# ESTIMATION OF APPARENT ELASTIC MODULUS OF CONCRETE BLOCK LAYER

A. Kasahara

Hokkaido Institute of Technology, Sapporo, Hokkaido, Japan

S. Matsuno

Interlocking Block Association, Tokyo, Japan

SUMMARY

A load spreading capacity of concrete block layer is one of the most important factor for establishing a theoretical design of concrete block pavements. The load spreading capacity of a structural layer of the pavement would be evaluated with a magnitude of an in situ elastic modulus of each layer. The conceret block pavement and asphalt pavement, both of which have same types of subbase and subgrade, were paved for FWD deflection survey. This paper describes the estimating procedures of an apparent elastic modulus of the concrete block layer. This modulus is the imaginary modulus under the assumption that the layer, consisting of both the concrete block and the sand bed, is made of only one combined material. First, the elastic moduli of the crushed stone subbase and subgrade in the concrete block pavements were estimated from deflection data on the asphalt treated base or asphalt binder course. Second, the apparent elastic moduli of the concrete block layer would be estimated with BISAR results and deflection data on the concrete block layer until six weeks from opening to traffic.

## 1. INTRODUCTION

Concrete block pavement has been designed by an experience procedure. It is aimed that a national design method should be established. A load spreading capacity of the concrete block layer is one of the most important factor for the theoretical design on the concrete block pavement. The load spreading capacity of a structural layer in a pavement will be generally evaluated by a magnitude of an in situ elastic modulus of each layer. Some studies [1,2,3] have been carried out on the estimation of the elastic modulus of the concrete block layer by deflection measurements. Those estimated elastic moduli of the concrete block layer varied from 415MPa [4] to 8000MPa [5]. It was reported by Reuben L.J.M. st al. [3] that elastic moduli of concrete block layer increased from 200MPa to 4000MPa, depending on the number of equivalent 80KN standard axle loads. It may be indicated that the elastic modulus of the concrete block layer essentially shows a wide variation.

In this study, the asphalt pavement and concrete block pavement, both of which have same pavement structure under the road surface, were paved for the test of the deflection measurements. The thickness of both road sur faces was 100mm. The deflections were measured by a falling weight deflectometer (FWD). The deflection of the concrete block pavement was compared with the deflection of the asphalt pavement. An apparent elastic modulus of both the concrete block layer (80mm thick) and a sand bed (20mm thick) would be estimated by means of the multi-layered systems using the FWD defelections data.

The apparent elastic modulus of concrete block layer, here used, is the imaginaly modulus under the assumption that the layer, consisting of both the concrete block (80mm thick) and the sand bed (20mm thick), is made of only one combined material as shown in Figure 2(a) and Figure 3(a). "A.E.M." is abridged from the apparent elastic modulus of the concrete block layer.

The A.E.M. was estimated with the simplified three or four layered system. The estimating procedures are shown as follows;

1) The deflection data are collected by FWD on the asphalt layer.
2) The pavement is simplified as the three layered system which consist of asphalt layer, subbase and subgrade.
3) Those elastic moduli of the subbase and the subgrade of the pavement are estimated with BISAR [6] using the deflection data.
4) The A.E.M is estimated with BISAR results and deflection data on the concrete block layer - the elastic moduli of the subbase and the subgrade of concrete block pavement are obtained in the previous step.

## 2. PAVEMENT STRUCTURE

The test road was constucted in 1987 at Sapporo city, Hokkaido. The road has same tyes of subbase and subgrade in both concrete block pavement and asphalt pavement. The objective is to compare the load spreading capasity of the concrete block layer with that of the as phalt layer. The concrete block pavement is located in a straight section of a shopping street which consists essentially of a 6m wide carriage-way with 2.45m wide footpaths both side. Each pavement has an overall length 270m, divided into four 50-87.5m long sections (Figure 1). Each cross section of the pavement structure is shown in Figure 2(a) and 3(a).

