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A STUDY ON THE BEHAVIOR OF PAVEMENT STRUCTURES

by

M. FARUK YANIK

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A STUDY ON THE BEHAVIOR OF PAVEMENT STRUCTURES

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ABSTRACT

In this thesis , in - situ density and moisture - density relationship of cement - treated base layer of a pavement layered system are tested within the programme of Kadıköy Yeldeğirmeni Project .Similar layered systems are analyzed by computer as a parametric study to find the expected solutions for stresses and deflections of the designed layered system under the design loads.

For this purpose , In place soil densities of cement - treated base layer are measured with field density test in Kadıköy Yeldeğirmeni Region and the results are compared with the compaction test results obtained in the laboratory.

Additionally, The expected solutions of similar layered systems are analyzed as a parametric study using multi - layered elastic system computer program determining the various component stresses and strains in a three dimensional ideal elastic layered system under expected vehicle loads .

ÖZET

Bu tezde , Kadıköy Yeldeğirmeni proje programına uygun olarak çimento stabilizasyonlu temel tabakanın arazideki yoğunluğu ve yoğunluk - nem ilişkisi deneysel olarak incelenmiştir. Arazideki temel tabakaya benzer sistemlerin proje yükleri altında beklenen gerilme ve deformasyon değerleri bilgisayarda parametrik olarak incelenmiştir.

Bu amaçla , çimento stabilizasyonlu temel tabakasının arazideki yoğunlukları , Kadıköy Yeldeğirmeni Bölgesinde arazi yoğunluk deneyi ile ölçülmüş ve sonuçlar laboratuvarda elde edilen kompaksiyon deney sonuçları ile karşılaştırılmıştır.

Bu çalışmaya ilave olarak , arazideki temel tabakaya benzer sistemlerin tahmini çözümü , tasarılan kamyon yükleri altında , üç boyutlu ideal elastik tabakalı sistemin çeşitli gerilme ve deformasyon değerlerini belirleyen çok tabakalı elastik sistem bilgisayar programı ile parametrik olarak incelenmiştir.

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LIST OF SYMBOLS

C_c = Curvature Coefficient

d_i = Deflection At r_i Distance Away From The Applied Load, Sensor - i Deflection

d_{max} = Maximum Deflection

E = Modulus Of Elasticity

f(r) = Function Of r, The Distance From The Center Of Applied Load

h = Thickness Of The Layer

I_p = Plasticity Index

P = Vertical Load Or Wheel Load

q = Tire Pressure

r = Distance Radially Away From The Applied Load

s = Percent Water Absorbed

s_d = Spreadability

U = Uniformity Coefficient

V_{hole} = Volume Of The Hole

z = Depth

σ = Stress

$(\sigma)_{\gamma dry}$ = Standard Deviation Of In-Situ Dry Unit Weight

σ_r = Horizontal (Radial) Stress At r Distance Radially Away From The Applied Load

σ_z = Vertical Compressive Stress At Depth = z

σ_Q = Tangential Stress

τ_{rz} = Shear Stress

ε_v = Vertical Strain

μ = Poisson's Ratio

ω = Water Content

ω_{opt} = Optimum Water Content

ω_n = Natural Water Content

ω_l = Liquid Limit

ω_p = Plastic Limit

γ_{dry} = Dry Unit Weight

$\gamma_{dry,av}$ = Average Dry Unit Weight

$\gamma_{d,max}$ = Maximum dry Unit Weight

γ_{wet} = Wet Unit Weight

laboratory and many field density tests using sand cone apparatus are performed within the Kadıköy Yeldeğirmeni Pavement Construction Project .

The used multi - layered elastic system computer program determines the various component stresses and strains in a three dimensional ideal elastic layered system with a single vertical uniform circular load at the surface of the system .

In chapter II , project description , geotechnical study of pavement structure , test procedures and evaluation of test results of a soil - cement base layer are presented .

In chapter III , the solution for stresses and deflections of elastic layered systems are given in the form of parametric study . In this study , two basic systems namely two and three layered system are studied using a computer program which is developed for CDC system from a commonly known program called Chevron 5L .

In chapter IV , the solutions for stresses and deflections of elastic layered systems are given as an auxiliary method to a new instrument called Dynaflect extensively used for moduli determination .

In chapter V , a brief summary of the work and conclusions are given . In Appendix A , soil laboratory test results are given. In Appendix B , the description of the computer program , operating notes , limitations , and a sample input data are given .

II - PROJECT DESCRIPTION AND GEOTECHNICAL STUDY OF PROPOSED PAVEMENT STRUCTURE

2.1 INTRODUCTION

Kadıköy municipality has planned to reconstruct the existing infra - structure and pavement system of the roads in Kadıköy . To achieve an economical , decorative and long lasting interlocking pavement system , Yeldeğirmeni region is chosen as a pilot area . (Figure 2.1)

- design criteria (axial load , traffic density)
- pavement layer properties (surface and base layer)
- subgrade layer properties

are taken into consideration and following cross - section is chosen according to serving criteria and subgrade layer properties of the pilot area. (Yeldeğirmeni region) (Figure 2.2) Geotechnical study of proposed pavement structure will be presented in this chapter.

2.2 PROPOSED CROSS - SECTION

The proposed cross - section prepared by the design firm Yapı Merkezi (Reseach , Design & Construction) given in Figure 2.2 is composed of interlocking concrete pavement layer overlying on a thin sand layer and cement treated base layer. Thickness of the layers are proposed as 8 cm for interlocking pavement , 3 cm for cushioning sand layer and 20 cm for base layer according to the design and properties of these layers.

2.2.1 Subgrade Layer

Ayrılıkçeşme Sokak is chosen as the first place of Yeldeğirmeni region for determination of existing subgrade layer properties and samples are taken from three different locations. Laboratory tests are performed on

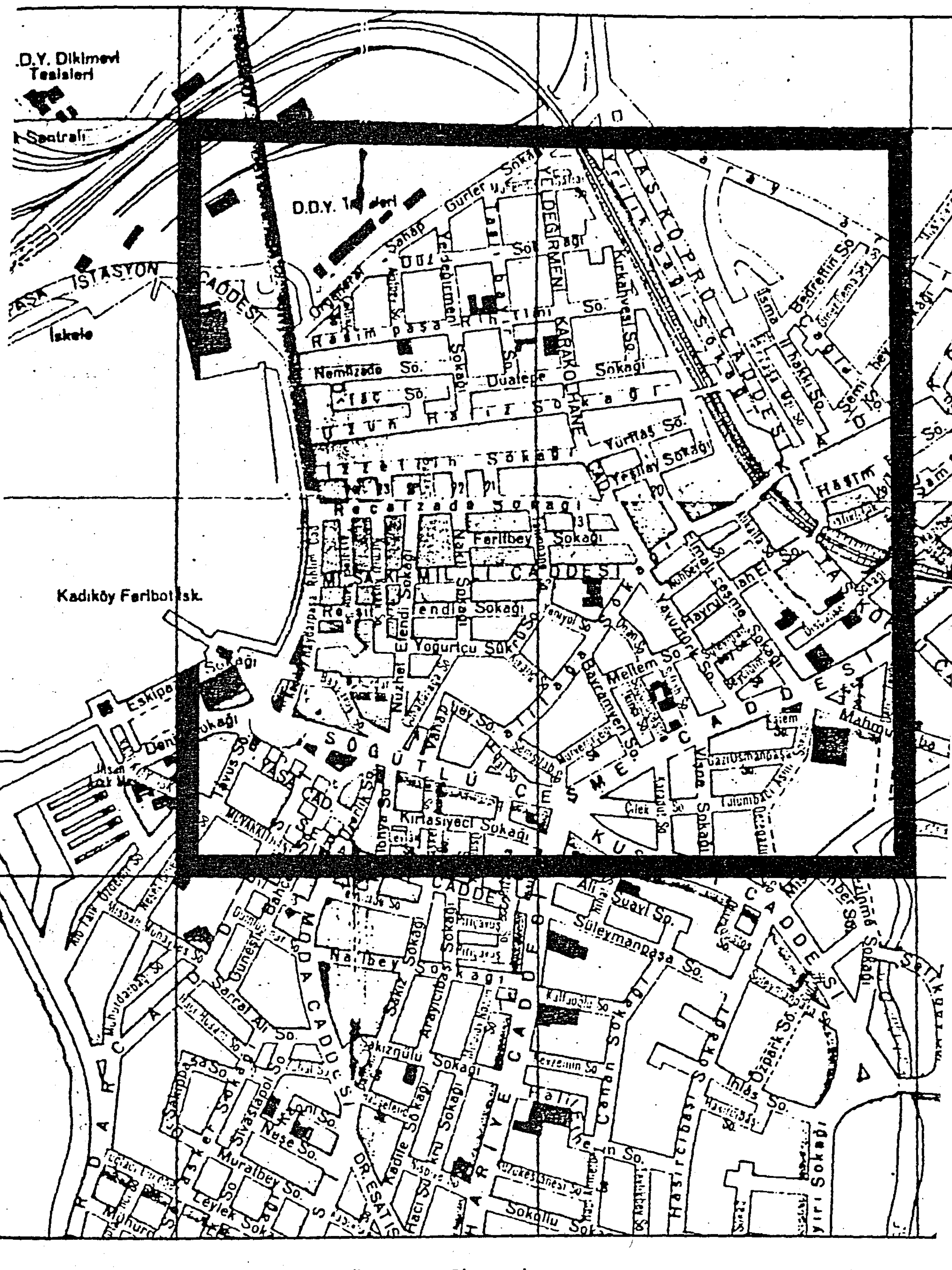

Figure 2.1. KADIKÖY YELDEĞİRMENİ REGION

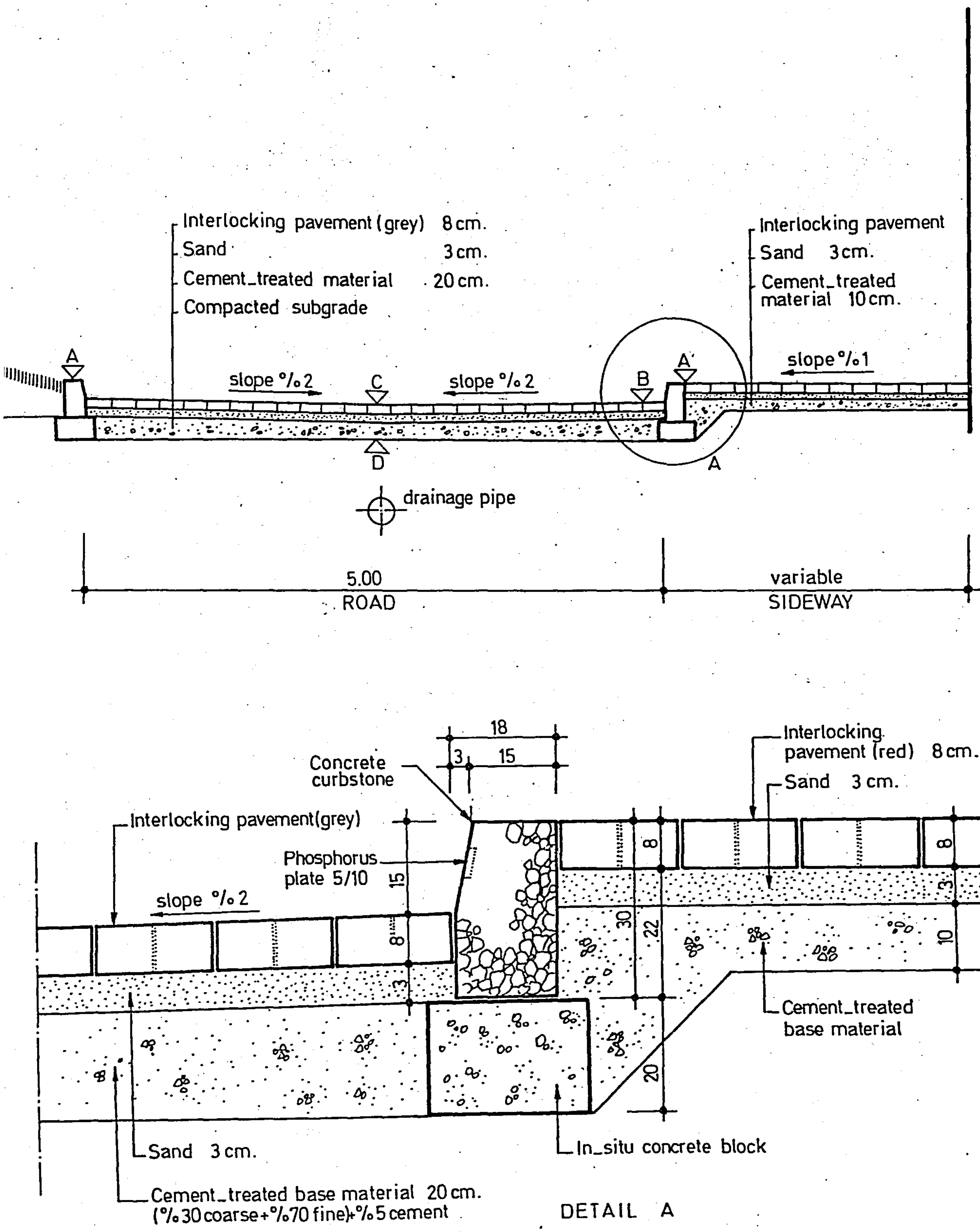

Figure 2.2_PROPOSED CROSS_SECTION PREPARED BY THE DESIGN FIRM (Yapı Merkezi_Research_Design_Construction)

these samples to determine the properties of existing subgrade layer and the results are tabulated in Table 2.1. According to the laboratory test results , subgrade layer is determined as clayey sand (SC). Plasticity index , Ip is found greater than 20 in some places (see sample no 3, Km 0+395) . Compaction criteria for the subgrade layer are also determined by standard proctor test (ASTM - D 698-70) and optimum water content , $\omega_{opt}(\%)$ is found as 16.4 and maximum dry density $\gamma_{dmax}(t/m3)$ is found as 1.67. (Table 2.1)

2.2.2 Base Layer

Cement - treated base layer having 20 cm thickness is decided to be used over the subgrade layer. For this purpose , a coarse material and a fine material which will be used as a base layer material are tested in the laboratory for the determination of the optimum mixing ratios .

Sieve Analyses of the coarse and fine materials are performed and the results are given in Appendix A. According to these sieve analyses and gradation curves , coarse material is found as well-graded gravel (GW ; A-1a) and fine material is found at the lower limit of well-graded gravel. Therefore , it is decided that both material will be mixed together to have an ideal gradation curve and well - graded base material. After the evaluation of test results, it is found that ideal mixing ratio of both material is 30 % of coarse material and 70 % of fine material in volume (Table 2.1) .

Standard and Modified Proctor Tests (ASTM-D698-70 and ASTM-D1557-70) are carried out for the mixed base layer material passing from no. 4 sieve and compaction

Table 2.1 _ KADIKÖY YELDEĞİRMENİ PROJECT _ SUMMARY OF SOIL LABORATORY TEST RESULTS

KADIKÖY YELDEĞİRMENİ PROJECT		ATTERBERG LIMITS				GRADATION						CLASSIFICATION		STANDARD PROCTOR		MODIFIED PROCTOR		CBR _TEST				
SOIL TYPE	LOCATION	ω_n %	ω_l %	ω_p %	I_p %	Gravel %	Sand %	_No.200 %	_2μ %	U	C_c	USCS	AASHTO	$\omega_{opt.}$ %	$\gamma_{dmax.}$ t/m3	$\omega_{opt.}$ %	$\gamma_{dmax.}$ t/m3	ω %	γ_d t/m3	s %	Dry	Wet
Subgrade Soil	Ayrılıkçeşme sokak km. 0+020	16.0	28.4	19.8	8.6	_	_	6.0	1.0	_	_	_	_									
	Ayrılıkçeşme sokak km. 0+210	15.8	36.7	20.9	15.8	27.0	61.0	12.0	1.0	21.7	_	SM_SC	A_2_6(0)									
	Ayrılıkçeşme sokak km. 0+395	18.2	43.2	20.4	22.8	34.0	53.0	13.0	3.0	34.0	_	SC	A_2_7(0)	16.4	1.670			17.6 18.7	1.73 1.70	1.33	8.3	9.3
Base Soil	Fine Material					52.0	44.0	4.0	_	8.9	1.4	GW	A_1a									
	Coarse Material					79.0	18.0	3.0	_	34.0	1.3	GW	A_1a									
	Mixed Material(1)					73.0	27.0	_	_	10.0	1.7	GW	A_1a	11.5	1.975	7.2	2.115	_	1.90	_	3.0	_
	Cement_Treated Material(2)					73.0	27.0	_	_	10.0	1.7	GW	A_1a	10.7	1.986	10.0	2.09			_	70.0	_
Sand	Sand Layer					9.0	91.0	0.0	_	1.7	1.03	SP										

DESCRIPTIONS :

ω_n (%) : Natural Water Content
ω_l (%) : Liquid Limit
ω_p (%) : Plastic Limit
I_p (%) : Plasticity Index

_No: 200 (%) : Silt+Clay Percent
_2μ (%) : Clay Percent
u : Uniformity Coefficient
C_c : Curvature Coefficient

USCS : Unified Soil Class. Syst.
ω_{opt} : Optimum Water Content
γ_{dmax}: Maximum Dry Unit Weight

s (%) : % Water Absorbed
(1) : %30 coarse+%70 fine (in Volume) base material
(2) : (%30 coarse+%70 fine)+%5 cement in Volume

properties of the base material are determined. According to compaction test results,(given in appendix A) optimum water content is found as 11.5 % for standard proctor test and 7.2 % for modified proctor test and maximum dry density is found 1.975 t/m3 for standard proctor test and 2.115 t/m3 for modified proctor test . However 45 % of the sample is above the no. 4 sieve , therefore required water amount which will be given in the field must be calculated accordingly .

