HUBUNGAN TINGKAT KONSENTRASI NOx DENGAN VOLUME LALU LINTAS DI PERSIMPANGAN TAK BERSINYAL

Ayi Tatang

RINGKASAN

Tulisan ini mengemukakan hasil pengamatan korelasi aktual antara karakteristik lalu lintas dengan tingkat NOx pada ruas jalan yang akan memasuki simpang tiga tanpa diatur traffic light .Tujuan dari pengamatan tersebut adalah untuk dapat mempertimbangkan manfaat tambahan dari penyempurnaan tata laksana lalu lintas di simpang tiga tanpa diatur traffic light ,dan mengusulkan penanganannya .Hasil evaluasi dari hubungan karakteristik lalu lintas dengan tingkat kandungan NOx dinyatakan dalam persamaan Multiple Regression. Nilai R^2 yang di peroleh adalah 0.5842.Hal ini menunjukan adanya pengaruh yang cukup kuat dari karakteristik lalu lintas terhadap konsentrasi NOx di udara pada ruas jalan yang diteliti

SUMMARY

The article paper describes observation result on actual correlation between traffic characteristic and NOx level on road link which have access to junctions without traffic lights. The aims of observation is to consider additional benefits of traffic management in junctions without traffic lights. The evaluation result of traffic characteristic and NOx level relationship is expresses in multiple regresion equation .R^2 value obtained from 0.5842 indicated there is a significant influence of trafic characteristic on NOx concentration in the air of observed road links.

I. PENDAHULUAN

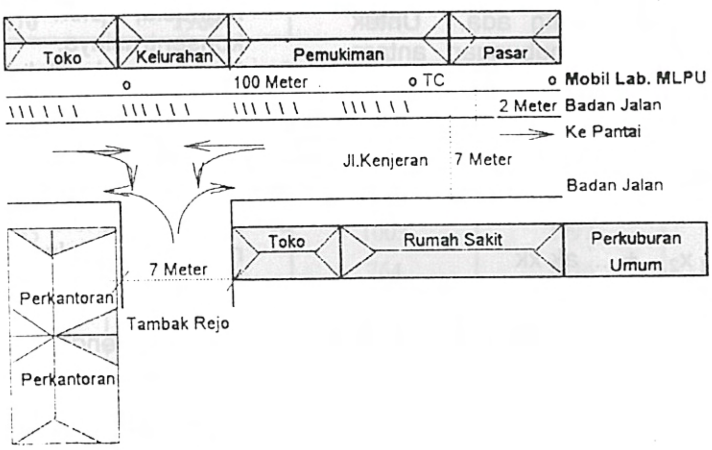
Kemacetan yang terjadi pada simpang tiga tanpa diatur lampu lalu lintas antara jalan Kenjeran dan Tampak Rejo di Kota Surabaya menyebabkan waktu tunda yang panjang pada jam-jam sibuk.Kondisi ini menyebabkan emisi kendaraan akan meningkat. Hal ini melarbelakangi dilakukan nya suatu penyelidikan untuk mengidentifikasi hubungan antara pencemaran udara (NOx), dengan kondisi lalu lintas serta manfaat tambahan dari tata laksana lalu lintas dalam rangka menanggulangi kemacetan di simpang tiga tersebut.

1.1. Karakteristik Lalu lintas dan tata Guna Lahan

Berdasarkan hasil pengamatan ,karateristik lalu lintas dan tata guna lahan pada ruas jalan ini adalah sebagai berikut :

- Arus lalu lintas pada ruas jalan Kenjeran yang akan memasuki simpang tiga jalan Tambak Rejo merupakan jalur yang padat. Ruas jalan ini memiliki dua jalur, dua arah, lebar perkerasan 7 meter dan bahu jalan dua meter yang dipergunakan untuk pedestrian dan pedagang kaki lima (lihat gbr. 1).
- Arus menuju simpang tiga jalan Tambak Rejo sering membentuk antrian yang panjang, hal ini disebabkan oleh :
  a. Rendahnya kapasitas simpang karena adanya konflik arus lalu lintas yang masuk dari jalan Kenjeran dan jalan Tambak Rejo.
  b. Adanya parkir kendaraan dan becak di dua sisi pada badan jalan pada mulut simpang tiga ini.
  c. Tata guna lahan di sekitar simpang tiga ini yang terdiri dari pertokoan, perumahan, perkuburan umum, pasar dan rumah sakit.

Gambar 1.
PETA SKETSA LOKASI PENELITIAN SIMPANG TIGA JALAN KENJERAN DAN JALAN TAMBAK REJO SURABAYA



1.2. Lingkup Penyelidikan

1. Evaluasi tingkat kemacetan pada jam-jam sibuk pada ruas jalan ini.
2. Evaluasi tingkat konsentrasi NOx dikaitkan dengan karakteristik lalu lintas pada jam-jam sibuk.
3. Evaluasi manfaat tambahan dari penyempurnaan tata laksana lalu lintas.

