

RELATIONSHIP BETWEEN THE SUBGRADE REACTION MODULUS AND THE STRAIN MODULUS OBTAINED USING A PLATE LOADING TEST

DaeSang Kim¹, SeongYong Park²

Biography of authors

1. Author 1

First Name : DaeSang Family Name : Kim
Affiliation : Principal Researcher, Director of Vehicle and Track Research Division, Korea Railroad
Research Institute, #360-1, Woram-dong, Uiwang-si, Gyeonggi-do, 437-757, Korea

2. Author 2

First Name : SeongYong Family Name : Park
Affiliation : Senior Researcher, Hanwha Research Institute of Technology, Hanwha Engineering &
Construction, #6 Shinshung-dong, Yousung-gu, Daejeon, 305-804, Korea

ABSTRACT : Plate loading tests (PLTs) have been used to evaluate the compaction quality of the railroad subgrade in Korea. Two methods to determine the design modulus are being used together; one is an unrepetitive plate loading test (uPLT) that obtains the subgrade reaction modulus (K_{30}) and the other is a repetitive plate loading test (rPLT) that obtains the strain modulus (E_v). There are some differences between the two methods, such as, the way in which the design modulus is evaluated, the number of loading steps, and the test procedures. Firstly, this paper compares the two test methods and summarizes the differences between them. Secondly, the relationship between the two moduli was obtained by using the results of 30 field tests of uPLT test and rPLT test carried out on the subgrade under railroad construction. The comparisons show that the two tests give large differences in stress-displacement relationship and that the correlations between the two moduli didn't indicate a good relationship. Consequently, it was found that corrections of two the moduli for stress and strain level are needed to evaluate the relationship between the two moduli, because the stress and strain level are different when K_{30} and E_{v2} are evaluated. Therefore, if the relationship between the two moduli is developed from the correction procedure, it will help field engineers in the management of compaction control for railway embankments.

Keywords: Railroad subgrade, plate loading test (PLT), compaction control, strain modulus, subgrade reaction modulus,

1. INTRODUCTION

A high-speed railroad with a concrete slab track system was constructed from Daegu to Busan in Korea. The concrete slab track is considered to be a relatively maintenance-free track construction and in Korea there is a move away from the use of ballasted track toward the use of concrete slab track, for mainline railway track systems. However, in spite of the many advantages of concrete slab track, it has a significant limitation on the permitted residual settlement of the embankment (or subgrade) after construction, compared to ballasted track. Significant settlements will result in a large maintenance cost for the concrete slab track, if the track deforms or settles unevenly. Therefore, the best way to minimize maintenance of the slab track, is to control the residual settlement below some tolerable level after construction. To do so, it is necessary to control the subgrade quality by maintaining a high density. However, it is not easy to control the subgrade density during construction, owing to the variable nature of the soil fill and the compaction effort required. Therefore the best approach is to use a plate loading test (PLT) to guarantee the subgrade quality to some level.

There are several methods for evaluating the bearing capacity of foundations. The PLT is one of the most popular methods of evaluating bearing capacity. It is classified depending on the way in which the test is performed. We could get different moduli according to the test methods. The subgrade reaction modulus (K_{30}) obtained from the uPLT test has been popular for use in Asia. More recently, the strain modulus (E_v) was newly introduced from Europe to evaluate the bearing capacity during railroad construction. The Korean standard specifies the use of both moduli for demonstrating compliance with the design criteria. Therefore, it is very beneficial for Korea to compare the two moduli and to establish the relationships between them.

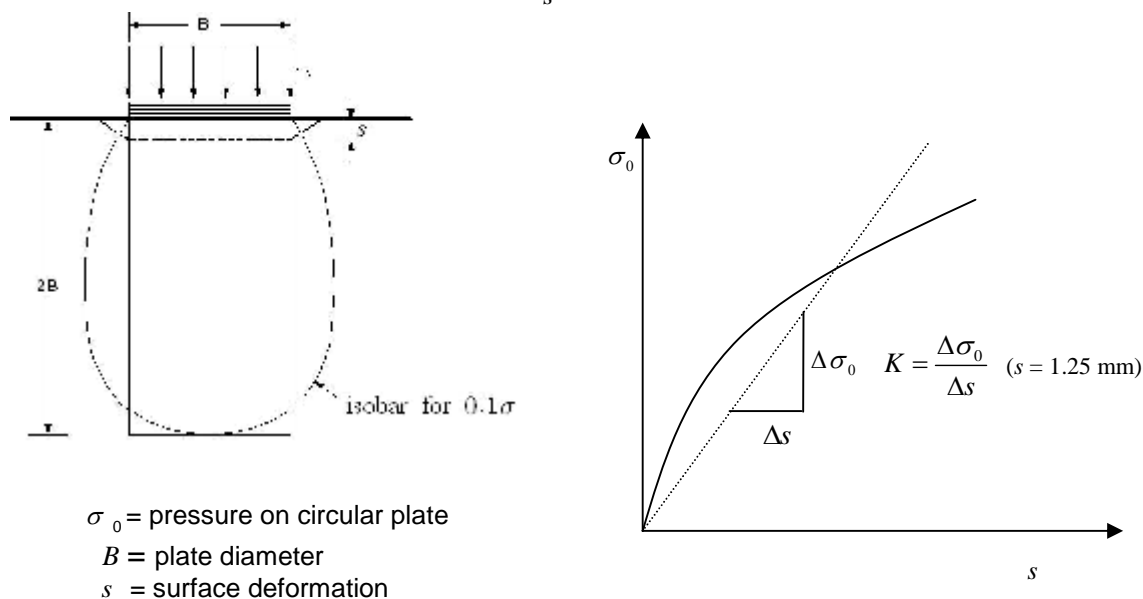
2. COMPARISON OF THE uPLT AND rPLT METHODS

