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Research Paper

Correlation between Resilient Modulus M_R and Deviator Stress for Subgrade soils of northern provinces in Vietnam

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ABSTRACT

Recently, Resilient Modulus is applied in pavement structural design in Vietnam. The resilient modulus of subgrade soil is an essential input parameter for a flexible pavement design. The resilient modulus depends on soil properties, stress state, and soil type. However, there is limited research on resilient modulus of soils and models to estimate resilient modulus in Vietnam. Therefore, in this study, soil samples were collected from two provinces in northern Vietnam, namely Bac Giang province and Ninh Binh province, and then physical and mechanical tests were conducted for these samples. In addition, a series of cyclic triaxial tests also conducted according to AASHTO T307 specification to obtain resilient modulus of these soils. The results showed that the resilient modulus decreased with the increase of deviator stress for Bac Giang samples and increased with the increase of deviator stress in the case of Ninh Binh samples. Simple deviator stress models have developed to estimate a resilient modulus of soils in the area.

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1 Introduction

Flexible pavement, or asphalt pavement, is widely used in Vietnam, as well as in other countries around the world. Currently, asphalt pavement is applied on about 80% of highways in Vietnam. Along with the development of society, the pressure from the rapid increase in the number of transport and loadings causes great pres-sure on the transport infrastructure, especially the road systems. The pavement structure consists of several materials such as asphalt and concrete, placed upon the foundation layers and the roadbed. The top layer plays an important role in creating the stability of the pavement structure and it is also the intermediate layer, in contact with the flexible pavement, evenly distributing the wheel load from the pavement to the ground.

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AASHTO (2003) recommends using resilient modulus for pavement design [1-3]. M_R is the ratio of peak axial cyclic stress and associated resilient strain [1, 2, 4]. Previous research showed that resilient modulus depends on stress for both coarse soil and fine soil [5-13]. Several models were developed to estimate the resilient modulus from stress (Table 1).

Recently, a new specification for the Design of Pavement Structures, namely TCCS37:2022/TCDBVN has been released [14]. This specification is built based on AASHTO standards and will be applied to pavement design in Vietnam. However, there is limited research on the resilient modulus of subgrade soils and the effect of stress on the resilient modulus of soils. Therefore, this paper focuses on laboratory tests including the cyclic triaxial test, compaction test, and CBR test for estimating the resilient modulus of soils, and a model of stress for M_R will be established.

Table 1 – Previous models to estimate resilient modulus, M_R

No.	Equation		Reference
1	$M_R = k_1 \times \left(\frac{\sigma_3}{P_a}\right)^{k_2}$	(1)	Dunlap [12]
2	$M_R = k_1 \times \left(\frac{\sigma_d}{P_a}\right)^{k_2}$	(2)	Moossazadeh and Witczak (1981) [8]
3	$M_R = k_1 \times P_a \times \left(\frac{\sigma_{sum}}{P_a}\right)^{k_2} \times \left(\frac{\sigma_d}{P_a}\right)^{k_3}$	(3)	Uzan (1985) [15]
4	$M_R = k_1 \times P_a \times \left(\frac{\sigma_{sum}}{P_a}\right)^{k_2} \times \left(\frac{\tau_{oct}}{P_a}+1\right)^{k_3}$	(4)	National highway cooperative research program project 1-28A, 2004) [16]

2 Materials and Methods

2.1 Materials

Soil samples were collected at Bac Giang province and Ninh Binh province and then dried in a room with an average temperature of 20°C.

2.2 Methods

2.2.1 Physical properties tests

Physical tests such as moisture content, Atteberg limit, and grain size analysis were conducted according to Vietnamese standards (TCVN) and ASTM standards for the Bac Giang sample and Ninh Binh samples (Table 2). After physical tests, the compaction test and CBR test were conducted according to the ASTM D698 standard and ASTM D1883, respectively.

Table 2 – Summary of the tests for Bac Gang sample and Ninh Binh sample

Type of test	Name of test	Standard
Physical test	Atterberg limit	TCVN 4197:2012
	Grain size analysis	TCVN 4198:2014
Mechanical tests	Compaction	ASTM D698
	CBR	ASTM D1883
Cyclic test	Cyclic triaxial test	AASHTO T307-99