II. METODOLOGI

2.1. Arah Evaluasi

Identifikasi masalah kemacetan lalu lintas akan melibatkan evaluasi tingkat volume, kecepatan dan kepadatan kendaraan pada simpang jalan tersebut. Timbulnya antrian yang panjang akan mengganggu kesehatan pemakai jalan dan orang yang ada di sekitarnya, jika dihubungkan dengan tingkat konsentrasi polutan NOx.

2.2. Hipotesa

Tingkat konsentrasi polutan NOx di udara dipengaruhi oleh perilaku lalu lintas kendaraan (jenis kendaraan, jumlah, kecepatan dan kepadatan), khususnya aliran lalu lintas yang akan memasuki simpang tiga tanpa diatur traffic light.

2.3. Pengumpulan Data

- Pengukuran data volume dan kecepatan lalu lintas, dilakukan secara manual yaitu menghitung jumlah kendaraan yang melalui satu ruas jalan pada jam-jam sibuk pagi, siang dan sore. Sedangkan pengukuran kecepatan lalu lintas dilakukan dengan menggunakan Speed Gun.
- Pengukuran konsentrasi NOx, dilakukan dengan menggunakan Mobil Laboratorium Polusi Udara bersamaan dengan pengukuran volume dan kecepatan lalu lintas. Pengumpulan data dilakukan pada bulan Oktober 1996, dengan hasil pengukuran seperti diuraikan pada lampiran 1.

III. ANALISIS

Besarnya hubungan tingkat konsentrasi NOx dengan karakteristiK lalu lintas sangat dipengaruhi oleh kondisi pergerakan lalu lintas yang ada. Untuk mengetahui kuat atau tidaknya hubungan antara variable bebas (volume, kecepatan dan kepadatan) dengan variabel tak bebas (tingkat konsentrasi NOx), disusun dalam suatu persamaan Multiple Linear Regresion. Persamaan tersebut adalah sebagai berikut :

$$Y = a_0 + a_1 x_1 + a_2 x_2 .. + ... ak\ xk$$
$$= a_0 + a_1 x_1 + a_2 x_2 + a_3 x_3 + a_4 x_4$$

Y = Tingkat NOx

a_0 , a_1 ,a_2 ,a_3 ... ak = Konstanta

x_1 = Volume Kendaraan Pribadi
x_2 = Volume Kendaraan Umum
x_3 = Kecepatan Kendaraan
x_4 = Kepadatan Kendaraan

Dari hasil analisis persamaan di atas, nilai R^2 menunjukan angka 0,5842. Hasil ini menunjukkan adanya hubungan yang kuat dari volume, kecepatan, dan kepadatan kendaraan terhadap konsentrasi NOx di udara.

Regresson Output :

Constant	= 0.062186
Std Err of Est	= 0.018181
R Squared	= 0.341331
-> coefficient of correlation	= 0.5842
No of Observations	= 35
Degrees of Freedom	= 30

X Coefficient (s) - 7.3E - 05 - 15E-05 0.003969-3.3E-08
Std Err of Coef. 0.000025 0.000026 0.00265 2.5E-07

IV. KESIMPULAN DAN SARAN

4.1. Kesimpulan

1. Konsentrasi polutan NOx di ruas jalan Kenjeran tersebut pada umumnya telah melampaui ambang batas yang ditetapkan (0.05) ppm yaitu rata-rata berkisar antara (0.051-0.070) ppm.
2. Kecenderungan tingginya kadar NOx di ruas jalan tersebut dipengaruhi oleh volume tinggi walaupun kecepatan rendah.
3. Hasil analisis statistik menunjukkan adanya hubungan yang cukup kuat/korelasi antara variabel data.
   Rata-rata volume lalu lintas di ruas jalan tersebut di atas yaitu antara 2319-32242 kendaraan, rata-rata kecepatan antara 36-44 km/jam dan rata-rata kepadatan lalu lintasnya antara 65-74 kendaraan/jam.

4.2. Saran-Saran

1. Tingginya konsentrasi polutan NOx di ruas jalan Kenjeran dapat membahayakan kesehatan manusia, oleh karena itu perlu direduksi konsentrasinya.
2. Perlu mulai dilakukan pengaturan lalu lintas, misalnya pemasangan lampu lalu lintas, sesuai dengan besarnya aliran lalu lintas yang masuk persimpangan untuk mereduksi kemacetan lalu lintas.
3. Pengaturan lalu lintas di persimpangan dengan menggunakan lampu lalu lintas diharapkan dapat berperan dalam mereduksi tingkat konsentrasi NOx.
4. Perlunya pengaturan parkir kendaraan agar tidak menyita badan jalan.