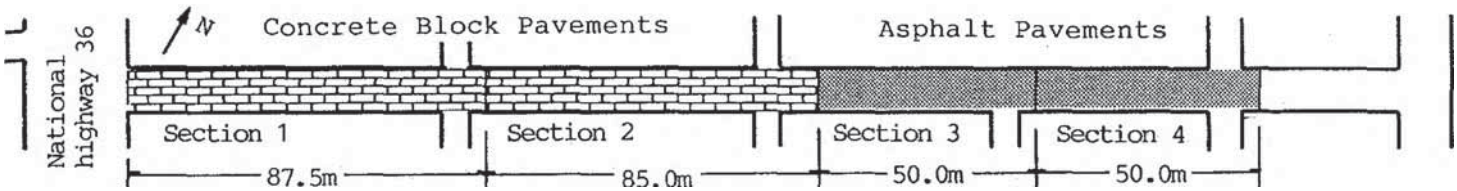



Figure 1 Plane of test pavements at Sapporo city

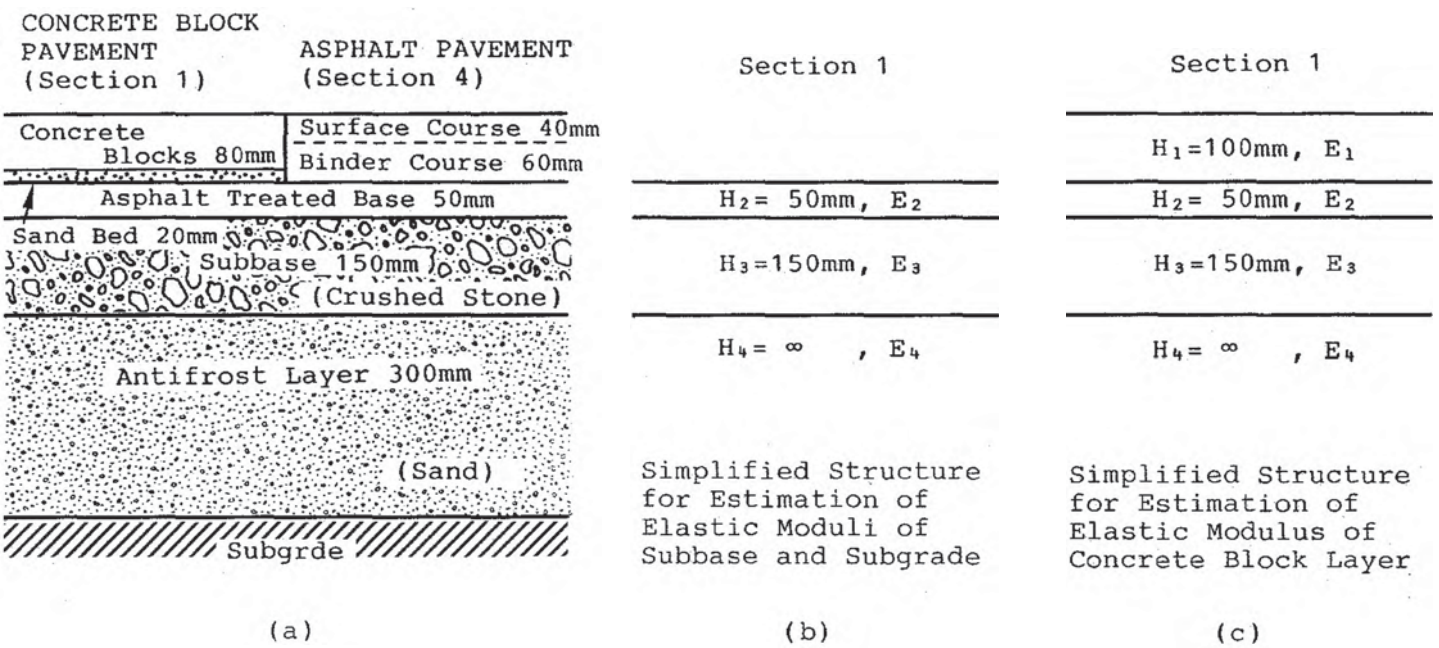



Figure 2 Cross sections of concrete block pavement (section 1) and asphalt pavement (section 4) with asphalt treated base