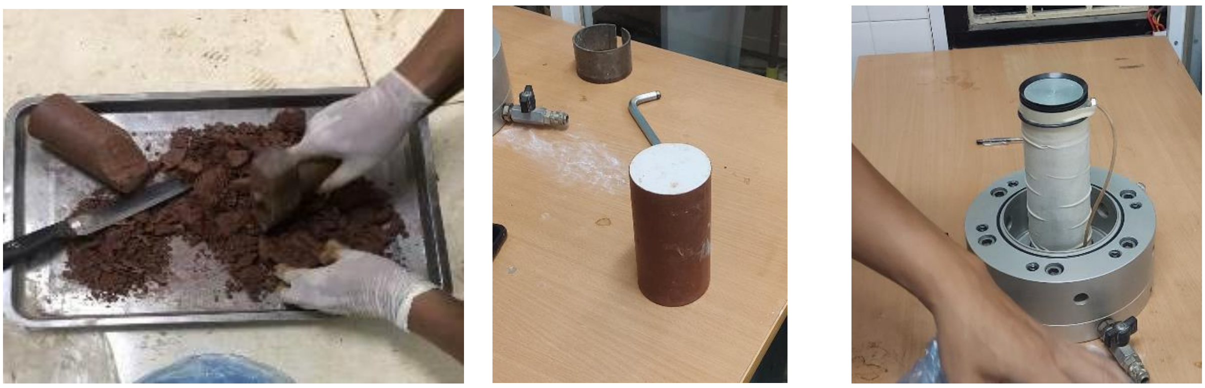
2.2.2 Cyclic triaxial tests

To use subgrade soil or untreated base/sub-base materials, resilient modulus (M_R) test was conducted by using a cyclic triaxial machine. Basically, the system consists of a computer-controlled loading frame that can provide cyclic loading on a soil sample mounted inside a triaxial cell. The cyclic triaxial test procedures followed the testing standard AASHTO T307-99 (2007) "Standard method of test for determining the resilient modulus of soils and aggregate materials" [1].

Table 3 – Detail of cyclic triaxial testing sequence for the experimental soils

No.	Confining Pressure, σ_3	Max. Axial Stress, σ_{max}	Number of load cycles (cycle)
1	41.4	13.8	1000
2	41.4	27.6	100
3	41.4	41.4	100
4	41.4	55.2	100
5	41.4	68.9	100
6	27.6	13.8	100
7	27.6	27.6	100
8	27.6	41.4	100
9	27.6	55.2	100
10	27.6	68.9	100
11	13.8	13.8	100
12	13.8	27.6	100
13	13.8	41.4	100
14	13.8	55.2	100
15	13.8	68.9	100

The triaxial specimens of 70 mm in diameter and 140 mm in height were prepared by using the compaction method. The triaxial specimens of 70 mm in diameter and 100 mm in height were prepared by using the compaction method. The samples were prepared at 95 % (R95) and 98% (R98) of dry unit weight and at optimum moisture content, which was obtained by compaction test for both Ninh Binh soil and Bac Giang soil.



(a) Sample preparation after compaction (b) Sample installation (c) Put the sample into the cyclic triaxial compression chamber

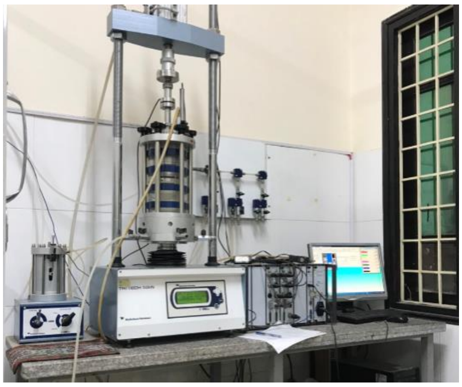
Fig. 1 – Sample preparation

The haversine-shaped load form was used and cyclic load duration of 0.1 seconds followed by a recovery duration of 0.9 seconds was applied. The details of the loading sequences and the number of cycles were shown in Table 3 and testing procedures are shown in Fig. 1 to Fig. 3.

(a) Install the sample into the cyclic triaxial compressor

(b) Saturated sample

Fig. 2 – Install the sample into the cyclic triaxial compressor and Sample preparation



(a) Conduct experiments

(b) Automatic data recording

Fig. 3 – Loading and recording data automatically

3 Results

3.1 Physical properties results

The particle distribution curves for Ninh Binh samples and Bac Giang samples are shown in Figure 4. The physical properties and mechanical properties of soil sam-ples are shown in Table 4. Bac Giang soil is classified as A2-7, according to the AASHTO standard, whereas Ninh Binh soil is A2-6.

3.2 Resilient modulus results

The resilient modulus of Ninh Binh soils at R95 and R98 tested under different confining pressures of 41.4 kPa, 27.6 kPa, and 13.8 kPa are shown in Figure 5 and Figure 6. The resilient modulus for both soils showed a similar trend. The resilient modulus is increased when σ_3 increases from 13.8 kPa to 41.4 kPa and the resilient modulus is reduced when deviator stress is increased. This behavior is consistent with previous research for soils [2, 4-6].In addition, resilient modulus for Ninh Binh soils were higher compared to those of Bac Giang soils, due to a higher of CBR value for Ninh Binh soil.

