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Estimation of the "C" Value Considered in the AASHTO-93 Guide for Back Analysis of the Elastic Modulus of the Subgrade

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GENERAL OBJECTIVE

- **Obtain the Subgrade Resilient Modulus based on laboratory tests on samples extracted from an existing road. (MRsite-sr)**
- **Obtain the Subgrade Resilient Modulus using the Back Analysis model included in the AASHTO-93 Guide using the FWD equipment for deflection measurement. (MRrc-sr)**
- **Estimate the "C" value considering the following relationship:**

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"Piliot"or Reference

$$\text{"C" Value} = \frac{MRsite\text{-}sr}{MRrc\text{-}sr}$$

"C" Value=0.33 (Recommended by AASHTO-93)

Key Words…

Soil Resilient Modulus (MR)

- **Measurement of the structural capacity of the unbound materials to support dynamic loads.**
- **Considers the nonlinear behaviour of the unbound materials.**
- **Considers the recoverable deformation after the application of the stress.**

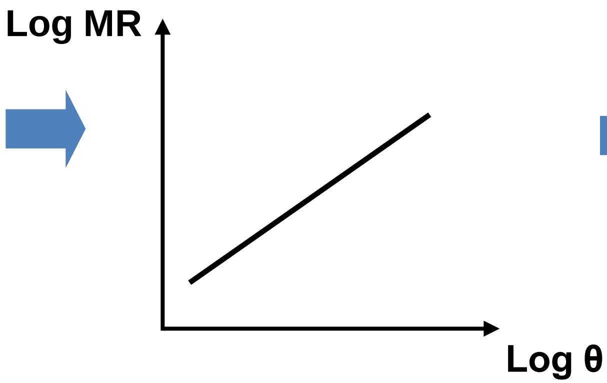
$$MR = \frac{\sigma_d}{\varepsilon_a}$$

σ_d (Axial deviator stress)

ε_a (Recoverable unit axial deformation)

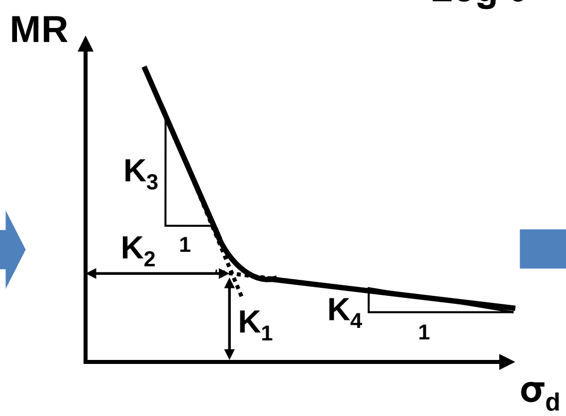
More…Key Words…

Frictional Soils



$$MR = K_1\,\theta^{K2}$$

Cohesive Soils



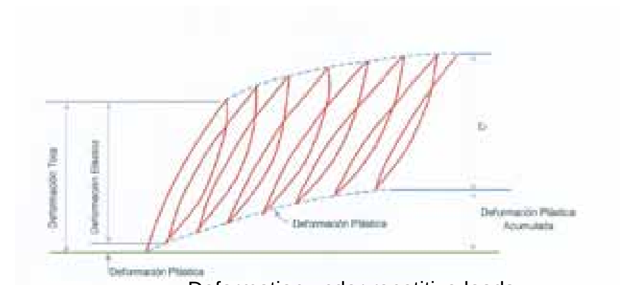
$$MR = K_1 + K_3\,(K_2 - \sigma_d), \text{ for } \sigma d < K2$$

$$MR = K_1 - K_4\,(\sigma_d - K_2), \text{ for } \sigma d > K2$$

Moisture, density, weather….

Loads….

More…Key Words…



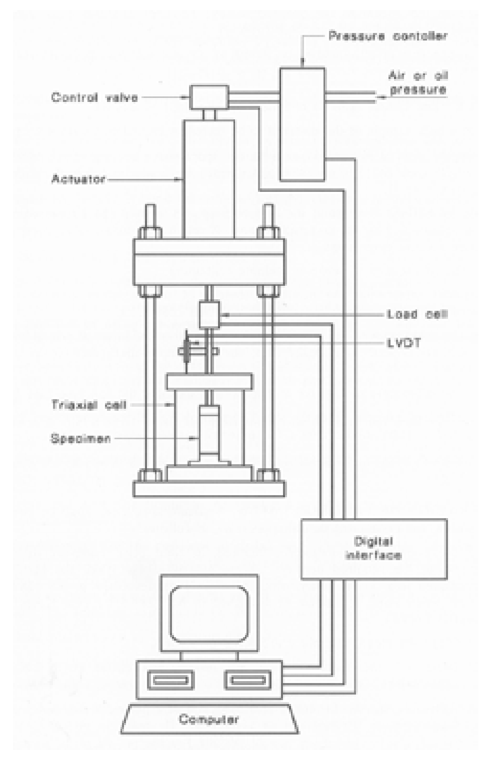
Deformation under repetitive loads

Source: F. Limaymanta, et al. "Resilient Modulus Test". XIV National Conference of Civil Engineering. Perú, 2003.