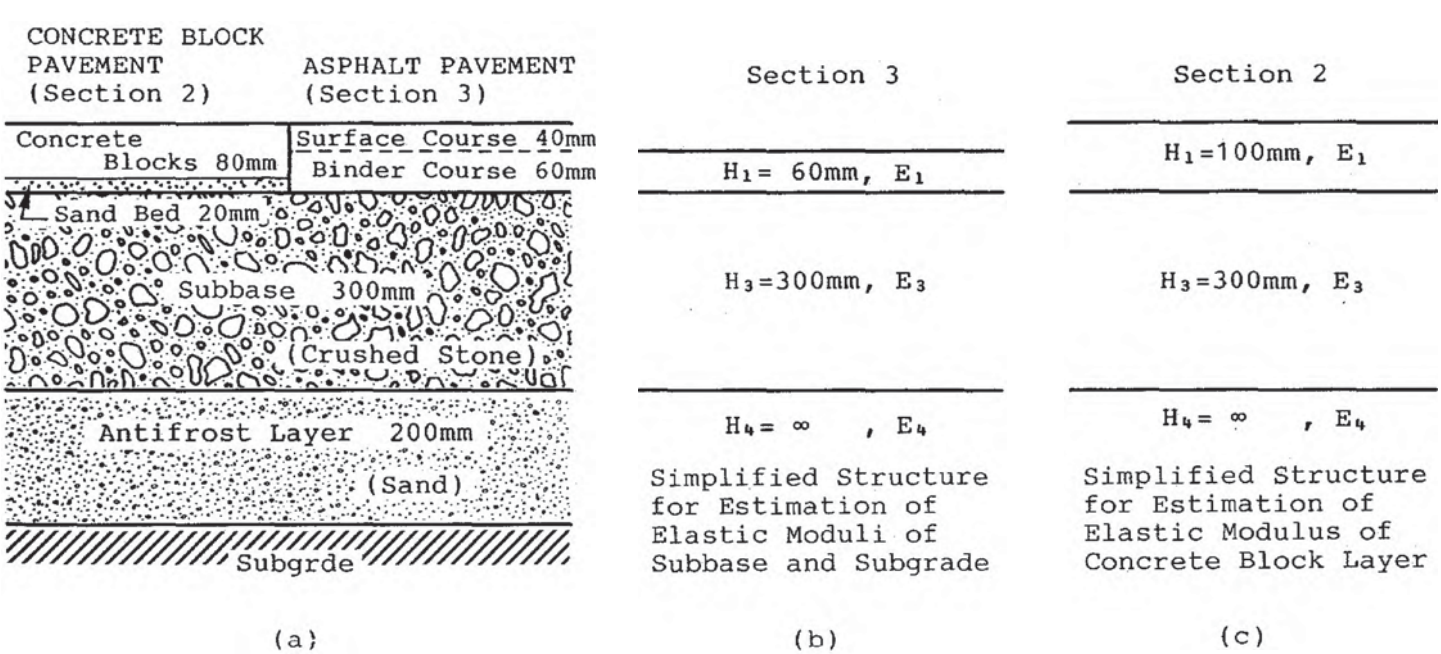



Figure 3 Cross sections of concrete block pavement (section 2) and asphalt pavement (section 3) without asphalt treated base

Section 1 and 4 in Figure 2 have the asphalt treated base (50mm thick) and the crushed stone subbase (150mm thick). Section 2 and 3 in Figure 3 have only crushed stone subbase (300mm thick). The size of the concrete block is of 100mm width, 200mm length and 80mm thick. The thickness of the sand bed is 20mm. The thickness of the road surface of the concrete block layer with the sand bed 100mm. Therefore the asphalt mixture surface, which is the same thickness of the concrete block layer, was paved.

In a cold resion of Japan, the required replacement thickness against a frost heave is 70% of the theoretical maximum frost penetration depth, which is calculated by the freezing index (°C days) [7], The thickness of the antifrost layer, which is not included in the designed thickness of pavement, is regarded as a part of the subgrade.

## 3. MEASUREMENT OF DEFLECTION ON ASPHALT LAYER

### 3.1 Falling Weight Deflectometer

Phonix type FWD (ML5000) as shown in Figure 4 was used for the deflection survey. The maximum of loading capacity of the FWD is 50KN and the radius of the loading plate is 150mm. This instrument can measure deflections at the center of the loading plate ($d_0$) and also at the point 300mm and 750mm off the center ($d_{300}$ and $d_{750}$).