2.1 Unrepetitive Plate Loading Test (uPLT)

The uPLT test consists of applying a static load in uniform increments on a circular plate that is in close contact with the surface to be tested and measuring the deflection for each load increment. In the uPLT test, a major portion of the total deformation occurs within a depth that is two times the diameter of the plate, as schematically shown in Fig. 1 (Ping and Ge, 1997). From the relationship between the average normal stress and the settlement of the plate, the stiffness of the soil is determined as the gradient of the secant line at the point corresponding to 1.25mm of settlement. The uPLT test uses three plate diameters for testing, 30cm, 40cm and 75cm, and a 35 kPa load increment for each load step of the test (KSF 2310).

The subgrade reaction modulus K_{30} (having 30cm diameter) is calculated using the following equation:

$$K_{30} = \frac{\sigma_0}{s} \quad (\text{at } s = 1.25 \text{ mm}) \quad (1)$$



(a) Major deformation element in a PLT (Ping and Ge, 1997)

(b) Definition of the subgrade reaction modulus (K)

Fig. 1 Schematic diagram of a PLT : (a) Major deformation element in a PLT (Ping and Ge, 1997), (b) Definition of the subgrade reaction modulus (K)

Here, σ_0 represents the average normal stress and s denotes the settlement of the loading plate.

Timoshenko and Goodier(1951) make a stress-settlement relation expressed as Eq. (2). This equation was based on the Boussinesq theory(1885), which defines the relationship between the settlement of a smooth, rigid circular footing and normal stress applying on a homogeneous space.

$$E_s = \frac{\pi\sigma_0 r}{2s} (1-\nu^2) \quad (2)$$

where E_s = elastic modulus; σ_0 = average normal stress; r = radius of the plate; s = settlement of the plate associated with the pressure; and ν = Poisson's ratio.

2.2 Repetitive Plate Loading Test (rPLT)

The rPLT test uses the same circular plate as the uPLT test. However, there are differences in the, number of loading cycles, maximum loading, load increment and steps, loading time for each step, and the way to determine the modulus. The uPLT test has only one loading stage, whereas the rPLT test has two loading stages and one unloading stage. The rPLT test has a short test time owing to the loading time in each loading stage being less than one minute. The load increment of the rPLT test for one load step is 80 to 90 kPa with a maximum normal stress of 500 kPa compared with 35kPa for one load step of the uPLT test.

Challenge E: Bringing the territories closer together at higher speeds

Fig. 2 shows a typical normal stress-settlement curve obtained from the rPLT test. The uPLT test has only one loading stage, whereas the rPLT test has the sequence of loading-unloading-reloading. The permanent plastic settlement was not recovered during the unloading stage and is relatively bigger than the permanent plastic settlement in the second loading stage. Therefore, the test method of the rPLT test makes it possible to accurately obtain the elastic deformation modulus by minimizing the plastic deformation.

One other big difference between the two test methods is the method to obtain the strain moduli (E_{v1} and E_{v2}) in the first and second loading stage of the rPLT test. The rPLT test uses a fitting method, whereas the uPLT test uses a secant method. In the fitting method, the settlement, s , can be expressed by the quadratic form of normal stress, σ_0 , as in Eq. (3):

$$s = a_0 + a_1 \cdot \sigma_0 + a_2 \cdot \sigma_0^2 \quad (3)$$

Here, σ_0 denotes the average normal stress (MPa) and a_0 , a_1 , a_2 represents the factors (mm, mm/(MN/m²), mm/(MN²/m⁴), respectively).

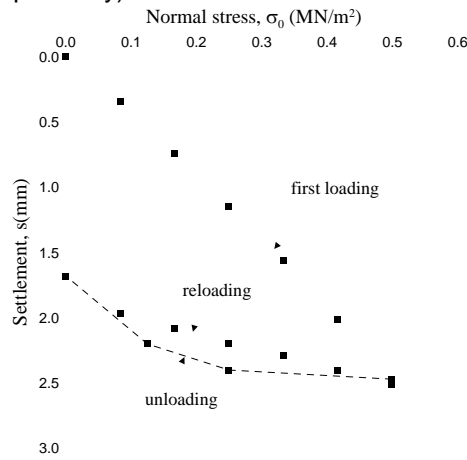


Fig. 2 Typical result of the rPLT test

The strain modulus E_v (MPa), Eq. (4).

$$E_v = \frac{1.5r}{a_1 + a_2 \cdot \sigma_{0\max}} \quad (4)$$

In Eq. (4), r denotes the radius of the loading plate which is calculated using the factors obtained in the fitting method (mm) and $\sigma_{0\max}$ is the maximum average normal stress (MN/m²). Eq. (4) can be derived using Eq. (2) by substituting Eq. (3) into Eq. (2). E_s can be derived by assuming an “zero” initial settlement as follows:

$$E_s = \frac{\pi\sigma_0 r(1-\nu^2)}{a_0 + a_1 \cdot \sigma_0 + a_2 \cdot \sigma_0^2} \cdot \frac{1}{2} \quad (5)$$

2.3 Major Differences between the Two Test Methods

There are some similarities between the two test methods such as using types of rigid steel plate, but also significant differences between the two test methods as follows:

1) The way to determine maximum loading conditions.