Sequence Nº	Pressure of Confinement -σ_3- (MPa)	Deviator Stress- σ_d- (MPa)	Nº Load Applications
0 (*)	0.0414 MPa (6 psi)	0.0276 (4 psi)	1000
1	0.0414 MPa (6 psi)	0.0138 (2 psi)	100
2		0.0276 (4 psi)	100
3		0.0414 (6 psi)	100
4		0.0552 (8 psi)	100
5		0.0690 (10 psi)	100
6	0.0207 MPa (3 psi)	0.0138 (2 psi)	100
7		0.0276 (4 psi)	100
8		0.0414 (6 psi)	100
9		0.0552 (8 psi)	100
10		0.0690 (10 psi)	100
11	0 MPa (0 psi)	0.0138 (2 psi)	100
12		0.0276 (4 psi)	100
13		0.0414 (6 psi)	100
14		0.0552 (8 psi)	100
15		0.0690 (10 psi)	100

(*) : Previous a conditioning

Resilient Modulus equipment for unbound materials. IMAE. University of Rosario, Argentina.



Source: Australian Standard. AS 1289.6.8.1-1995. "Methods of Testing Soils for Engineering Purposes". Australia, 1995.

More…Key Words…

Asphalt Concrete Dynamic Modulus (Edim)

Edim is a functional relationship between the applied tensions and the resulting deformations for a particular temperature and time or frequency of the applied load.

$$\text{Edim}(T,t) = \frac{\sigma_d \ (\text{stress})}{\varepsilon_a \ (\text{deformation})}$$

Magnitude…

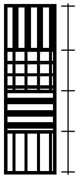
Weather / Speed

Estimation of the "C" Value Considered in the AASHTO-93 Guide for Back Analysis of the Elastic Modulus of the Subgrade

More…Key Words…

Core Drill-Profile C4

Date: 04-15-2004



Layer	Tick.(cm)
W. Course	4.25
BASE 1	9.15
BASE 2	5.55
BASE 3	6.2

	Wearing Course	BASE 1		BASE 2	BASE 3
	C4-T1-1	C4-T1-2	C4-T1-3	C4-T1-4	C4-T1-5
Density (gr/cm^3)	2.461	2.418	2.456	2.449	2.390
Hight (mm)	46.50	42.50	40.50	48.25	46.00

TABLE 1

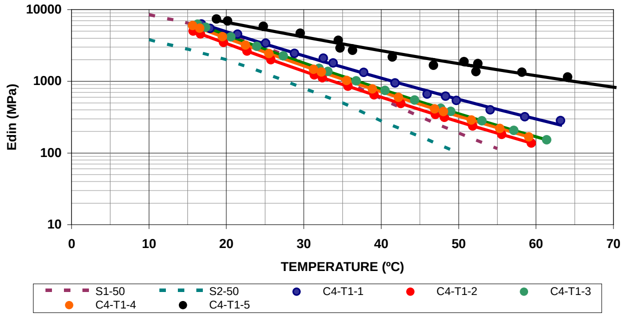
T(frec. Cte.) = (1/((1/Te)-k*Ln(10/(Frequency-Hz-)))-273

E(regres.) = 10^(c+b*LOG(Frequency-Hz-)+a*1/Temp.(˚K))

		Modulus (Mpa)				
TEMP.(˚C)	FREQUENCY (Hz)	C4-T1-1	C4-T1-2	C4-T1-3	C4-T1-4	C4-T1-5
10	2.50	6295	5696	7472	7199	7379
10	2.00	5471	5001	6743	6432	6947
10	1.00	4532	3908	5118	4793	5851
10	0.50	3392	2840	-	3394	4685
10	0.25	2454	2009	2711	2364	3727
25	2.50	2099	1181	1084	1109	2913
25	2.00	1796	1003	970	1040	2710
25	1.00	1328	670	778	873	2180
25	0.50	948	544	572	658	1676
25	0.25	663	359	390	490	1363
40	2.50	618	322	497	428	1883
40	2.00	540	294	437	414	1768
40	1.00	400	284	321	329	1339
40	0.50	319	220	250	255	1147
40	0.25	283	172	184	195	871