5. Variabel-variabel yang ada menunjukkan hubungan data yang kurang kuat, namun diyakini bahwa pengaruh tingginya konsentrasi NOx di udara dipengaruhi oleh kondisi lalu lintas (kecepatan dan kepadatan). Oleh karena itu perlu dilakukan penelitian lanjutan dan lebih mendalam mengenai tata laksana lalu lintas.
6. Perlu segera diadakan pelebaran jalan untuk meningkatkan kapasitas persimpangan mengingat ruas jalan tersebut merupakan daerah wisata pantai, dan dalam akses program yang sudah direncanakan diperuntukan diberbagai daerah.

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Penulis :

Drs. Ayi Tatang, Ajun Peneliti Muda Bidang Teknik Lalu Lintas dan Lingkungan Jalan, Pusat Litbang Jalan.

Lampiran 1.

PENGUKURAN KARAKTERISTIK LALU LINTAS DAN KONSENTRASI POLUTAN NOx DI RUAS JALAN KENJERAN

Hari : Senin

Waktu	Konsentrasi NOx (ppm)	Kendaraan Pribadi	Kendaraan Umum	Total	Kecepatan Km/Jam	Kepadatan/ Km
08.00 - 09.00	0.049	2111	734	2845	38	76
12.00 - 13.00	0.042	1983	1058	3041	40	77
13.00 - 14.00	0.052	2333	790	3123	42	74
16.00 - 17.00	0.064	1846	960	2806	37	76
17.00 - 18.00	0..090	1596	670	2266	35	64
Rata - rata	**0.059**	**1974**	**842**	**2816**	**38**	**73**

Hari : Selasa

Waktu	Konsentrasi NOx (ppm)	Kendaraan Pribadi	Kendaraan Umum	Total	Kecepatan Km/Jam	Kepadatan/ Km
08.00 - 09.00	0.059	2130	925	3055	40	77
12.00 - 13.00	0.048	1949	1063	3012	40	75
13.00 - 14.00	0.064	2310	810	3120	43	72
16.00 - 17.00	0.082	1826	997	2823	38	74
17.00 - 18.00	0..095	1625	644	2269	36	62
Rata - rata	**0.070**	**1968**	**888**	**2856**	**40**	**72**

Hari : Rabu

Waktu	Konsentrasi NOx (ppm)	Kendaraan Pribadi	Kendaraan Umum	Total	Kecepatan Km/Jam	Kepadatan/ Km
08.00 - 09.00	0.061	2218	716	2934	39	74
12.00 - 13.00	0.065	1994	1003	2997	40	75
13.00 - 14.00	0.015	2212	764	2976	40	74
16.00 - 17.00	0.038	1821	969	2790	38	74
17.00 - 18.00	0.078	1584	681	2265	35	64
Rata - rata	**0.051**	**1966**	**827**	**2792**	**39**	**72**

Hari : Kamis

W a k t u	Konsentrasi NOx (ppm)	Kendaraan Pribadi	Kendaraan Umum	T o t a l	Kecepatan Km/Jam	Kepadatan/ Km
08.00 - 09.00	0.055	2003	746	2749	37	74
12.00 - 13.00	0.063	1921	1041	2962	39	76
13.00 - 14.00	0.066	2276	745	3021	40	75
16.00 - 17.00	0.077	1934	979	2913	39	75
17.00 - 18.00	0.102	1540	694	2234	36	63
Rata - rata	**0.073**	1935	**841**	**2776**	**38**	73

Hari : Jumat

W a k t u	Konsentrasi NOx (ppm)	Kendaraan Pribadi	Kendaraan Umum	T o t a l	Kecepatan Km/Jam	Kepadatan/ Km
08.00 - 09.00	0.065	2216	771	2987	40	76
12.00 - 13.00	0.077	2082	1111	3193	44	73
13.00 - 14.00	0.020	2450	823	3273	44	74
16.00 - 17.00	0.038	1938	1008	2946	39	76
17.00 - 18.00	0.068	1676	703	2379	36	66
Rata - rata	**0.054**	**2072**	**883**	**2956**	**41**	73

Hari : Sabtu

W a k t u	Konsentrasi NOx (ppm)	Kendaraan Pribadi	Kendaraan Umum	T o t a l	Kecepatan Km/Jam	Kepadatan/ Km
08.00 - 09.00	0.048	2385	829	3214	44	73
12.00 - 13.00	0.059	2241	1196	3437	46	75
13.00 - 14.00	0.034	2636	1085	3721	46	81
16.00 - 17.00	0.070	2123	1104	3227	44	73
17.00 - 18.00	0.096	1839	771	2610	37	70
Rata - rata	**0.061**	2245	997	3242	44	74