The uPLT test is continued until the normal stress arrives at the required maximum normal stress or is larger than the yield stress or, 15 mm settlement occurs, whereas the rPLT test is continued until the normal stress is equal to 500 kPa.

2) The way to increase load.

The uPLT test has a load increment of 35 kPa, which takes time to attain a maximum load simulating a train load. However, in the rPLT test, the normal stress increment for one step is between 80 to 90 kPa. Therefore, the time to reach the maximum load in the rPLT test is shorter than the time required in the uPLT test. The uPLT test proceeds to the next loading

stage after sufficient convergence of settlement. However, in the rPLT test, the time required for each load increment is typically less than one minute. So, the two test methods reflect different plastic and creep characteristics of the soil.

3) The way to determine the modulus.

The subgrade reaction modulus is determined as the ratio between the normal stress and the settlement from 0 to 1.25mm. However, the strain modulus is determined by the curve fitting method for the overall normal stress-settlement data. Therefore, if the soil has large plastic or viscous characteristics, the result gives a large difference.

Table 1. Comparison of the uPLT test with the rPLT test

Contents	Test methods	uPLT	rPLT
Modulus		Subgrade reaction modulus (K_{30})	Strain modulus (E_v)
How to determine Maximum load (kPa)		At required maximum normal stress or larger than yield stress or, at 15 mm settlement	500
Load increment at each step(kPa)		35	80 ~ 90
Ways to increase load		Until a deflection during 1 minute to the deflection at each loading step is not more than 1%	Each load increase shall be completed within 1 minute

3. uPLT AND rPLT FIELD TEST RESULTS

3.1 Field Test Program

Total 15 sets of uPLTs and rPLTs (total 30 tests) were conducted on the subgrade at high-speed railway construction sites between Daegu and Busan in South Korea. The objective of field tests was to evaluate the correlation between the subgrade reaction modulus obtained from the uPLT test and the strain modulus obtained from the rPLT test. To minimize the local site effects, the uPLT and rPLT tests were performed at very close positions. All tests followed the KSF 2310 (for the uPLT test) and DIN 18134 (for the rPLT test). Table 2 summarizes the test locations and the physical properties of the test materials. The subgrade layers at the 11-1 and 14-1 sites were composed of ripping rock materials and soils. Laboratory tests, such as the abrasion test (KSF 2508), the absorption test (KSF 2503), and a soundness test (KSF 2507), to determine physical properties of the rock specimens, were also conducted.

Table 2. Physical properties of test materials

Locations	Test No.	Section type	USCS	PL(%)	LL(%)	M.C (%)	γ_{dmax} (kN/m ³)	RA	PW	Soundness
11-1	1, 2, 3, 4	Subgrade	GP	N.P	N.P	5.87	22.15	1.49	22.9	4.1
14-1	5, 6	Subgrade	GP	N.P	N.P	5.75	22.25	0.75	12.8	3.34
10-4	7, 8, 9	Subgrade	SM-SC	N.P	N.P	12.8	19.11	-	-	-
12-4	10, 11, 12	Subgrade	SC	19.1	28.4	12.5	18.72	-	-	-
12-5	13, 14, 15	Subgrade	SM	2.0	24.1	10.3	18.42	-	-	-

Note: PL = plastic limit; LL = liquid limit; M.C = moisture content; RA = ratio of absorption; PW = percent wear and; N.P = non-plastic

3.2 Test Results

Challenge E: Bringing the territories closer together at higher speeds

Table 3 summarizes the test results for the uPLT and rPLT tests for all sites. Fig. 3 shows a typical normal stress-settlement curves for the uPLT test and the rPLT test. Fig. 3(a) shows the normal stress-settlement curve obtained from the uPLT test in the case of Test No.3. The value of K_{30} was obtained from the slope of the secant line that passes from the origin to the point that corresponds to a settlement of 1.25 mm. Fig. 3(b) shows the normal stress-settlement curves obtained from the rPLT test in the case of Test No.3. The strain modulus E_{v1} and E_{v2} were obtained using Eq. (4).

Fig. 4 shows K_{30} and E_{v2} values of all sites. The values of K_{30} ranged from 183.3 to 478.5MN/m³ and average value was 249.0MN/m³. The all test result satisfied the minimum requirement value, 110MN/m³, of the specification to control the compaction quality. The E_{v2} values varied from 48.1 to 254.2MPa with an average value of 118.7MPa. 11 tests among total 15 tests satisfied the minimum requirement value, 80MPa, but 4 tests among them did not satisfy the minimum requirement value. The wide range of K_{30} and E_{v2} , paradoxically, indicates how difficult it is to control the quality of compaction with those moduli.

