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COMPARING THE PREDICTED ELASTIC MODULUS RESULTS OF GRANULAR MATERIAL OF BASE LAYERS OF A FLEXIBLE PAVEMENT STRUCTURE FROM FWD TESTING WITH SOME OTHER EXPERIMENTS

SO SÁNH KẾT QUẢ DỰ ĐOÁN MÔ ĐUN ĐÀN HỒI CỦA VẬT LIỆU ĐÁ LÀM LỚP NỀN CHO MỘT KẾT CẤU ÁO ĐƯỜNG MỀM TỪ THÍ NGHIỆM FWD VỚI MỘT SỐ THÍ NGHIỆM KHÁC

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ABSTRACT

FWD testing are currently used and studied worldwide. This is a non-destructive testing, used to evaluate the load capacity of a pavement structure. Results obtained from experiments are the elastic modulus of pavement structure layers, estimated based on deflection surface under a load caused by falling heavy object. Domestically, several researchers remain skeptical about the authenticity of the results predicted from FWD. This study refers to the process of comparing granular modulus of pavement base layers obtained from FWD testing, determined by BISAR-GAs, with some other experiments as Seismic Pavement Analyzer (SPA), Dynamic Cone Penetration (DCP), and in Laboratory (LAB).

Keywords: *Falling Weight Deflectometer, Semic Pavement Analyser, Dynamic Cone Penetration, Backcalculation modulus.*

TÓM TẮT

Thí nghiệm FWD hiện đang được sử dụng và nghiên cứu trên toàn thế giới. Đây là dạng thí nghiệm không phá hủy, được sử dụng để đánh giá khả năng chịu tải của một kết cấu đường. Kết quả có được từ thí nghiệm là mô đun đàn hồi của các lớp kết cấu áo đường, dự đoán dựa vào bề mặt võng dưới một lực gây ra bởi vật nặng rơi. Trong nước, nhiều nhà nghiên cứu vẫn còn nghi ngờ về tính xác thực của các kết quả dự đoán từ FWD. Nghiên cứu này đề cập đến quá trình so sánh mô đun đàn hồi của đá dăm làm lớp nền đường có được từ thí nghiệm FWD, xác định bằng BISAR-GAs, với một số thí nghiệm khác như thí nghiệm phân tích đáp ứng động (SPA),thí nghiệm xuyên côn động (DCP), và trong phòng thí nghiệm (LAB)

Từ khóa: *Đo biến dạng dưới tải rơi, Phân tích đáp ứng động, Xuyên côn động, Mô-đun tính toán ngược.*

1. INTRODUCTION

Maintenance pavement is scope of this paper. A pavement structure is checked regularly during its service period. Modulus of material layers are parameter related to load bearing capacity of a pavement structure. In highway engineering, dynamic modulus is considered because it relates to the response of material under dynamic load as vehicle loads.

There are several experiment methods using for dynamic modulus prediction. It could be listed as Seismic Pavement Analyzer (SPA), Dynamic Cone Penetration (DCP), and Falling Weight Deflectometer (FWD). FWD is being widely used in highway engineering. Dynamic moduli obtained from FWD are results of a backcalculation process.

A program named as BISAR-GAs was developed in HCMC University of Technology and Education (UTE). It was developed for backcalculation, determine dynamic modulus based on pavement surface deflection under a falling weight of the FWD experiment.

The reliable of modulus evaluated from BISAR-GAs is a question of several pavement research experts in Viet Nam.

The comparison of modulus of granular materials in a base layer of flexible pavement structure determined from FWD experiment and some other experiments is a topic of the paper. Modulus of other layers, such as Asphalt concrete surface and subgrade, will not be considered in the paper.

Due to lack of experiments in Viet Nam, the experimental results obtained from test in the city Brownwood, Brown County, Texas, United States were used in the study. This is part of a project carried out at the Center for Transportation Research (CTR) and at The University of Texas at El Paso (UTEP).

