SSRG International Journal of Civil Engineering
ISSN: 2348-8352/ https://doi.org/10.14445/23488352/IJCE-V12I7P107

Volume 12 Issue 7, 83-95, July 2025


*Original Article*

# Estimating of Subbase Reaction Modulus Under Rigid Pavement

Tjatur Haripriambodo[1*], Sofia W. Alisjahbana[2], Najid[3], Jack Widjajakusuma[4]

[1]*Civil Engineering Doctoral, Universitas Tarumanagara, Grogol Petamburan, Jakarta Barat, Indonesia.*
[2]*Bakrie University, Kuningan, Jakarta Selatan, Indonesia.*
[3]*Civil Engineering Doctoral, Universitas Tarumanagara, Grogol Petamburan, Jakarta Barat, Indonesia.*
[4]*Pelita Harapan University, Lippo Karawaci, Tangerang, Indonesia.*

**Corresponding Author : tjatur264@gmail.com*

Received: 05 May 2025 Revised: 08 June 2025 Accepted: 08 July 2025 Published: 31 July 2025

***Abstract*** *- Several points on the Indonesia toll road have found cracks in the concrete slab early, especially on toll roads with large volumes of vehicles (trucks) transporting materials and industrial products. The most common failure modes that occur in rigid pavements are fatigue cracks in the concrete slab and/or erosion of the material in the subbase. The two are linked to excessive stress and deflections in the concrete slab. Models and analytical solutions are generated from a number of studies to regulate the mechanical properties occurring in concrete pavements, especially related to stress and deflection. Subbase serves as a foundation to bear the pavement's structure. The significant geotechnical parameters that describe the association between stress and associated settlement of subbase are the modulus of subbase reaction (k). This study aims to predict the modulus of subbase reaction by executing an in situ test. The in situ test was a test that obtained elastic modulus by implementing the Light Weight Deflectometer (LWD), predicting the modulus of subbase reaction. Other in situ research involved taking an undisturbed soil sample and testing it in a laboratory. A Triaxial test was conducted to collect the elastic modulus, and then the modulus of subbase reaction was calculated. The location of the field study was in Cikampek – Palimanan (Cipali) toll road, West Java, Indonesia. Two elastic modulus, which were obtained from LWD and Triaxial. Modulus of elasticity from LWD statistically had 15.632 MN/m$^2$ as the average. The maximum value was 33.53 MN/m$^2$ and 5.94 MN/m$^2$ as the minimum value. The modulus of elasticity from Triaxial had 12.69 MN/m$^2$ as the average. The maximum value was 19.30 MN/m$^2$ and 8.70 MN/m$^2$ as the minimum value. The calculated subbase reaction modulus (k) was 27.78 MN/m$^3$ on average. The minimum value was 18.90 MN/m$^{3,}$ and 38.01 MN/m$^3$ was the maximum value.*

***Keywords*** *- Elastic modulus, Rigid pavement, Subbase reaction modulus.*

## 1. Introduction

Several points on the Indonesia toll road found cracks in the concrete slab very early, not long after the road was opened, especially on toll roads with large volumes of vehicles (trucks) transporting materials and industrial products. The most frequent types of failure in rigid pavements are fatigue cracking in the concrete slab and disintegration of the subbase material. These failures are primarily caused by excessive stress and deflection within the slab.

Numerous models and analytical approaches have been developed to understand the mechanical behavior of concrete pavements, particularly regarding stress and deflection. However, creating a universal analytical solution that applies to all possible conditions in concrete slabs remains a significant challenge. [9]

The subgrade refers to the soil layer that serves as the base for pavement and any unbound soil layers above it. It functions as the foundational support for the pavement structure. The modulus of subgrade reaction is a key geotechnical parameter that describes how the subgrade responds to applied stress in terms of resulting settlement. It plays a vital role in assessing the structural performance of rigid pavements. [7]

In structural engineering, instead of modeling the entire complexity of subsoil conditions, a simplified geotechnical parameter called the subgrade reaction modulus (Ks) is commonly utilized. Ks represents the ratio between the pressure exerted on the soil over a defined area and the corresponding settlement at a specific point. Introduced by Winkler in applied mechanics, this concept treats the soil as a collection of uniformly spaced, independent linear springs. [6]

Studies on foundation models of concrete plates showed that the spring layer varied from one model to another. The coefficient of spring is represented by the modulus of subbase reaction. Winkler's foundation implements one layer of spring (k). Pasternak's foundation model implements one layer of spring by putting a shearing layer between the plate and spring layer. Instead of one spring layer, Kerr puts two layers of spring in his foundation model. Between two spring layers, Kerr puts a shearing layer.

Jawad (2016) conducted research to estimate the modulus of subgrade reaction using an in situ testing approach. The method involves measuring the elastic modulus with a Light Weight Deflectometer (LWD), a portable and non-destructive device used to predict the subgrade reaction modulus. Also known as the dynamic plate load test, the LWD assesses the properties of soil layers subjected to dynamic loads. [7]

This study was conducted to predict subbase reaction modulus on a toll road in Indonesia by implementing primary data (in situ). The mentioned data were LWD and an undisturbed soil sample coming from the soil layer under the demolished rigid pavement. By conducting Triaxial testing in the laboratory, the elastic modulus was obtained, and then the modulus of subbase reaction could be calculated.

## 2. Literature Review

Sall et al. (2013) carried out a study to investigate the impact of the elastic modulus of soil and concrete on the displacement of a mat foundation. The research focused on evaluating the behavior of a plate foundation on subsoil using plate theory, incorporating the effects of soil-structure interaction.

The main aim was to assess how the stiffness of both soil and concrete affects the subgrade reaction (k) and the vertical displacement of the mat (plate) foundation. The findings showed that the resulting equations were more strongly influenced by subgrade properties than by the characteristics of the concrete foundation. [12]

A lot of research was conducted on modulus subbase reaction (k). In 2010, Setiadji and FWA performed a study on the correlation between modulus subbase reaction (k) and subbase modulus of elasticity (E). Setiadji and FWA found that the comparable k-E models based on the $l_k$-$l_E$ relationship outperformed the other k-E correlations in their capability to predict the k number that closely matches those obtained from field measurements. [10]

[10] Setiadji, FWA. (2010). "Estimating Modulus of Subgrade Reaction for Rigid Pavement Design", Journal of the Eastern Asia Society for Transportation Studies, Volume 8, 2010. identified six k-E relationships, those are AASHTO in 1986 and 1993, Khazanovich in 2001, Vesic and Saxena in 1974, Ullidtz in 1987, the equivalent k and E model based on $l_k$-$l_E$ and the equivalent k and E models based on k-E correlation. Vesic and Ullidtz involved slab thickness in their equations. [10] Other research predicted subgrade modulus reaction on clayey soil by implementing group method of data handling, also called Group Method of Data Handling (GMDH) – type Neural Network (NN). This study utilizes 123 data sets from Qasvin, Iran, to conduct the simulation. The results indicated that the modulus of subgrade reaction estimated using GMDH-based equations closely matched the values obtained from the Plate Load Test (PLT). [6]