Table 3. Subgrade reaction modulus K_{30} and strain modulus (E_{v1} and E_{v2}) from the rPLT test

Test No.	uPLT		rPLT						
	K_{30}	First cycle			Second cycle				
		a_0	a_1	a_2	E_{v1}	a_0	a_1	a_2	E_{v2}
1	217.2	-0.001	4.561	0.490	46.8	0.571	5.073	-1.729	53.5
2	183.3	-0.331	11.336	-3.329	23.3	2.716	5.655	-1.961	48.1
3	240.6	-0.132	3.888	1.445	48.8	1.216	2.869	-1.187	98.9
4	216.4	0.099	4.565	-0.697	53.4	1.564	2.077	-0.877	137.3
5	478.5	-0.089	2.802	-1.781	117.7	0.341	1.926	-1.781	217.2
6	316.1	0.030	1.438	-0.258	171.9	0.229	1.233	-0.697	254.2
7	193.2	-0.032	4.416	1.187	44.9	1.860	1.348	-0.103	173.5
8	393.5	0.050	3.302	-0.568	74.6	1.013	1.138	0.181	183.2
9	133.0	-0.058	2.505	1.703	67.0	0.799	1.813	-0.129	128.7
10	190.4	1.733	7.746	-2.555	34.8	2.726	0.241	6.864	61.3
11	380.7	0.979	3.788	0.903	53.1	1.119	0.989	2.968	91.0
12	161.3	0.911	3.545	1.161	54.5	0.973	1.280	2.503	88.9
13	217.2	1.629	5.213	-1.161	48.6	1.719	2.560	-0.439	96.1
14	230.7	1.460	5.843	-2.632	49.7	1.706	2.328	-0.052	97.7
15	188.9	1.397	12.373	-7.871	26.7	3.586	6.029	-3.252	51.1