Table 4 – Physical and mechanical properties of Ninh Binh soils and Bac Giang soils

No.	Experimental criteria	Symbol	Unit	Ninh Binh soil (A2-7)	Bac Giang soil (A2-6)
1	#200 passing	-	%	14.3	25
2	Liquid limit	LL	%	42.53	32.7
3	Plastic index	PI	%	11.69	21.21
4	Maximum dry unit weight	$\gamma_{max\ d}$	g/cm^3	1.765	1.878
5	Optimum water content	W_{opt}	%	17.7	17
6	CBR at95 percent of maximum dry density (R95)	CBR	%	12.4	10.4

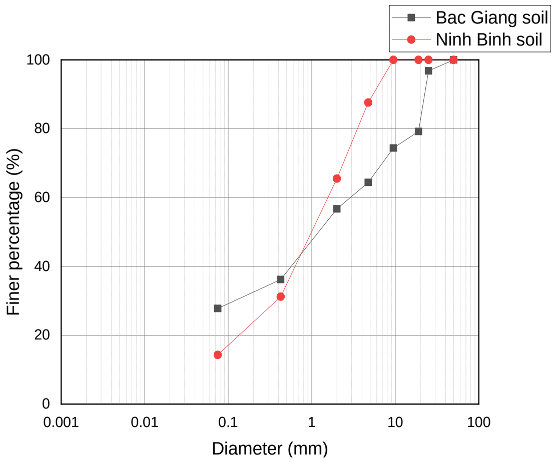


Fig. 4 – Particle size distribution curve for Ninh Binh soil and Bac Giang soil

In this research, resilient modulus dependent on stress was proposed, which was similar to equation (2). A non-linear regression of modulus and deviator stress was developed by using the Origin program. These regressions showed that the resilient modulus depends on deviator stress with a high value of R2.

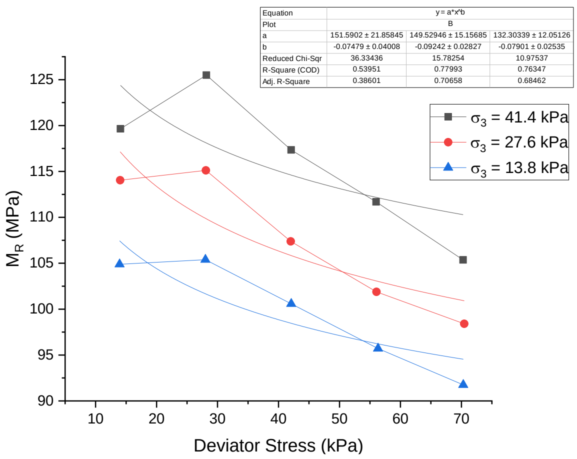


Fig. 5 – Test results of sample NB-1-R95

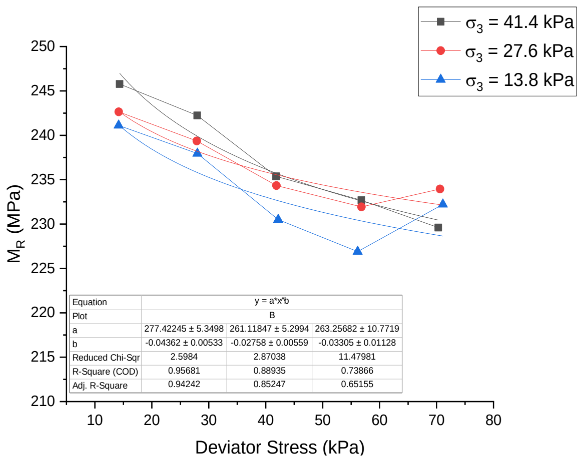


Fig. 6. Test results of sample NB-2-R98

Correlation between M_R and Deviator stress NB-1-R95:

$$+\ M_R = 151.59\left(\sigma_d\right)^{-0.07} \text{ in case } \sigma_3 = 41.4kPa \ (R^2 = 0.386)$$

$$+\ M_R = 149.52\left(\sigma_d\right)^{-0.09} \text{ in case } \sigma_3 = 27.6kPa \ (R^2 = 0.706)$$

$$+\ M_R = 132.30\left(\sigma_d\right)^{-0.08} \text{ in case } \sigma_3 = 13.8kPa \ (R^2 = 0.684)$$