Hari : Minggu

W a k t u	Konsentrasi NOx (ppm)	Kendaraan Pribadi	Kendaraan Umum	T o t a l	Kecepatan Km/Jam	Kepadatan/ Km
08.00 - 09.00	0.044	1794	624	2418	36	67
12.00 - 13.00	0.030	1686	526	2212	35	63
13.00 - 14.00	0.048	1983	672	2655	37	71
16.00 - 17.00	0.060	1569	816	2385	36	67
17.00 - 18.00	0..091	1357	570	1927	34	56
Rata - rata	**0.055**	**1678**	642	2319	36	65

EFFECTS OF STATE AND ENVIRONMENTAL FACTORS ON ELASTIC PARAMETERS OF ANISOTROPIC SUBGRADE MATERIAL

Kemas Ahmad Zamhari

RINGKASAN

Dalam kenyataan, bahan perkerasan tidak hanya nonlinear dan inelastik tetapi juga anisotropik. Ini berarti bahwa bahan mempunyai karakteristik yang berbeda dalam berbagai arah. Bentuk paling sederhana dari anisotropi adalah cross-anisotropy dimana bahan mempunyai suatu sumbu simetri. Diperlukan lima parameter elastik untuk menunjukkan anisotropi bahan cross-anisotropic. Parameter yang demikian banyak menimbulkan kesulitan tersendiri dalam pengukurannya. Akibatnya, usaha untuk mengukur karakteristik yang riel dari bahan anisotropik menjadi sangat langka.

Salah satu pendekatan praktis yang dapat dilakukan untuk mengukur lima besaran elastik dari bahan tanah dasar yang cross-anisotropic diperkenalkan oleh Graham dan Houlsby. Pendekatan itu melibatkan prosedur pengukuran di laboratorium yang menggunakan alat uji true-triaxial berbentuk kubus dengan pembebanan berulang. Dalam makalah ini pendekatan dan alat uji tersebut diuraikan secara ringkas.

Selanjutnya, pendekatan dan prosedur pengujian tersebut diterapkan pada suatu bahan tanah dasar. Rancangan penelitian memungkinkan dilakukannya analisa statistik pada tiga tingkat kepadatan, dua tingkat kejenuhan, dan dua cara pemadatan. Dengan demikian, diperoleh gambaran mengenai pengaruh faktor-faktor tersebut terhadap kelima parameter elastik dari bahan tanah dasar.

SUMMARY

In reality, pavement materials are not only inelastic and nonlinear but are also anisotropic. The latter means that their characteristics differ according to direction. The simplest form of material anisotropy is cross-anisotropy where the material has an axis of symmetry of rotation. Five elastic constants are required to describe cross-anisotropic material. So far, due to the complexity of the problems, there have been few attempts to measure the true properties of anisotropic pavement materials.

A practical approach introduced by Graham and Houlsby enabled determination of the five elastic constants required to describe material anisotropy. The technique required the use of a repeated loading cubical-true-triaxial test apparatus. The approach and related laboratory procedure are briefly described.

The technique was applied on a selected subgrade material. The experimental design allowed three levels of density, two levels of saturation, and two methods of compaction to be analysed statistically. The results allowed the identification of the effects of physical factors to the five elastic parameters.

I. INTRODUCTION

The complexity of road pavements has necessitated the simplification of the mathematical models used to described the system. The models represent an idealisation of the real pavement. Linear elastic theory, being the simplest approach, has been used extensively for pavement analysis. Current advancement in computers and numerical techniques have enabled increasingly realistic models of material behavior to be incorporated into the solutions of boundary value problems. Solutions, based on a simple linear isotropic elastic have been supplemented by solutions embracing inelasticity and nonlinearity.

In reality, however, pavement materials are not only inelastic and nonlinear but are also anisotropic. The latter means that their characteristics differ according to direction. The simplest form of material anisotropy is cross-anisotropy where the material has an axis of symmetry of rotation. The elastic properties of such a material are equivalent in all directions perpendicular to the axis of symmetry but differ, in general, from those in a direction parallel to the axis.
Australia is the first country in the world to adopt material anisotropy in its national road pavement design procedure [1]. The policy was based on a fundamental assumption that all unbound materials are cross-anisotropic. This policy was stimulated by development of a computer program, CIRCLY, by the Commonwealth Scientific and Industrial Research Organisation of Australia (CSIRO) [2]. The program enables the analysis of the response of multilayered cross-anisotropic media under multiple complex circular loads to be calculated.