Challenge E: Bringing the territories closer together at higher speeds

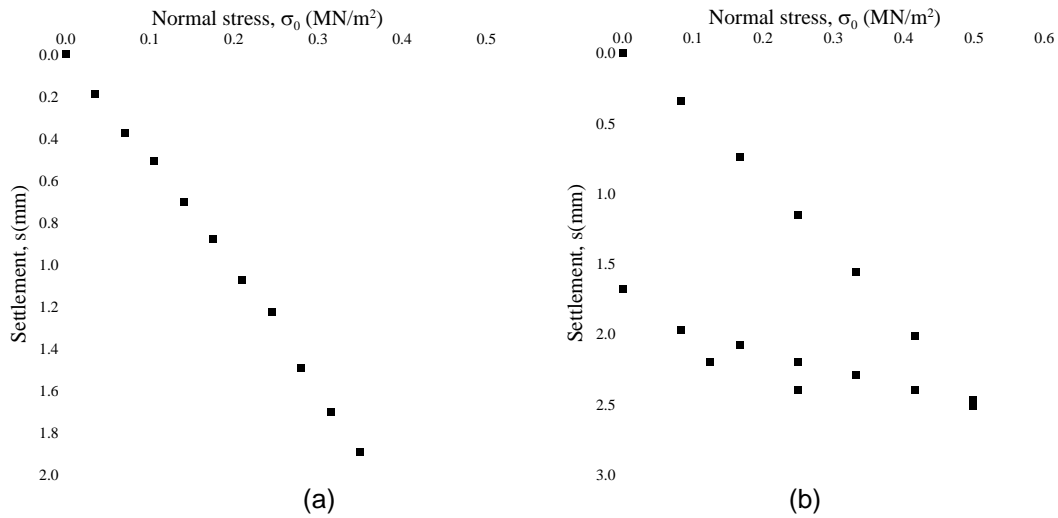


Fig. 3 Test results from (a) the uPLT and (b) the rPLT

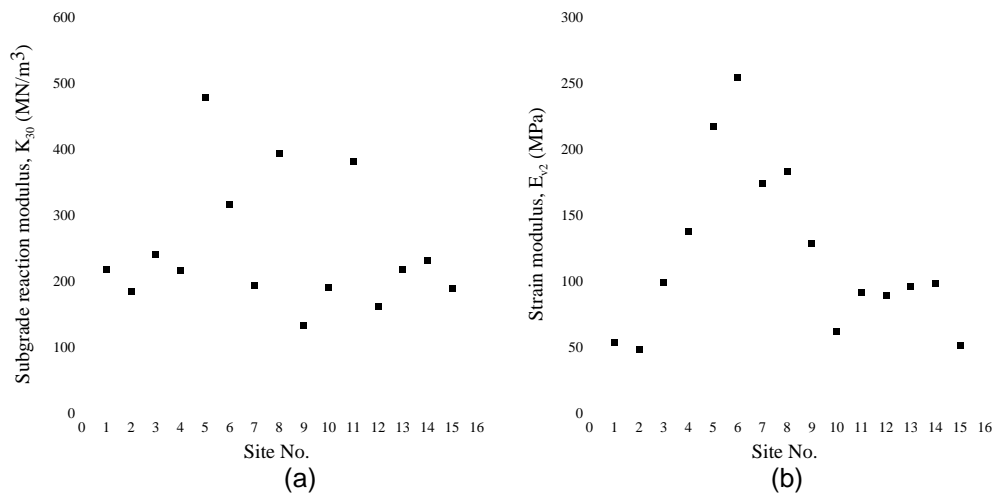


Fig. 4 (a) K_{30} and (b) E_{v2} values of all sites

4. ANALYSIS OF FIELD TEST RESULTS

4.1 Correlation between K_{30} and E_{v2}

Fig. 5 shows the relationship between the subgrade reaction modulus (K_{30}) obtained from the uPLT test and the strain modulus (E_{v2}) from the rPLT test. From a regression analysis, the slope of the linear regression line that passes through the origin was 0.36. The value of the correlation coefficient (R^2) was 0.34, and the P-value was less than 0.0001. The slopes of the upper and lower 95% confidence limit (CL) line were 0.71 and 0.04, respectively. These relationships are represented as follows:

$$E_{v2} = \alpha K_{30} \quad (6)$$

Here, E_{v2} denotes the strain modulus in MPa, K_{30} is the subgrade reaction modulus in MN/m^3 , and α is the coefficient (ranges between 0.04~0.71 with a best fit of 0.36).

Eq. (6) can be used to evaluate E_{v2} from K_{30} or K_{30} from E_{v2} . However, in Eq. (6), the range of the coefficient α is too wide and the range of the E_{v2} values increases as the value of K_{30} increases. Furthermore, there are some inherent factors which make it difficult to compare the two moduli. Firstly, in the uPLT test, K_{30} is obtained under a condition in which the plate settlement is 1.25mm. However, E_{v2} is obtained from the normal stress-settlement relationship up to the applied maximum loading. Secondly, even though a test is conducted at very close positions, the soil may experience different strain and stress levels. In order to accurately correlate K_{30} with E_{v2} , it is necessary to consider the strain and stress level. Thirdly, because the dimensions of E_{v2} and K_{30} differ, it is more reasonable to compare E_{v2} with the modulus of elasticity, E_s , which is obtained from Eq. (2) as it has the same units in MPa.

Challenge E: Bringing the territories closer together at higher speeds

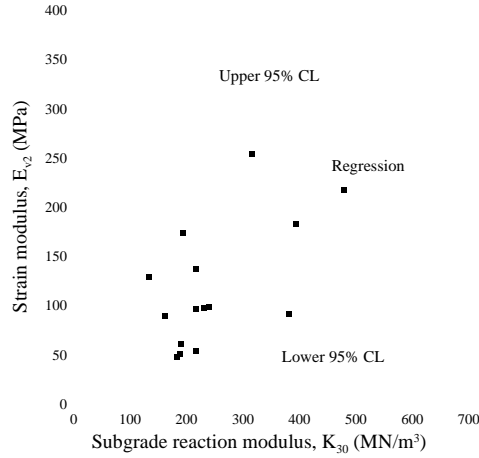


Fig. 5 Relationship between the subgrade reaction modulus (K_{30}) and the strain modulus (E_{v2})

4.2 Correction for Strain and Stress Level

To consider the strain level induced from the uPLT and rPLT tests, it is necessary to determine the influence of depth for the field tests. According to the previous research, a major portion of the total deformation occurs within a depth that is two times the diameter of the plate (Burmister, 1947; Ping et al., 1997). The vertical strain induced in the soil by the applied plate load can be calculated using the strain influence factor proposed by Schmertmann et al. (1978). The variation of the vertical strain influence factor with the depth ratio is represented by the depth over the plate diameter. The vertical strain below the center of the plate is obtained from Eq. (7).

$$\varepsilon_v = \frac{q}{E_s} I_z \quad (7)$$

Here, q represents the normal stress applied on the plate, E_s is the modulus of elasticity of a soil mass, and I_z is the strain influence factor.

By substituting Eq. (2) into Eq. (7), the vertical strain, ε_v , can be expressed as follows:

$$\varepsilon_v = \frac{4s}{\pi D(1-\nu^2)} I_z \quad (8)$$

Using Eq. (8), the vertical strain induced with depth can be obtained in the plate loading test. In order to determine a vertical strain value within the influence range, a representative depth for the strain value must be determined. Kim et al. (2005) suggested that a nearly identical deformation characteristic is obtained regardless of the value of the vertical strain influence factor under the same soil conditions if the strain influence factor corresponding to the representative depth is applied. This study uses a value of 0.4, which is the vertical strain influence factor at a depth equal to the plate diameter, as the representative vertical strain influence factor.