TABLE 2

	C4-T1-1	C4-T1-2	C4-T1-3	C4-T1-4	C4-T1-5
a =	**2970.49**	**3433.87**	**3460.77**	**3431.91**	**1823.26**
b =	**0.41**	**0.40**	**0.44**	**0.39**	**0.32**
c =	**-6.86**	**-8.59**	**-8.61**	**-8.50**	**-2.72**
K =	**6.0E-05**	**5.1E-05**	**5.5E-05**	**5.0E-05**	**7.6E-05**
Multiple Correlation Coeficient =	0.9979668	0.9907779	0.9806264	0.9900732	0.9847322
Coeficient R^2 =	0.9959377	0.9816409	0.9616281	0.9802449	0.9696974
R^2 adjusted =	0.9952607	0.9785811	0.9546514	0.9769523	0.9646470
Typical Error =	0.0312815	0.0760995	0.1141747	0.0788429	0.0551173
Observations =	15	15	14	15	15



To Sum up…

From Laboratory Tests → **Get the "Site Resilient Modulus" of the different materials including the subgrade (MRsite-sr).**

↓

MRsite-sr will be the "Pilot" or "Reference"

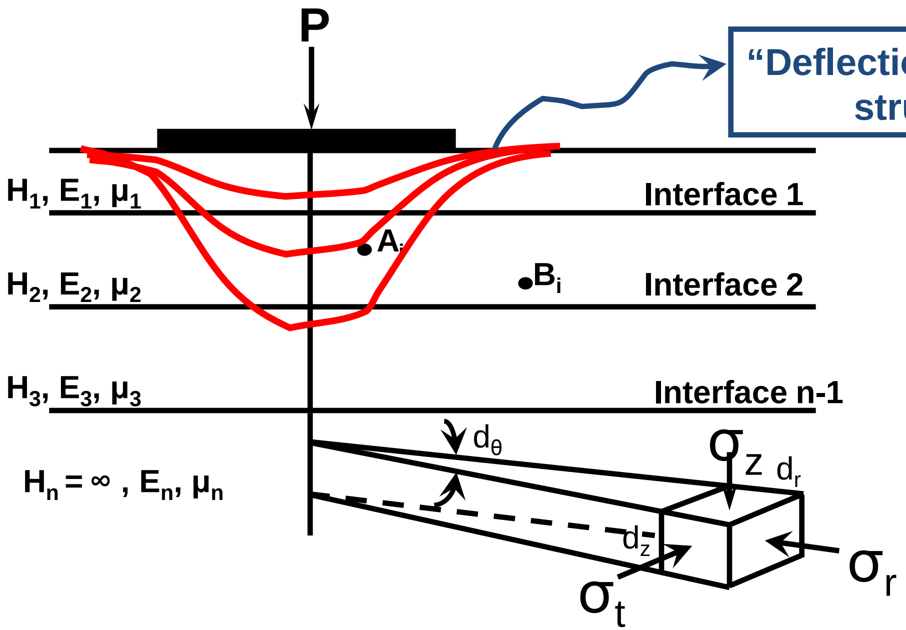
↓

Kenlayer Computer Program (Huang, Kentucky University, 1993) → **Const. Eq. / Edim 40 kN / 10 Hz**

More…Key Words…

Back-Analysis → **The back analysis process is an approach of the state of stresses within a pavement structure based on superficial deflections measured during the application of a load.**

Multi Layer Theory



“Deflection” as a response of the pavement structure under an applied load

Direct relationship between “Deflection”, applied load and stresses (HVEEM 1955-1962)