In 2017, Baruonis and Philpot conducted a study focused on estimating vertical subgrade reaction using Cone Penetration Test (CPT) data for shallow foundations on cohesionless soils (Das, Braja M., 2010). They proposed a methodology to derive an equivalent value to that obtained through the Standard Penetration Test (SPT) method introduced by Scott for determining the subgrade reaction modulus ($k_1$) using a 300 mm plate. The resulting foundation value, KF, was found to be equivalent to the value derived from the traditional SPT-based approach. [2]

In 2009, Baruonis et al. carried out a study to determine the subgrade reaction modulus for clay-based foundations by utilizing unconfined compression tests. Their findings demonstrated that this laboratory method can effectively be used to estimate the subgrade reaction modulus. Compared to in situ plate load tests, the unconfined compression test proved to be more cost-effective and time-efficient. [3] Various studies of subgrade reaction modulus utilize soil elastic modulus as the main parameter. Thus, the procedure for obtaining soil elastic modulus becomes very important. Adem (2015) conducted research on the estimation of modulus of elasticity in unsaturated expansive soils by estimating the vertical movement. Said vertical movements are heave or shrinkage, which frequently occur on expansive soils. [14]

Alisjahbana et al. studied the dynamic behaviour of pavement modelled as a thin orthotropic plate supported by the Kerr foundation concept. The research employed a semi-analytical method to evaluate deflection dynamics and the internal force distribution within the plate subjected to constant velocity loading. This approach aimed to resolve the maximum dynamic deflection under varying soil conditions and elastic foundation types to improve rigid pavement design. The findings revealed that both the dynamic response and resonance velocity are heavily influenced by the stiffness of the resilient foundation. Specifically, when concrete pavement is built on soft soil, it is more susceptible to loading, especially at lower resonant frequencies. Additionally, the study found that the Kerr model results in significantly lower maximum dynamic deflections than the Pasternak model, suggesting potential cost advantages when using the Kerr model to represent the structural response of rigid pavements.

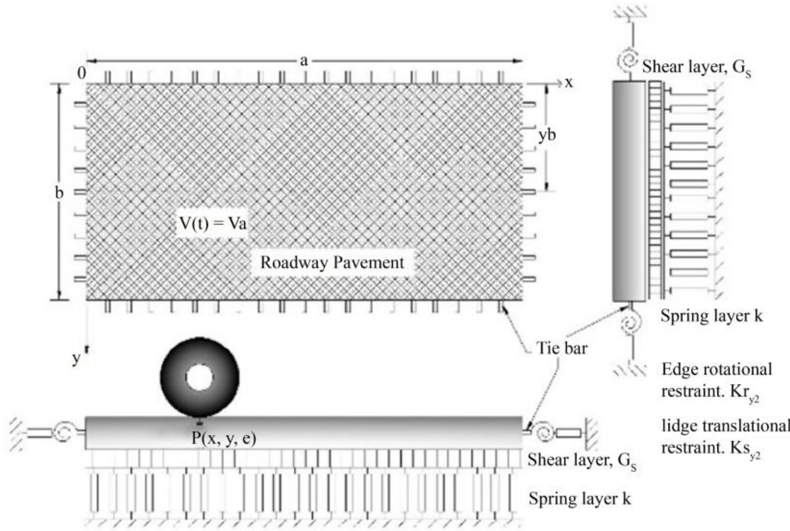


**Fig. 1 Pasternak foundation modelling**

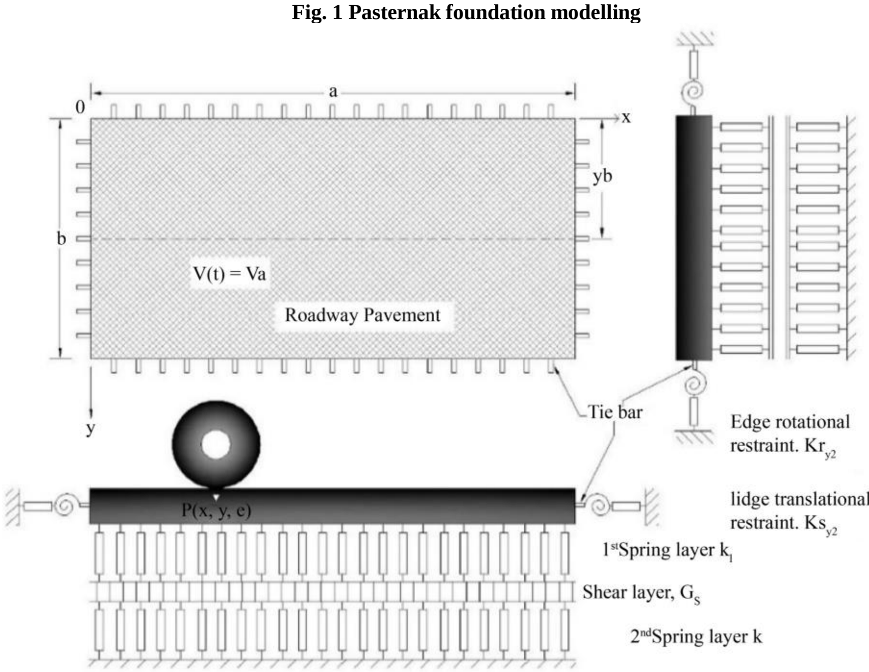


**Fig. 2 Kerr foundation modelling**

The Pasternak foundation model consists of one spring layer, where the spring layer represents the subbase layer supporting the slab (see Figure 1). Kerr refined the modeling by adding springs into two layers separated by a shearing layer (see Figure 2).

## 3. Research Methods

The AASHTO Pavement Design Guide (1993) specifies that rigid pavement design requires either the subgrade reaction modulus (k), the subgrade elastic modulus (E), or a correlation between them. This k-E relationship was introduced because performing plate load tests to directly measure k is generally not practical on-site. To develop this relationship, AASHTO assumed that the pavement slab could be represented by a finite circular plate with a 30-inch (762 mm) diameter, irrespective of the slab's actual dimensions. [10]

The flow of the research adhered to the procedure outlined below. Furthermore, this study had specific boundaries and limitations. The field activities included LWD testing and undisturbed soil sampling. LWD testing yielded the elastic modulus directly. The soil samples were dispatched to the laboratory. A triaxial test was conducted to determine the elastic modulus. The subbase reaction modulus was established by applying two empirical formulas.