In CBR test , it is seen that , CBR value can be very low (CBR=3.0 , Table 2.1) , if the required water content is not calculated correctly. Therefore , it is decided that , base layer material will be stabilized with cement when such base thickness is considered.

For this purpose , mixed base material is treated with 5 % cement in volume. Water content of the cement-treated base material is chosen 12.5 % considering the additional water amount for cement hydration during compaction. Required curing period of compacted cement treated base layer is determined as 48 hours to gain the required strength. Standard and modified proctor tests are also performed for cement-treated base material. Optimum water content and maximum dry density are found as 10.7 % and 1.986 t/m3 for standard proctor test , and 10 % and 2.090 t/m3 for modified proctor test. (Appendix A)

CBR value of the compacted base material is measured as 70 when the cement-treated sample is compacted according to the standard proctor test. This value is sufficient for the base material under the design loads and thicknesses . (Soil-Cement Construction Handbook, Portland Cement Association)

2.2.3 Sand Layer

It is proposed in literature (*) that, 3 cm sand layer thickness will be sufficient for interlocking pavement layer. Sand particles interlock concrete blocks under the vertical loads when the sand layer is compacted with concrete blocks. The comparison of sand gradation values with the values given in literature are tabulated in Table 2.2. It is seen that , sand passing no. 100 sieve is not in the limits given in literature. Therefore fine sand was added to the selected sand to provide the proper gradation curve .

Table 2.2.- SIEVE ANALYSIS OF SAND

Sieve No.	Literature % Passing	Sand Used (Appendix A) % Passing
3/8 inch	100	100
No.4	85 - 100	98
No.100	10 - 30	2

2.2.4 Pavement Thickness

It is obvious that the pavement thickness is related to the design criteria . Ayrılıkçeşme has a traffic density of less than 50 vehicles/hour. It is classified as H-1. (Concrete Block Pavement, Design and Construction National Concrete Masonry Association). Accordingly, for a base

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(*) "Concrete Block Pavement Design and Construction" , National Concrete Masonry Association layer of CBR = 8 - 9,(Table 2.1) required layer thicknesses are given in Table 2.3. This table shows that, the pavement thicknesses of the proposed cross-section are within the limits recommended in the literature .

Table 2.3 - LAYER THICKNESSES FOR H - 1 TYPE ROAD

Layer Type	Proposed Thickness	
	inch	cm
Interlocking Pavement	3 1/8 - 3 5/8	7.9 - 9.2
Sand Layer	1 - 2	2.5 - 5.0
Crushed Stone Base Layer(1)	8	20

(1) When cement treated base material is used instead of crushed stone base material , required thickness will be lesser

2.3 EQUIPMENT AND COMPACTION

It is proposed that the cement-treated base layer having optimum water content should be compacted till to achieve minimum relative compaction value (*) , 95 % for standard proctor test or 90 % for modified proctor test . Base material (70 % fine + 30 % coarse) having 5 % cement-treated in volume should be laid down and compacted until the final base thickness became 20 cm. Compaction should be performed with vibratory roller and relative compaction values should be at least the values stated above as a design criteria. The variation of base thickness should be ∓ 1 cm to prevent the relative deformations of the interlocking pavement.

(*) Design criteria given in ASTM compaction tests (D698-70 and D1557-70)

It was recommended that the sand layer having 3 cm thickness should be laid down after the gradation curve of sand material is corrected according to the literature. Interlocking pavement layer is placed on the sand layer and compacted together with a hand vibrator.

2.4 COMPACTION CONTROL

The aim of the compaction control is to show the adequacy of the compacted cement-treated base layer in comparison to the design criteria. For this purpose , in-situ unit weights of the base layer were measured with a sand cone apparatus in Kadıköy Yeldeğirmeni region. These in-place unit weights are compared with the maximum dry unit weight obtained from laboratory compaction tests (Table 2.1 and Appendix A) according to the proposed design criteria.

For a brief information , methods for the laboratory compaction tests to obtain the moisture - density relationship and methods for the field density test to determine the in-situ density of soil will be discussed in the following section .

2.4.1 Laboratory Compaction Tests

A. Standard Compaction Test (*)

The standard test consist of taking about 3 kg of soil sample and passing it through a No:4 sieve , adding water and compacting it into a 944 cm3 mold in three layers with 25 blows per layer , using a 24.5 N compacting hammer dropping 0.305 m onto the soil . This delivers a nominal compaction energy (kilojoules or kJ) to the soil of

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(*) Standard Proctor Test , ASTM D698-70

$$CE = \frac{3\ (25)\ (24.5)\ (0.305)}{9.44 \times E-4\ \ (1000)} = 593.7\ kJ/m3$$

The compacted sample is broken down to the No:4 sieve size as determined visually , water - content samples are taken , more water is added the soil thoroughly remixed , and the process of compacting a mold of soil is repeated . This sequence is repeated a sufficient number of times that a curve of dry density vs. water content can be drawn which has a zero slope (a maximum value) with sufficient points on either side of the maximum density point to adequately define its location . Dry density is always the ordinate of the curve . The maximum ordinate value is termed maximum density and the water content at which this dry density occurs is termed the optimum moisture content.

Relative compaction is the term used to compare the in - situ compacted soil to the laboratory compaction curve . Relative compaction is defined as

$$\underset{(\%)}{R.Comp.} = \frac{\text{density of compacted field soil}}{\text{maximum laboratory dry density}} \times 100 \quad .. (2.1)$$

B. Modified Compaction Test (*)

The modified compacted test consist of about 4 kg soil sample and passing it through a No:4 sieve , adding water and compacting in into a 944 cm3 mold in five layers with

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(*) Modified Proctor Test , ASTM D1557-70

25 blows per layer , using 44.5 N compacting hammer dropping 0.46 m onto the soil . This delivers a nominal compaction energy into the soil of 2710 kJ/m3 which is about 5 times the compaction energy of standard test .

2.4.2 Field Density Test

Once compaction criteria are established for the soil at the laboratory , field density of the soil is determined with sand-cone apparatus.(*) The sand-cone enable to find the volume of the hole and one obtains a known weight of damp (or wet) soil from a small excavation of some what irregular shape (a hole) in the ground , the wet density is simply computed as

$$\gamma_{wet} = \frac{\text{Weight of damp soil}}{\text{Volume of hole}} \qquad .. (2.2)$$

and if one obtains the water content, ω of the excavated material , the dry unit weight of the material is

$$\gamma_{dry} = \frac{\gamma_{wet}}{1 + \omega} \qquad .. (2.3)$$

γ_{wet} = wet unit weight of the material

ω = water content of the material

The sand - cone method is an indirect means of obtaining the volume of the hole . If one has a constant - density material , the hole volume is

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(*) Sand Cone Method , ASTM D 1556-64

$$V_{hole} = \frac{\text{Weight of material used to fill hole}}{\text{Unit weight of material}} \quad .. (2.4)$$

2.5 TEST PROCEDURES AND EVALUATION OF TEST RESULTS

Standard and modified compaction tests are carried out for both base material (70 % fine + 30 % coarse) and 5 % cement - treated base material. Maximum dry unit weight and optimum moisture content are determined and given in both Table 2.1 and Table 2.4.

Field density tests are carried out in Kadıköy Yeldeğirmeni region using sand - cone apparatus during the project . Figures 2.3 and 2.4 show two pictures taken during the field density test procedure . The locations of the field density tests are shown in Figure 2.5 .

Table 2.4 - COMPACTION TEST RESULTS

	Standard Proctor		Modified Proctor	
	Without Cement	With Cement	Without Cement	With Cement
Optimum Water Content, ω_{opt} %	11.5	10.7	7.2	10.0
Maximum Dry Unit Weight γ_{dmax} t/m3	1.975	1.986	2.115	2.090

Note : Test records are given in Appendix A.

Figure 2.3 _ FIELD DENSITY TEST _ BASE PLATE PLACEMENT AT KADIKÖY YELDEĞİRMENİ REGION

Figure 2.4 _ FIELD DENSITY TEST WITH SAND CONE APPARATUS AT KADIKÖY YELDEĞİRMENİ REGION

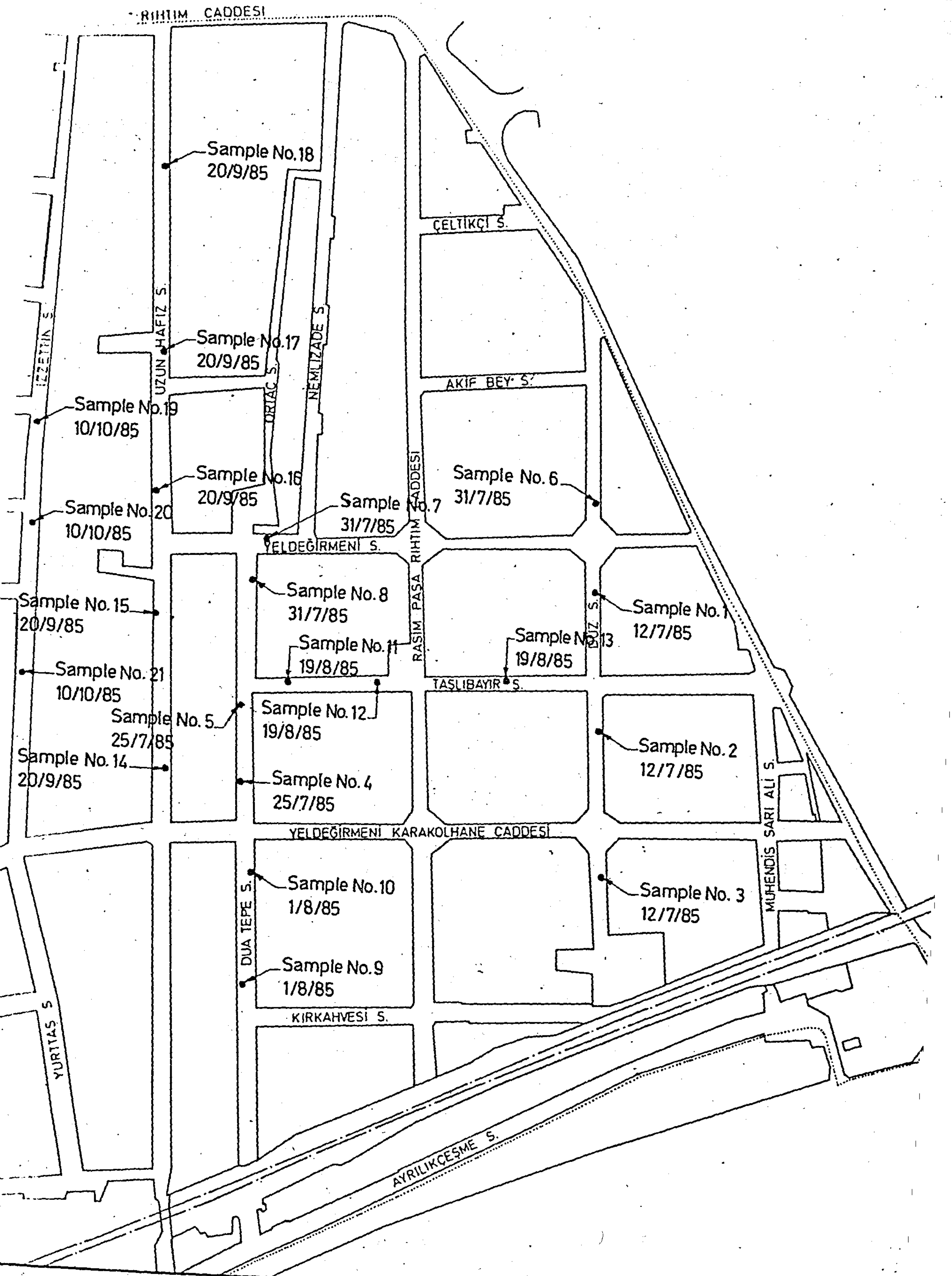

Figure 2.5 _ FIELD DENSITY TEST LOCATIONS

In - place wet soil density and dry soil density are determined and given in Table 2.5. Relative compaction values for both standard and modified proctor tests are also presented in this table According to the design criteria , relative compaction values should be 95 % for standard proctor test and 90 % for modified proctor test . As it is seen from Table 2.5 , relative compaction values obtained from the in-situ density tests satisfy the design criteria. The mean dry unit weight is calculated as 1.996 t/m3 which is almost the same value obtained in standard proctor test . Standard deviation value is calculated as 0.086 . This is approximately equal to 4 % of the mean dry unit weight obtained from the experiments .

2.6 SUMMARY AND CONCLUSION

Geotechnical study of the proposed pavement structure is given in this chapter. For this purpose , layer parameters of proposed pavement structure are chosen according to design criteria and subgrade layer properties . Afterwards laboratory tests are conducted on the samples of pavement materials to define the layer properties . Finally, field density tests are performed on the compacted base layer to determine the adequacy for the selected design criteria.

As it is seen from both laboratory and field tests, proposed pavement structure is sufficient according to the design .

Table 2.5 - FIELD DENSITY TEST RESULTS

Location	Exp. #	In - place γ_{dry} - t/m3	Relative Compaction % Standard Proctor (1)	Relative Compaction % Modified Proctor (2)
Düz Sokak	1	2.00	100.7	95.7
	2	1.85	93.2	88.5
	3	1.93	97.2	92.3
	6	1.94	97.7	92.8
Duatepe Sokak	4	1.94	97.7	92.8
	5	1.99	100.0	95.2
	8	1.91	96.2	91.4
	9	2.07	104.2	99.0
	10	2.05	103.2	98.1
Yel Değirmeni	7	1.93	97.2	92.3
Taşlı Bayır Sokak	11	1.90	96.2	91.4
	12	2.07	104.2	99.0
	13	1.99	100.2	95.2
Uzun Hafız Sokak	14	2.05	103.2	98.1
	15	2.00	100.7	95.7
	16	1.90	95.7	90.9
	17	2.03	102.2	97.1
	18	1.94	97.7	92.8
İzzettin Sokak	19	1.96	98.7	93.8
	20	2.15	108.3	102.9
	21	2.06	103.7	98.6
Neşet Ömer Sokak	22	1.92	96.7	91.9
	23	2.18	109.8	104.3
Gülşen Sokak	24	2.16	108.8	103.4
	25	1.99	100.2	95.2

(1) γ_{dmax} = 1.986 t/m3 γ_{dry} (av) = 1.996 t/m3

(2) γ_{dmax} = 2.090 t/m3 $(\bar{\sigma})\gamma_{dry}$ = 0.086

Note : Test records are given in Appendix A .

III - THE SOLUTIONS FOR STRESSES AND DEFLECTION OF PROPOSED PAVEMENT STRUCTURE

3.1 INTRODUCTION

The solutions for stresses and deflections of the proposed pavement structure will be given as a part of the design study in this chapter. For this purpose , two construction stages of the proposed pavement structure are taken into consideration. These are;

- Section taken from Kadıköy Yeldeğirmeni region before the pavement surface covering of interlocking concrete blocks.

- Section taken from Kadıköy Yeldeğirmeni region after the pavement surface covering of interlocking concrete blocks.

In this chapter, the section taken before the pavement covering will be defined as " Two Layered System " and composed of subgrade layer and cement- treated base layer . Similarly , the section taken after the pavement surface covering will be defined as " Three Layered System " and composed of subgrade layer , cement-treated base layer and pavement surface layer and pavement suface layer is assumed as a single layer due to the fact that , sand layer under the interlocking pavement helps to interlock the concrete blocks each other when both layers are compacted together.

Both sections are studied using a computer program(*) which is developed for CDC system from a commonly known computer program called Chevron 5L. This program is based on the

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(*) Michelow J., "Analysis Of Stresses and Displacements In An N - Layered Elastic System Under A Load Uniformly Distributed On A Circular Area", Chevron Research Comp.1968 assumption that , all the layers are homogeneous , isotropic and elastic. Program solutions are given in British Units. Wheel load and tire pressure is taken from the design criteria. The expected stresses and deflections of both systems for various depths and material properties are given in the form of parametric study in this chapter.