Development of new equipment to measure deflection

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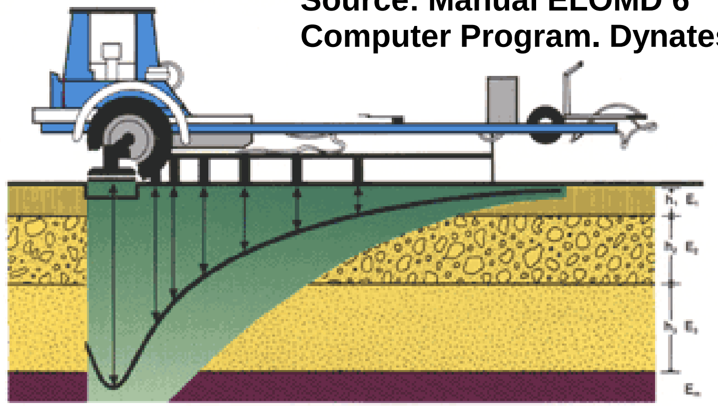
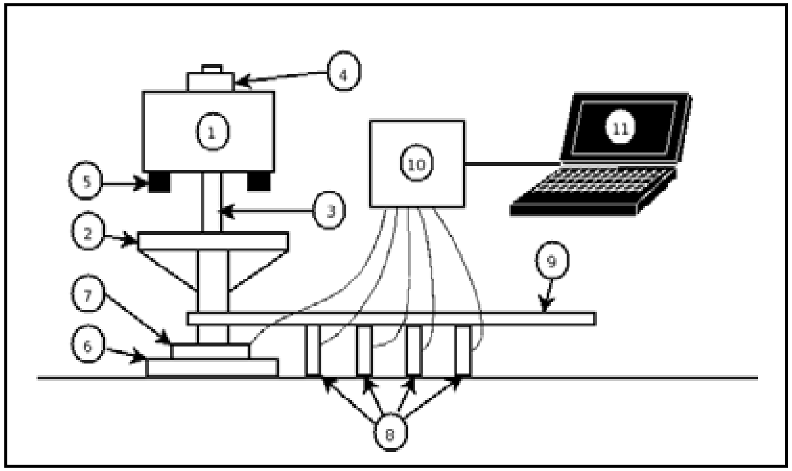
Source: Manual ELOMD 6 Computer Program. Dynatest.



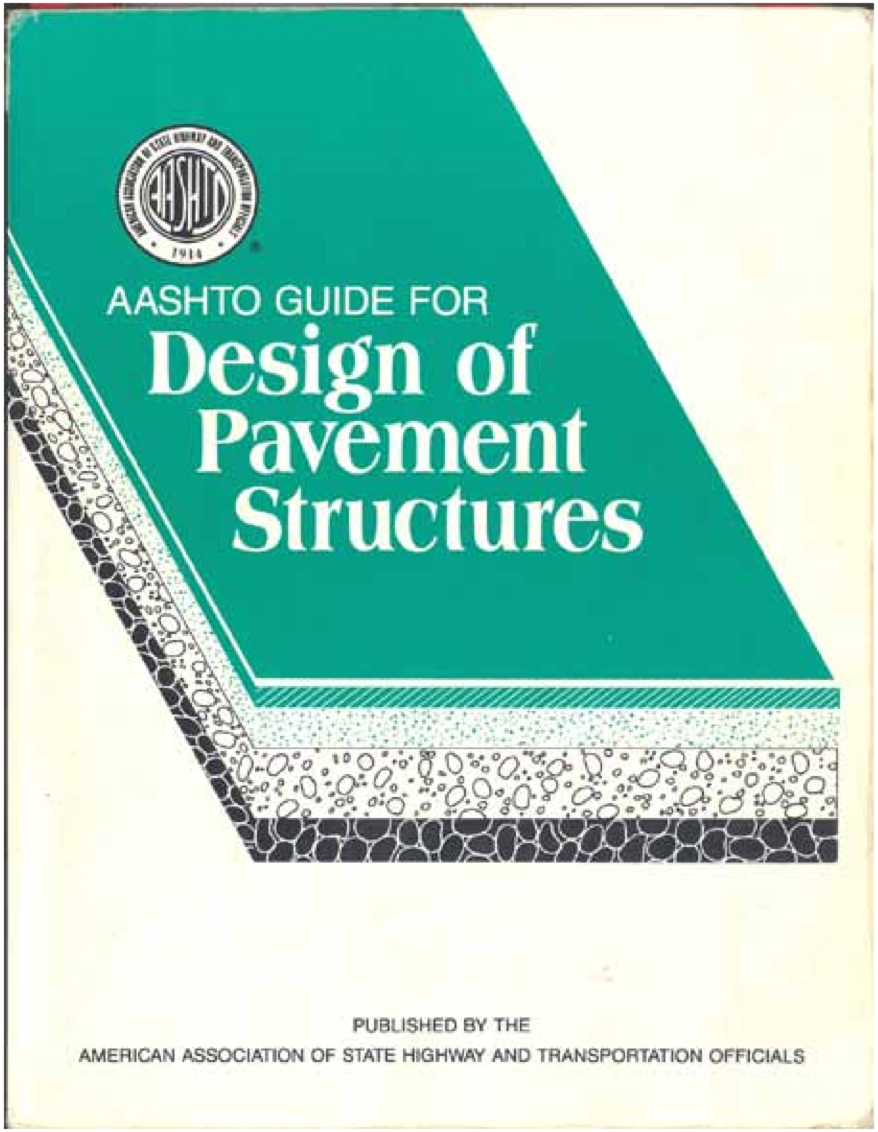
Source: G. Rada, et al. "Falling Weight Deflectometer (FWD). Testing and Analysis Guidelines, Vol 1. FHWA-FLH-07-001, 2007. U.S.A



1.- Weight Package.
2.- Strike Plate.
3.- Raise Weight Cylinder
4.- Catch.
5.- Buffers.
6.- Load Plate.
7.- Load Cell.
8.- Deflection Sensor
9.- Sensor bar.
10.- Signal Processor
11.- Data Collection Computer.

