable number of load repetitions to fatigue cracking.

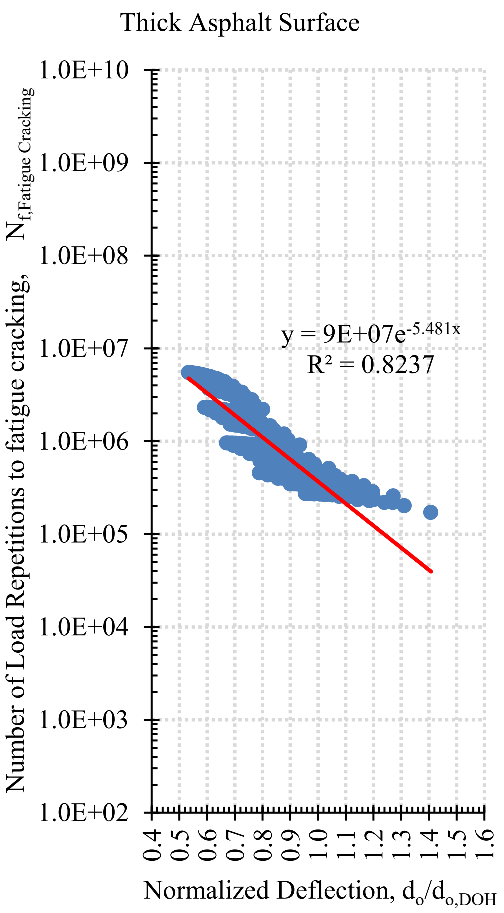

Fig.8 Allowable number of load repetitions to fatigue cracking as a function of the normalized deflections for thick asphalt surface

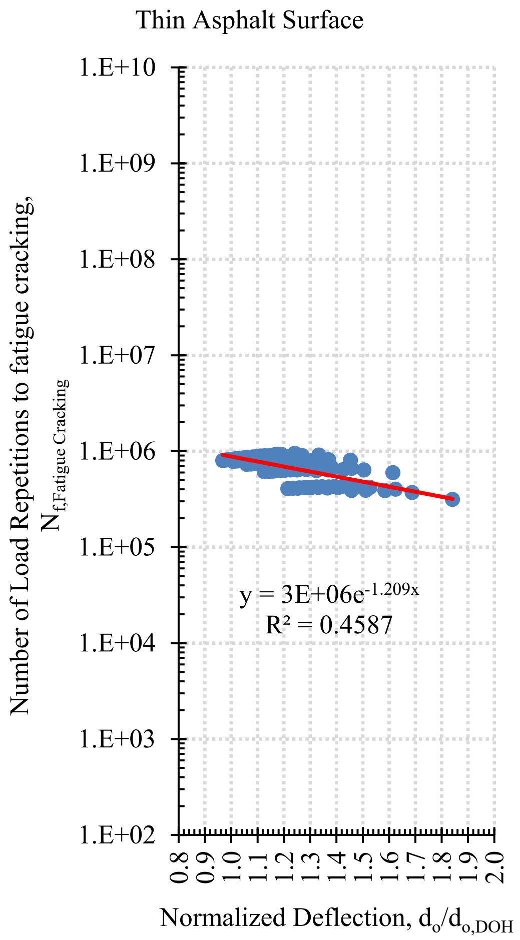

Fig.9 Allowable number of load repetitions to fatigue cracking as a function of the normalized deflections for thin asphalt surface

6.3 Allowable Number of Load Repetitions to Permanent Deformation based on Normalized Deflections

The vertical compressive strains above the subgrade obtained from multi-layered elastic analysis by KENLAYER computer program were used to determine the allowable number of load repetitions to permanent deformation. According to the comparison results from Sections 6.1.1 and 6.1.3, the compressive strains from the 800-kPa FWD were selected for determining allowable number of load repetitions to permanent deformation based on normalized deflections.

Figs. 10 and 11 show the allowable number of load repetitions to permanent deformation as a function of the normalized deflections for thick and thin asphalt surfaces, respectively. As expected, smaller normalized deflections would result in higher allowable number of load repetitions to permanent deformation, while larger normalized deflections would result in lower allowable number of load repetitions to permanent deformation.