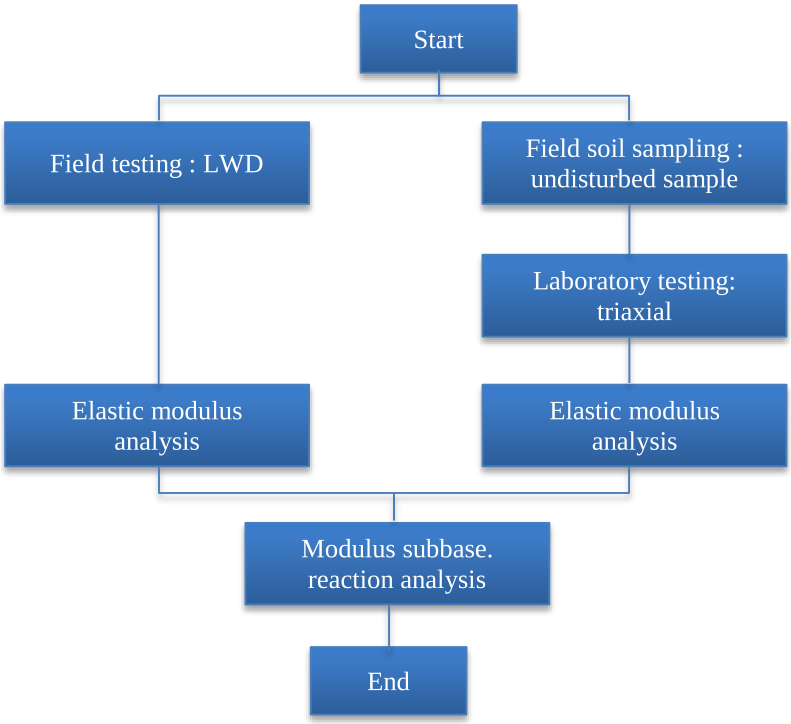


**Fig. 3 Flow of research**

### *3.1. Rigid Pavement on a Toll Road*

The location of the field study was in Cikampek – Palimanan (Cipali) tollway as part of the trans Java toll road. Cipali tollway stretches from Cikampek (Karawang regency) to Palimanan (Cirebon regency). The total length of the Cipali toll road is 116 kms. The original pavement type of the Cipali Toll Road is concrete (rigid) pavement. Nonetheless, some locations have been overlaid by asphalt. The definite location where the field study was conducted was in Sta. 178 Jakarta direction. In this location, the pavement is concrete (rigid) with layers as shown below.