Generic Diagram of an FWD

More…Key Words…



Basic AASHTO-93 Equation

$$MR = \frac{0.24 \times P}{dr \times r}$$

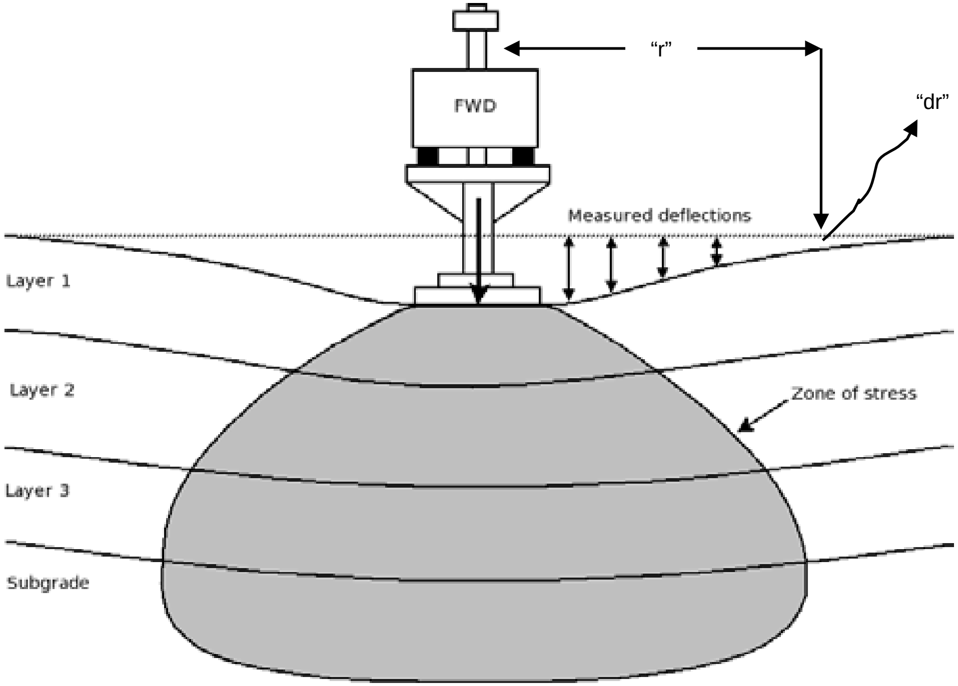
Where:

MR : Resilient Modulus of the Subgrade, psi.

P : Applied Load, pounds.

dr : Measure Deflection at "r" distance from the maximum deflection (applied load).

r : Distance from "dr".



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Schematic of FWD Test – Deflection Basin and Zone of Stresses

To know the modulus, it is trial and error process, following:

$$d_o = 1.5 * p * a * \left\{ \frac{1}{MR\sqrt{1 + \left(\frac{D}{a}\sqrt[3]{\frac{Ep}{MR}}\right)^2}} + \frac{\left[1 - \frac{1}{\sqrt{1 + (D/a)^2}}\right]}{Ep} \right\}$$

Or used the graph from the AASHTO-93 Method

Where:

do : Maximum deflection at the applied load.