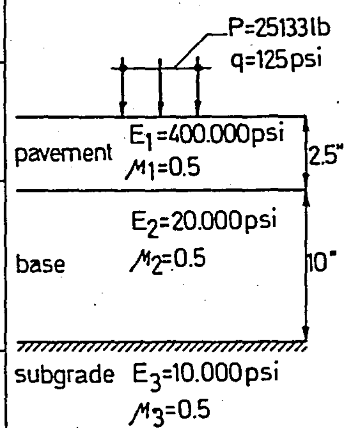
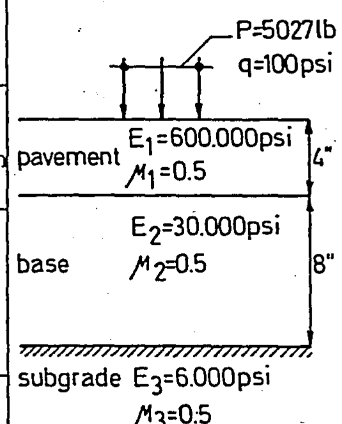
3.2 THE COMPARISON OF THE COMPUTER SOLUTION WITH THE OTHER EXISTING SOLUTIONS

In order to verify the exactness of the computer program solutions after the adaptation to the CDC system , two different pavement structures having elastic modulus decreasing with depth and vertical uniform circular load on the surface (given in Table 3.1) are analyzed . The stress, strain and deflection values at the center of the loaded area are compared with the values given by Acum & Fox (1951) based on the assumption that two elastic layers on a semi-infinite elastic subgrade and continuous interface and it is seen that stress, strain and deflection values are almost the same for both cases.(Table 3.1)

Another comparison is made between the computer solution and Vaswani(*) solution. The results are given in Figure 3.1 . It is seen that maximum deflection values for different base thicknesses and elastic moduli of base layer are approximately the same .

(*) Vaswani,Nari K. , "Method For Separately Evaluating Structural Performance Of Subgrade And Overlying Flexible Pavements " , Highway Research , Number 362

Table 3.1 - A COMPARISON BETWEEN THE COMPUTER SOLUTION AND ACUM & FOX SOLUTION

Solution For	Computer Solution	Acum & Fox Solution	Problem Type
Vertical Stress At Base/Subgrade Interface	32.85 psi	32.85 psi	
Maximum Deflection At the Surface	0.0896 inch	0.092 inch	
Radial & Tangential Stress At Base / Subgrade Interface	23.04 psi	23.04 psi	
Radial & Tangential Strain At Base / Subgrade Interface	0.001397	0.001397	
Vertical Stress At Base/Subgrade Interface	3.587 psi	3.640 psi	
Maximum Deflection At the Surface	0.0186 inch	0.0192 inch	
Radial & Tangential Stress At Base / Subgrade Interface	11.04 psi	11.06 psi	
Radial & Tangential Strain At Base / Subgrade Interface	0.000244	0.000245	

Note : The stress, strain and deflection values are calculated at the center of the loaded area.

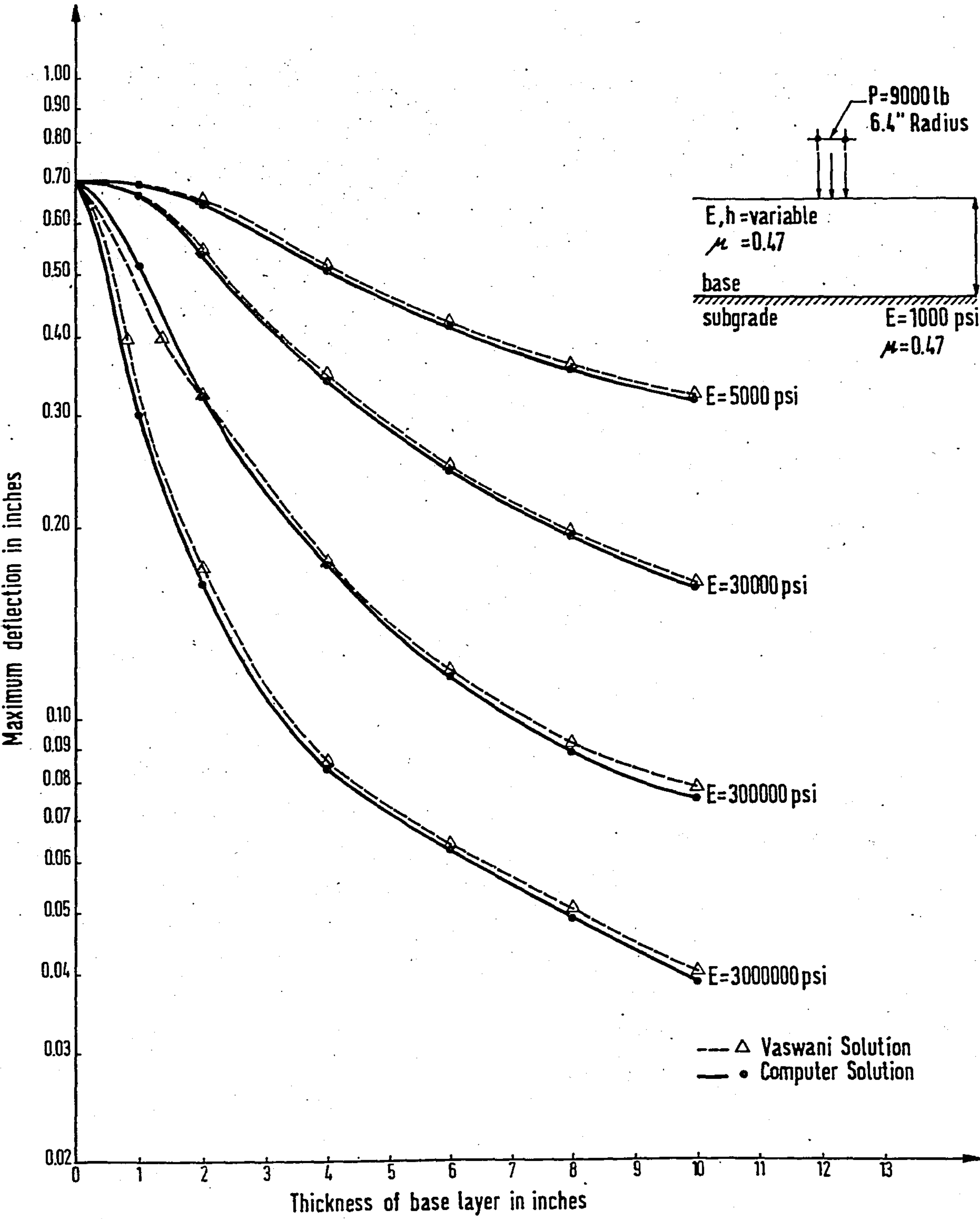


Figure 3.1 _ A COMPARISON BETWEEN THE COMPUTER SOLUTION AND VASWANI SOLUTION

3.3 TWO LAYERED SYSTEM

As stated earlier the pavement structure defined as " Three Layered System " is the section taken from Kadıköy Yeldeğirmeni region before the pavement surface covering of concrete blocks. Two layered system composed of subgrade layer and cement-treated base layer, is studied for the purpose of determination of expected stresses and deflections of two layered system under the design loads. Design loads are determined according to the design criteria . Chevron 5L gives the solution for stresses and deflections in British Units. Some of the layer parameters are taken as variable to perform a sensitivity analysis and to define the behavior of two layered system under the design loads. Values given for layer parameters in the parametric study of two layered system are given in Table 3.2.

In the parametric study, cement -treated base layer thickness is taken as variable . Elastic modulus of subgrade layer is assumed as 1000 psi for weak soil type. Elastic modulus of base layer and poisson's ratio of the subgrade are assumed as variables. Radial distances away from the applied load for deflections are taken according to the Dynaflect measuring array (see Chapter IV). Two layered system profile and system parameters are shown in Figure 3.2 .

3.3.1 Maximum Deflection Of Two Layered Systems Under A Uniform Circular Load On The Surface

A parametric study on maximum deflection of Two Layered System under a uniform circular load on the surface is performed and the relationships are presented in Figures 3.3 - 3.4 .

Table 3.2 - VALUES USED IN THE PARAMETRIC STUDY OF TWO LAYERED SYSTEM

Layer Type	Wheel Load, P = 9000 lb , Tire Pressure, q = 70 psi, Load Radius = 6.4 inch			
	Thickness h inch	Elas.Modulus E psi	Poisson's R. μ	Radial Dist. Away From Applied Load r inch
Subgrade Layer	Semi-Infi.	a) 1000	a) 0.20 b) 0.40 c) 0.47	a) 0.0 b) 10.0 c) 15.6 d) 26.0 e) 37.4 f) 49.0
Cement Treated Base Layer	a) 1 b) 2 c) 4 d) 6 e) 8 f) 10	a) 5000 b) 30000 c) 300000 d) 3000000	a) 0.20 b) 0.40 c) 0.47	a) 0.0 b) 10.0 c) 15.6 d) 26.0 e) 37.4 f) 49.0

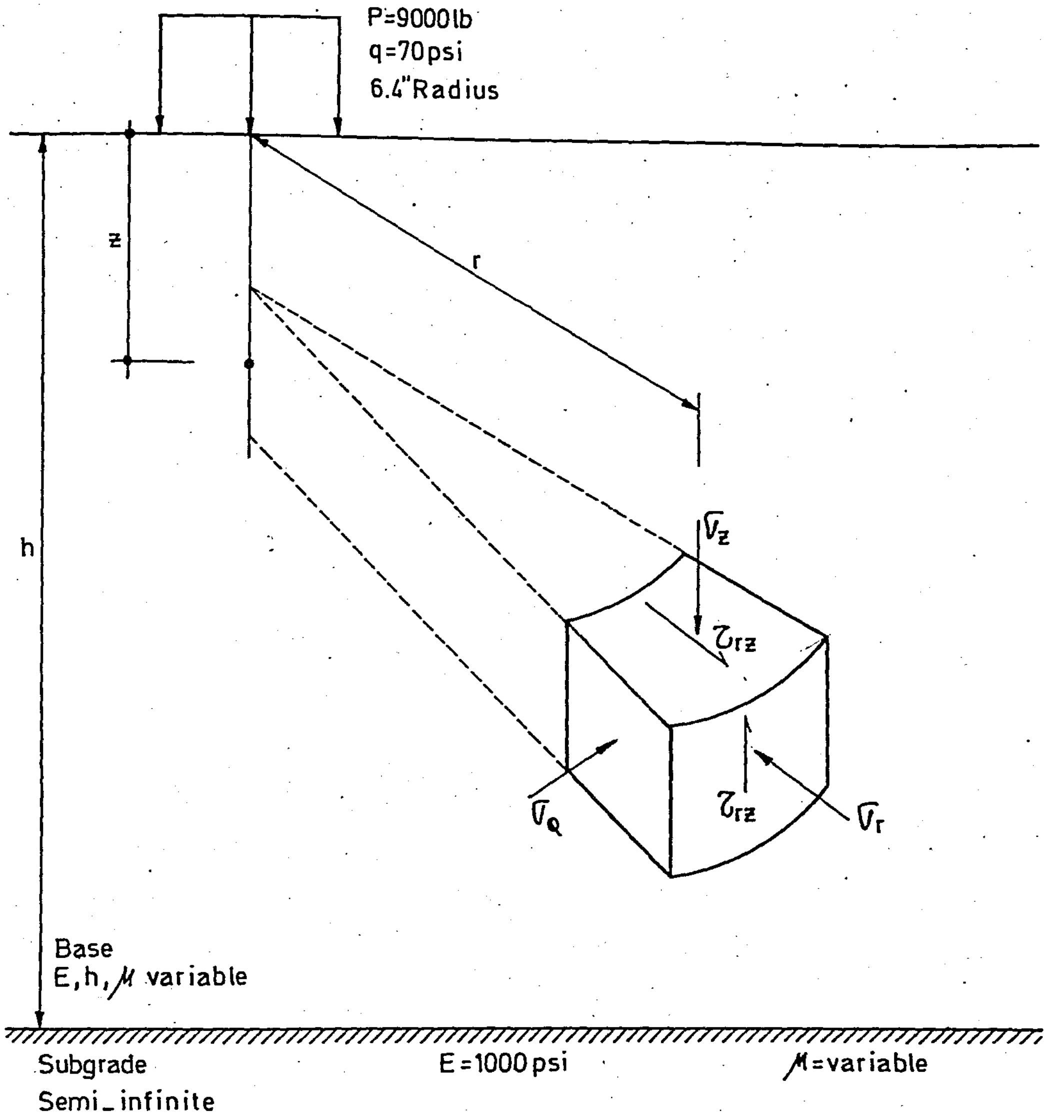


Figure 3.2_TWO LAYERED SYSTEM PROFILE AND SYSTEM PARAMETERS

The effect of elastic modulus of base layer on maximum deflection at surface is shown in Figure 3.3. Maximum deflection values are plotted against distances away from the center of the applied load. Subgrade material properties and base layer thickness are taken as constants. The values used for elastic modulus of base layer vary from 5.000 psi to 3.000.000 psi for weak and stiff base material accordingly.
It is seen from Figure 3.3 that, the effect of elastic modulus of the base layer on maximum deflection stays almost constant after a little decrease for stiff base material , However decreases extensively for weak base material when the distance from the center of applied load increases.

The effect of poisson's ratio of the layered system on maximum deflection at surface is presented in Figure 3.4. Maximum deflection values are plotted against distances away from the center of the applied load for two types of base material - weak type , E = 5.000 psi and stiff type , E = 300.000 psi . Base thickness is taken as constant. It is determined that , the effect of elastic modulus of base layer on maximum deflection is much greater than the effect of poisson's ratio for the same pavement structure.

3.3.2 Stresses And Strains Of Two Layered System Under A Uniform Circular Load On The Surface

A parametric study on stresses and strains of Two Layered System under a uniform circular load on the surface is performed and the relationships are presented in Figure 3.5 - 3.9 .

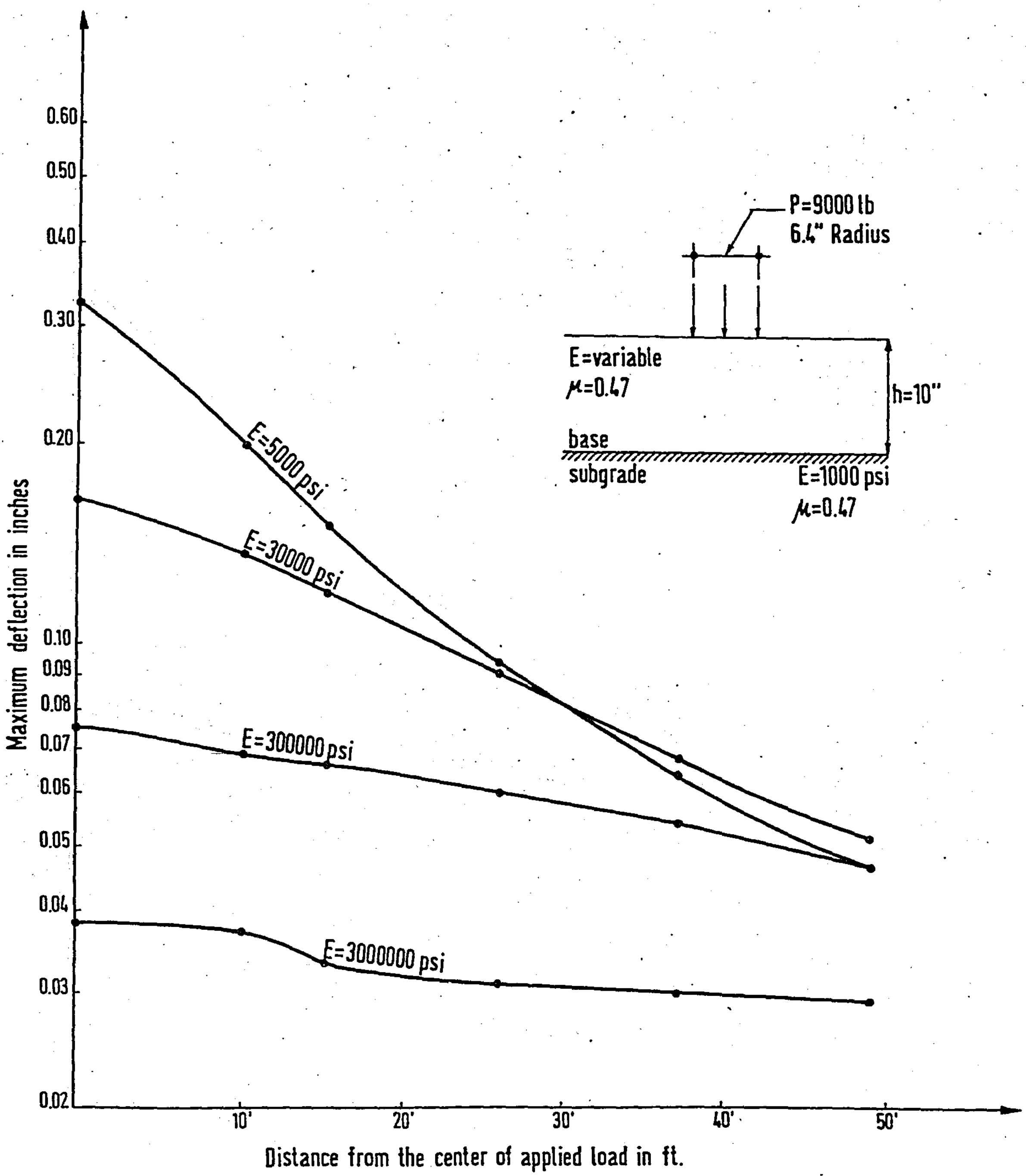


Figure 3. 3 _ THE RELATIONSHIP BETWEEN MAXIMUM DEFLECTION AND DISTANCE FROM THE CENTER OF APPLIED LOAD WITH DIFFERENT ELASTIC MODULI OF BASE