Since it was firstly introduced in 1987 many engineers became accustomed to assuming that unbound materials are anisotropic. Nevertheless, there have been few attempts to measure the true properties of anisotropic pavement materials. Meanwhile, for an unclear reason, Australia seemed to confined to an assumption that all unbound materials to have a degree of anisotropy of two.

The work describe in this paper intended to address the problem. It embraced a study on the effects of physical state conditions on the cross-anisotropic elastic behavior of typical subgrade material.

II. MATHEMATICAL MODEL AND LABORATORY PROCEDURE

The constitutive equation of an elastic cross-anisotropic material in a three-dimensional space may be written as:

$$[\sigma_{ij}] = [S_{rs}][\varepsilon_{ij}] \qquad (1)$$

Where elasticity stiffness matrix $[S_{rs}]$ consists of five independent elastic constants. In order to be able to determine the five elastic constants, a laboratory test apparatus should have the capability to vary all three of the normal stresses as well at least two shear stresses. None of the currently existing apparatus is capable to fulfilling the requirements to fully characterised cross-anisotropic materials such as that given by Equation (1) unless assumptions are made regarding further relationships between the five elastic constants. This has been discussed in detail elsewhere [3].

Graham and Houlsby [4] proposed a model that considers cross-anisotropy to be a special case of isotropy, by multiplying the stiffness coefficients to change the stiffness material in the horizontal direction by anisotropy factor. This is followed by multiplying the second and third columns by the same factor to fulfill the requirement of symmetrical matrix. This implies that the equation for isotropic material under a cubical true triaxial test (in which three normal stresses can be varied independently but no shear stresses applied), becomes :

$$\begin{bmatrix} \delta\sigma_1 \\ \delta\sigma_2 \\ \delta\sigma_3 \end{bmatrix} = \begin{bmatrix} A & \alpha B & \alpha B \\ \alpha\ B & \alpha^2\ A & \alpha^2\ B \\ \alpha\ B & \alpha^2\ B & \alpha^2\ A \end{bmatrix} \begin{bmatrix} \delta\varepsilon_1 \\ \delta\varepsilon_2 \\ \delta\varepsilon_3 \end{bmatrix} \qquad (2)$$

An extension of Eq. (2) into Eq. (1) implies an interrelation between the five independent elastic constants,

$$[D/B]^2 = C/A = [(C-D)\ F]^2 = \alpha^2 \qquad (3)$$

The value of α determines the material anisotropy. That is, the material is isotropic if = 1; it is stiffer horizontally if < 1; and it is stiffer vertically if > 1.

A substitution of the interrelationship (3) into the compliant matrix of the Generalised Hook's law for cross-anisotropic material in engineering terms established the following relationship :

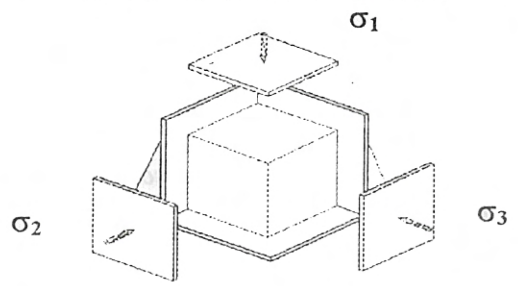
$$\begin{aligned} E_v &= E^* \\ E_h &= \alpha^2\ E^* \\ \upsilon_{vh} &= \upsilon^*/\alpha \\ \upsilon_{hh} &= \upsilon^* \\ 2G_{vh} &= \alpha\ E^*/(1+\upsilon) \qquad (4) \end{aligned}$$

Eq. (4) shows that the five elastic constants, E_v, E_h, υ_{vh}, υ_{hh} and G_{vh} are now reduced to E^*, υ^*, and α. For a cubical true-triaxial, the compliant of Eq. (3) is,

$$\begin{bmatrix} \delta\varepsilon_1 \\ \delta\varepsilon_2 \\ \delta\varepsilon_3 \end{bmatrix} = \frac{1}{E^*} \begin{bmatrix} 1 & -\frac{\upsilon^*}{\alpha} & -\frac{\upsilon^*}{\alpha} \\ -\frac{\upsilon^*}{\alpha} & \frac{1}{\alpha^2} & -\frac{\upsilon^*}{\alpha^2} \\ -\frac{\upsilon^*}{\alpha} & -\frac{\upsilon^*}{\alpha^2} & \frac{1}{\alpha^2} \end{bmatrix} \begin{bmatrix} \delta\sigma_1 \\ \delta\sigma_2 \\ \delta\sigma_3 \end{bmatrix} \qquad (5)$$

This expression (5) is a three-unknow-in-three-equation problem. It suggests that a cubical true-triaxial test is the ideal apparatus for determining the three unknown elastic parameters.