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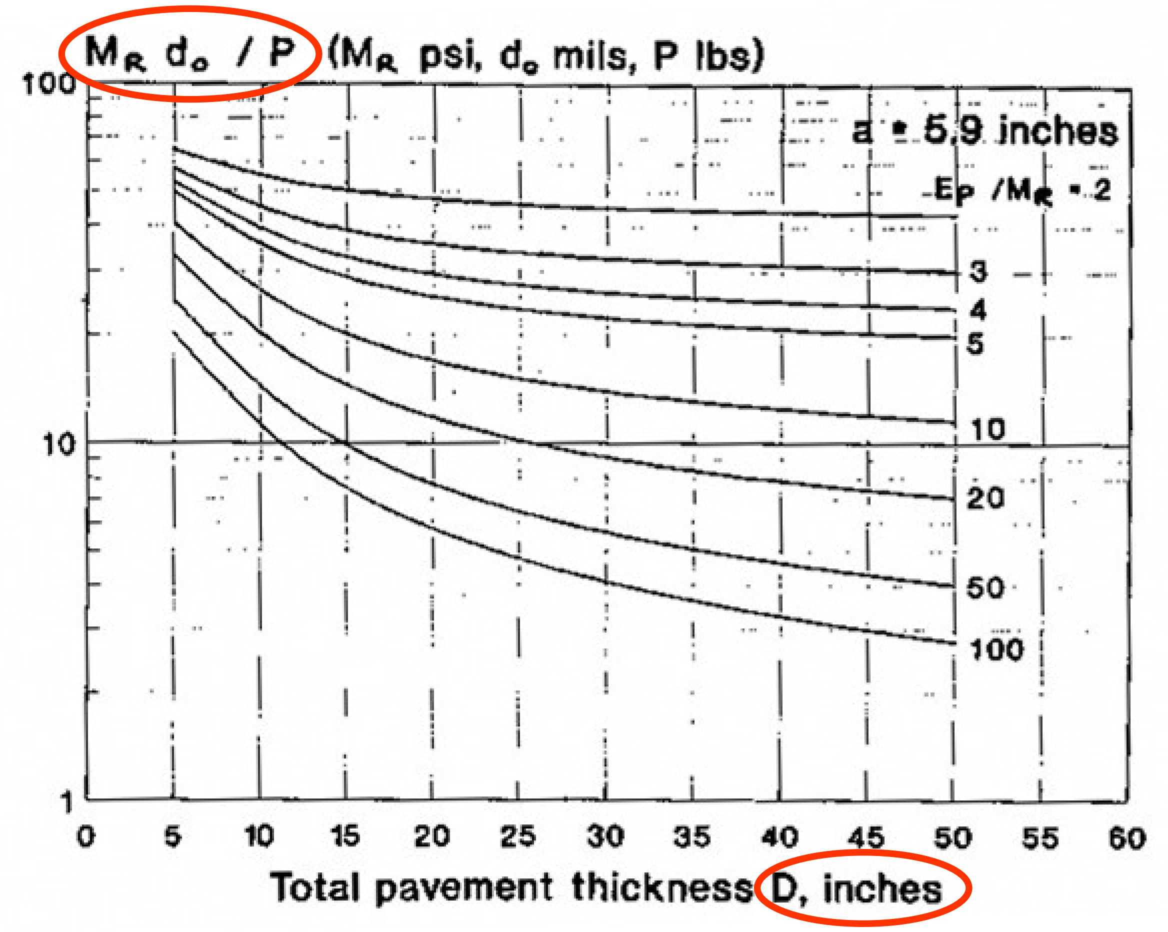


Relationship between the Total Pavement Thickness (D) and MR*do/P

Again…

From AASHTO-93 Back analysis Methodology → **Get the "Back analysed subgrade modulus" (MRrc-sr).**

↓

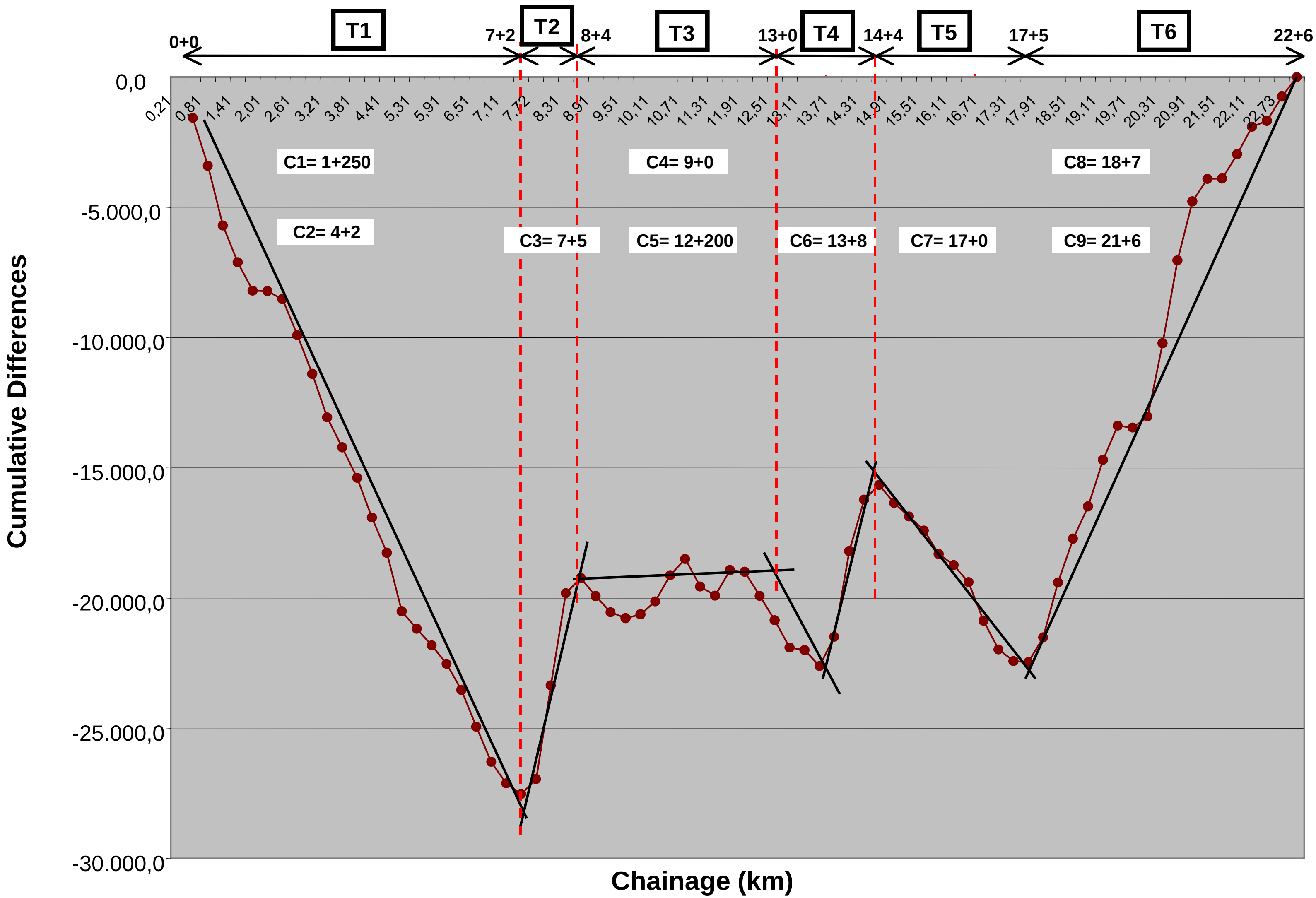
$$\text{"C" Value} = \frac{MRsite\text{-}sr}{MRrc\text{-}sr}$$