Table 1*. Thickness of the pavement in Brownwood, Texas (USA)*

Section	Thickness of the pavement (mm)		
	Asphalt Concrete	Base	Subgrade
1	66	272	∞
2	52	256	
3	53	216	
4	59	241	
5	62	290	
6	74	265	
7	75	202	

Materials used for the base layer material was taken from the primitive natural quarries in use for a year, then conduct empirical measure. Standard load depending on the position for the survey different load, average load is of 40kN. Pavement structure including asphalt concrete layer, the base layer is quarry material and subgrade. Table 1 synthesis of the layer thickness in each section. [2]

Results of modules value are expressed in the form compared to other test. It is found that the modulus evaluated form FWD tests are relatively close to those of SPA and DCP testing.

2. EXPERIMENT OF PAVEMENT STRUCTURE

2.1 SPA

The Seismic Pavement Analyzer (SPA) is an instrument designed to monitor pavement deterioration. It measures such conditions as voids, loss of support under a rigid pavement, softening of asphalt-concrete pavement layers, and delamination of overlays. The SPA detects these types of pavement conditions by estimating Young's and shear moduli in the pavement, base, and subgrade from wave propagation measurements.

Five different tests are carried out with the SPA:

1. Spectral Analysis of Surface Waves (SASW),
2. Impulse Response (IR),
3. Ultrasonic Body Wave (UBW),
4. Ultrasonic Surface Wave (USW),
5. Impact Echo (IE).

The data from the SASW tests were used to estimate the modulus of each layer of the pavement at each testing section. The SASW method used to determine the modulus profile of a pavement section, detail of the theoretical and test aspects of the SASW method can be found in Nazarian et al. (1995) and Yuan et al. (1998). Modulus value of SPA testing shown in Table 2.[3]

2.2 DCP

Dynamic Cone Penetration (DCP) is a testing that vertical confinement effects on DCP values (due to upper asphalt layers) do exist. Since this is the true effect of the pavement structure, any DCP measurement for pavement evaluation purposes should be performed through a narrow hole in the asphalt layers and not after removal of a wide strip of asphalt (Livneh et al.,1995). Then, the DCP was started on the top of the base layer. Figure 1 shows the results of DCP via index CBR% according to the thickness of the layer base. Modulus values of DCP testing are shown in Table 3. [4][5]

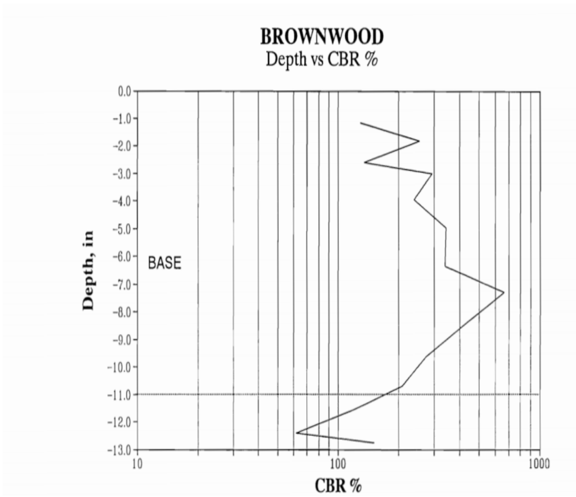

Fig. 1*. Chart showing the relationship of the index CBR% and thickness of the base layer.*

2.3 Laboratory (LAB)

In the laboratory, the resilient modulus tests performed by triaxial testing under repeated loading, consisted of applying various deviatoric stresses at different confining pressures. The confining pressure is either applied by subjecting the specimen to vacuum or by compressed air inside the acrylic cell surrounding the specimen. The pressure is monitored by a pressure gage.