Figure 1
REPEATED LOADING TRUE TRIAXIAL TEST



A new repeated-loading-cubical-true-triaxial-test equipment was developed for this experiment. The system employed only three platens loaded by three mutually-perpendicular pneumatic jacks. Three reaction walls were placed in the opposite side of each loading platen. Figure 1 presents the basic principle of this equipment. It consisted of an advanced pneumatic loading system which was controlled through a personal computer. The system provided a versatile control of forces in three perpendicular directions, enabling a good, if incomplete, simulation of the in-situ stress conditions in pavement. In brief the whole operation of the true-triaxial test equipment may be described as follows:

The required load histories were programmed into the computer which then generated the required electronic command signal for input to the Force Control Module. The loads were then applied to the test specimen by pneumatic actuators which were controlled precisely by a closed-loop servo system incorporating the electric servo-valves, the load cells,

the major principal stress. Thus the test specimen was subjected to major principal stress in its vertical position for the whole test series. It is believed that this is arrangement is a reflection of in-situ stress condition.
Before the design stress state was set, the test specimen was subjected to 50 isotropic principal stresses applications of 50 kPa. The purpose of this conditioning load was twofold. Firstly, it functioned as the sample and equipment conditioning. Secondly, the elastic strains measured during this stage indicated the stiffness of the specimen in the three directions. The latter was important for determining which horizontal actuator was to act as the intermediate and which one as the minor principal stresses.

Experimental Results and Discussion. The effects of the initial density and saturation on the elastic parameters are presented in Table 1. The design of experiment allowed three levels of density and two levels of saturation (Sr = 65% and 85%) to be analysed statistically. Typical analysis of variance of this data is summarised in Table 2. The effects of each variable are considered in detail in the following section.

Table 1

THE EFFECTS OF MATERIAL STATE ON ELASTIC PARAMETERS at 10,000 STRESS APPLICATIONS

State Conditions		Static Compaction			Dynamic Compaction		
γd (t/m^3)	Sr (%)	n (Ev/Eh)	Ev (MPa)	υ_{vh}	n (Ev/Eh)	Ev (MPa)	υ_{vh}
	65	1.39	135	0.444	1.36	174	0.428
1.78	75	1.20	127	0.390	1.14	122	0.363
	85	1.36	112	0.446	1.09	115	0.348
	65	1.16	215	0.334	1.33	182	0.451
1.88	80	1.08	177	0.395	1.34	175	0.468
	85	1.12	180	0.412	1.24	164	0.448
	65	1.23	286	0.392	1.34	270	0.426
1.98	85	1.18	331	0.393	1.37	287	0.492
	97	1.01	210	0.39	1.33	215	0.506

Effects of the number of stress applications. The elastic strains were found to be relatively unaffected by an increase in the number of stress applications. A tendency for increases in the major principal strain was found at relatively high saturation, this is mostly related to static compaction. However, these variations were small. After about 2000 stress applications the strains were practically constant with a further increase in the number of stress applications. As a consequence, it may be postulated that the effects on the elastic parameters were not affected in the long term by increases in the number of stress applications. This is confirmed by an analysis of variance, as summarised in Table 3.

This table shows that the effects of the number of stress applications, either as a single factor or in terms of a two-way interaction between the states factors, were statistically insignificant. An evaluation of the results as a whole showed that, within the domain of the number of stress applications, the largest differences between the maximum and minimum values of E_v, υ_{vh}, and the degree of anisotropy, n, were 20%, 15% and 11% respectively. On average, the differences were not more than 7%. It was therefore considered reasonable to limit the observation to the condition related to the highest number of stress applications (i.e. N = 10,000 stress applications).

Figure 3 presents typical test result on the effects of material state on the elastic constants at 10,000 stress applications at the saturation, Sr, of 85%.

Table 2

Typical Analysis of Variance on Effects of Initial State and Number of Stress Applications on Elastic Parameters. Dependent Variable: Degree of Anisotropy, n (= Ev/Eh)

Source of Variation	Sum of Squares	DF	Mean Square	F	p(F)	Significant at (%)
Variables black	0.234	8	0.029.	19.137	0.000	1
Compaction Method (C.M)	0.013	1	0.013	8.450	0.007	1
γ_d	0.184	2	0.092	60.152	0.000	1
Sr	0.036	1	0.036	23.261	0.000	1
N(Stress Rept.)	0.002	4	0.000	0.271	0.894	NS
2-way interactions	0.477	21	0.023	14.885	0.000	1
C.M-γ_d	0.313	2	0.157	102.520	0.000	1
C.M-Sr	0.005	1	0.005	3.422	0.074	10
C.M-N	0.002	4	0.001	0.389	0.815	NS
γ_d *-Sr*	0.135	2	0.068	44.235	0.000	1
γ_d *- N*	0.018	8	0.002	1.479	0.206	NS
Sr - N	0.003	4	0.001	0.566	0.689	NS
Residual	0.711	29	0.025	16.058	0.000	1
Residual	0.046	30	0.002			
Total	0.757	59	0.013			

Effects of Initial Density. Within the range of the experimental saturation, irrespective of the methods of compaction, the stiffness in the vertical direction, E_v, tended to increase with an increase in the initial density.