Even under the same soil conditions, if the stress levels differ, the moduli obtained from the different tests can also differ because the stress level in the soil affects the modulus. The stress levels to obtain K_{30} from the uPLT test differ from those to obtain E_{v2} from the rPLT test. It is more reasonable to compare between the two moduli at identical stress levels. Therefore, to accurately compare K_{30} with E_{v2} , any corrections should be made using a reference stress. This could be done using Eq. (9). In this equation, n is the influence factor for confining pressure, which can be obtained from the laboratory test results at different effective confining pressures or from the recommended values of the particular soil type. The stress exponent for gravel or compact sand is often considered to be $n = 0.5$ (Kramer, 1996; Rainer, 1994).

$$E_{v,reference} = E_{v,field} \left(\frac{\sigma'_{m,reference}}{\sigma'_{m,field}} \right)^n \quad (9)$$

Challenge E: Bringing the territories closer together at higher speeds

Here, $E_{v,reference}$ = strain modulus at reference stress; $E_{v,field}$ = strain modulus at mean effective stress of field tests; $\sigma'_{m,reference}$ = mean reference effective stress; $\sigma'_{m,field}$ = mean effective stress of field tests.

If the elastic and the strain modulus are corrected using Eq. (9), they can be compared under identical stress levels. The mean effective stress from field tests, $\sigma'_{m,field}$ in Eq. (9), can be determined from Eq. (10).

$$\sigma'_m = \frac{1}{3}(\sigma'_v + \Delta\sigma'_v + 2\sigma'_h + 2\Delta\sigma'_h) \quad (10)$$

where σ'_m indicates the mean effective stress, σ'_v is the vertical effective stress, σ'_h is the horizontal effective stress ($=K_0\sigma'_v$), K_0 is the coefficient of horizontal stress at rest, $\Delta\sigma'_v$ is the vertical stress increment caused by the plate loading, and $\Delta\sigma'_h$ is the horizontal stress increment caused by the plate loading.

Using Eq. (9), K_{30} and E_{v2} are corrected for the mean effective stress obtained from Eq. (10). As the two tests are performed under static conditions, the coefficient of horizontal stress at rest, K_0 , is assumed to be 0.5. The average value of the mean effective stress of the subgrade in the rPLT test was 50.4 kPa. So, the reference stress is assumed as 50 kPa. Fig. 6 is an example to show the variation of the elastic modulus (E_s) according to the vertical strain between uncorrected and corrected values in the uPLT of Test No.1. Fig. 7 is an example to show the variation of strain modulus (E_v) according to the vertical strain between the uncorrected and corrected values in the rPLT of Test No.1.

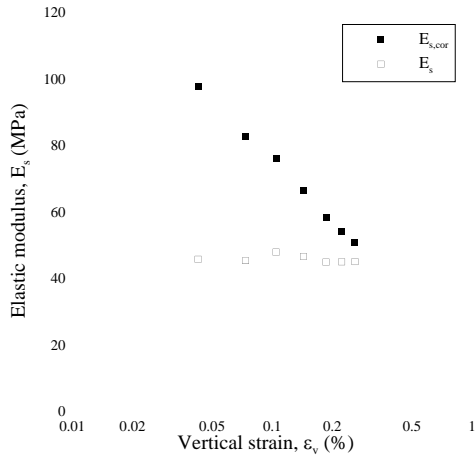


Fig. 6 Variation of Elastic modulus, E_s according to vertical strain in the uPLT (Test No.1)

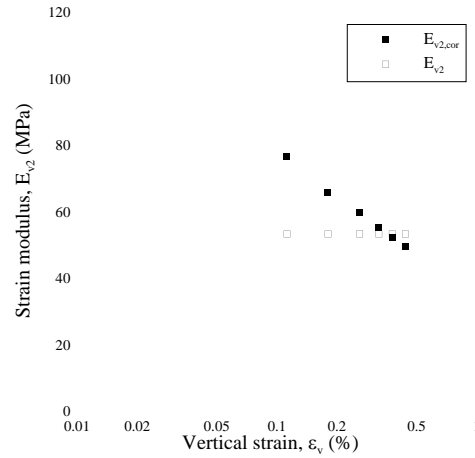


Fig. 7 Variation of strain modulus, E_{v2} according to vertical strain in the rPLT (Test No.1)

Fig. 8 shows the relationship between the corrected elastic modulus $E_{s,cor}$ and the corrected strain modulus $E_{v2,cor}$ with the vertical strain for Test No.1. From the figure, it is shown that the variation of the modulus with a vertical strain is similar. These results are in agreement with those obtained in other studies (Kim et al., 1997; Tatsuoka et al., 1992). In this figure, the strain range of the E_s reduction curve varied from 0.043 to 0.223%, whereas the strain range of the E_{v2} reduction curve varied from 0.112 to 0.439%. The minimum, average, and maximum strains in the overlapped strain range were 0.112, 0.168, and 0.223, respectively. For the comparison of E_s with E_{v2} , E_s and E_{v2} corresponding to the average vertical strain (ϵ_v^*) were obtained for each test. Using the same procedure, the values of $E_{s,cor}^*$ and $E_{v2,cor}^*$ were determined for all of the tests.