↓

AASHTO-93 Recommends: C=0.33

Estimation of the "C" Value Considered in the AASHTO-93 Guide for Back Analysis of the Elastic Modulus of the Subgrade

Homogeneous Sections Analysis of Provincial Route No. 6, Argentina. Based on Maximum Deflection. Location of the Test Pits



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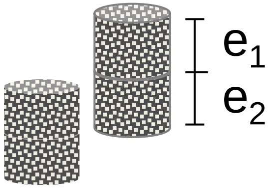
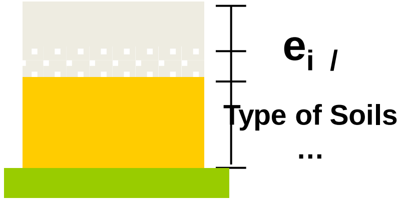


Ü **Moisture / Density**

MR; E = ??? → **f (***d Measured***)**



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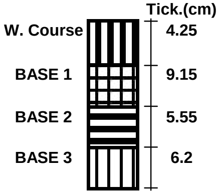
Laboratory Test



Date: 04-15-2004

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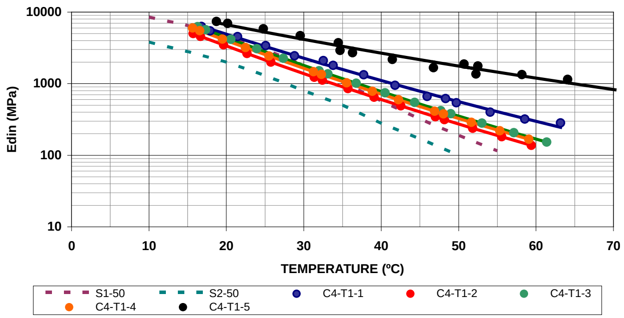

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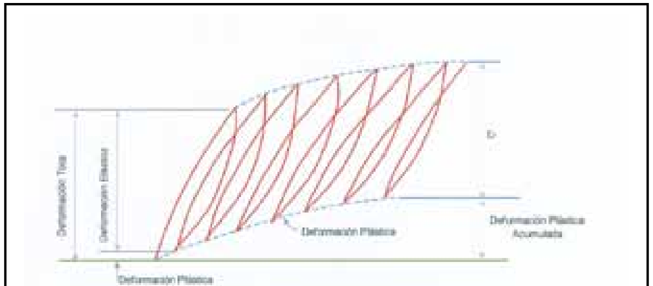
Laboratory Test



Deformaciones Bajo Carga Repetida

Source: F. Limaymanta, et al. "Resilient Modulus Test". XIV National Conference of Civil Engineering. Perú, 2003.