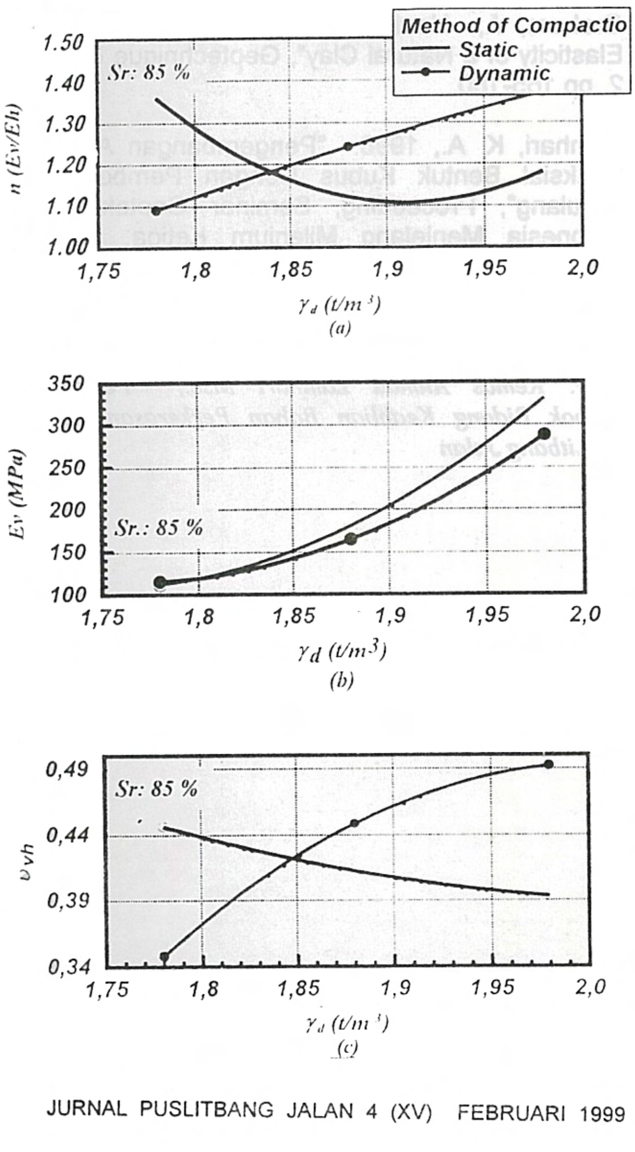
The effects of the initial density on the Poisson's ratio were dependent on both the methods of compaction and the degree of saturation. The test specimen prepared under dynamic compaction and a relatively high degree of saturation had a Poisson's ratio which tended to increase with an increase in the initial density. By contrast, irrespective of the degree of saturation, those samples prepared under static compaction had a Poisson's ratio which decreased with an increase in the initial density.

The effects of the initial density on the degree of anisotropy, n, were similar to those of the Poisson's ratio, υ_{vh}. That is, n tended to decrease with an increase in the initial density for the sample prepared under static compaction, and tended to increase for the sample prepared under dynamic compaction at a higher degree of saturation. This phenomenon was probably reflected the interrelated effects of the density, the methods of compaction and the degree of saturation on the alignment of soil particles which, in turn, determined the degree of anisotropy.

Effects of Saturation. Regardless the method of compaction, and for almost all levels of initial density, the vertical stiffness, E_v, tended to decrease with an increase in the degree of saturation.

By contrast, the effects of saturation on the Poisson's ratio, υ_{vh}, were dependent on the method of compaction and the dry density. Within the saturation domain, the Poisson's ratio, υ_{vh}, of statically compacted specimens (to standard and intermediate densities) tended to increase with an increase in the degree of saturation. The test specimens prepared by dynamic compaction (to standard and intermediate densities) had Poisson's ratios, υ_{vh}, which decreased with an increase in the degree of saturation. However, at the maximum modified dry density, the Poisson's ratio remained constant with a variation of the saturation regardless of the methods of compaction. Irrespective of the methods of compaction, the degree of anisotropy, n, tended to decrease with an increase in saturation.

