Determination of Modulus of Subgrade Reaction k_s or Westergaard Modulus and Resilient Modulus Mr using the Plate Load Test

Theory behind Modulus of Subgrade Reaction ks or Westergaard Modulus

The assumption that the footing will behave as a rigid body is usually not applicable for large and multi-column foundations, and in such conditions, engineers prefer flexible analysis using numerous available software. These computer programs often ask for an input parameter known as the “modulus of subgrade reaction”.

Structural engineers widely uses this modulus in the design of slab foundations, pavements, high-rise buildings, bridge footings, rail infrastructure, over-ground tanks, windfarm foundations, temporary platforms etc. However, a geotechnical engineer is responsible for providing the appropriate subgrade reaction modulus. The appropriate estimation of subgrade reaction modulus would result in the accurate design of structures.

The modulus of subgrade reaction, $k_{s,}$ (also called coefficient of subgrade reaction or Westergaard Modulus), is defined as the pressure per unit deformation of the subgrade, and it is often expressed as kN/m2/m or kN/m3.

Mathematically, the modulus of subgrade reaction (k_s) is expressed as:

$k_s = \sigma / s$

Where σ = applied pressure and s = soil settlement

The k_s value can be determined by field tests or by correlation with other tests. There is no direct laboratory procedure for determining the k_s value.

In road and airport construction, the Westergaard modulus k, with a loading plate of 762 mm diameter is calculated as follows:

$$k_{s\ 762} = \frac{\sigma 0}{s}\ [\frac{MN}{m3}]$$

σ_0 is the compressive strain that corresponds to a mean settlement of s = 1.25 mm for the initial loading.

In case of a plate diameter of 300 mm, k_s, is corrected with a quotient of d =2.22. The ideal quotient is d=2.54 (the ratio of 762 mm / 300 mm). Literature, based on experimental studies, recommends the use of a quotient of d = 2.22 in the place of the ideal quotient d = 2.54.

$$k_{s\ 300} = \frac{\sigma 0}{s \text{ x } 2.22}\ [\frac{MN}{m3}]$$

The latter plate diameter may be used when the layer below the loading plate is homogeneous to a depth of 1.5 x plate diameter (information without liability).

Calculating the Modulus of Subgrade Reaction k_s using the Plate Load Test AX01a

It is not possible to calculate the modulus of subgrade reaction k_s from the values Ev1 or Ev2 only. However, when you have all values of the test - you can use the second order polynomial described in the DIN18134 standard to extrapolate modulus of subgrade k_s.

In our Plate Load Test AX01a, we have a function to approximate/extrapolate k_s from the standard Ev1, Ev2 load cycles using the second order polynomial.

However, in case the test does not reach 1.25mm settlement, it is possible that the extrapolation failed, because sometimes there is no solution for the 2nd order polynomial at 1.25mm.

The Westergaard modulus, k_s, is determined by the software and shown in the results.

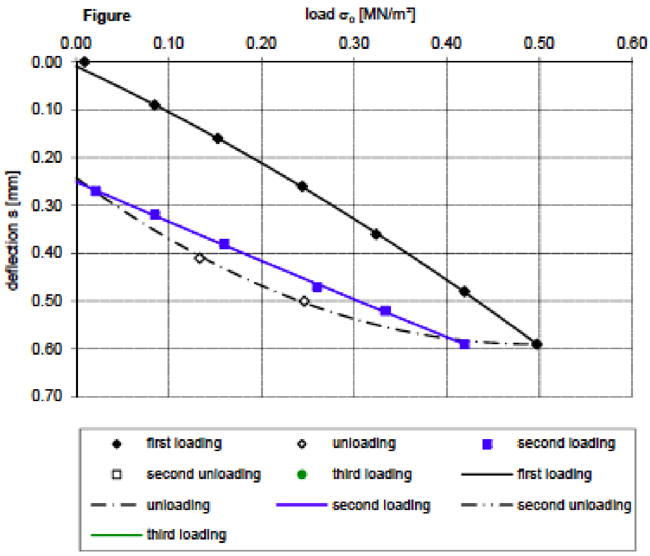
Plate Bearing Test according to DIN 18134-300

Institute:
Client: [redacted]
Project: [redacted] Windfarm
Test depth: Surface
Layer: FSL
Remarks:
Weather/Temp.: Windy 20

Record number: 32
Card number.: 210917101656
Start of test: 19/3/18 9:27
End of test: 19/3/18 9:41
Device number: 5713
Ø-Plate: 300 mm

Operator: Daniel Pearce
Lever ratio: -1:1.00
Equipment: Manufacturer: Anix GmbH, LVDT sensor 15mm, force sensor 100kN