Fig. 9 shows the relationship between $E_{s,cor}^*$ and $E_{v2,cor}^*$. From a regression analysis, the slope of the linear regression line was 1.72 and the coefficient of correlation (R^2) was 0.71. This can be expressed as follows:

$$E_{v2,cor}^* = 1.72E_{s,cor}^* \quad (R^2=0.71) \quad (11)$$

Challenge E: Bringing the territories closer together at higher speeds

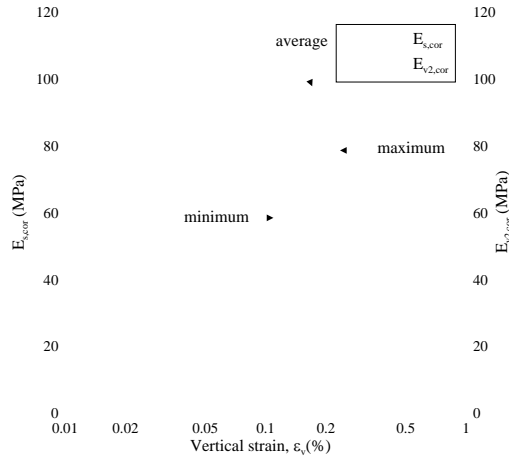


Fig. 8 $E_{s,cor}$ and $E_{v2,cor}$ reduction curves (Test No.1)

This relationship was derived for a value of stress component n , equal to 0.5 in Eq. (9). In general, n can be uniquely decided for individual soils from the results of laboratory tests at different effective confining pressures. However, this is not representative of the natural variability of field conditions. In order to consider field conditions, we put the range of n from 0.3 to 0.7. Fig. 10 and Table 4 show the analysis results. It is found that the slope of the linear regression line gradually decreases as n increases, and R^2 is highest in the case that n is equal to 0.5.

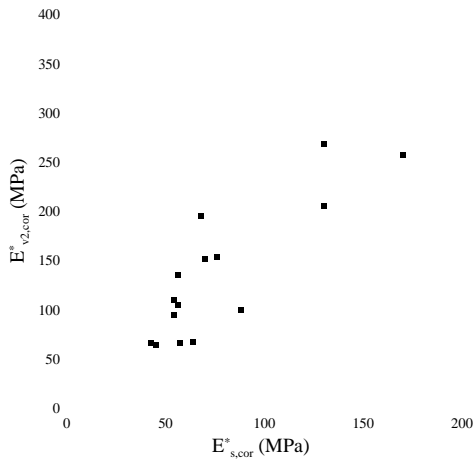


Fig. 9 Relationship between $E_{s,cor}^*$ and $E_{v2,cor}^*$

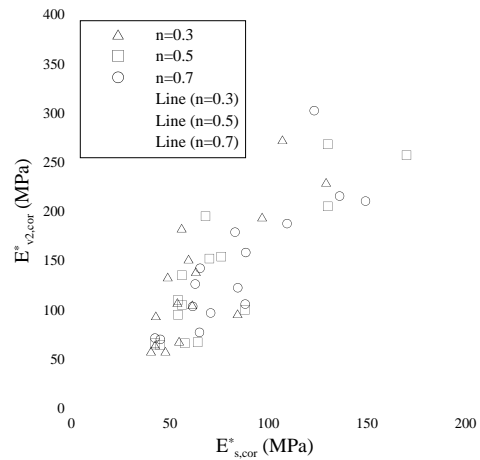


Fig. 10 Relationship between $E_{s,cor}^*$ and $E_{v2,cor}^*$ for the stress exponent, n

Table 4. Relationship between $E_{s,cor}^*$ and $E_{v2,cor}^*$ for $n = 0.3, 0.5$ and, 0.7

n	Linear Regression Line	R^2
0.3	$E_{v2,cor}^* = 1.98E_{s,cor}^*$	0.57
0.5	$E_{v2,cor}^* = 1.72E_{s,cor}^*$	0.71
0.7	$E_{v2,cor}^* = 1.70E_{s,cor}^*$	0.70

4.3 Estimation of E_{v2} from uPLT test Results

In the previous section, the correlation relationship between $E_{s,cor}^*$ and $E_{v2,cor}^*$ was proposed (see Eq. (11)). In order to estimate the E_{v2} value from the uPLT test, $E_{s,cor}^*$ from the uPLT test should be determined. However, $E_{s,cor}^*$ is not an elastic modulus that corresponds to the reference strain but is one that corresponds to the average vertical strain ϵ_v^* within the overlapped vertical strain range as shown in Fig. 8. So, the average vertical strain ϵ_v^* must be firstly determined. Fig. 11 gives us the relationship between E_s and the average vertical strain ϵ_v^* . From the regression analysis, this relationship can be expressed as a power function, as follows:

$$\varepsilon_v^* = 14.94E_s^{-1.24} \quad (R^2=0.825) \quad (12)$$

The ε_v^* has a tendency to decrease and converge as the E_s increases.

To obtain the corrected elastic modulus ($E_{s,cor}^*$) at average vertical strain (ε_v^*), we can use the E_s reduction curve in Fig. 6. $E_{v2,cor}^*$ can be obtained inserting the corrected elastic modulus ($E_{s,cor}^*$) to Eq. (11). $E_{v2,cor}^*$ is the strain modulus for the reference stress (50 kPa) at an average vertical strain.

According to the procedure described above, the calculated E_{v2} was obtained from the uPLT test. Fig. 12 shows the relationship between the measured strain modulus $E_{v2,rPLT}$ and the calculated strain modulus $E_{v2,uPLT}$. The figure shows that most of the data are close to the line of equality. Therefore, if we have the uPLT test results, E_{v2} can be evaluated using the proposed procedure.