### 3.2 Results of Deflection Measurement

In the section 1 and 4 of the test road, deflection measurements were carried out on the asphalt treated base (50mm thick) to estimate the in situ elastic moduli of subbases and subgrades in each section. The deflection data in the section 3 were obtained on the asphalt binder course (60mm thick). In the section 2, no deflection data were collected on the crushed stone subbase which was the unbonded layer. The subbase was not restrainted by the asphalt layer.

Table 1 shows mean values and standard deviations (σ) of twenty deflection data in each section. The representative temperature of the asphalt layer is the one at the bottom of small hole which was dug by an electric drill up to the half of thickness of the layer.



Figure 4 Falling weight deflectometer

## 4 ELASTIC MODULI OF SUBBASE AND SUBGRADE

The estimation method of in situ elastic moduli of both the crushed stone subbase ($E_3$) and the Subgrade ($E_4$) in the section 1,4 and 3 is as follows [8];

1) The pavement is stratified into three layers as shown in Figure 2(b) and Figure 3(b).
2) The elastic modulus of asphalt layer ($E_1$) is estimated from a relationship between the elastic moduli of asphalt mixtures and temperatures (Figure 5) [8], The moduli were obtained by the dynamic indirect tensile test [9] coresponding to the loading time of the FWD. In Figure 5, the value of E1 will be determined from the temperature of the asphalt layer.

Table 1 Deflection data on asphalt treated base (Section 1 and 4) and asphalt binder course (Section 3)

| Pavement section no. | Deflections (mm) | | | | | | Applied load (KN) | Temperature of asphalt layer (°C) |
|---|---|---|---|---|---|---|---|---|
| | $d_0$ | σ | $d_{300}$ | σ | $d_{750}$ | σ | | |
| 1 | 1 .680 | 0.215 | 0.959 | 0.130 | 0.382 | 0.065 | 34.90 | 22.6 |
| 4 | 1 .790 | 0.128 | 1 .096 | 0.061 | 0.475 | 0.022 | 42.36 | 22.6 |
| 3 | 1 .237 | 0.080 | 0.772 | 0.059 | 0.352 | 0.020 | 37.30 | 22.6 |

3) For the applied load at the time of the deflection measurements, the theoretical deflections were calculated at three locations - the center of the loading plate ($D_0$), the point 300mm off the center ($D_{300}$) and the point 750mm off the center ($D_{750}$). The BISAR was applied to the calculation. The calculation was carried out, changing the elastic moduli of the subbase ($E_3$) and the subgrade ($E_4$) in iteration. A example is shown for the diagram in Figure 6 in which the ordinate represents ($D_{300}$-$D_{750}$) and the abscissa represents $D_{750}$ with parameters of $E_3$ and $E_4$.

4) The co-ordinate of the value of the measured deflection ($d_{750}$, $d_{300}$-$d_{750}$) is plotted as shown in Figure 6. Thus both of $E_3$ and $E_4$ can be estimated by the interpolation.

The elastic moduli of the crushed stone subbase ($E_3$) and the subgrade (E-.) in the section 3 were estimated in same procedure (Figure 7). The estimated elastic moduli of subbases and subgrades in section 1 , 4 and 3 are shown in Table 2. Table 3 shows the comparison between the deflections measured by the FWD and the deflections calculated by BISAR from the estimated elastic moduli in each section. The table may indicate that the elastic moduli of each layer are appropriate.