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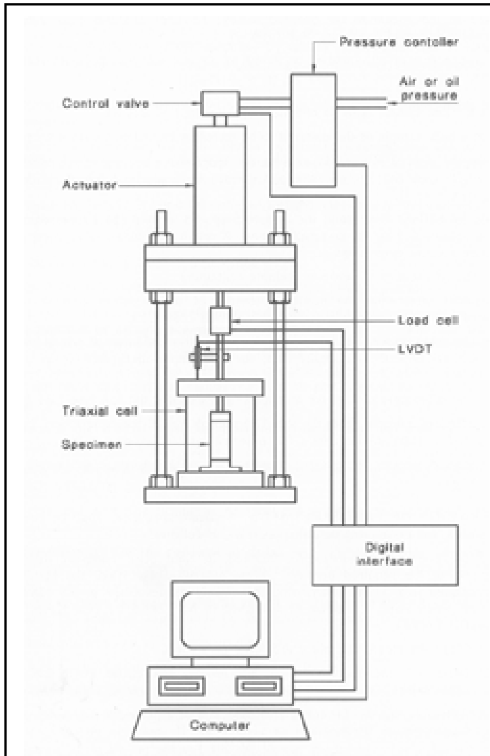

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12		0.0276 (4 psi)	100
13		0.0414 (6 psi)	100
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15		0.0690 (10 psi)	100

(*) : Previous a conditioning

Estimation of the “C” Value Considered in the AASHTO-93 Guide for Back Analysis of the Elastic Modulus of the Subgrade

		Site Resilient Modulus (MRsite-sr) –KENLAYER Computer Program-	
CAL. No.	MAT.	MPa	psi
1	SR	46	6643
2	SR	50	7282
3	SR	50	7225
4	SR	53	7659
5	SR	47	6852
6	SR	50	7239
7	SR	50	7270
8	SR	45	6583
9	SR	45	6525

Site Resilient Modulus of the Subgrade (MRsite-sr)
–KENLAYER Computer Program-

Estimation of the "C" Value Considered in the AASHTO-93 Guide for Back Analysis of the Elastic Modulus of the Subgrade

		Back analysed Resilient Modulus of the Subgrade –Method AASHTO-93-	
CAL. No.	MAT	MPa	psi
1	SR	70	10191
2	SR	62	9011
3	SR	89	12956
4	SR	69	10034
5	SR	63	9121
6	SR	45	6456
7	SR	43	6225
8	SR	58	8377
9	SR	63	9060

>> More than Expected!!!!

Subgrade Resilient Modulus, Based on AASHTO-93

Estimation of the “C” Value Considered in the AASHTO-93 Guide for Back Analysis of the Elastic Modulus of the Subgrade

Estimation of the “C” Adjustment Factor

Test Pit No.	Mat.	Classif. (HRB)	“C”Value–Method AASHTO-93- Based on: MRsite-sr(KENLAYER)
1	SR	A-6(11)	0.66
2	SR	A-7-6(19)	0.81
3	SR	A-7-6(16)	0.56
4	SR	A-7-6(16)	0.77
5	SR	A-7-6(18)	0.75
6	SR	A-7-6(19)	1.11
7	SR	A-7-6(12)	1.16
8	SR	A-6(6)	0.78
9	SR	A-6(8)	0.71
General Average			0.81 ü

C6 & C7: Moisture content not representative

≠ 0.33 Recommended by AASHTO-93!!!

Soils similar to the AASHTO-93 Experiment

↓

Obtained “C” Value=0.72 >>> AASHTO-93 “C” Value Recommended=0.33

Conclusion and Recommendations

- The AASHTO-93 back analysed subgrade resilient modulus (MRrc-sr) (cohesive soil), higher than the site conditions. It is consistent with the results of AASHTO-93 Guide.

- The "C" factor showed an average value of 0.72. This value is 2.2 times higher than that recommended by the AASHTO-93 Guide (0.33).

- The AASHTO-93 Guide is conservative with regard to the estimation of the back analysis Resilient Modulus of the subgrade. It will produce a thick pavement which will impact the final cost of the rehabilitation treatment.

Conclusion and Recommendations

- **Natural moisture content and density play an important role to estimate the site resilient modulus.**

- **The AASHTO-93 Guide procedure is considered useful, simple and less computational tool. Nevertheless, it should be used considering a "C" Value adequate for the materials under study.**

- **Additional investigations are recommended, in order to increase the number and type of soils being analysed.**

- **Behaviour of frictional soils varies with respect to cohesive soil. Hence, its study is highly recommended.**

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Venezuela….


Thank you for your attention....
ERNESTO....
THE ISLETAS, PUERTO PÍRITU, VENEZUELA