No.	Load σ_0 [MN/m²]	Deflection s [mm]
first loading		
1	0.0092	0.00
2	0.0849	0.09
3	0.1530	0.16
4	0.2442	0.26
5	0.3239	0.36
6	0.4193	0.48
7	0.4974	0.59
unloading		
8	0.2463	0.50
9	0.1334	0.41
second loading		
10	0.0212	0.27
11	0.0851	0.32
12	0.1600	0.38
13	0.2603	0.47
14	0.3336	0.52
15	0.4193	0.59
second unloading		
third loading		



Results	Actual	Nominal	Rating
σ_{1max} [MN/m²]	0.4974		
E_{v1} [MN/m²]	192.75		
E_{v2} [MN/m²]	279.93	45	OK
E_{v2}/E_{v1}:	1.452	2.2	OK
E_{v3} [MN/m²]			
E_{v3}/E_{v1}:			
Westergaard modulus:	326	MN/m³	
remarks:	South East		

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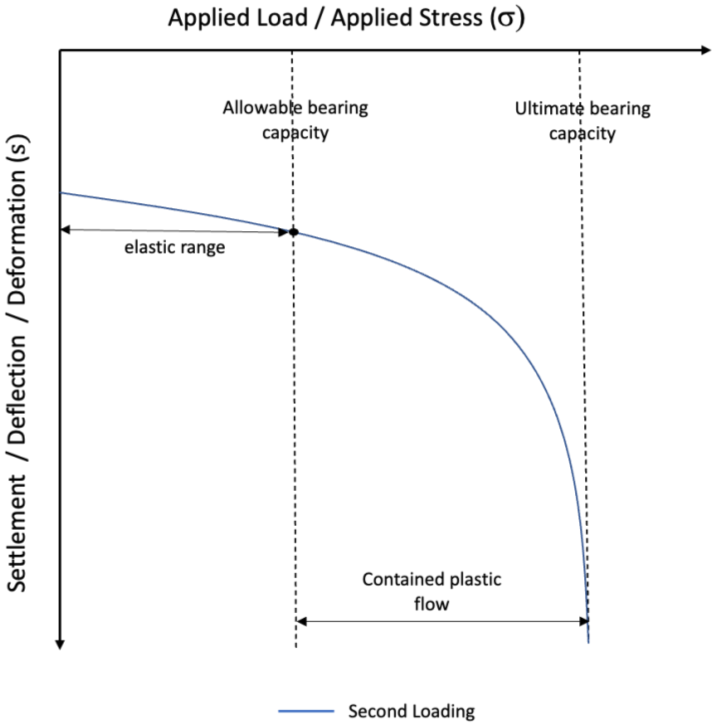
What is the Difference Between Resilient Modulus Mr and Elastic Modulus (Youngs Modulus)

When we load and unload the ground, a portion of the deformation maybe recoverable (elastic deformation) whilst a portion maybe unrecoverable (plastic deformation).

- Recoverable means the ground will return to it's original shape and is in the elastic range. The load / deflection relationship is linear.
- Unrecoverable means the ground will be permanently deformed and is in the plastic range.



Modulus is a stress / strain relationship.

For Elastic Modulus (Es) and Resilient Modulus (Mr), we are interested in the elastic range, where elastic deformation is occurring.

Elastic Modulus (sometimes referred to as Youngs Modulus) refers to just loading and unloading a single time. With the Plate Load Test, we define this as Ev1 for the first loading or Ev2 for the second loading.

Resilient Modulus (Mr) refers to repeatedly loading and unloading to simulated traffic loading, for 10,0000 or 100,000 cycles, for example. The resilient modulus (Mr) parameter is defined as the ratio of applied deviatoric stress to the resilient (elastic / recoverable) strain experienced by the material under repeated loadings (i.e. traffic). The Resilient Modulus is commonly used in structural design of pavements.

Note: **Vertical modulus** is referred to in the Austroads Guide to Pavement Design - Part 2: Pavement Structural Design. It is not defined.

Determining the Resilient Modulus Mr using the Plate Load Test

The relationship between k_s values from a Plate Bearing Test / Plate Load Test (PLT) and was updated in the fall of 2011 to better reflect published test results.

This relationship suggested in the 1993 AASHTO Guide for Design of Pavement Structures is no longer used.

$$Mr = ks \times 19.4$$

This web applet, based on the conversion factors included in NCHRP Report 128, "Evaluation of AASHTO Interim Guide for the Design of Pavement Structures", allows you to quickly estimate the subgrade resilient modulus (Mr) from either a California Bearing Ratio (CBR) or Resistance Value (R-value) measurement. Care with US units.