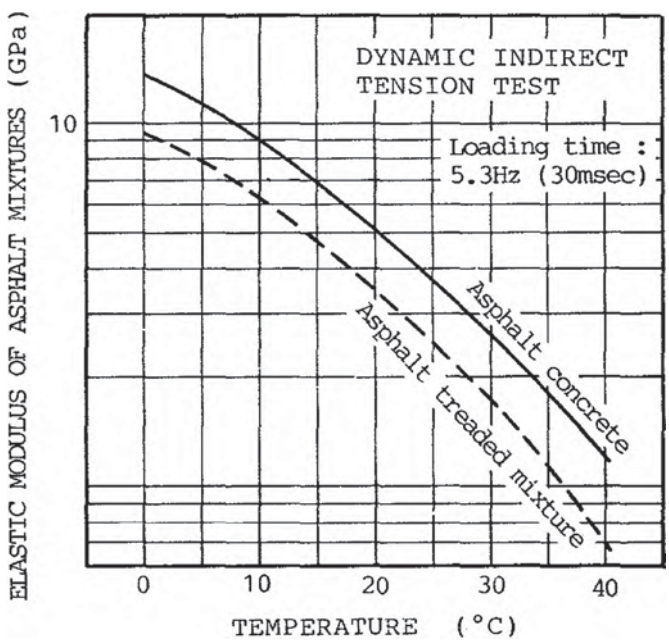



Figure 5 Elastic modulus of asphalt layer

Table 2 Estimated elastic moduli of subbase and subgrade, (MPa)

| | Asphalt layer | Subbase | Subgrade |
|---|---|---|---|
| Section 1 | 3,000 | 90 | 34 |
| Section 4 | 3,000 | 90 | 35 |
| Section 3 | 4,000 | 82 | 39 |