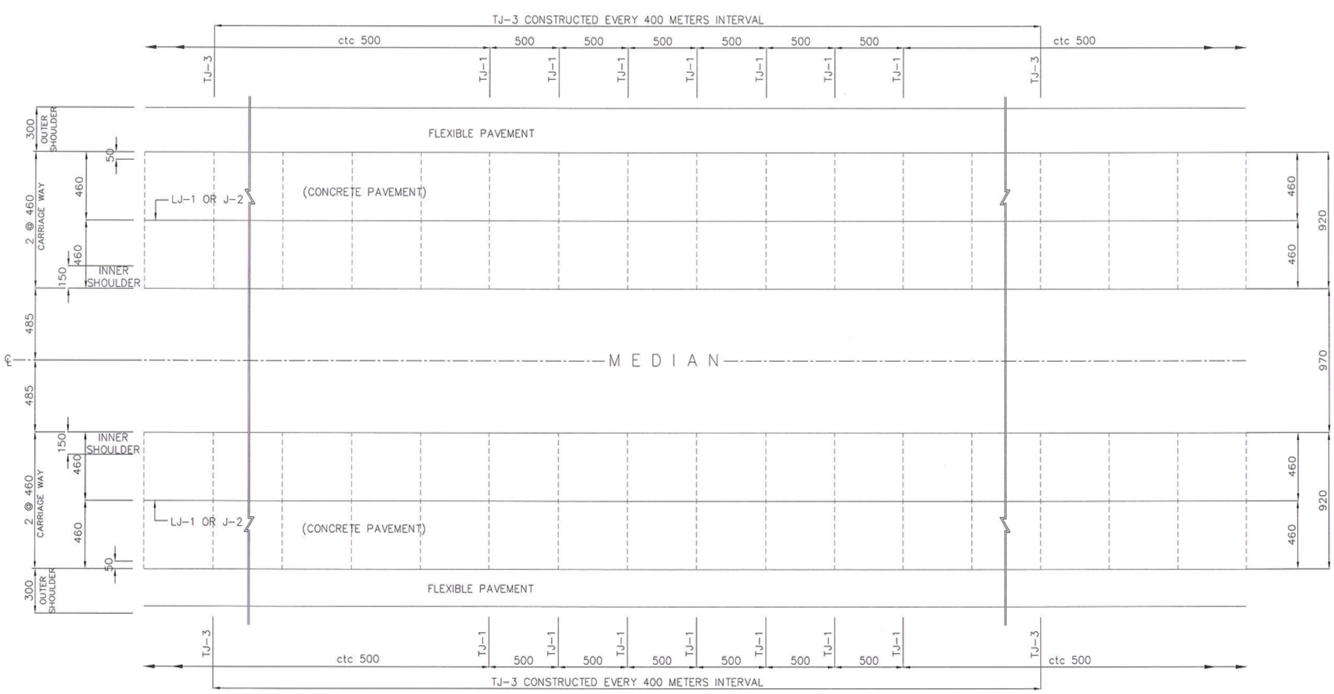


**Fig. 4 Pavement plan**

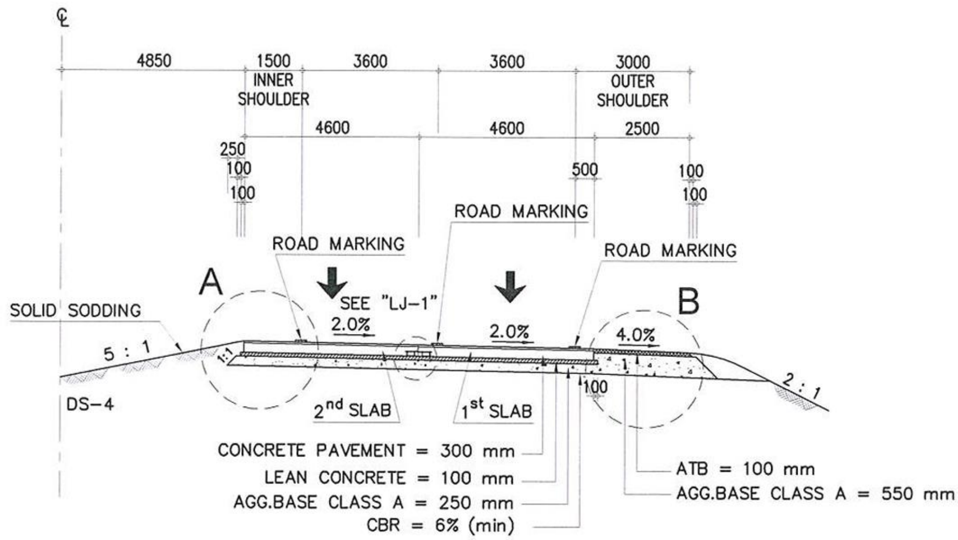


**Fig. 5 Typical cross-section of concrete pavement**

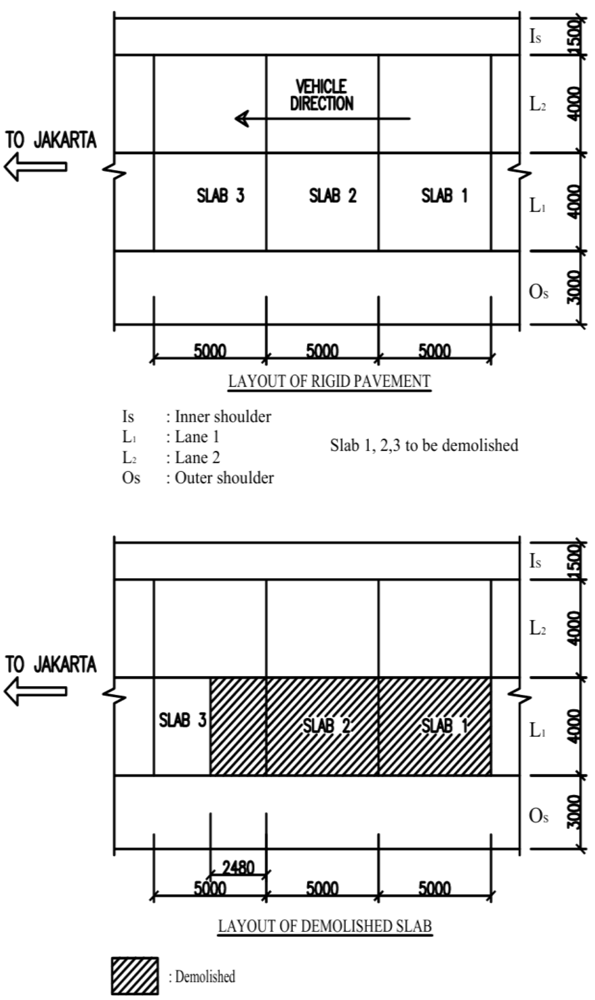


**Fig. 6 Location of field study**

The original design of the Cipali toll road is two lanes in each direction. The typical dimension of a slab is 5.0 x 4.0 m. A cross-section is presented in Figure 5. The testing was specifically intended to understand the subbase condition beneath the rigid pavement on a toll road in Indonesia. The initial condition of the existing rigid pavement was cracks in whole areas; consequently, the reconstruction was held. The concrete slab was crushed by a breaker, debris was removed, and LWD tests and soil sampling were carried out. The concrete slab was reconstructed at the 1st lane of the traffic lane while the 2nd traffic lane was still active. The following figure depicts a definite slab in Sta-178, where the field study took place.

### *3.2. Elastic Modulus from LWD*

A Light Weight Deflectometer (LWD) is a non-damaging testing apparatus that measures vertical deformation caused by falling mass to determine the bearing capacity of soil and the quality of soil compaction. The references for the LWD test are Pd 03-2016-B, ASTM E2835-11, and ASTM E2583-07. The LWD apparatus applied in this research was HMP LFG4, which was produced by Magdeburger Prufgeratebau GmbH, Germany. The specifications of the applied LWD are as follows:

| | |
|---|---|
| Mechanical loading mechanism. | |
| Total weight | : 15.0 kg |
| Weight of drop-weight | : 10.0 kg |
| Maximum impact force | : 7.07 kg |
| Duration of impact | : 17.0 +/- 1.5 ms |
| Load plate. | |
| Diameter | : 300 mm |
| Plate thickness | : 20.0 mm |
| Weight | : 15.0 kg |

Figure 8 depicts LWD field testing. The total amount of LWD testing is 40 points conducted on an area of 4 x 12 m as shown in Figure 9.

### *3.3. Elastic Modulus by using Soil Mechanical Properties*

The modulus of Elasticity (E) can also be resolved through various laboratory tests, such as unconfined compression and triaxial tests. Unconfined compression tests often yield conservative estimates of E, typically resulting in lower initial tangent modulus values, which in turn cause the calculated displacement (DH) to be higher than observed measurements. Triaxial tests, on the other hand, generally provide more realistic estimates of E because the applied confining pressure increases the soil's stiffness, producing a higher initial tangent modulus. The specific type of triaxial test—whether it is unconfined (U), consolidated undrained (CU), or K0 consolidated undrained (CK0U) can also influence the value of E obtained. In general, while triaxial tests still tend to be conservative, they are less so compared to unconfined compression tests. [4]

Undisturbed samples were taken in the same location and at the same time where LWD tests were conducted. Points of sample were distributed evenly with a total sample of 20. The samples were taken by using a hand auger apparatus and then sent to the laboratory in paraffin-sealed tubes. The length of the tubes is 60 cm. Photos during the test are presented in Figure 11.


**Fig. 7 LWD apparatus**

**Fig. 8 LWD field testing**


**Fig. 9 LWD point of test**

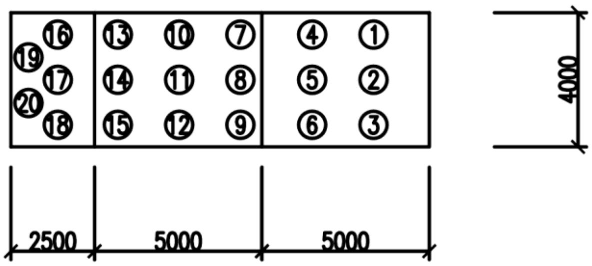


**Fig. 10 Undisturbed soil sampling (UDS) point of sampling**

**Fig. 11 UDS sampling using a hand auger**

### *3.4. Properties of Soil*

Soil samples tested in the laboratory also showed the characteristics of the soil, which were indicated by the index and engineering properties. Index properties include grain size, relative density, Atterberg limits and consistency.

Engineering properties consisted of cohesion, internal friction angle, permeability, elasticity, and compressibility. Another important result was soil classification, which was guided by the above properties.

Laboratory testing revealed that the soil's specific gravity ranges between 2.555 and 2.679 ton/m³, and the plasticity index varies from 24.49% to 44.84%.

Referring to the Unified Soil Classification System (USCS), the soils are identified as silts and clays, specifically classified as MH (inorganic silts), CH (inorganic clays with high plasticity), and OH (organic clays with medium to high plasticity). Under the AASHTO classification system, the soils are categorized as clayey silts with a liquid limit exceeding 40%.