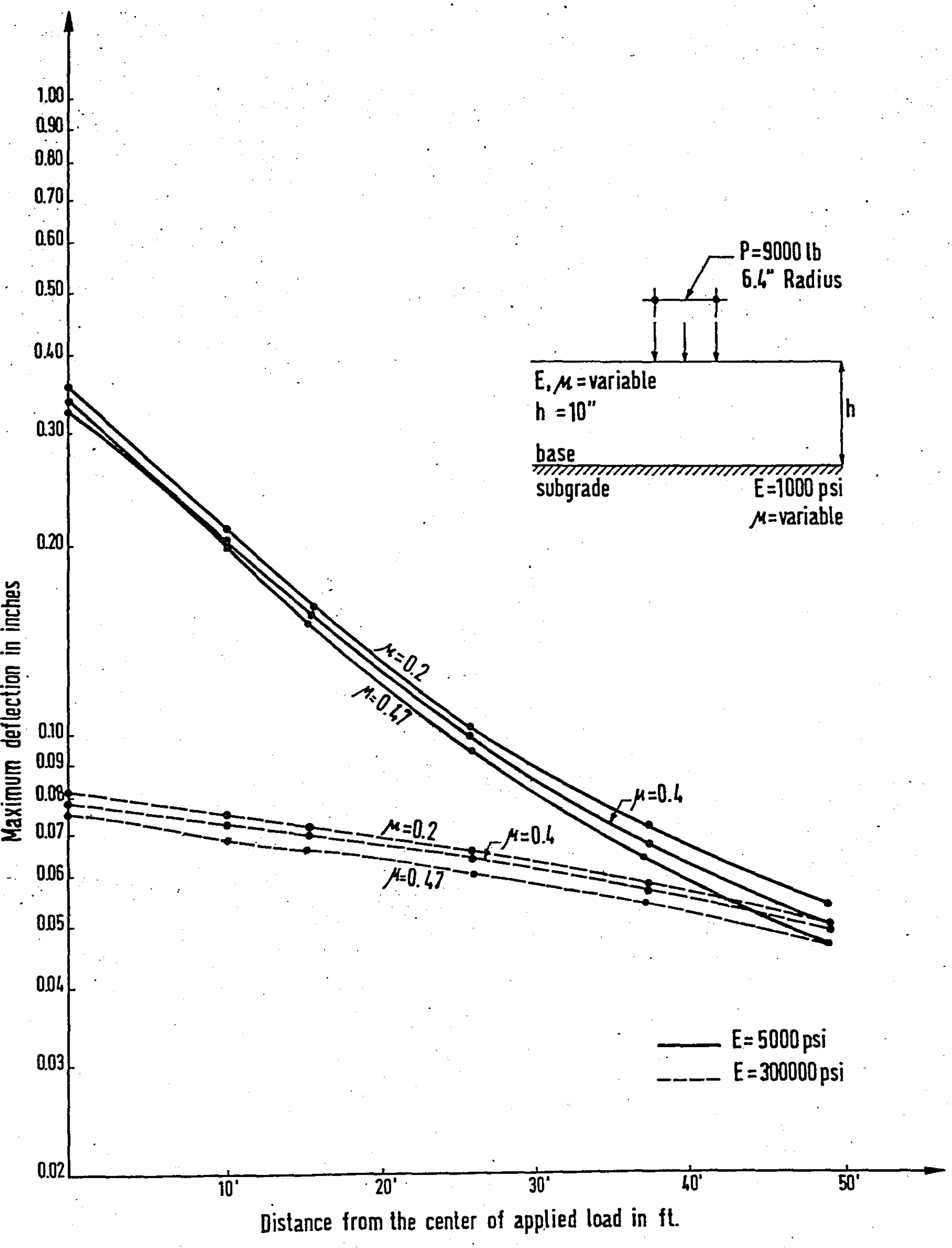


Figure 3. 4 _ THE RELATIONSHIP BETWEEN MAXIMUM DEFLECTION AND DISTANCE FROM THE CENTER OF APPLIED LOAD WITH DIFFERENT POISSON'S RATIOS

Vertical stress values at subgrade - base interface are plotted in Figure 3.5 for the base layer having different elastic moduli and base thicknesses. Elastic modulus of subgrade and poisson's ratios of the layered system are taken as constants. It is possible to determine the required base thickness against maximum vertical stress for the base layer having specific material properties from Figure 3.5 and it is also possible to determine the required material properties against maximum vertical stress for the base layer having constant height.

The relationship between vertical strain and base thickness with different elastic moduli of base layer is presented in Figure 3.6. It is determined that , vertical strain value at subgrade - base interface increases extensively when the elastic modulus of subgrade decreases however, increases very little when the base thickness increases.

Tangential stress values at subgrade - base interface are plotted against thickness of the base layer having different elastic moduli of base layer and presented in Figure 3.7. Elastic modulus of subgrade and poisson's ratios of the layered system are taken as constants. It can be concluded from the figure that, tangential stress values calculated for various elastic moduli of base layer decrease linearly when the base thickness increases linearly. It is also possible to determine the required base thickness or base material properties according to maximum tangential stress.

The relationship between tangential strain and base thickness with different elastic moduli of base layer is presented in Figure 3.8. It can be concluded from the figure that, the effect of elastic modulus of base layer