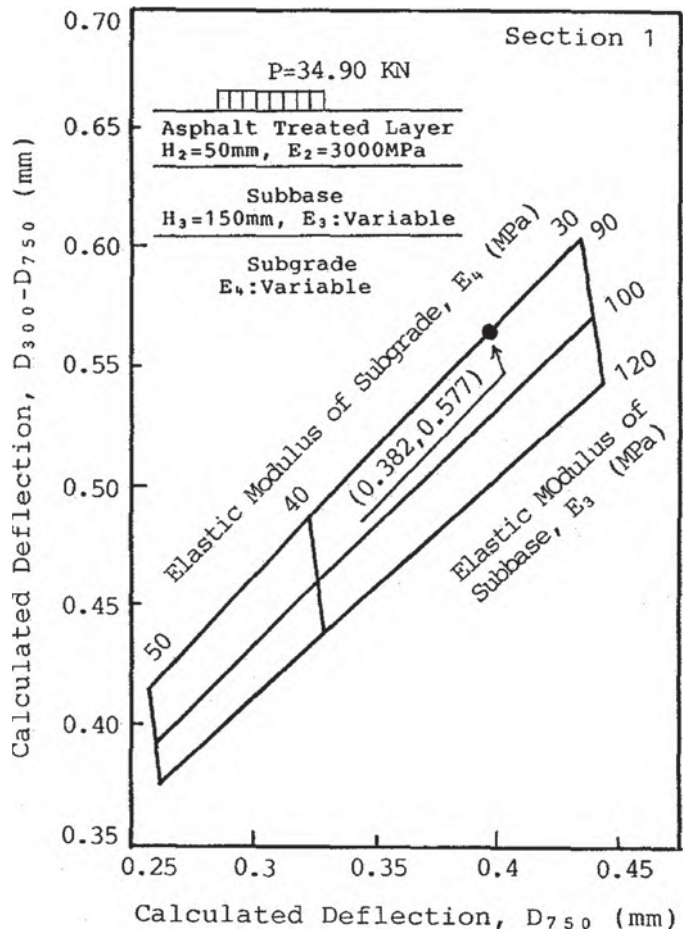



Figure 6 Estimation of elastic moduli of subbase and subgrade in section 1

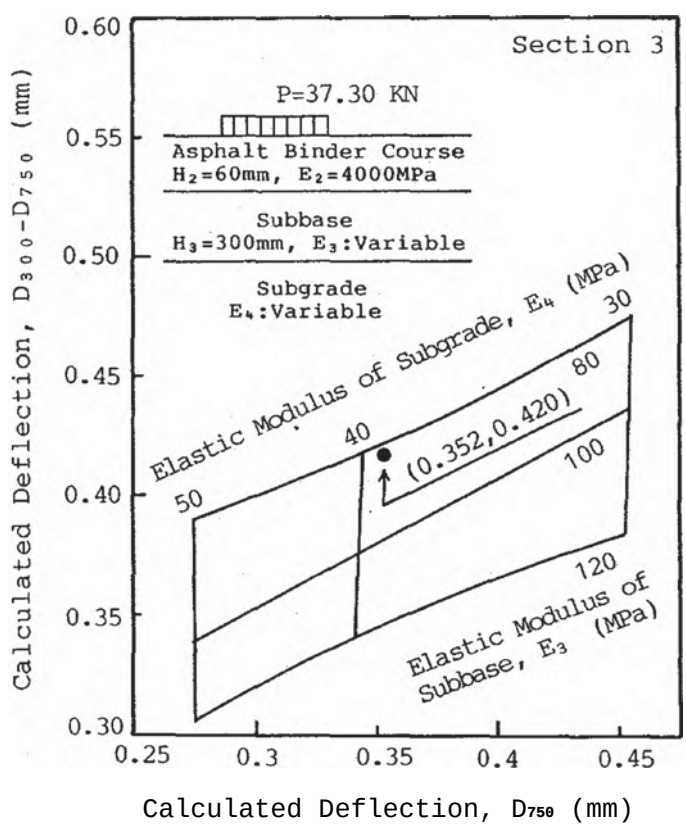



Figure 7 Estimation of elastic moduli of subbase and subgrade in section 3

Table 3 Measured deflections and calculated deflections, (mm)

| | | $d_0$ | $d_{300}$ | $d_{750}$ |
|---|---|---|---|---|
| Section 1 | M | 1.680 | 0.959 | 0.382 |
| | C | 1.670 | 0.921 | 0.385 |
| Section 4 | M | 1.790 | 1.096 | 0.475 |
| | C | 1.990 | 1.090 | 0.453 |
| Section 3 | M | 1.237 | 0.772 | 0.352 |
| | C | 1.300 | 0.771 | 0.352 |

M : Measured, C : Calculated

## 5. ELASTIC MODULUS OF CONCRETE BLOCK LAYER

### 5.1 Deflection of Concrete Block Pavement

The load spreading property of concrete block layer will increase with the traffic loading [3]. The deflection data in the inner wheel track had been collected on two concrete block pavements (section 1 and 2) until six weeks after opening to traffic. The deflection data of both concrete block pavements and asphalt pavements (section 3 and 4) are shown in Table 4. The deflections of concrete block pavement decrease with weeks elapsing. After six weeks, the deflections of concrete block pavement were about 50% larger than the deflections of asphalt pavement subjected to relatively high temperatures. The traffic volume (Vehicles/ direction•day) on the test road was 1400 of passenger cars and 26 of light commarcial cars. The number of equivalent 100KN standard axle load in a day will be approximately 2.

### 5.2 Elastic Moduli of Concrete Block Layer in Pavement with Asphalt Treated Base

The elastic moduli of the subbase and the subgrade were estimated correspondingly as 80MPa and 35MPa in the section 1. The elastic modulus of the asphalt treated base was determined from the temperature of the asphalt treated base (Figure 5). The deflections were measured on the concrete block pavement by the FWD. In same conditions, the theoretical deflections ($D_0$) are calculated with BISAR in the four-layered system as shown in Figure 2(c). The A.E.M., corresponding to the measured deflections ($d_0$) at the center of the loading plate, would be found in Figure 8. Using the same procedures, the values of A.E.M. were obtained at each week.

### 5.3 Elastic Moduli of Concrete Block Layer in Pavement with Unbounded Subbase

The elastic moduli of the subbase and the subgrade in the section 2 would be equal to these of the subbase and the subgrade in the section 3. The deflections were measured on the concrete block pavement (section 2) by the FWD. In same conditions, the theoretical deflections ($D_0$) are calculated by BISAR, varying values of the A.E.M.($E_L$). The relationship between the calculated deflection in three layered system in Figure 3(c) and the A.E.M. is shown in Figure 9. The value of A.E.M., corresponding to the measured deflection at the center of the loading plate ($d_0$), would be found in Figure 9. Using the same procedures, the values of A.E.M. we-re obtained at each week.

The estimated values of A.E.M. are shown in Table 5. The A.E.M. increases with the weeks elapsing. The A.E.M. on the asphalt treated base is about 50% of that on the crushed stone subbase.