Correlation between M_R and Deviator stress NB-2-R98:

$$+\ M_R = 277.42(\sigma_d)^{-0.04} \text{ in case } \sigma_3 = 41.4kPa \ (R^2 = 0.942)$$

$$+\ M_R = 261.12(\sigma_d)^{-0.03} \text{ in case } \sigma_3 = 27.6kPa \ (R^2 = 0.852)$$

$$+\ M_R = 263.27(\sigma_d)^{-0.03} \text{ in case } \sigma_3 = 13.8kPa \ (R^2 = 0.651)$$

The cyclic triaxial test for Bac Giang samples (BG-1-R95 and BG-1-R98) are shown in Fig. 7 and Fig. 8. For this case, linear regression showed that the resilient modulus depends on deviator stress also.

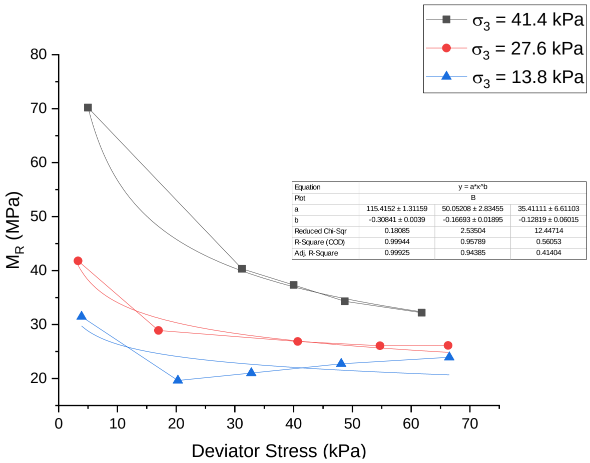


Fig. 7 – Test results of sample BG-1-R95

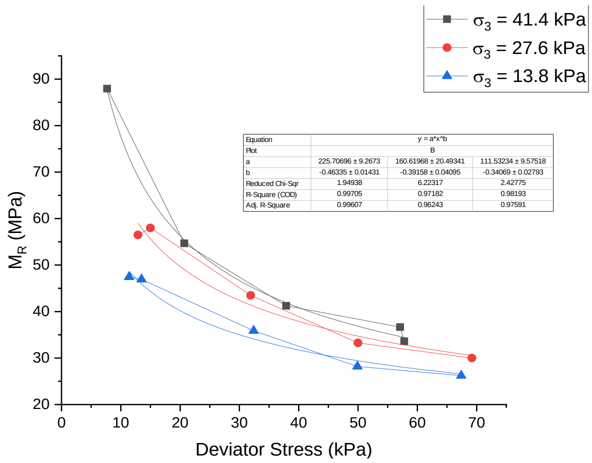


Fig. 8 – Test results of sample BG-2-R98

Correlation between M_R and Deviator stress BG-1-R95:

$$+\ M_R = 115.41(\sigma_d)^{-0.31} \text{ in case } \sigma_3 = 41.4kPa \ (R^2 = 0.999)$$

$$+\ M_R = 50.05(\sigma_d)^{-0.17} \text{ in case } \sigma_3 = 27.6kPa \ (R^2 = 0.943)$$

$$+\ M_R = 35.11(\sigma_d)^{-0.13} \text{ in case } \sigma_3 = 13.8kPa \ (R^2 = 0.414)$$

Correlation between M_R and Deviator stress BG-2-R98:

$$+\ M_R = 225.71(\sigma_d)^{-0.46} \text{ in case } \sigma_3 = 41.4kPa \ (R^2 = 0.996)$$

$$+\ M_R = 160.61(\sigma_d)^{-0.39} \text{ in case } \sigma_3 = 27.6kPa \ (R^2 = 0.962)$$

$$+\ M_R = 111.53(\sigma_d)^{-0.34} \text{ in case } \sigma_3 = 13.8kPa \ (R^2 = 0.976)$$

4 Conclusions and Recommendations

Resilient modulus of subgrade is an important factor for pavement design and analysis. Cyclic triaxial tests were conducted for soils for both Bac Giang province and Ninh Binh Province in Vietnam.

The experimental results in the laboratory initially determined the correlation between the resilient modulus M_R and the deviator stress. Almost all regression models of resilient modulus were found to be 0.9 for Ninh Binh soils and Bac Giang soils, indicating a significant fit of M_R with the deviator stress model. The developed models would be applicable for estimating the resilient modulus of soils from deviator stress value. In addition, typical values of M_R for Ninh Binh and Bac Giang soils can be recommended for the design of pavement in these provinces.

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