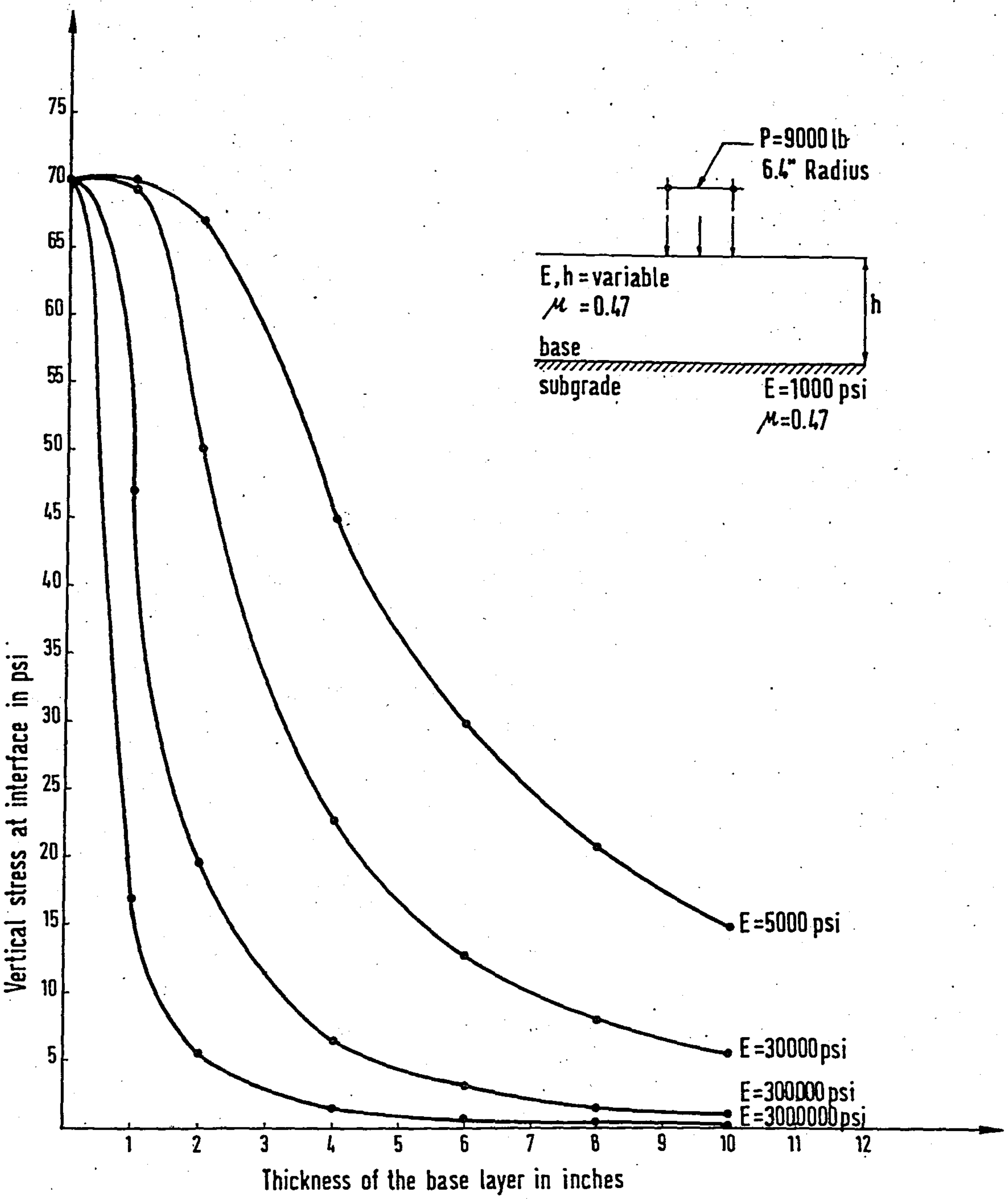


Figure 3.5 _ THE RELATIONSHIP BETWEEN VERTICAL STRESS AND BASE THICKNESS WITH DIFFERENT ELASTIC MODULI OF BASE

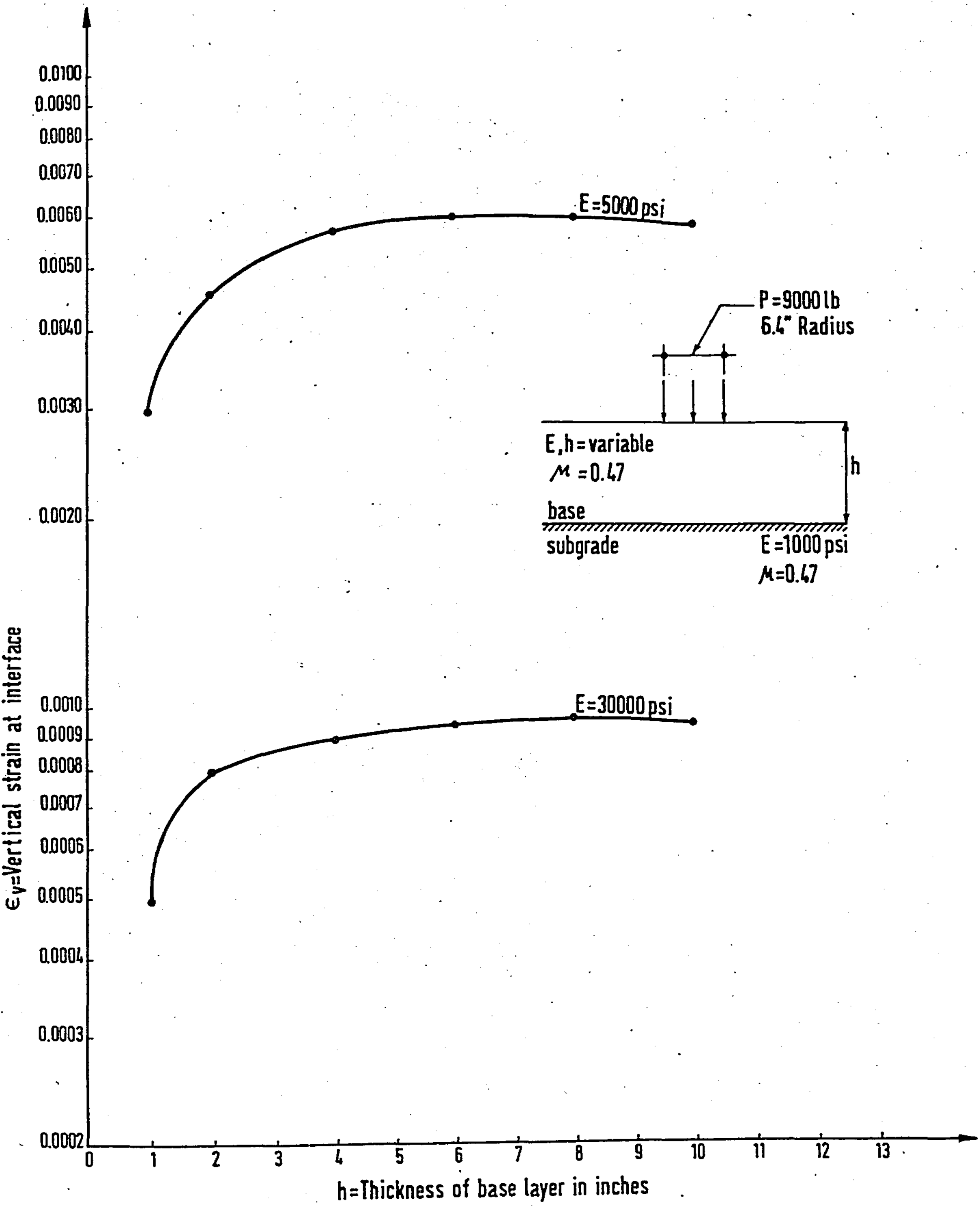


Figure 3.6 _ THE RELATIONSHIP BETWEEN VERTICAL STRAIN AND BASE THICKNESS WITH GIVEN MODULI OF ELASTICITY

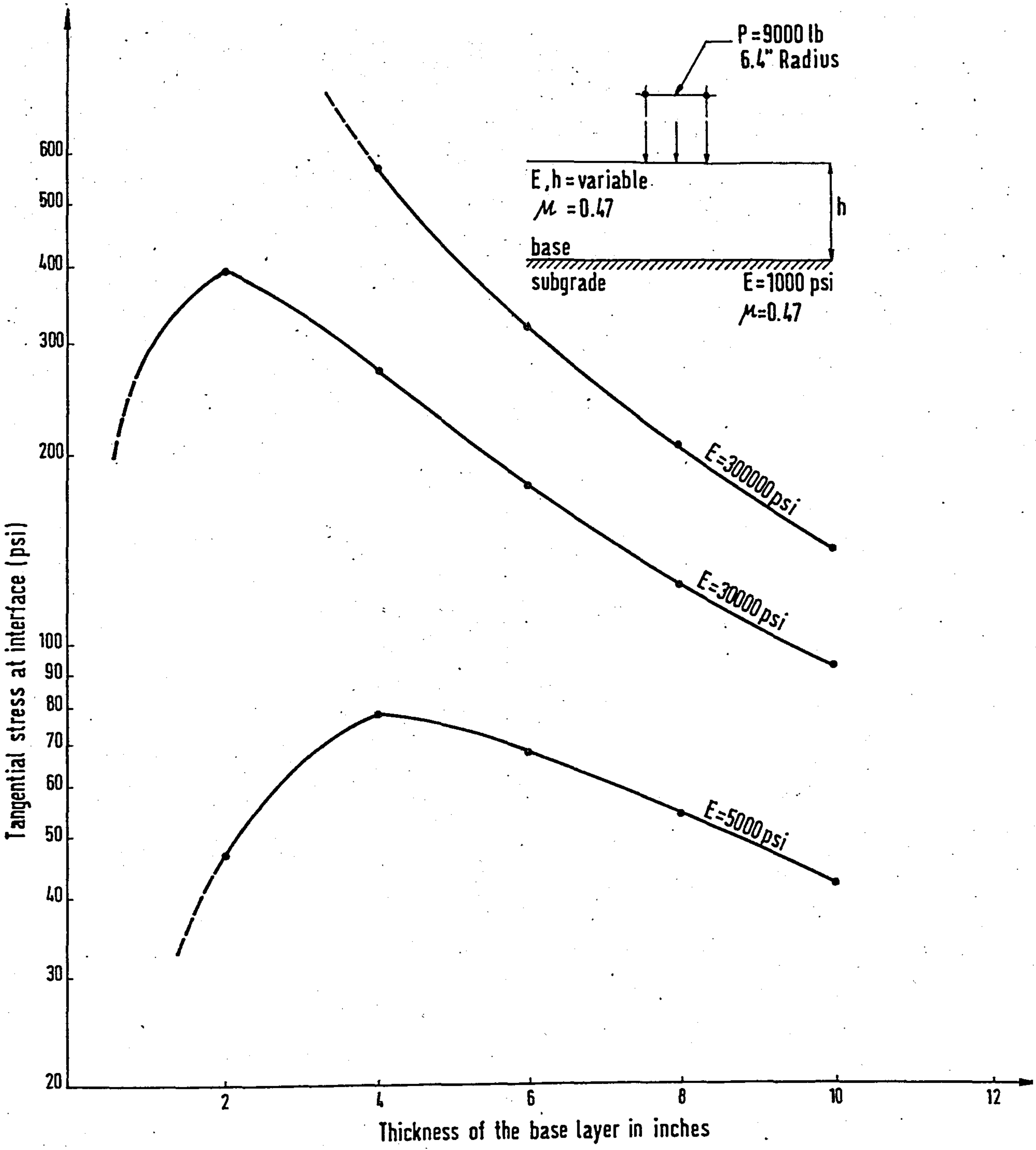


Figure 3.7 _ THE RELATIONSHIP BETWEEN TANGENTIAL STRESS AND BASE THICKNESS WITH GIVEN MODULI OF ELASTICITY

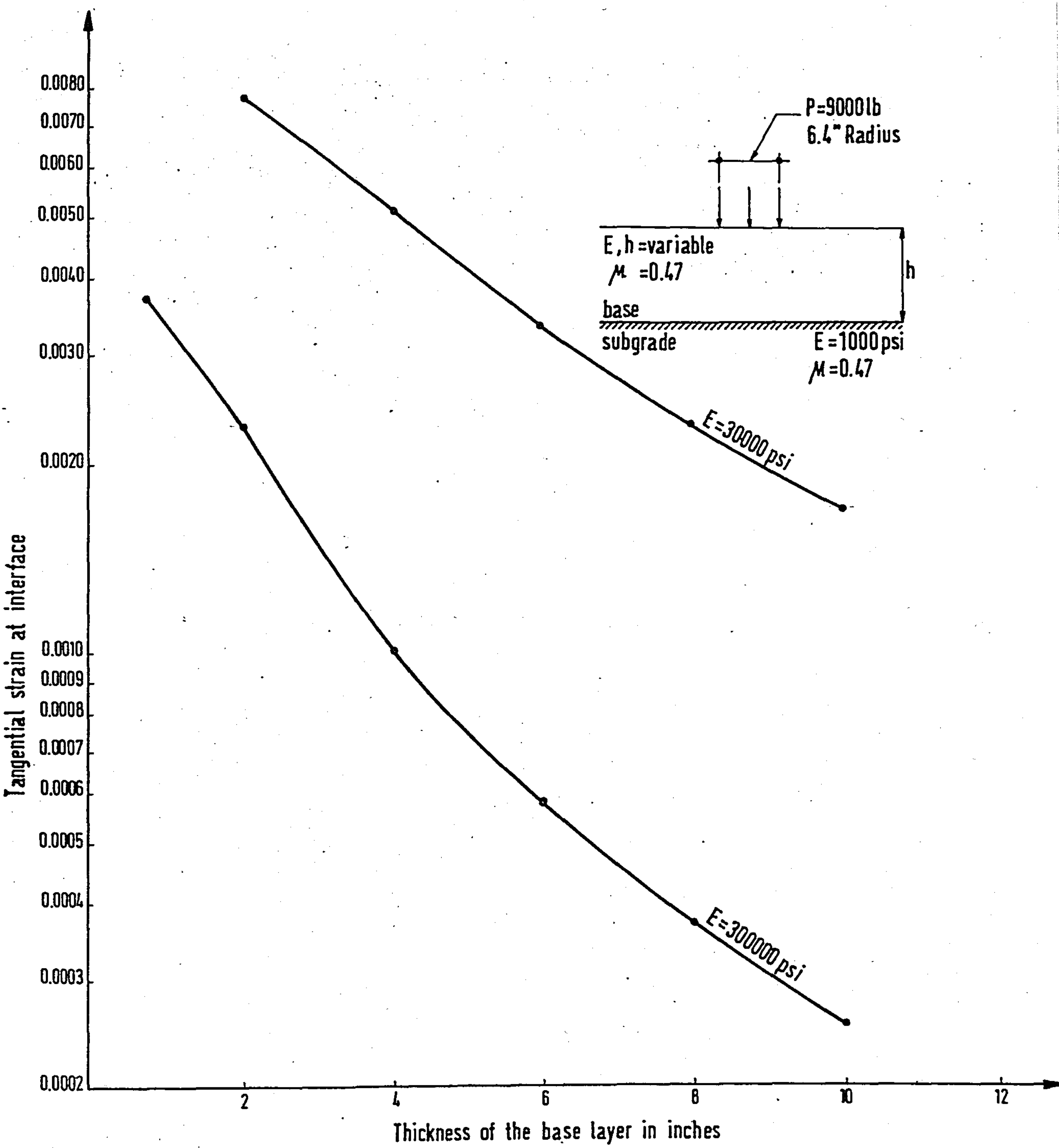


Figure 3.8 _ THE RELATIONSHIP BETWEEN TANGENTIAL STRAIN AND BASE THICKNESS WITH GIVEN MODULI OF ELASTICITY

on tangential strain at subgrade - base interface is the same with the effect of base thickness. When the same increment ratio is used for the values of base thickness and elastic modulus of base material, tangential strain value decreases linearly according to the increment ratio.

The effect of elastic modulus of base layer on shear stress at subgrade - base interface is shown in Figure 3.9. Shear stress values are plotted against distances away from the center of the applied load. It is seen from the figure that , the effect of elastic modulus of base layer on shear stress decreases extensively when the distance from the center of the applied load increases.

3.4 THREE LAYERED SYSTEM

The pavement structure defined as " Three Layered System " is the section taken from Kadıköy Yeldeğirmeni region after the pavement surface covering of interlocking concrete blocks. Three layered system composed of subgrade layer , cement - treated base layer and pavement layer is studied similar to two layered system. Values used in the parametric study of three layered system are given in Table 3.3.

In the parametric study , pavement thickness is taken as 4 inch (interlocking pavement + sand layer). Modulus of elasticity of pavement layer is taken as 4.000.000 psi which is equal to elastic modulus of concrete. Elastic modulus and thickness of the cement-treated base layer are taken as variables. Elastic modulus of subgrade is also taken as variable. The effect of poisson's ratios of both layers are also studied. Radial distance away from the applied load for deflections are taken according to Dynaflect measuring array (see chapter IV). Three layered system profile is shown in Figure 3.10 .

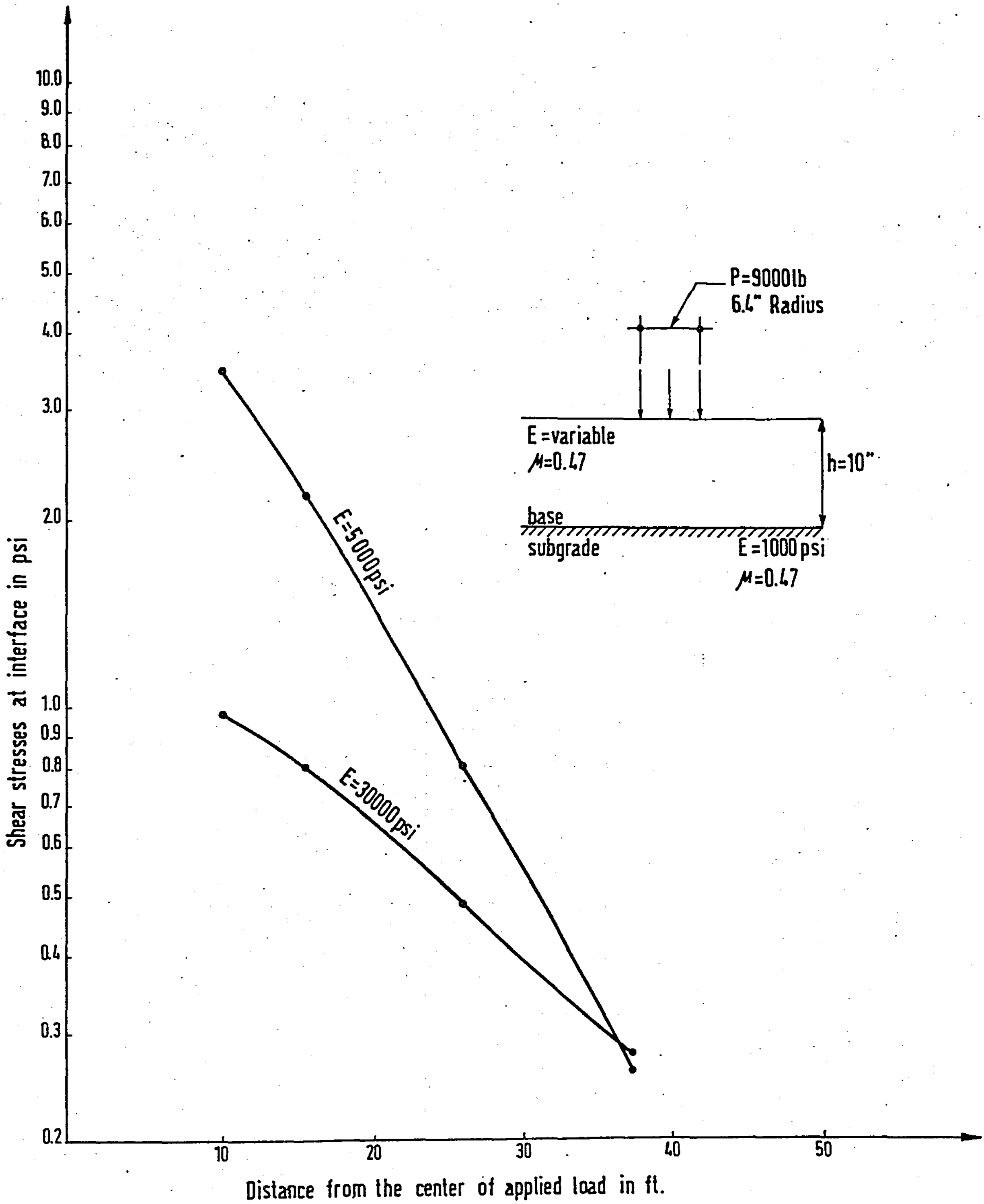


Figure 3.9 _ THE RELATIONSHIP BETWEEN SHEAR STRESS AND DISTANCE FROM THE CENTER OF APPLIED LOAD WITH GIVEN MODULI OF ELASTICITY

Table 3.3 - VALUES USED IN THE PARAMETRIC STUDY OF THREE LAYERED SYSTEM

Layer Type	Wheel Load, P = 9000 lb , Tire Pressure, q = 70 psi, Load Radius = 6.4 inch			
	Thickness h inch	Elas.Modulus E psi	Poisson's R. μ	Radial Dist. Away From Applied Load r inch
Subgrade Layer	Semi-Infi.	a) 1000 b) 5000 c) 10000 d) 50000	a) 0.20 b) 0.40	a) 0.0 b) 10.0 c) 15.6 d) 26.0 e) 37.4 f) 49.0
Cement Treated Base Layer	a) 5 b) 10 c) 15 d) 20 e) 25	a) 100000 b)1000000	a) 0.20 b) 0.40	a) 0.0 b) 10.0 c) 15.6 d) 26.0 e) 37.4 f) 49.0
Pavement Layer	a) 4	a)4000000	a) 0.20 b) 0.40	a) 0.0 b) 10.0 c) 15.6 d) 26.0 e) 37.4 f) 49.0

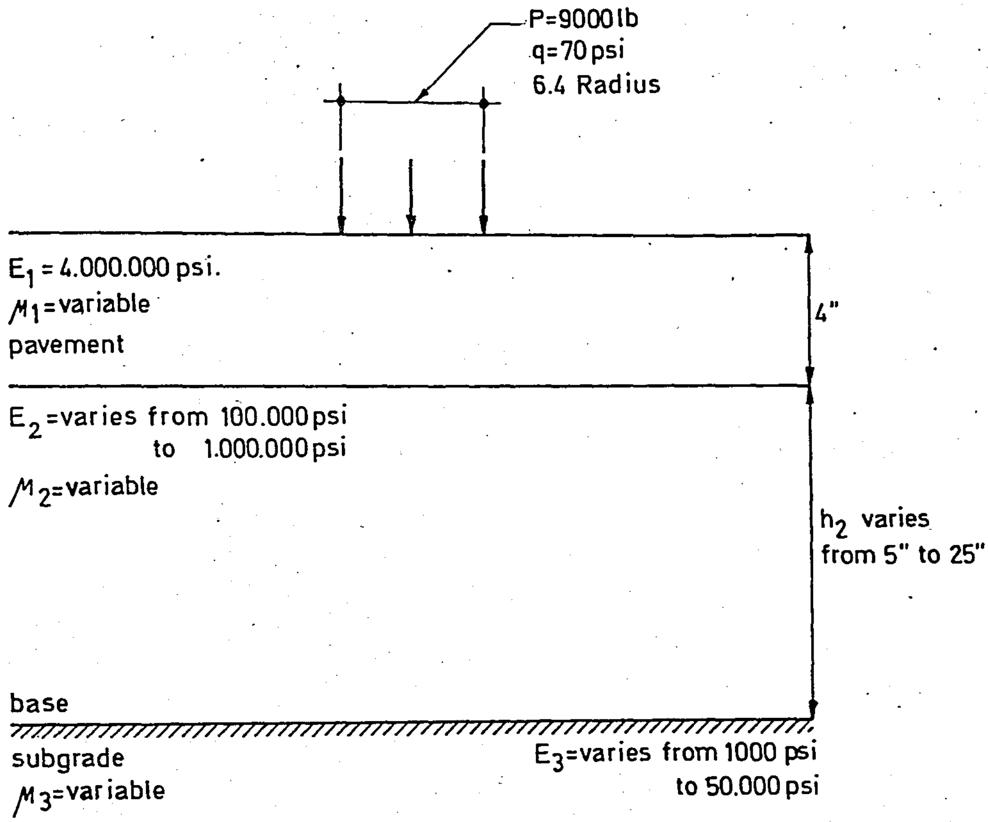


Figure 3.10 _ THREE LAYERED SYSTEM PROFILE

3.4.1 Maximum Deflection Of Three Layered System Under A Uniform Circular Load On The Surface

A parametric study on maximum deflection of Three Layered System under a uniform circular load on the surface is performed and the relationships are presented in Figures 3.11 - 3.16 .

The effect of elastic modulus of subgrade layer on maximum deflection at surface is presented in Figure 3.11. Maximum deflection values are plotted against base thicknesses. Elastic moduli of pavement layer and base layer are taken as 4.000.000 psi for interlocking concrete blocks and 1.000.000 psi for stiff base material. The values used for elastic modulus of subgrade layer vary from 1.000 psi to 10.000 psi. As it is seen from Figure 3.11 , the required base thickness against maximum deflection at surface can be determined for the subgrade layer having different elastic moduli.

The effect of elastic modulus of subgrade layer on maximum deflection at surface is presented in Figure 3.12 similar to the Figure 3.11. Additional curves (dotted lines) are plotted for the base layer having weak soil properties (E_2 = 100.000 psi) to see the effects of elastic moduli of base and subgrade layers on maximum deflection at surface. It is determined that, the increment on the value of elastic modulus of subgrade layer affects the maximum deflection at the surface more than the increment on the value of elastic modulus of base layer.