Table 4 Measured deflections of concrete block pavements (Section 1 and 2) and asphalt pavemnts (Section 3 and 4)

| Section no. | Time/ weeks | Deflection (mm) | | | | | | Applied load (KN) | Temp, of asphalt layer (°C) |
|---|---|---|---|---|---|---|---|---|---|
| | | $d_0$ | σ | $d_{300}$ | σ | $d_{750}$ | σ. | | |
| 1 | 0 | 1.683 | 0.183 | 0.973 | 0.143 | 0.440 | 0.066 | 41.74 | 24.0 |
| | 1 | 1.759 | 0.248 | 1.021 | 0.149 | 0.465 | 0.077 | 41.03 | 21.5 |
| | 2 | 1.709 | 0.260 | 1.027 | 0.159 | 0.446 | 0.058 | 41.31 | 24.3 |
| | 3 | 1.673 | 0.196 | 0.972 | 0.145 | 0.454 | 0.060 | 41.22 | 22.2 |
| | 6 | 1.464 | 0.188 | 0.873 | 0.118 | 0.416 | 0.056 | 41.66 | 17.3 |
| 2 | 0 | 2.210 | 0.111 | 1.158 | 0.124 | 0.528 | 0.045 | 41.30 | — |
| | 1 | 1.750 | 0.108 | 1.011 | 0.107 | 0.453 | 0.049 | 41.81 | — |
| | 2 | 1.641 | 0.147 | 0.879 | 0.084 | 0.430 | 0.044 | 41.18 | — |
| | 3 | 1.532 | 0.153 | 0.835 | 0.076 | 0.414 | 6.049 | 41.22 | — |
| | 6 | 1.565 | 0.163 | 0.867 | 0.088 | 0.420 | 0.044 | 41.13 | — |
| 3 | 1 | 1.150 | 0.074 | 0.747 | 0.050 | 0.360 | 0.016 | 41.40 | 34.0 |
| 4 | 1 | 1.011 | 0.103 | 0.708 | 0.048 | 0.361 | 0.012 | 41.91 | 34.8 |

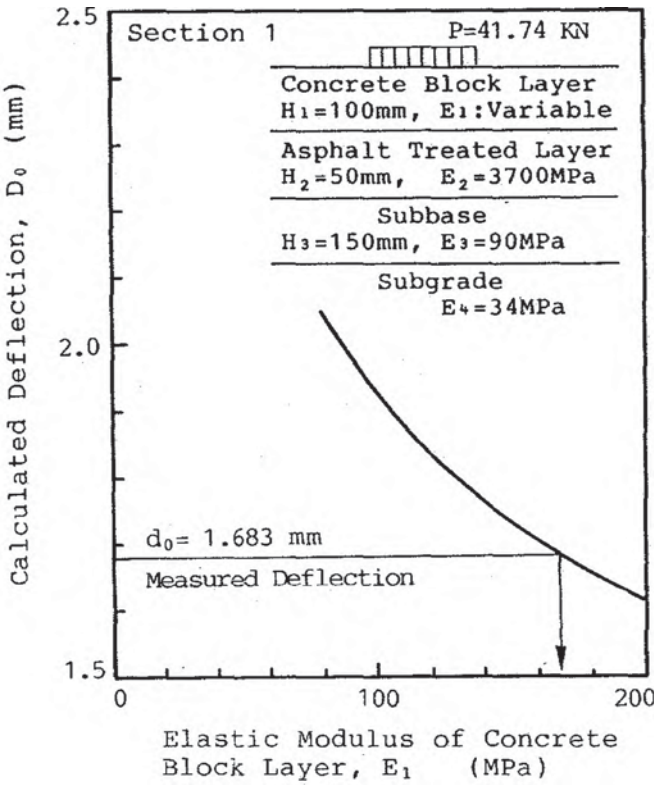



Figure 8 Example of estimation of elastic modulus of concrete block layer in section 1