**Table 1. Soil classification**

| ID | Particle Size Distribution | | | | | Atterberg Limits | | | USCS Classification | AASHTO Classification |
|---|---|---|---|---|---|---|---|---|---|---|
| | Gravel (%) | Sand (%) | Silt (%) | Clay (%) | Fines (%) | LL (%) | PL (%) | PI (%) | | |
| **BH-01** | 3.94 | 17.57 | 38.99 | 39.51 | 78.5 | 72.97 | 40.96 | 32.02 | MH or OH | A-7-5 |
| **BH-02** | 4.82 | 17 | 51.15 | 27.04 | 78.19 | 76.52 | 41.14 | 35.38 | MH or OH | A-7-5 |
| **BH-03** | 3.94 | 16.57 | 39.48 | 40.01 | 79.5 | 73.12 | 38.22 | 34.9 | MH or OH | A-7-5 |
| **BH-04** | 1.96 | 18.27 | 46.08 | 33.69 | 79.77 | 77.5 | 37.65 | 39.85 | MH or OH | A-7-5 |
| **BH-05** | 3.39 | 18.87 | 43.3 | 34.45 | 77.75 | 77.09 | 43.78 | 33.31 | MH or OH | A-7-5 |
| **BH-06** | 2.46 | 16.28 | 40.42 | 40.85 | 81.27 | 77.93 | 40.68 | 37.25 | MH or OH | A-7-5 |
| **BH-07** | 2.67 | 15.45 | 55.52 | 26.36 | 81.89 | 78.32 | 42.71 | 35.61 | MH or OH | A-7-5 |
| **BH-08** | 1.61 | 11.74 | 37.88 | 48.78 | 86.66 | 77.4 | 41.53 | 35.87 | MH or OH | A-7-5 |
| **BH-09** | 4.9 | 18.47 | 39.47 | 27.17 | 76.64 | 74.9 | 35.34 | 39.56 | MH or OH | A-7-5 |
| **BH-10** | 3.35 | 15.78 | 38.44 | 42.44 | 80.88 | 80.62 | 31.96 | 48.66 | CH | A-7-5 |
| **BH-11** | 3.47 | 18.04 | 45.16 | 33.34 | 78.5 | 68.91 | 35.7 | 33.21 | MH or OH | A-7-5 |
| **BH-12** | 14.87 | 19.88 | 42.01 | 23.25 | 65.26 | 70.21 | 34.32 | 35.89 | MH or OH | A-7-5 |
| **BH-13** | 9.21 | 19.48 | 42.47 | 28.85 | 71.32 | 71.16 | 34.56 | 36.6 | MH or OH | A-7-5 |
| **BH-14** | 8.96 | 17.98 | 39.29 | 33.77 | 73.07 | 81.2 | 36.36 | 44.84 | CH | A-7-5 |
| **BH-15** | 13.38 | 22.29 | 34.91 | 29.42 | 64.34 | 63.73 | 33.06 | 30.67 | MH or OH | A-7-5 |
| **BH-16** | 9.68 | 22.19 | 39.73 | 28.4 | 68.13 | 54.48 | 29.98 | 24.49 | MH or OH | A-7-6 |
| **BH-17** | 7.86 | 25.71 | 41.23 | 25.2 | 66.43 | 51.43 | 26.31 | 25.13 | CH | A-7-6 |
| **BH-18** | 4.02 | 19.77 | 42.13 | 34.08 | 76.22 | 58.77 | 28.94 | 29.83 | CH | A-7-6 |
| **BH-19** | 21.9 | 17.93 | 36.39 | 23.79 | 60.18 | 55.91 | 28.18 | 27.73 | CH | A-7-6 |
| **BH-20** | 11.32 | 32.92 | 37.82 | 17.95 | 55.77 | 67.37 | 34.04 | 33.33 | MH or OH | A-7-5 |

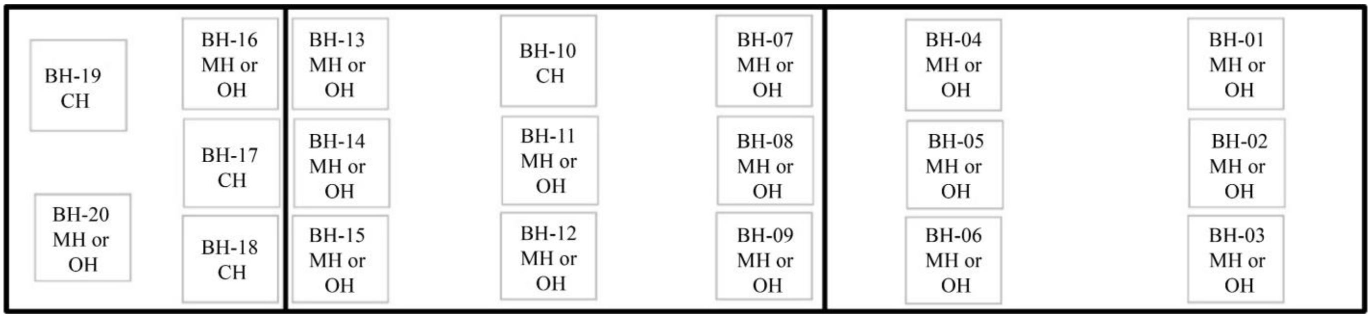


**Fig. 12 Mapping of USCS soil classification**

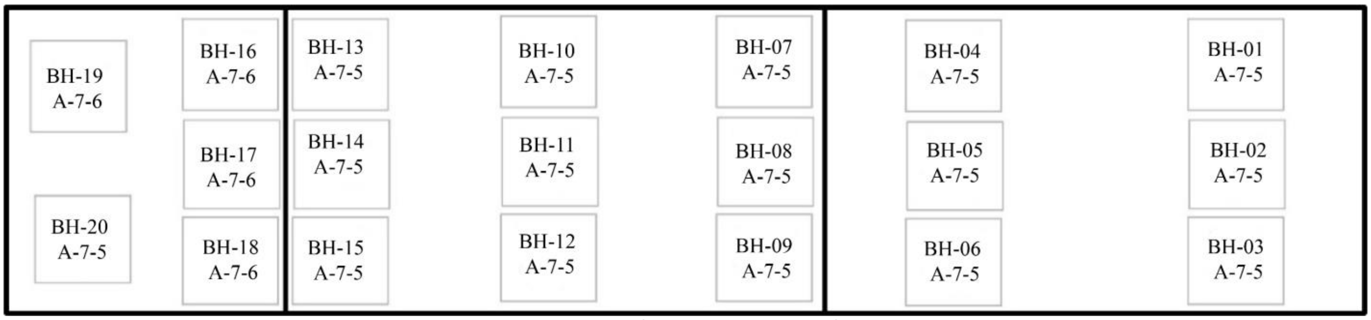


**Fig. 13 Mapping of AASHTO soil classification**

The soil classification was plotted at the point where the samples were taken, and then a map of soil classification was developed. The USCS soil classification map is shown in Figure 12. The ASHTO soil classification map is presented in Figure 13.

Other laboratory test results were Triaxial and one-dimensional consolidation, which provided engineering properties. Cohesion was at 0.25 – 0.89 gr/cm$^{3,}$ and the internal friction angle was in the range of 2.10 – 5.33$^{0}$. Compression index ranges from 0.224 to 0.634.

## 4. Results and Discussions

### *4.1. Modulus of Elasticity from LWD Testing*

Processes to have elastic modulus were described by taking testing on point no 8 as a calculation example, which is shown below. From three attempts, both for settlement and velocity were calculated (s(m) and v(m) respectively). By implementing a formula correlation between settlement and velocity, the elastic modulus ($E_{vd}$, notation which is taken from the LWD apparatus) of the subbase was obtained ($E_{vd}$ = 11.33 MN/m$^2$). By using similar calculations, 40 $E_{vd}$ were successfully measured.