The relationship between maximum deflection at surface and distance from the center of applied load with different base thicknesses is presented in Figure 3.13. It can be concluded from the figure that, the effect of base

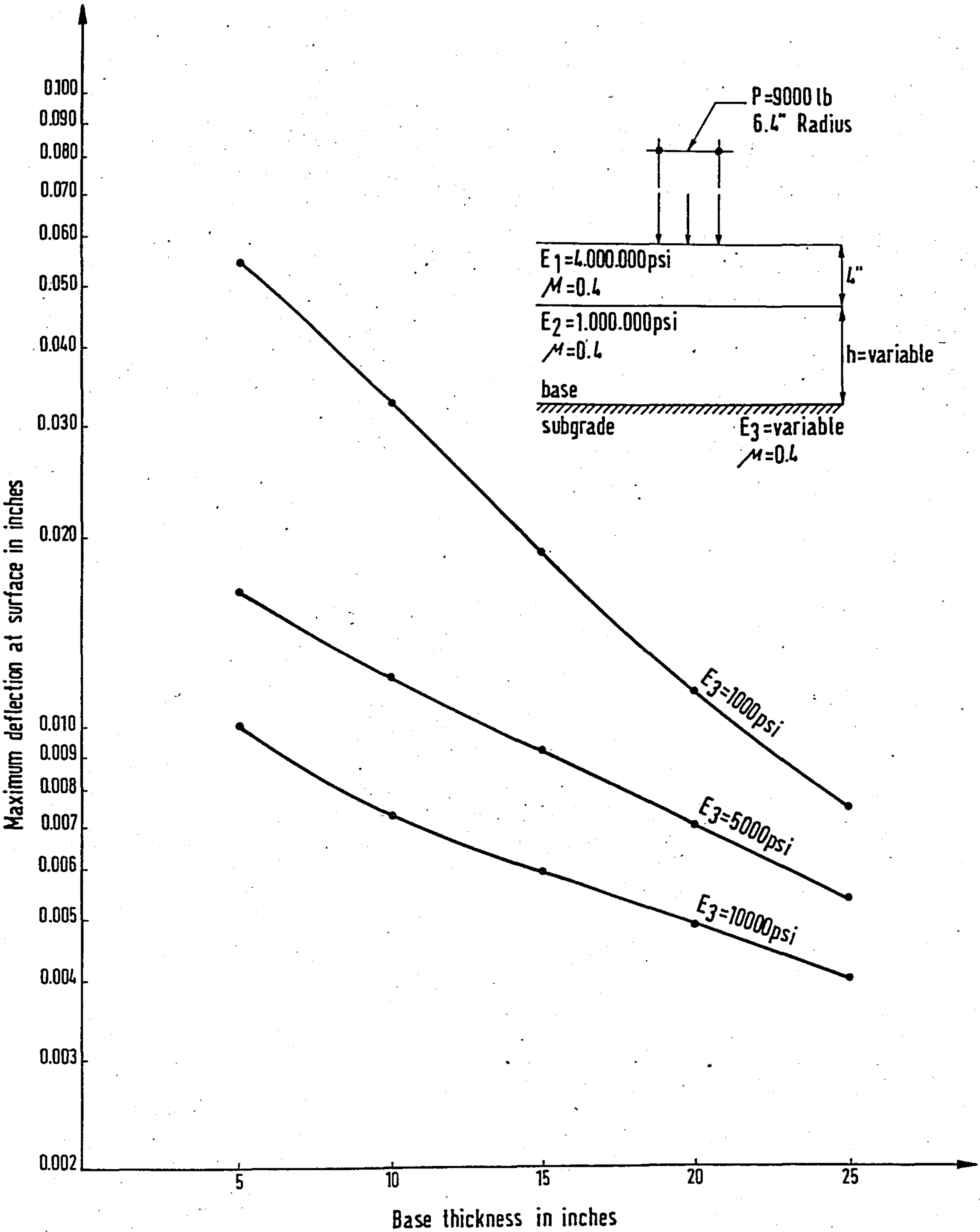


Figure 3.11_ THE RELATIONSHIP BETWEEN MAXIMUM DEFLECTION AT SURFACE AND BASE THICKNESS WITH DIFFERENT ELASTIC MODULI OF SUBGRADE

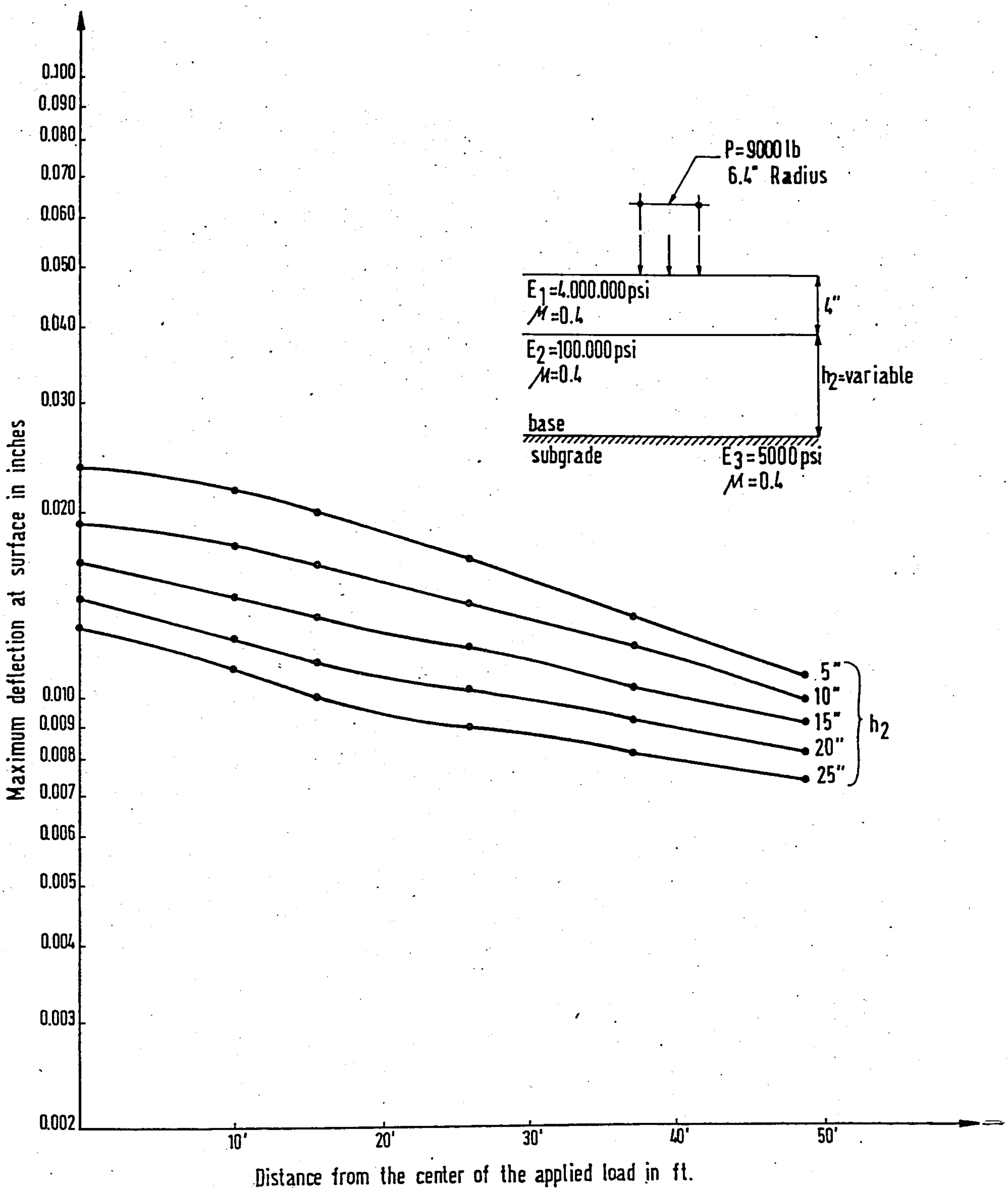


Figure 3.13 _ THE RELATIONSHIP BETWEEN MAXIMUM DEFLECTION AT SURFACE AND DISTANCE FROM THE CENTER OF APPLIED LOAD WITH DIFFERENT BASE THICKNESSES

thickness on maximum deflection at the surface is much less than the effect of elastic modulus of base layer shown in Figure 3.14.

The effect of elastic moduli of base and subgrade layer on maximum deflection at surface is studied against distances from the center of applied load and presented in Figure 3.14. The conclusion given for Figure 3.12 is also valid for this figure.

The relationship between maximum deflection at surface and distance from the center of the applied load with different poisson's ratios is presented in Figure 3.15. It is determined that, the effect of poisson's ratio on maximum deflection at surface is much less than the effect of elastic modulus for the pavement structure having same layer thicknesses.

The relationship between required base thickness for the layered system having maximum 0.01 inch deflection at surface and elastic modulus of subgrade layer with different elastic moduli of base layer is given in Figure 3.16. It is possible to determine the required base thickness according to the maximum allowable deflection at the surface for the pavement structure having specific material properties (*). For example, to have a maximum deflection 0.01 inch at surface, the required base thickness is found as 5 inch from the Figure 3.16 for the pavement structure having elastic moduli 1.000.000 psi for base layer and 10.000 psi for subgrade layer.

(*) Mitchell , J.K. , " Theoretical Approaches To Soil - Cement Pavement Thickness Design " , Presented At 49.th Annual Meeting Of The Highway Research Board , January 1970

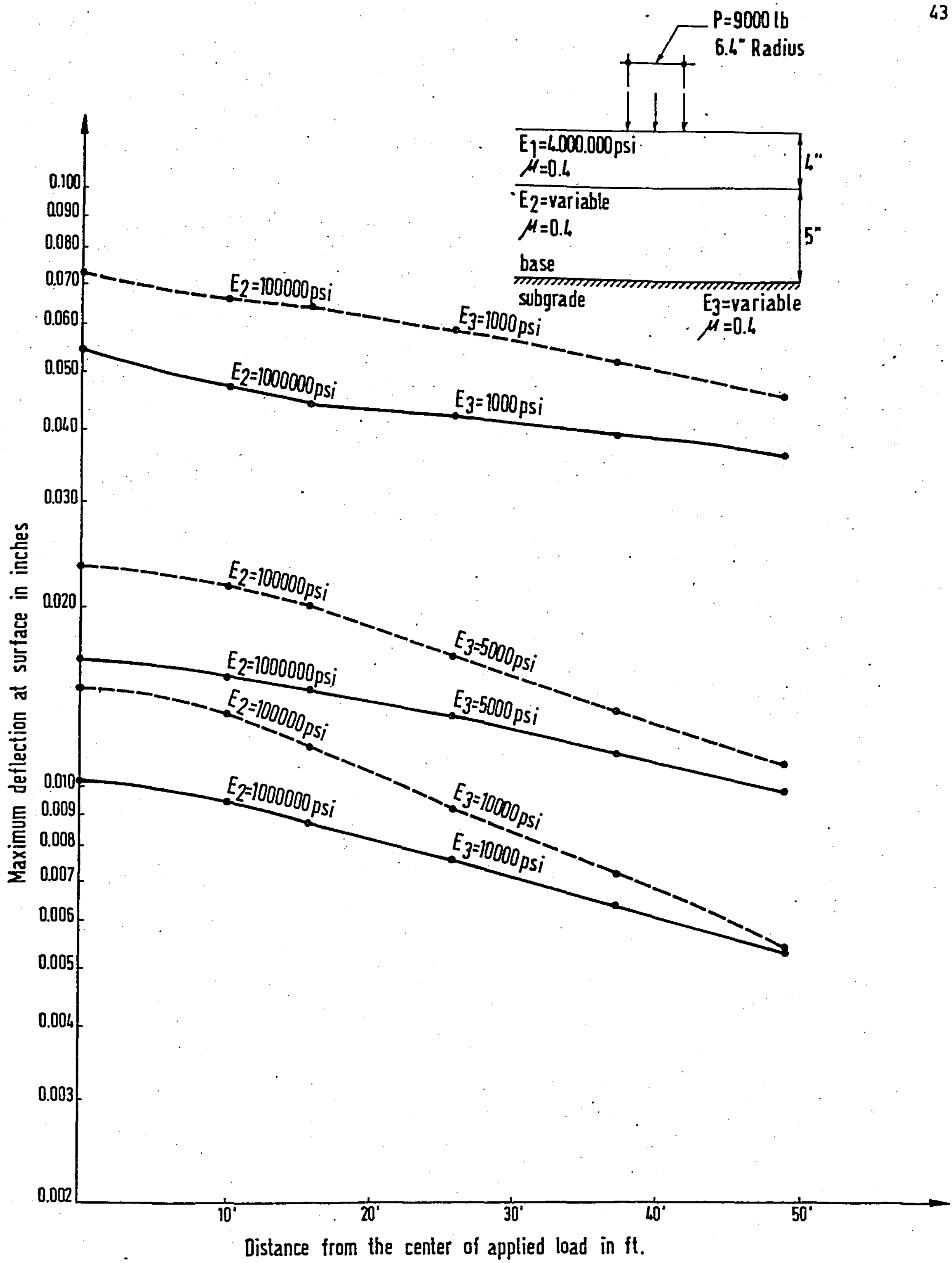


Figure 3.14 _ THE RELATIONSHIP BETWEEN MAXIMUM DEFLECTION AT SURFACE AND THE DISTANCE FROM THE CENTER OF APPLIED LOAD WITH DIFFERENT ELASTIC MODULI OF BASE AND SUBGRADE

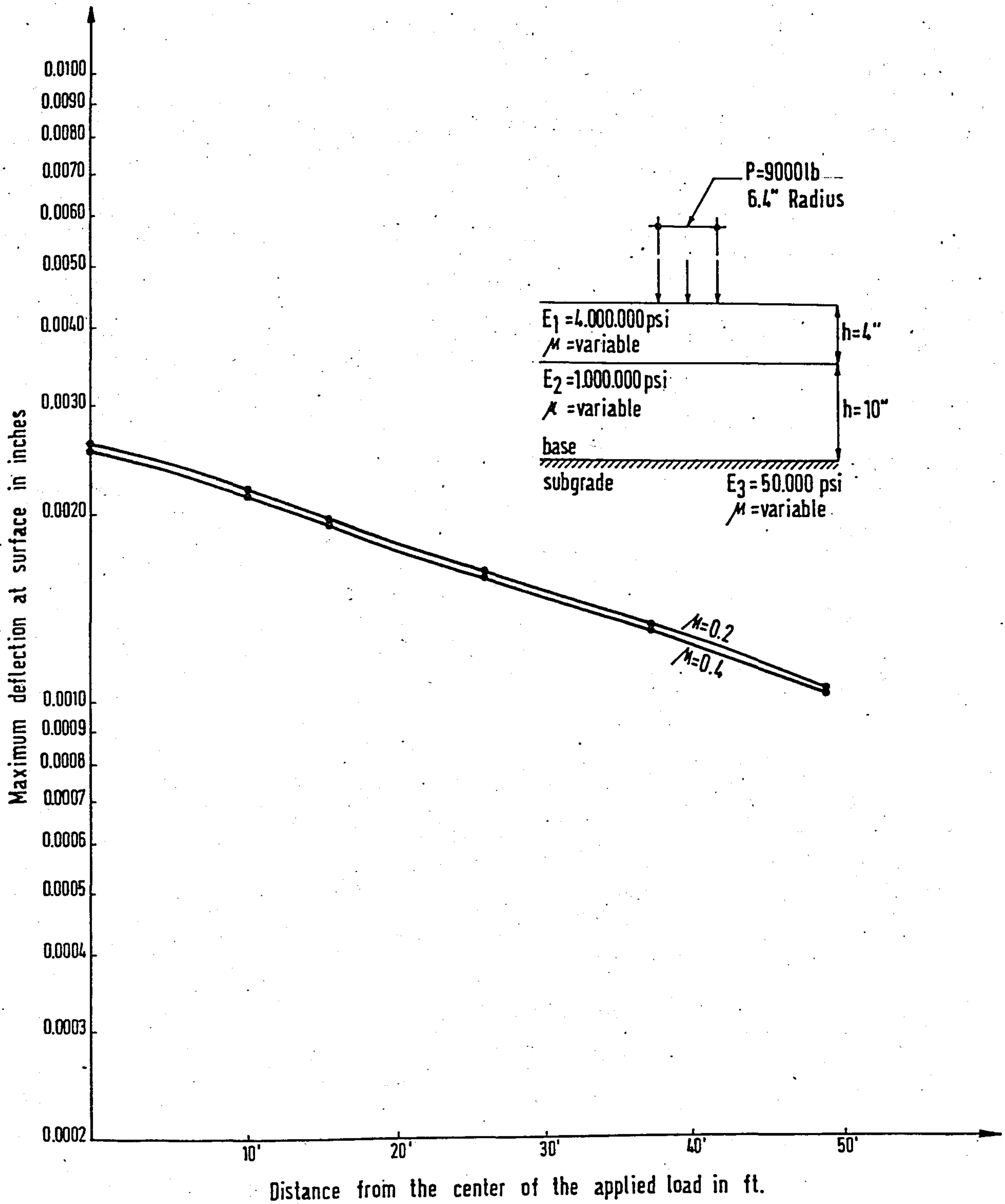


Figure 3.15 _ THE RELATIONSHIP BETWEEN MAXIMUM DEFLECTION AT SURFACE AND THE DISTANCE FROM THE CENTER OF APPLIED LOAD WITH DIFFERENT POISSON'S RATIOS

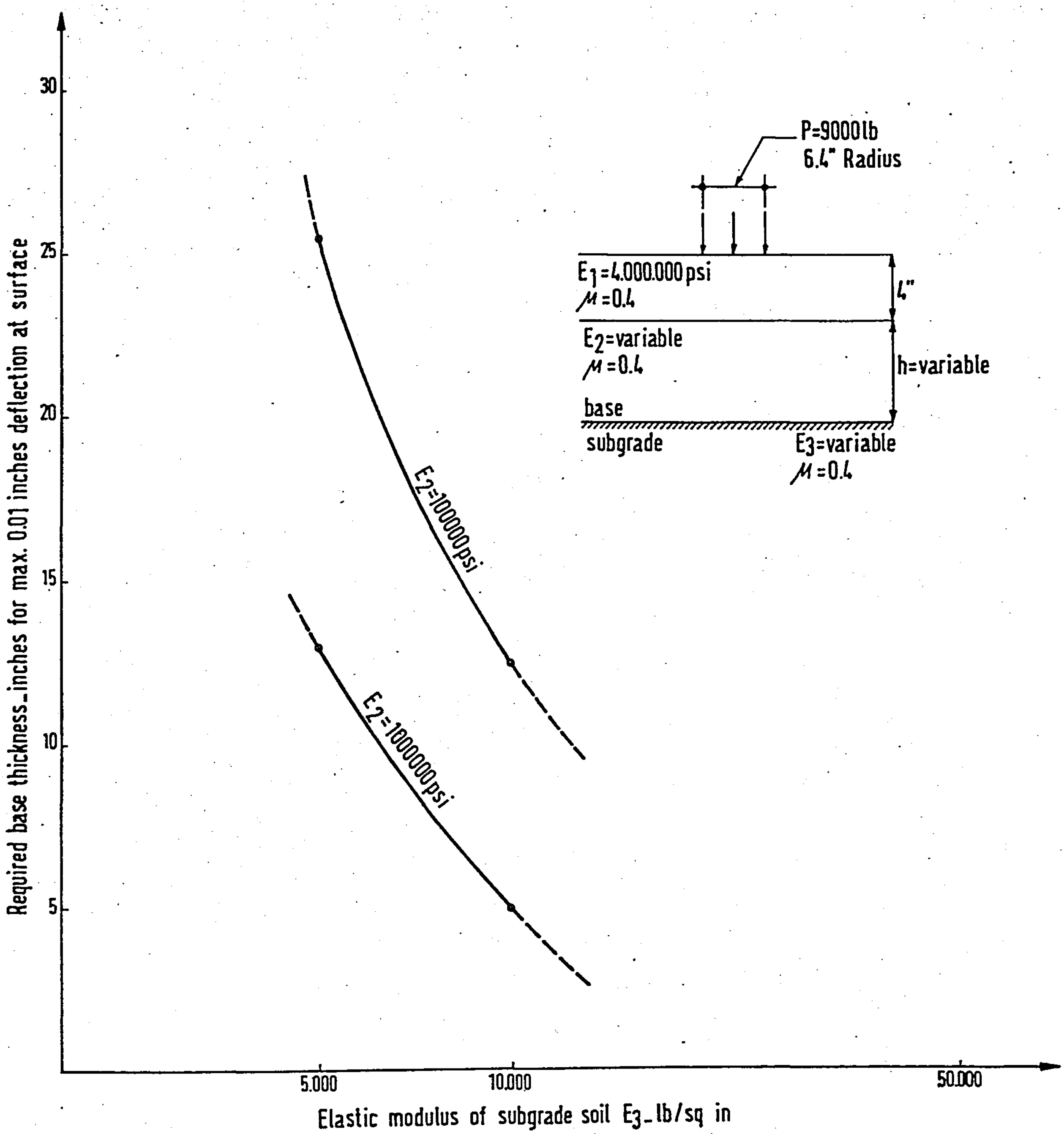


Figure 3.16 _ THE RELATIONSHIP BETWEEN REQUIRED BASE THICKNESS AND ELASTIC MODULUS OF SUBGRADE HAVING DIFFERENT ELASTIC MODULI OF BASE

3.4.2 Stresses And Strains Of Three Layered System Under A Uniform Circular Load On The Surface

A parametric study on stresses and strains of Three Layered System under a uniform circular load on the surface is performed and the relationships are presented in Figure.3.17 - 3.24 .