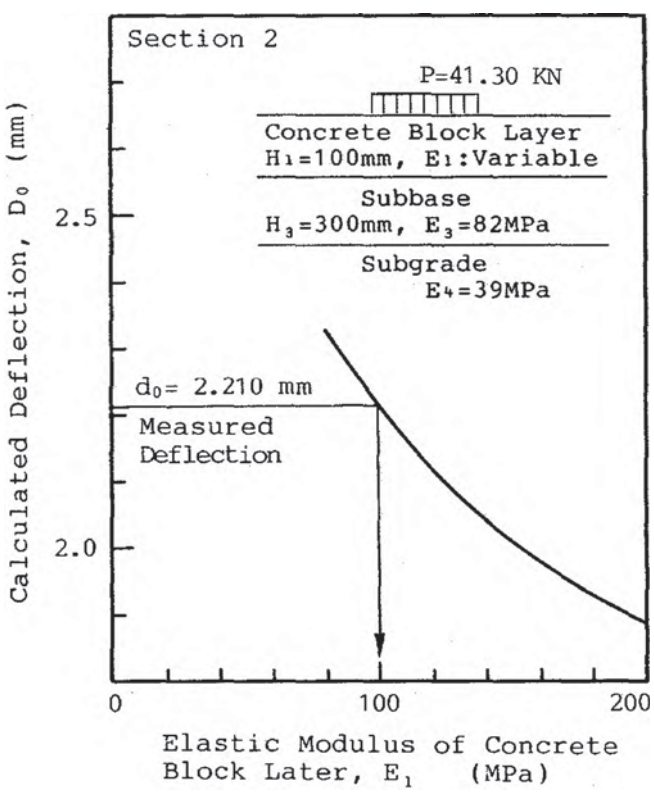



Figure 9 Example of estimation of elastic modulus of concret block layer in section 2

Table 5 Estimated apparent elastic of concrete block layer, (A.E.M.)

| Section no. | Time/weeks | Elastic moduli ( MPa ) |
|---|---|---|
| 1 | 0 | 165 |
| | 1 | 125 |
| | 2 | 155 |
| | 3 | 160 |
| | 6 | 270 |
| 2 | 0 | 100 |
| | 1 | 320 |
| | 2 | 430 |
| | 3 | 620 |
| | 6 | 550 |

## 6. COCLUSIONS

The findings of this research are summarized as follows;

(1) The appparent elastic moduli of the concrete block layer including the sand bed (20mm thick) were from 100MPa to 620MPa.

(2) The apparent elastic modulus of the concrete block layer on the asphalt treated base is about 50^ of that on the crushed stone subbase.

(3) The deflection of the concrete block pavement shows a wider variation, compared with that of the asphalt pavement.

(4) The deflections on the concrete block pavement are larger than those on the asphalt pavement at high temperatures - the comparision was made under the same condition of the subbase and the subgrade.

## REFERENCE

[1] Shackel B., The Design of Interlocking Concrete Block Pavements for Road Traffic, Proceedings of First International Conference on Concrete Block Paving, University of Newcastle, U.K., 1980

[2] Seddon P.A., The Behaviour of Concrete Block Paving under Loading, Proceedings of First International Conference on Concrete Block Paving, University of Newcastle, U.K., 1980

[3] Reuben L.J.M., A.A.A. Molenaar, G.H.A.M. Fuches and H.O. Moll, Analysis and Design of Concrete Block Pavements, Proceedings of Second International Conference on Concrete Block Paving, Delft University of Technology 1984

[4] Seddon P.A., The Behaviour of Interlocking Concrete Block Paving at the Canterbury Test Track, 10th Aust. Rd. Res. Bd. Conference, Sydoney, 1980

[5] Tait J.B., Heavy Duty Pavements in Interlocking Concrete, New Zealand Concrete Construction, November 1978

[6] De Jong, D.L., M.G.F. Peuta and A.R. Korsxagen, Computer Program BISAR, External Report AMSR. 0006.73, Koninkijke/Shell-Laboratoriun, Amsterdam, 1973

[7] Aldrich H.P., Frost Penetration below Highway and Airfield Pavements, Bui.135, H.R.B. 1956

[8] Kasahara A., H. Kubo and T. Sugawara, Estimation of In Situ Elastic Moduli of Pavement Structural Layer with Falling-Weight-Deflectometer Deflection Basin, Sixth International Conference on Structural Design of Asphalt Pavements, Procedings Vol.1, University of Michiban, 1987

[9] Anagnos J.N. and T.W. Kennedy, Practical Method of Conducting the Indirect Tensile Test, Research Report 92-10, Center for Highway Resarch, The University of Texas & Austin, 1972