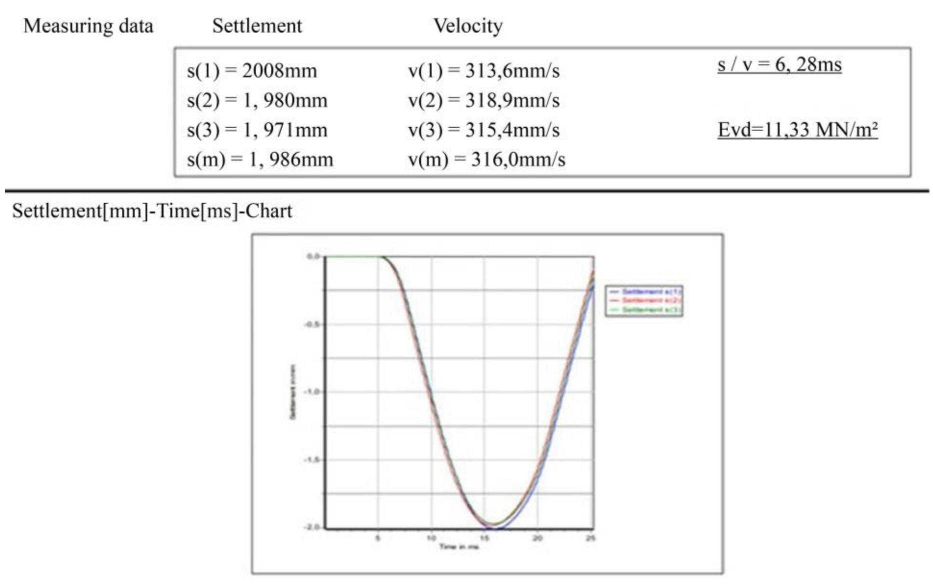


**Fig. 14 Measuring data of LWD**

**Table 2. Modulus of elasticity from LWD ($E_{vd}$)**

| **Point** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** |
|---|---|---|---|---|---|---|---|---|---|---|
| **Evd [MN/m²]** | 31.91 | 13.94 | 23.36 | 33.53 | 12.35 | 13.7 | 5.94 | 11.33 | 10.58 | 9.84 |
| **Point** | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** | **19** | **20** |
| **Evd [MN/m²]** | 10.2 | 14.8 | 10.18 | 19.89 | 21.84 | 13.2 | 17.4 | 22.52 | 17.12 | 10.89 |
| **Point** | **21** | **22** | **23** | **24** | **25** | **26** | **27** | **28** | **29** | **30** |
| **Evd [MN/m²]** | 11.44 | 20.16 | 24.86 | 8.45 | 11.49 | 8.25 | 19.75 | 15.09 | 18.44 | 19.82 |
| **Point** | **31** | **32** | **33** | **34** | **35** | **36** | **37** | **38** | **39** | **40** |
| **Evd [MN/m²]** | 7.93 | 8.73 | 16.36 | 21.87 | 15.96 | 15.2 | 8.6 | 15.72 | 15.19 | 17.44 |

The modulus of elasticity for 40 points is presented in Table 2.

Modulus of elasticity from LWD ($E_{vd}$) as listed above statistically has 15.632 MN/m$^2$ as the average. The maximum value is 33.53 MN/m$^2$ and 5.94 MN/m$^2$ as the minimum value.

### *4.2. Modulus of Elasticity from Soil Engineering Properties*

Modulus of elasticity from engineering properties was approached by implementing equation 1 as suggested by [13], which is stated as the following:

$$E = \frac{\Delta\sigma}{\Delta\varepsilon} \quad (1)$$

E: modulus of elasticity

Δσ: deviator stress/increment of axial effective stress

$$\Delta\sigma = \sigma_1 - \sigma_3 \quad (2)$$

$\sigma_1$: major principal stress

$\sigma_3$: minor principal stress

Δε: increment of strain

The calculation of the modulus of elasticity (E) was taken as the secant modulus. It was calculated by incrementing stress and strain, most often referring to the initial values at the stage of the test. [12]

$$\Delta\sigma = \Delta\sigma_i - \Delta\sigma_0 \quad (3)$$

The calculation of the modulus of elasticity (E) from the Triaxial test results (ASTM D2850-03) is shown through the triaxial bore hole 1 (BH 01) data, as explained below.

$$\Delta\sigma = 0.121 - 0.00 = 0.121 \text{ kg/cm2}$$

$$\Delta\varepsilon = 0.1 - 0 = 0.1\%$$

$$E = \frac{0.121}{0.1\%} = 121 \text{ kg/cm2}$$

$$E = 11{,}866 \text{ kN/m2}$$

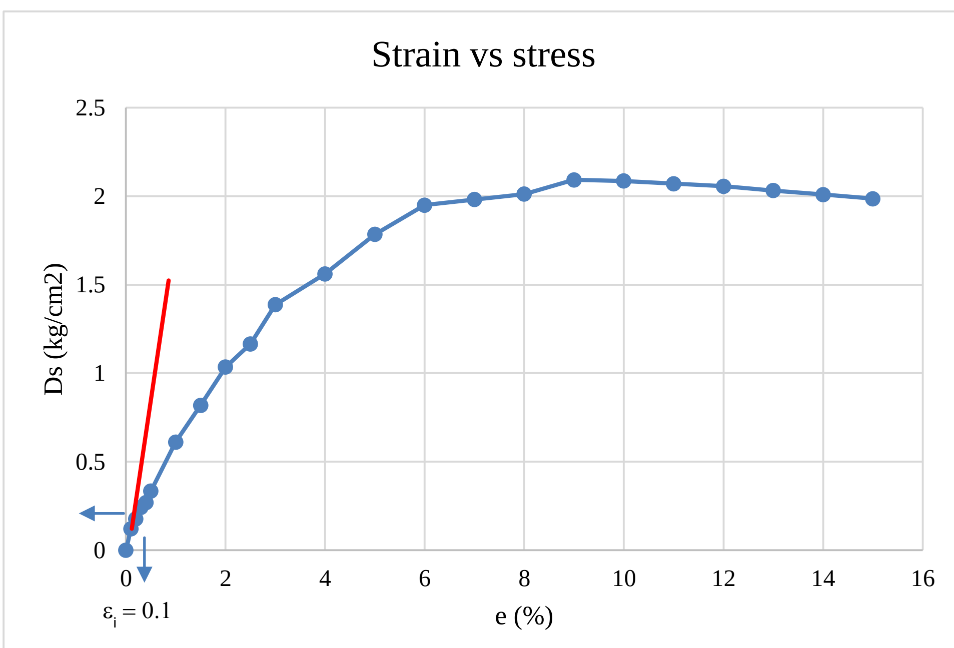


**Fig. 15 Strain vs stress curve of borehole 1**

**Table 3. Modulus of elasticity from Triaxial ($E_{TRX}$)**

| Bore Hole | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| $E_{TRX}$ (kN/m$^2$) | 12,100 | 11,200 | 10,300 | 9,300 | 9,300 | 11,200 | 12,100 | 14,000 | 12,100 | 9,300 |
| $E_{TRX}$ (MN/m$^2$) | 12.10 | 11.20 | 10.30 | 9.30 | 9.30 | 11.20 | 12.10 | 14.00 | 12.10 | 9.30 |
| **Bore Hole** | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** | **19** | **20** |
| $E_{TRX}$ (kN/m$^2$) | 14,000 | 9,300 | 9,300 | 11,200 | 16,800 | 18,700 | 15,900 | 12,100 | 16,800 | 18,700 |
| $E_{TRX}$ (MN/m$^2$) | 14.00 | 9.30 | 9.30 | 11.20 | 16.80 | 18.70 | 15.90 | 12.10 | 16.80 | 18.70 |

By having a similar procedure, the modulus of elasticity for another borehole was obtained. Comprehend the modulus of elasticity, which has been calculated and listed in Table 3. Modulus of elasticity from Triaxial ($E_{TRX}$) as presented above statistically has 12.685 MN/m$^2$ as the average. The maximum value was 18.700 MN/m$^2$ and 9.300 MN/m$^2$ as the minimum value.

### *4.3. Analysis of Elastic Modulus*

There are two elastic modulus that were obtained from in situ tests (LWD, $E_{vd}$) and laboratory tests (Triaxial, $E_{TRX}$) as explained above. Analysis of the two source data is presented in Table 4.