5. Summary and Conclusions

This paper compared two kinds of plate loading test to control compaction quality of the subgrade of a high speed railroad. One is an unrepetitive plate loading test (uPLT) to obtain the subgrade reaction modulus (K_{30}) which is used in Asia and two is a repetitive plate loading test (rPLT) to obtain strain modulus (E_v) which is used in Europe.

There are major differences between the two test methods such as, the way to determine the maximum loading conditions, the way to determine the modulus for example. A detailed comparison between the two test methods is performed to understand the correlation between the two moduli obtained from the tests; the subgrade reaction modulus and the strain modulus.

To establish the correlation between the two moduli, a total of 30 field tests were performed. The test results were treated statistically using regression methods. Because the soil experiences different stress and strain level for each test, in order to accurately correlate between the two moduli, corrections were made considering the strain and stress level. Finally, a correlation equation between the strain modulus and the elastic modulus $E_{v2,cor}^* = 1.72E_{s,cor}^*$ was developed. The calculated strain modulus using K_{30} ($E_{v2,uPLT}$) obtained from the uPLT test had a good agreement with the measured strain modulus E_v ($E_{v2,rPLT}$) obtained from the rPLT test.

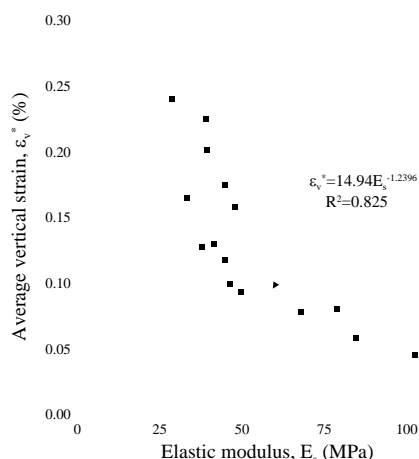


Fig. 11 Relationship between average vertical strain (ε_v^*) and elastic modulus (E_s)

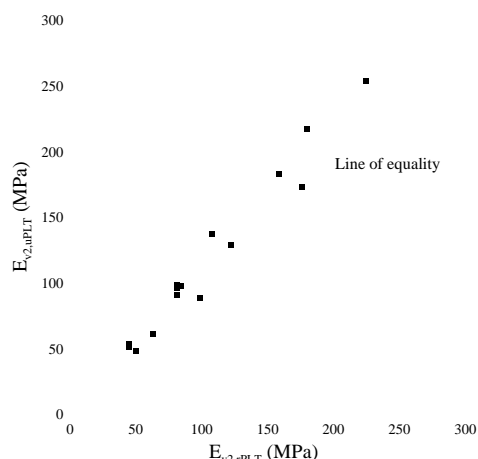


Fig. 12 Relationship between calculated strain modulus ($E_{v2,uPLT}$) and measured strain modulus ($E_{v2,rPLT}$)

References

1. Burmister, D. M. (1947). Discussion. Special Technical Publication 79, ASTM, 139-146.
2. DIN 18134 (2001). "Determining the deformation and strength characteristics of soil by the plate loading test." German Construction Industry Standards Committee, Berlin, Germany.
3. Janbu, N. (1963). "Soil compressibility as determined by oedometer and triaxial tests." European Conference on Soil Mechanics and Foundation Engineering, Wiesbaden, Vol. 1, 19-25 and Vol. 2, 17-21.
4. Kim, D.S., Kweon, G. C., and Lee, K. H. (1997). "Alternative method of determining resilient modulus of compacted subgrade soils using free-free resonant column test." Transportation Research Record, 1557, 62-69.
5. Kim, D. S., Seo, W. S., and Kweon, G. C (2005). "Evaluation of field modulus of subgrade soils using repetitive static plate bearing load test." J. Korean Geotech. Eng., 21(6), 67-79.

Challenge E: Bringing the territories closer together at higher speeds

6. KSF 2310 (2000). "Method for Plate Load Test on Soils for Road.", Korea Standards Association, Seoul, Korea (in Korean language).
7. Kramer S. L. (1996). Geotechnical Earthquake Engineering, Prentice-Hall, Englewood Cliffs, N.J., 232-237.
8. Massarsch, K. R. (1994). "Settlement analysis of compacted granular fill", XIII ICSMFE 1994, New Delhi, India, 325-328.
9. Ping, W. V., and Ge, L. (1997). "Field verification of laboratory resilient modulus measurements on subgrade Soils", Transportation Research Record, 1557, 53-61.
10. Schmertmann, J. H., Hartmann, J. P., and Brown, P. R. (1978). "Improved strain influence factor diagrams." J. Geotech. Eng. Div., ASCE, 104(GT8), 1131-1135.
11. Tatsuoka, F., and Shibuya, S. (1992). "Deformation characteristics of soils and rocks from field and laboratory tests." Key Note Lecture for Session No. 1, The 9th Asian Regional Conference on Soil Mechanics and Foundation Engineering, Bangkok, 101-170.
12. Timoshenko, S., and Goodier, J. N. (1951). Theory of Elasticity, McGraw-Hill Book Co., Inc., New York, 368-372.