Vertical stress values at base - subgrade interface are plotted in Figure 3.17 for the pavement structure having different base thicknesses. Elastic moduli of base and subgrade layers are taken as variables. It is determined that, the effect of elastic modulus of subgrade layer on vertical stress at base - subgrade interface is much greater than the effect of elastic modulus of base layer. The required base thickness against maximum vertical stress can be determined for the base and subgrade layers having different moduli of elasticity.

The effect of elastic moduli of base and subgrade layers on compressive stress at base - subgrade interface is presented in Figure 3.18. Base layer thickness is taken as constant. It is possible to determine the required elastic modulus of base or subgrade layer according to a certain vertical compressive stress value at subgrade - base layer for the pavement structure having constant base thickness.

The relationship between vertical compressive stress at base - subgrade interface and base thickness with different poisson's ratios and elastic moduli of base layer is presented in Figure 3.19. It is seen from the figure that, the effect of poisson's ratio on vertical stress at base - subgrade interface is much less than the effect of elastic modulus of base layer. It is possible to determine the required base thickness according to the

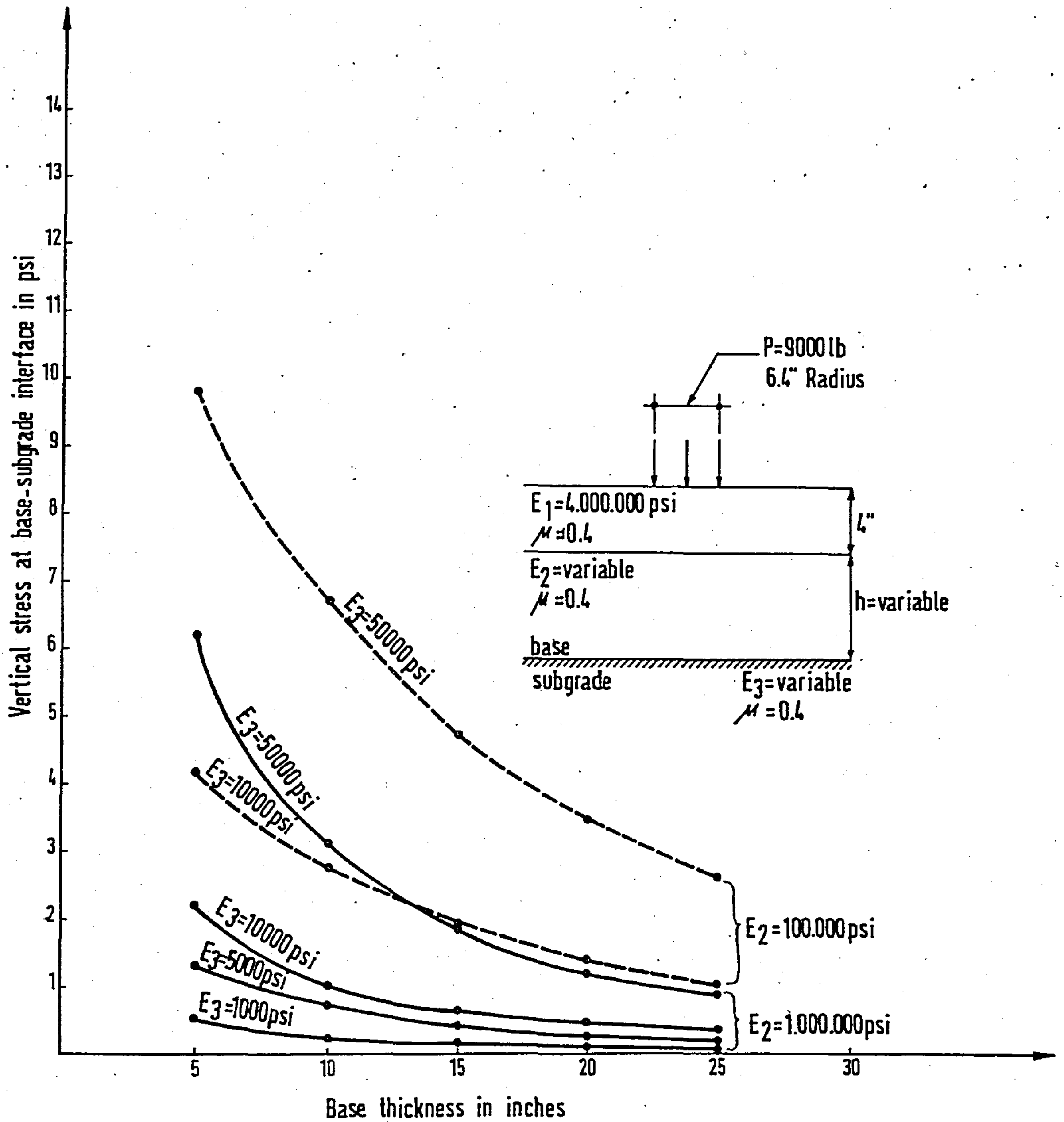


Figure 3.17 _ THE RELATIONSHIP BETWEEN VERTICAL STRESS AT BASE_SUBGRADE INTERFACE AND BASE THICKNESS WITH GIVEN MODULI OF ELASTICITY

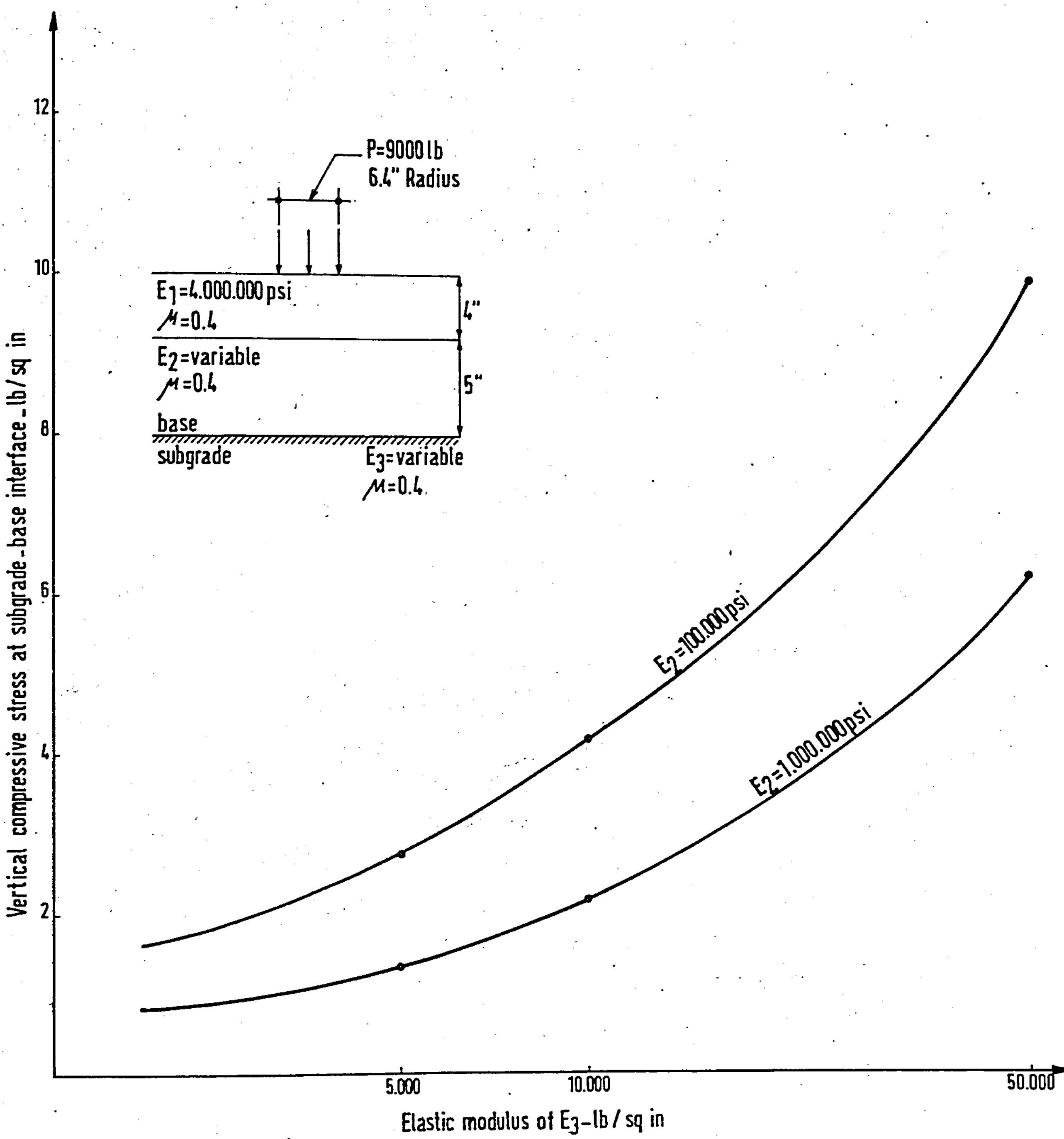


Figure 3.18 - THE RELATIONSHIP BETWEEN VERTICAL COMPRESSIVE STRESS AT BASE-SUBGRADE INTERFACE AND ELASTIC MODULUS OF SUBGRADE HAVING DIFFERENT ELASTIC MODULI OF BASE

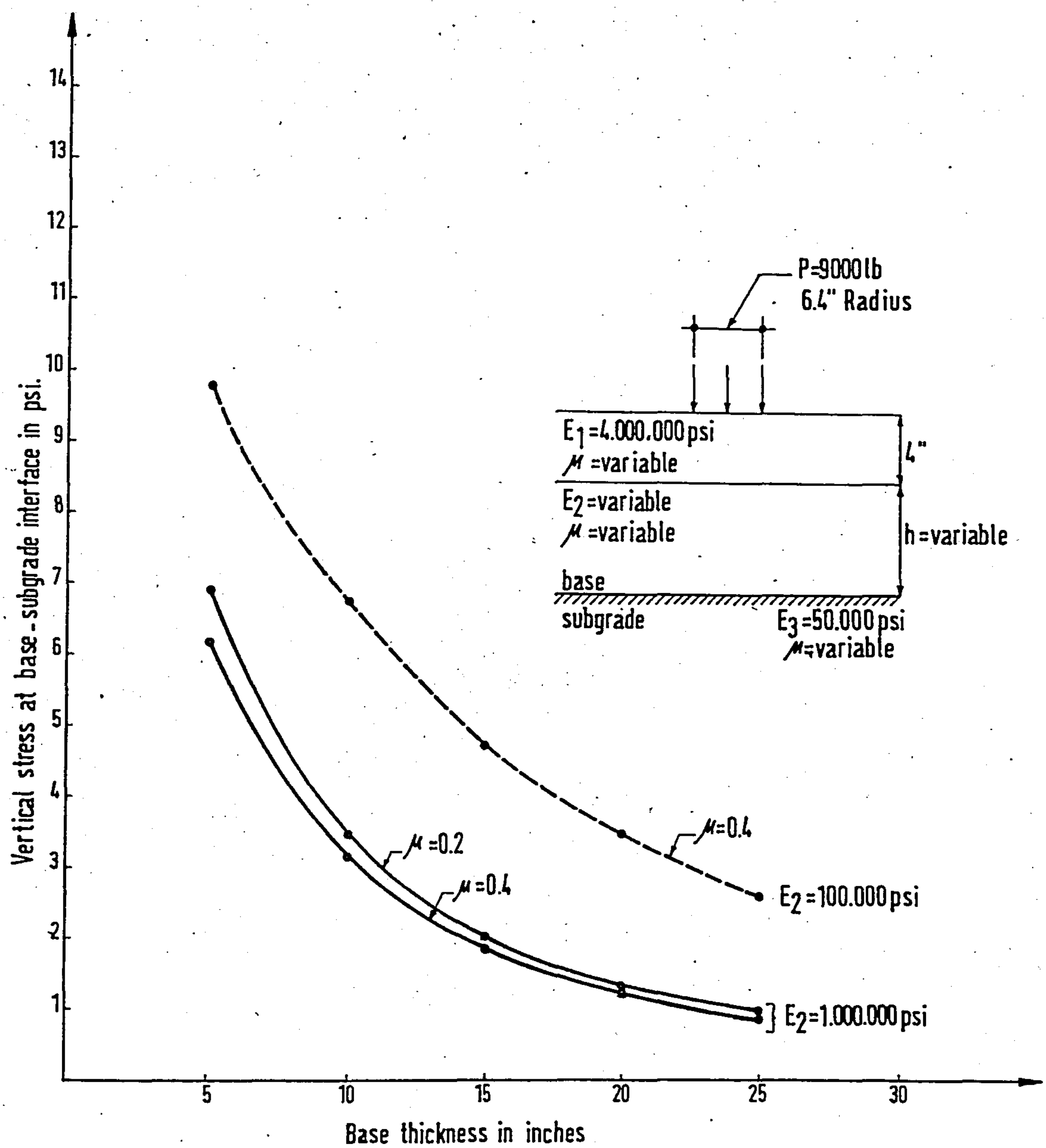


Figure 3.19 _ THE RELATIONSHIP BETWEEN VERTICAL COMPRESSIVE STRESS AT BASE_SUBGRADE INTERFACE AND BASE THICKNESS WITH DIFFERENT POISSON'S RATIOS AND ELASTIC MODULI OF BASE

vertical stress at base - subgrade interface for the pavement structure having specific values shown in Figure 3.19.

The relationship between vertical compressive stress at base - subgrade interface and distance from the center of the applied load with different poisson's ratios is presented in Figure 3.20. It is determined that the effect of poisson's ratio on the vertical stress at base - subgrade interface stays almost constant for different poisson's ratio values when the distance from the center of the applied load increases.

Vertical strain values at base - subgrade interface are plotted in Figure 3.21 for the pavement structure having different base thicknesses. Elastic moduli of base and subgrade layers are taken as variables. The effect of elastic modulus of subgrade layer on vertical strain at base - subgrade interface is much greater than the effect of elastic modulus of base layer. The required base thickness can be determined from the figure for a certain vertical strain and elastic moduli of base and subgrade layers.

Tangential stress and strain values at base - subgrade interface are plotted in Figures 3.22 and 3.23 for the pavement structure having different base thicknesses. Elastic modulus of subgrade layer is taken as variable. The required base thickness against maximum tangential stress and strain can be determined for the pavement structure having different elastic moduli of subgrade layer from Figures 3.22 and 3.23.