The statistical analysis in Table 4 shows that the mean of Triaxial 12.69 MN/m$^2$) was lower than LWD's (15.63 MN/m$^2$). The standard error of Triaxial (0.71) was lower than LWD's (0.99). Bowles (1988) proposed reference value of elastic modulus for a few types of soil as presented in Table 5. [4] By referring to Bowles' table, the range of E may be at 2 – 20 (silt) (see sub-3.4).

Compared to the reference, Triaxial's modulus (9.30 – 18.70) was closer to silt (2 – 20); therefore, for the next analysis of k, Triaxial's modulus was implemented. Figure 16 shows the diagram that compares E, where Triaxial's modulus is likely close to Bowles's.

**Table 4. Descriptive statistics of elastic modulus from LWD and Triaxial**

| | LWD | Triaxial |
|---|---|---|
| **Mean** | 15.63 | 12.69 |
| **Standard Error** | 0.99 | 0.71 |
| **Median** | 15.14 | 12.10 |
| **Standard Deviation** | 6.24 | 1.00 |
| **Sample Variance** | 38.99 | 31.70 |
| **Kurtosis** | 1.05 | -0.67 |
| **Skewness** | 0.95 | 0.72 |
| **Range** | 27.59 | 9.40 |
| **Minimum** | 5.94 | 9.30 |
| **Maximum** | 33.53 | 18.70 |

**Table 5. Bowles' modulus of elasticity**

| Type of soil | E (MN/m$^2$) | | |
|---|---|---|---|
| Clay | | | |
| Very Soft | 2 | - | 15 |
| Soft | 5 | - | 25 |
| Medium | 15 | - | 50 |
| Hard | 50 | - | 100 |
| Sandy | 25 | - | 250 |
| Sand | | | |
| Silty | 5 | - | 20 |
| Loose | 10 | - | 25 |
| Dense | 50 | - | 81 |
| Sand and gravel | | | |
| Loose | 50 | - | 150 |
| Dense | 100 | - | 200 |
| Silt | 2 | - | 20 |

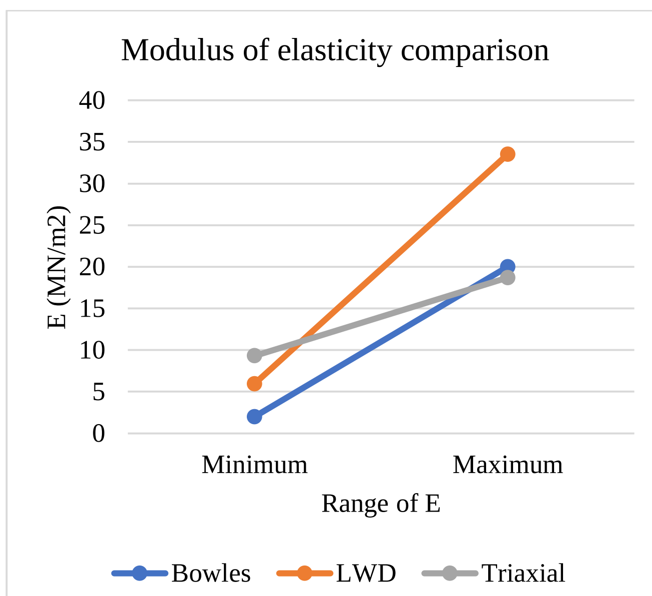


**Fig. 16 Modulus of elasticity comparison**

Triaxial elastic modulus (ETRX) was shown to be smaller than LWD elastic Modulus (ELWD). These value discrepancies may come from the testing method, where LWD is 'a pure' in situ test, while Triaxial is a laboratory-based test.

### *4.4. Estimating Modulus Subbase Reaction (k)*

By calculating the elastic modulus of subbase as presented above, subbase modulus reaction (k) may be obtained easily. AAHSTO (1993) proposed an empirical equation to be calculated using the elastic modulus (E). [1] Khazanovich et al (2001) also proposed their empirical equation, which needs the elastic modulus parameter only. Other researchers proposed other empirical equations that need different parameters other than the elastic modulus. [10]

The AASHTO 1993 equation is expressed below.

$$k = \frac{E}{0.492} \quad (4)$$

Khazanovich's is stated as follows.

$$k = 0.296E \quad (5)$$

Since the elastic modulus from Triaxial ($E_{TRX}$) was more accepted, the calculated k by using the elastic modulus from Triaxial is presented in Table 6. Descriptive statistical analysis is presented in Table 7. The scattered chart for k is described in Figure 17.

**Table 6. Calculated k by using E from triaxial**

| Bore hole | $E_{TRX}$ (MN/m$^2$) | k-AASHTO | k-Khazanovich |
|---|---|---|---|
| 1 | 12.1 | 24.59 | 3.58 |
| 2 | 11.2 | 22.76 | 3.32 |
| 3 | 10.3 | 20.93 | 3.05 |
| 4 | 9.3 | 18.90 | 2.75 |
| 5 | 9.3 | 18.90 | 2.75 |
| 6 | 11.2 | 22.76 | 3.32 |
| 7 | 12.1 | 24.59 | 3.58 |
| 8 | 14.0 | 28.46 | 4.14 |
| 9 | 12.1 | 24.59 | 3.58 |
| 10 | 9.3 | 18.90 | 2.75 |
| 11 | 14.0 | 28.46 | 4.14 |
| 12 | 9.3 | 18.90 | 2.75 |
| 13 | 9.3 | 18.90 | 2.75 |
| 14 | 11.2 | 22.76 | 3.32 |
| 15 | 16.8 | 34.15 | 4.97 |
| 16 | 18.7 | 38.01 | 5.54 |
| 17 | 15.9 | 32.32 | 4.71 |
| 18 | 12.1 | 24.59 | 3.58 |
| 19 | 16.8 | 34.15 | 4.97 |
| 20 | 18.7 | 38.01 | 5.54 |

**Table 7. Statistical analysis on calculated k**

| k-AASHTO | | k-Khazanovich | |
|---|---|---|---|
| Mean | 25.78 | Mean | 3.75 |
| Standard Error | 1.44 | Standard Error | 0.21 |
| Median | 24.59 | Median | 3.58 |
| Mode | 18.90 | Mode | 2.75 |
| Standard Deviation | 6.44 | Standard Deviation | 0.94 |
| Sample Variance | 41.53 | Sample Variance | 0.88 |
| Kurtosis | -0.67 | Kurtosis | -0.67 |
| Skewness | 0.72 | Skewness | 0.72 |
| Range | 19.11 | Range | 2.78 |
| Minimum | 18.90 | Minimum | 2.75 |
| Maximum | 38.01 | Maximum | 5.54 |
| Sum | 515.65 | Sum | 75.10 |
| Count | 20 | Count | 20 |