Figure 3
EFFECTS OF MATERIAL STATE ON ELASTIC PARAMETERS
[i.e. Vertical Stiffness Modulus (E_v), Degree of Anisotropy (n), and Poisson's Ratio (υ_{vh})] at Sr = 85%



Effects of the Method of Compaction. The experimental results showed a very strong similarity for the variation of the vertical stiffness, E_v, with the density between the two methods of compaction. A closer observation suggested that it was possible to expect a higher vertical stiffness for statically compacted soil, as was reported by others. However, the variation was so small so it did not reflected in the analysis of variance. Furthermore, the associated stress level required to yield such a condition was perhaps lay below the stress state which was used in this experimental work.
A distinction should be made between the test specimens prepared at different saturations, regarding the effects of the methods of compaction on the Poisson's ratio, υ_{vh}. At relatively low saturations, for a given density, the Poisson's ratio, υ_{vh}, approached similar values for both methods of compaction. By contrast, at a higher saturation, the specimens prepared by dynamic compaction had a Poisson's ratio, υ_{vh}, which increased with an increase in density, whilst the specimen prepared by static compaction had a Poisson's ratio, υ_{vh}, which increased with an increase in the initial density.

The effects of the methods of compaction on the degree of anisotropy, n, were similar to the effects on the Poisson's ratio, υ_{vh}. This meant, very small effects at lower saturations and marked effects at high saturations. At high saturations, the static compaction tended to yield to increase in the degree of anisotropy with an increase in density. By contrast, the dynamic compaction tended to yield a decrease in the degree of anisotropy with an increase in density.

No direct observation of the orientation of the clay fabric was made in this experimental work. However, it is believed that the variation of the elastic response of test specimens for different methods of compaction may be attributed to differences in the clay fabric of the soil, caused by different methods of compaction.

IV. CONCLUSIONS

The experimental work reported in this paper concerned the development of the characterisation procedure of anisotropic pavement materials. The work was focussed on cross-anisotropic subgrade soils. One of the aims of the experiment was to study the effects of the physical conditions on the elastic behavior of cross-anisotropic subgrade soils. The effects were studied under a constant stress state.

The Graham and Houlsby elastic-cross-anisotropic matrix equation was established by multiplying the stiffness coefficients of an isotropic material by the factor of anisotropy, α, to increase or decrease stiffness in one direction relative to the others. This approach reduced the number of the cross-anisotropic elastic parameters from five to three, i.e. by adding a new factor, α, to the two isotropic elastic parameters. The 3x3 matrix equation of principal stresses made the cubical true-triaxial test the ideal apparatus for determining the elastic cross-anisotropic parameters. The proposed matrix equation had been proven to yield admissible cross-anisotropic elastic parameters.

Because more than one factor was studied, the work was designed to be a factorial experiment. An analysis of variance was used to examine the results. The analysis was applied, essentially, as a guide to the reliability of the conclusions derived from the experiments. It was demonstrated that this approach permits the examination of the relative significance of the effects of various physical state factors on any elastic parameter required to describe cross-anisotropic material.

V. LIST OF PRINCIPAL NOTATION

E^* : modified Young's Modulus

E_h : modulus of elasticity in the horizontal direction

E_V : modulus of elasticity in the vertical direction

G_{VH} : shear modulus of cross-anisotropic material

G^* : modified shear modulus

k : octahedral stress ratio, $K = \dfrac{\delta\tau_{oct}}{\delta\sigma_{oct}}$

n : degree of anisotropy, $n = \dfrac{E_v}{E_h}$

$\delta\varepsilon_i$: incremental recoverable principal strain; i = 1, 2, 3

$\delta\sigma_i$: incremental principal stress, i = 1, 2, 3

$\delta\sigma_{oct}$: incremental octahedral normal stress, $\delta\sigma_{oct} = (\delta\sigma_1 + \delta\sigma_2 + \delta\sigma_3)/3$

$\delta\tau_{oct}$: incremental octahedral shear stress, ($\delta\tau_{oct} = \sqrt{[(\delta\sigma_1 - \delta\sigma_2)^2+(\delta\sigma_2 - \delta\sigma_3)^2+(\delta\sigma_3 - \delta\sigma_1)^2}]/3$

γ_d : dry density

υ^* : modified Poisson's ratio

υ_{hh} : Poisson's ratio, effect of horizontal strain on complimentary horizontal strain

υ_{vh} : Poisson's ratio, effect of vertical strain on horizontal strain

ζ : Nadai-Lode stress parameter (in terms of incremental principal stresses) $\zeta = (2\delta\sigma_2 - \delta\sigma_1 - \delta\sigma_3 / (\delta\sigma_1 - \delta\sigma_3)$

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