In Figure 2, a haver-sine loading waveform with a loading duration of 0.1 seconds and rest period of 0.9 seconds is used. The axial deformations are measured along the middle one-third of the specimen with six non-contact proximeter sensors. Two non-contact probes are used to measure lateral deformations so that Poisson's ratios can also be determined. Five cycles of loading are applied at every stage to optimize testing time, and to minimize the degradation of the specimen. From the measured axial and lateral displacements at a particular deviatoric stress and confining pressure, the resilient modulus and Poisson's ratio of the specimen are determined. Moduli of several depths are evaluated corresponding specimen depths. Values of LAB experiments and those of FWD testing are shown in Table 4. [2]

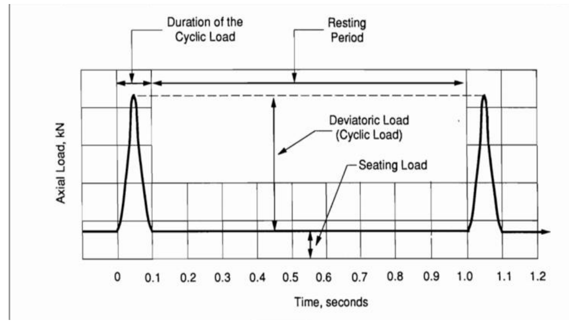

Fig. 2*. Definition of the Loading Rate, Wave Form and Terms*

2.4 FWD

The falling weight deflectometer (FWD) is a non-destructive testing (NDT) and non-intrusive device. The FWD has been widely used in pavement engineering to evaluate pavement structural condition. The FWD plays a dominant role in selecting optimum pavement maintenance and rehabilitation strategies. The FWD is a tool used to achieve rapid and repeatable in-situ characterization of the pavement layer stiffness.

In the study, load plate diameter 30cm, 7 sensor D0, D1, D2, D3, D4, D5, D6 with the distance respectively 12, 24, 36, 48, 60, 72 inches, and depending on the position of the thickness of the different layers and different loads. These parameters are inputs data for a backcalculation process determining modulus of pavement layers.

3. BACKCALCULATION PROCESS

BISAR-GAs is the combination of BISAR and the genetic algorithms (GA).

BISAR is a program developed to do analysis for series of multi elastic layers such as a pavement structure.

GA is the combination of direct and random search. It searches an optimum solution based on a set of solutions (called as population). GA has its own advantages compared with some other existing methods, it don't need the derivative of objective function. The number of variables is coded into a chromosome (NST), a string of 0 and 1. New generation is born based on the natural genetic solution including hybridization or mutant process of strong chromosomes.

The objective function is used to assess the strongest chromosome. This function is also known as "Evaluation Function".

$$\text{Maximize} \quad f=\frac{1}{1+RMS}=1 \qquad (1)$$

Where:

f = function evaluation;

RMS = squared error.

RMS (Root Mean Square) is defined as error of pavement surface deflection calculated by BISAR and that measured from, as follows:

$$RMS=100x\sqrt{\frac{1}{m}\sum_{j=1}^{m}\left(\frac{d_j-D_j}{D_j}\right)}<\varepsilon \qquad (2)$$

Where:

m = number of sensors;

d_j = deflection calculations measured at sensor j;

D_j = deflection measured at the j^{th} sensor.

The ε of 3% is a good enough value that gives the optimum solution [1]. The main procedures of the BISAR-GAs are showed in the Figure 3.

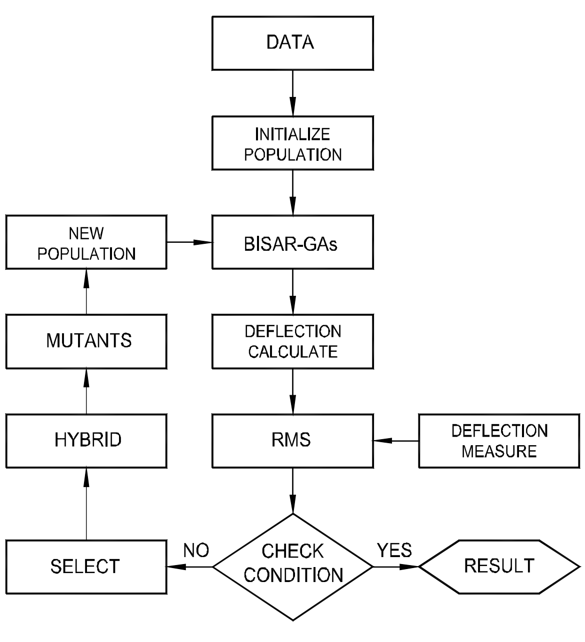

***Fig. 3**. Procedures in BISAR-GAs program.*

4. COMPARISON OF MODULI FOR BISAR-GAs AND OTHER TEST

Comparisons of the modulus values from different test methods are presented in Figure 4. The FWD determined moduli of base layers are close to those obtained from SPA testing.