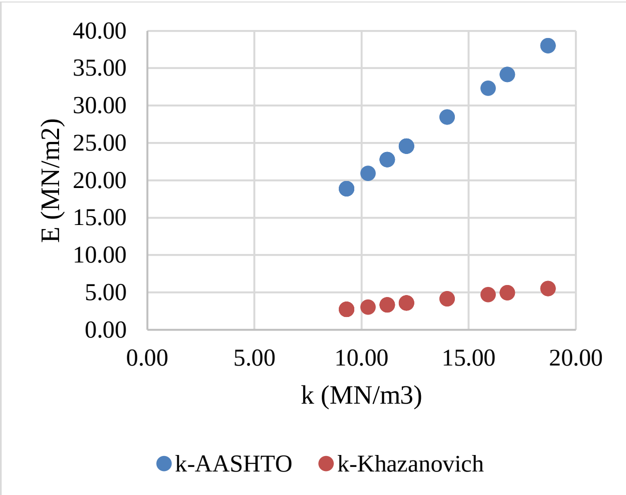


**Fig. 17 Modulus subbase reaction**

**Table 8. Das's modulus subbase reaction (k)**

| **Soil type** | | **k (MN/m³)** |
|---|---|---|
| Dry or moist sand | | |
| Loose | | 8 – 25 |
| Medium | | 25 - 125 |
| Dense | | 125 - 375 |
| Saturated sand | | |
| Loose | | 10 – 15 |
| Medium | | 35 – 40 |
| Dense | | 130 - 150 |
| Clay | | |
| Stiff | | 10 – 25 |
| Very Stiff | | 25 – 50 |
| Hard | | >50 |

Das, in his book (8th edition), presented k, which is taken as a reference. [6]

Comparison k with Das's (Clay stiff and very stiff; 10 – 50), k-AASHTO tended to be similar (18.9 – 38.01). The diagram presented in Figure 18 demonstrates that k-AASHTO is closer to Das's.

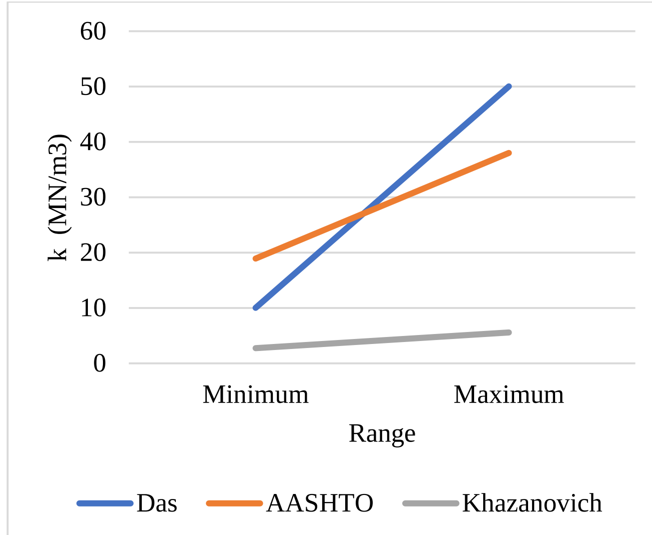


**Fig. 18 Modulus subbase reaction comparison**

## 5. Conclusion

Subbase modulus reaction (k) value from the AASHTO equation ranges between 18.9 and 38.01 MN/m$^3$. It is close to the k value suggested by Das. This value may become a reference as subbase modulus reaction (k) for dynamic analysis or other related purposes.

Subbase layers in the Cipali toll road were classified into silts and clays. Its elastic modulus ranges between 9.30 and 18.70 MN/m$^2$. This value is relatively close to Bowles's elastic modulus.

Compared to Bowles's elastic modulus, LWD's modulus tended to be higher (5.94 – 33.53 MN/m$^2$). Triaxial modulus was more accepted (9.30 – 18.70 MN/m$^2$).

The findings of this study can contribute to further pavement design to achieve more efficient design and produce long-lasting pavement performance.

## References

[1] American Society of State Highway and Transportation Officials, *AASHTO Guide for Design of Pavement Structures*, The Association, pp. 1-600, 1993. [Google Scholar] [Publisher Link]

[2] Nick Barounis, and J. Philpot, "Estimation of the Static Vertical Subgrade Reaction Modulus $K_s$ from CPT for Flexible Shallow Foundations on Cohesionless Soils," *Proceeding 20th NZSEE Geotechnical Symposium Conference*, pp. 1-8, 2017. [Google Scholar] [Publisher Link]

[3] Nick Barounis et al., "Modulus of Subgrade Reaction for Foundations on Clay from Unconfined Compression Tests," *Proceedings of the 17th International Conference on Soil Mechanics and Geotechnical Engineering*, pp. 249-252, 2009. [CrossRef] [Google Scholar] [Publisher Link]

[4] Joseph E. Bowles, *Foundation Analysis and Design*, 5th ed., McGraw-Hill, pp. 1-1175, 1997. [Google Scholar] [Publisher Link]

[5] Mostafa Yousefi Darestani et al., "Dynamic Response of Concrete Pavements under Vehicular Loads," *IABSE Symposium: Responding to Tomorrow's Challenges in Structural Engineering*, Budapest, Hungary, pp. 59-66, 2006. [CrossRef] [Google Scholar] [Publisher Link]

[6] Braja M. Das, *Principles of Geotechnical Engineering*, Cengage Learning, pp. 1-666, 2010. [Google Scholar] [Publisher Link]

[7] Ahelah Alaa Jawad, "*Assessment of Modulus of Subgrade Reaction of Different Soils Using Light Weight Deflectometer*," Master Thesis, University of Kerbala, pp. 1-163, 2016. [Publisher Link]

[8] S.A. Naeini et al., "Prediction of Subgrade Reaction Modulus of Clayey Soil using Group Method of Data Handling," *Scientia Iranica*, vol. 27, no. 4, pp. 1740-1750, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[9] Y.H. Parjoko, "Sensitivity Analysis of Concrete Performance Using Finite Element Approach," *Journal of the Civil Engineering Forum*, vol. 21, no. 1, pp. 1171-1182, 2012. [CrossRef] [Google Scholar] [Publisher Link]

[10] Bagus Hario Setiadji, and T.F. FWA, "Estimating Modulus of Subgrade Reaction for Rigid Pavement Design," *Journal of the Eastern Asia Society for Transportation Studies*, vol. 8, pp. 1502-1512, 2010. [CrossRef] [Google Scholar] [Publisher Link]

[11] Vishwas Sawant, "Dynamic Analysis of Rigid Pavement with Vehicle–Pavement Interaction," *International Journal of Pavement Engineering*, vol. 10, no. 1, pp. 63-72, 2009. [CrossRef] [Google Scholar] [Publisher Link]

[12] Oustasse Abdoulaye Sall et al., "Influence of the Elastic Modulus of the Soil and Concrete Foundation on the Displacements of a Mat Foundation," *Open Journal of Civil Engineering*, vol. 3, no. 4, pp. 228-233, 2013. [CrossRef] [Google Scholar] [Publisher Link]

[13] Matylda Tankiewicz, and Magdalena Kowalska, "Stiffness Moduli in Triaxial Tests on a Loess-Sand Mixture," *E3S Web of Conference Proceeding of the 8$^{th}$ International Symposium on Deformation Characteristics of Geomaterials (IS-Porto 2023)*, vol. 544, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[14] Hana Hussin Adem, "*Modulus of Elasticity Based Method for Estimating the Vertical Movement of Natural Unsaturated Expansive Soils*," Thesis of Doctor of Philosophy, University of Ottawa, pp. 1-267, 2015. [CrossRef] [Google Scholar] [Publisher Link]