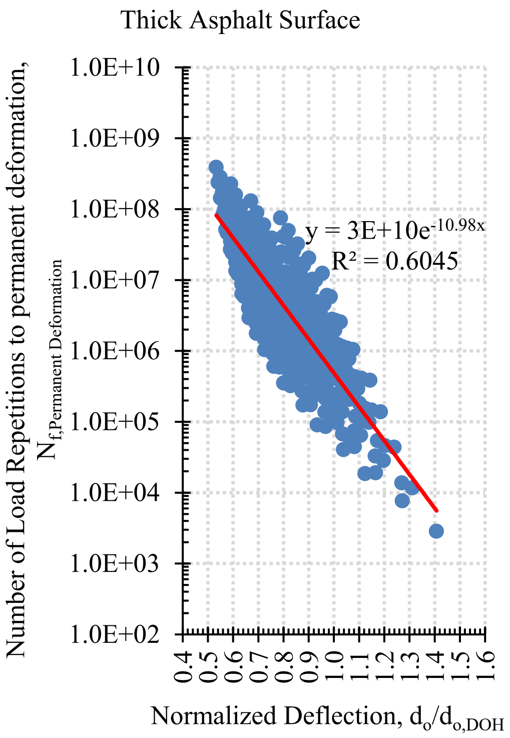

Fig.10 Allowable number of load repetitions to permanent deformation as a function of the normalized deflections for thick asphalt surface

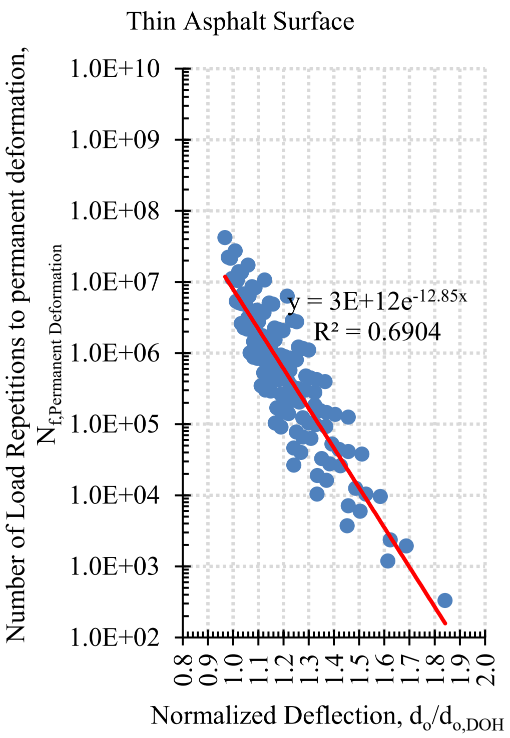

Fig.11 Allowable number of load repetitions to permanent deformation as a function of the normalized deflections for thin asphalt surface

8. CONCLUSION AND RECOMMENDATIONS

This study examined the structural responses of 625 flexible pavements under 700-kPa FWD, 800-kPa FWD, and 690-kPa standard Thai truck loads. A total of 625 LEA cases was performed to investigate the pavement structural responses. The responses from both 700-kPa and 800-kPa FWD were compared with standard Thai truck in order to determine the most suitable loading pressure of FWD.

The comparison results indicated that the average error was about 10% for 800-kPa FWD-standard Thai truck deflections, while 21% for 700-kPa FWD-standard Thai truck deflections. The average error was respectively 2% and 14% for 800-kPa FWD-standard Thai truck and 700-kPa FWD-standard Thai truck tensile strain at the bottom of thin asphalt surface.

The average error was respectively 38% and 21% for 800-kPa FWD-standard Thai truck and 700-kPa FWD-standard Thai truck tensile strain at the bottom of thick asphalt surface. The average error ranged from 7% to 11% for 800-kPa FWD-standard Thai truck and 8% to 12% for 700-kPa FWD-standard Thai truck compressive strain above the subgrade.

Furthermore, smaller normalized deflections resulted in higher allowable number of load repetitions to fatigue cracking and permanent deformation. On the other hand, larger normalized deflections resulted in lower allowable number of load repetitions to fatigue cracking and permanent deformation.

On the other hand, the paired samples t-test results at significance level 0.05 indicated that 800-kPa FWD deflection and tensile strain means for thin asphalt surfaces with thickness less than 100 mm were closer to 690-kPa standard Thai truck deflection and tensile strain means than 700-kPa FWD deflection and tensile strain means. Moreover, for compressive strains less than 400 microstrains, the difference between 800-kPa FWD and 690-kPa standard Thai truck compressive strain means was statistically insignificant.

This study suggested that 800-kPa FWD deflection was closer to 690-kPa standard Thai truck deflection than 700-kPa FWD deflection. Therefore, it is recommended that 800-kPa FWD could be considered in the development of future deflection-based design approach in Thailand. In addition, the normalized deflections and the number of load repetitions to fatigue cracking and permanent deformation were proposed for the deflection-based approach for flexible pavement design. However, the nonlinear analysis could be considered in the future study.

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