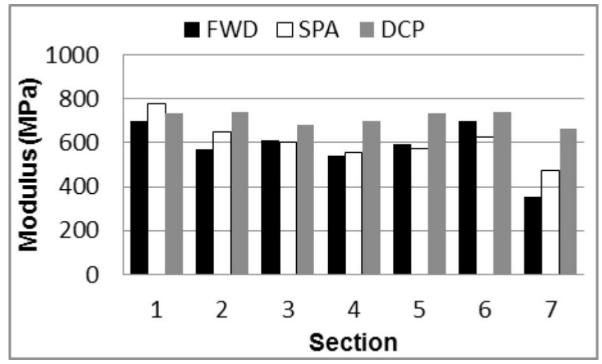

***Fig. 4**. Comparisons of the modulus values from three testing.*

Table 2 shows the comparison of modulus values of SPA testing and those values of BISAR-GAs. An average error between the two testing from the survey sections is 5%. The moduli of base layer obtained from SPA testing were about 1.04 (=608/581) times BISAR-GAs.

***Table 2.** Comparisons modulus of BISAR-GAs and SPA*

Location	Modulus (MPa)		Error (%)
	BISAR-GAs	SPA	
1	699	778	11.3
2	570	647	13.5
3	613	601	2.0
4	541	556	2.8
5	592	571	3.5
6	698	627	10.2
7	355	476	34.1
Averages	581	608	4.6

Table 3 shows the comparison of modulus values of DCP testing and those values of BISAR-GAs. Moduli of base layers from DCP are slightly higher than those obtained from BISAR-GAs, an average error of 18%. The moduli of base layer obtained from DCP testing are about 1.2 (=713/581) times BISAR-GAs.

***Table 3.** Comparisons modulus of BISAR-GAs and DCP*

Location	Modulus (MPa)		Error (%)
	BISAR-GAs	DCP	
1	699	736	5.3
2	570	739	29.6
3	613	682	11.3
4	541	699	29.2
5	592	734	24.0
6	698	737	5.6
7	355	662	86.5
Averages	581	713	22.7

Table 4 shows the comparison of modulus values of LAB experiments and those values of BISAR-GAs. The BISAR-GAs determined base moduli were only slightly higher than those obtained from laboratory, an average error of 21%. The moduli of base layer obtained from BISAR-GAs were about 1.2 (= 509/414) times testing in laboratory.

***Table 4.** Comparisons modulus of BISAR-GAs and LAB*

Depth from Top of Base (mm)	Modulus (MPa)		Error (%)
	BISAR-GAs	LAB	
25	540	501	7.2
50	540	470	13.0
75	540	442	18.1
100	541	416	23.1
125	540	395	26.9
150	541	378	30.1
175	535	363	32.1
200	299	350	17.1
Averages	509.5	414.4	21.0

5. CONCLUSION

This study is to compare the results from non-destructive field tests, such as FWD, to those results obtained from other tests including a complexity experiment in laboratory.

From the study, the conclusions are given as follows:

- The results obtained from tests are often not homogeneous. The results of BISAR-GAs and SPA testing are relatively closer than the other test, error of 5%.

- The error of DCP testing and BISAR-GAs is relatively high, average error of 22.7%. The results of BISAR-GAs lower than SPA testing are 20%.

- The results of BISAR-GAs higher than laboratory experiments are 20%.

In scope of the modulus of base layers in a pavement structure, the results show that the BISAR-GAs program on FWD experiment is a realistic approach. The BISAR-GAs gives relatively stable and good results.

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