The relationship between shear stress at base - subgrade interface and distance from the center of the applied load

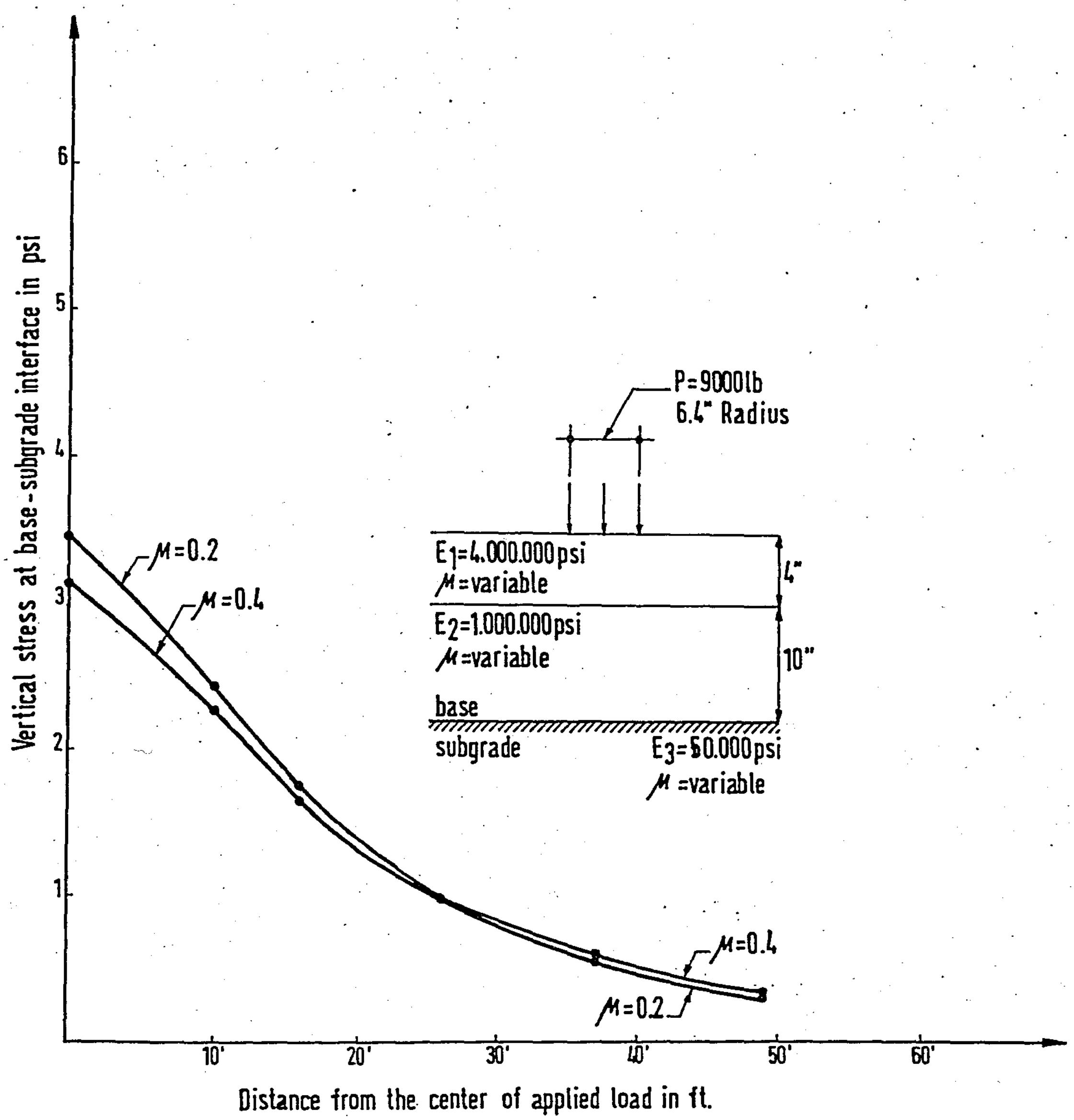


Figure 3.20 _ THE RELATIONSHIP BETWEEN VERTICAL COMPRESSIVE STRESS AT BASE_SUBGRADE INTERFACE AND DISTANCE FROM THE CENTER OF APPLIED LOAD WITH DIFFERENT POISSON'S RATIOS

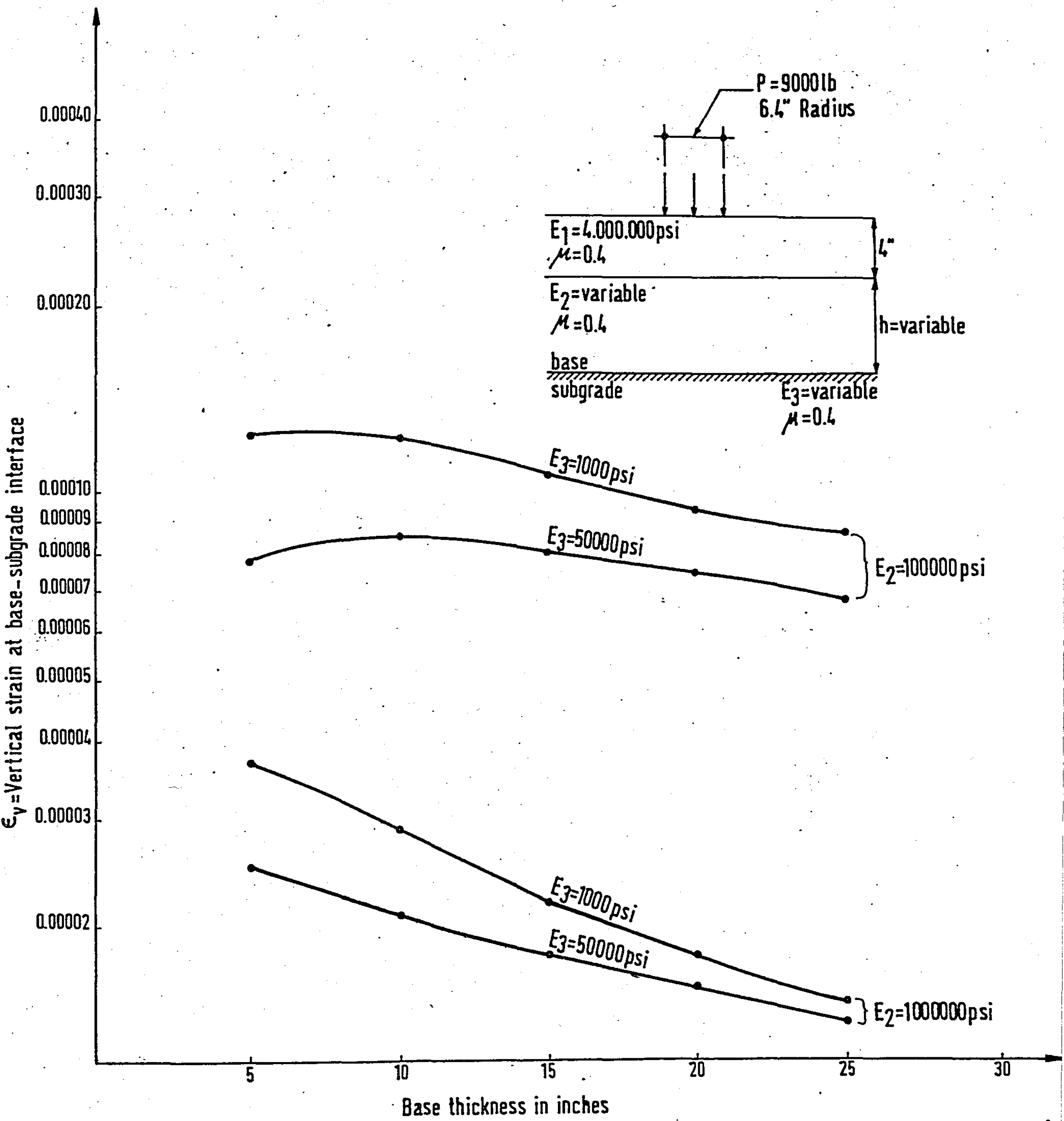


Figure 3.21_ THE RELATIONSHIP BETWEEN VERTICAL STRAIN AT BASE_SUBGRADE INTERFACE AND BASE THICKNESS WITH DIFFERENT ELASTIC MODULI OF BASE AND SUBGRADE

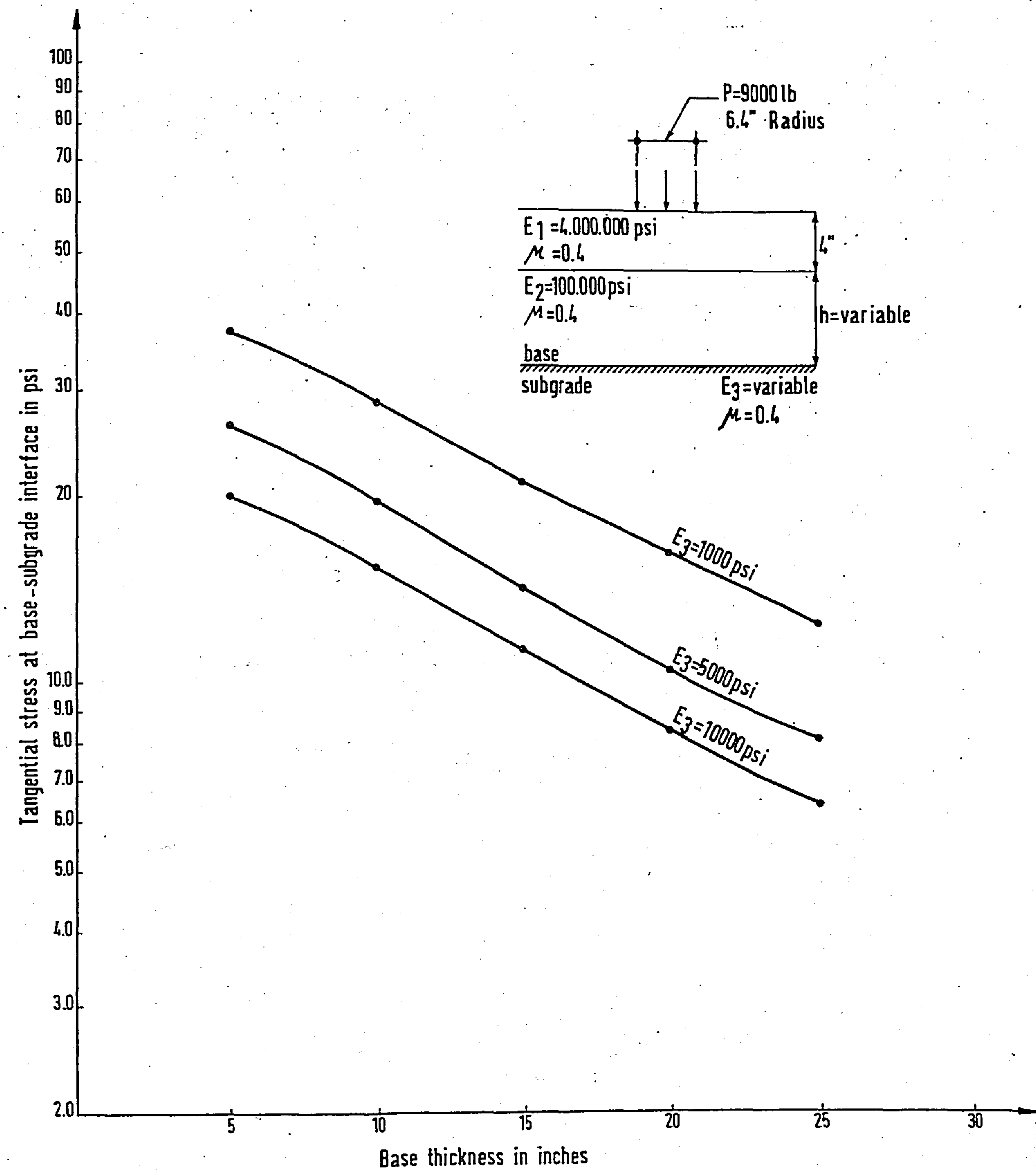


Figure 3.22 – THE RELATIONSHIP BETWEEN TANGENTIAL STRESS AT BASE-SUBGRADE INTERFACE AND BASE THICKNESS WITH DIFFERENT ELASTIC MODULI OF SUBGRADE

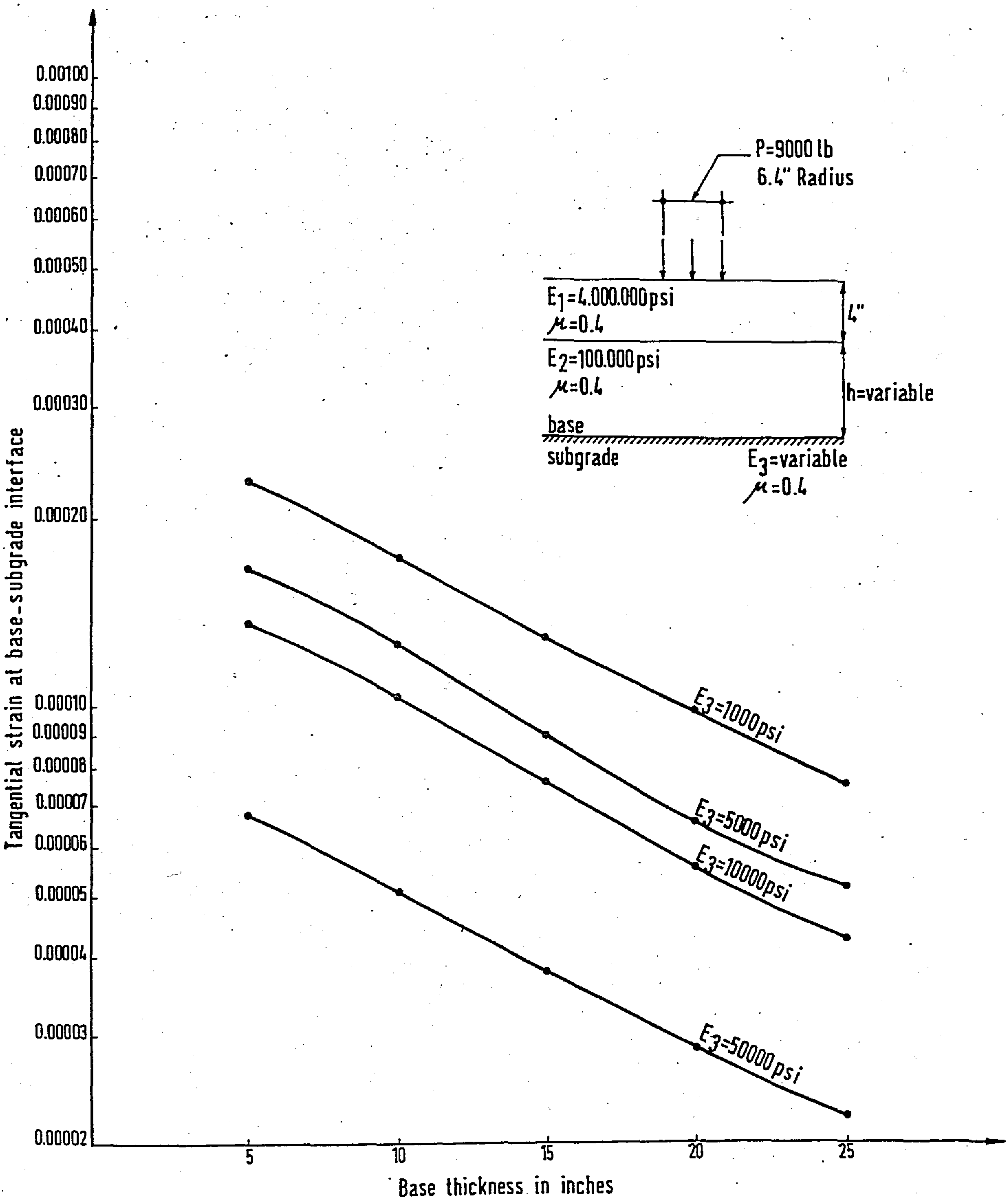


Figure 3.23 _ THE RELATIONSHIP BETWEEN TANGENTIAL STRAIN AT BASE_SUBGRADE INTERFACE AND BASE THICKNESS WITH DIFFERENT ELASTIC MODULI OF SUBGRADE

with different elastic modulus of subgrade is presented in Figure 3.24. It is seen from the figure that, the effect of elastic modulus of subgrade layer on shear stress at base - subgrade interface decreases extensively when the distance from the center of the applied load increases.

3.5 SUMMARY AND CONCLUSIONS

The solutions for stresses and deflections of the proposed pavement structure are given in the form of parametric study in this chapter. Two construction stages of the proposed pavement structure defined as Two Layered System and Three Layered System are taken from Kadıköy Yeldeğirmeni region and studied using a commonly known computer program called Chevron 5L.

The behavior of the proposed pavement structure are studied for various depths and material properties under the design loads. The expected stresses and deflection of pavement structure are given in the form of charts by showing their relationships with layer parameters.

It is possible to determine the required base thickness from the charts for the pavement structure having certain material properties. The effect of elastic modulus on stresses and deflection is much greater than the effect of poisson's ratio of the same pavement structure and it is also determined that the effect of elastic modulus of subgrade layer on stresses and deflection is much greater than the effect of elastic modulus of base layer.

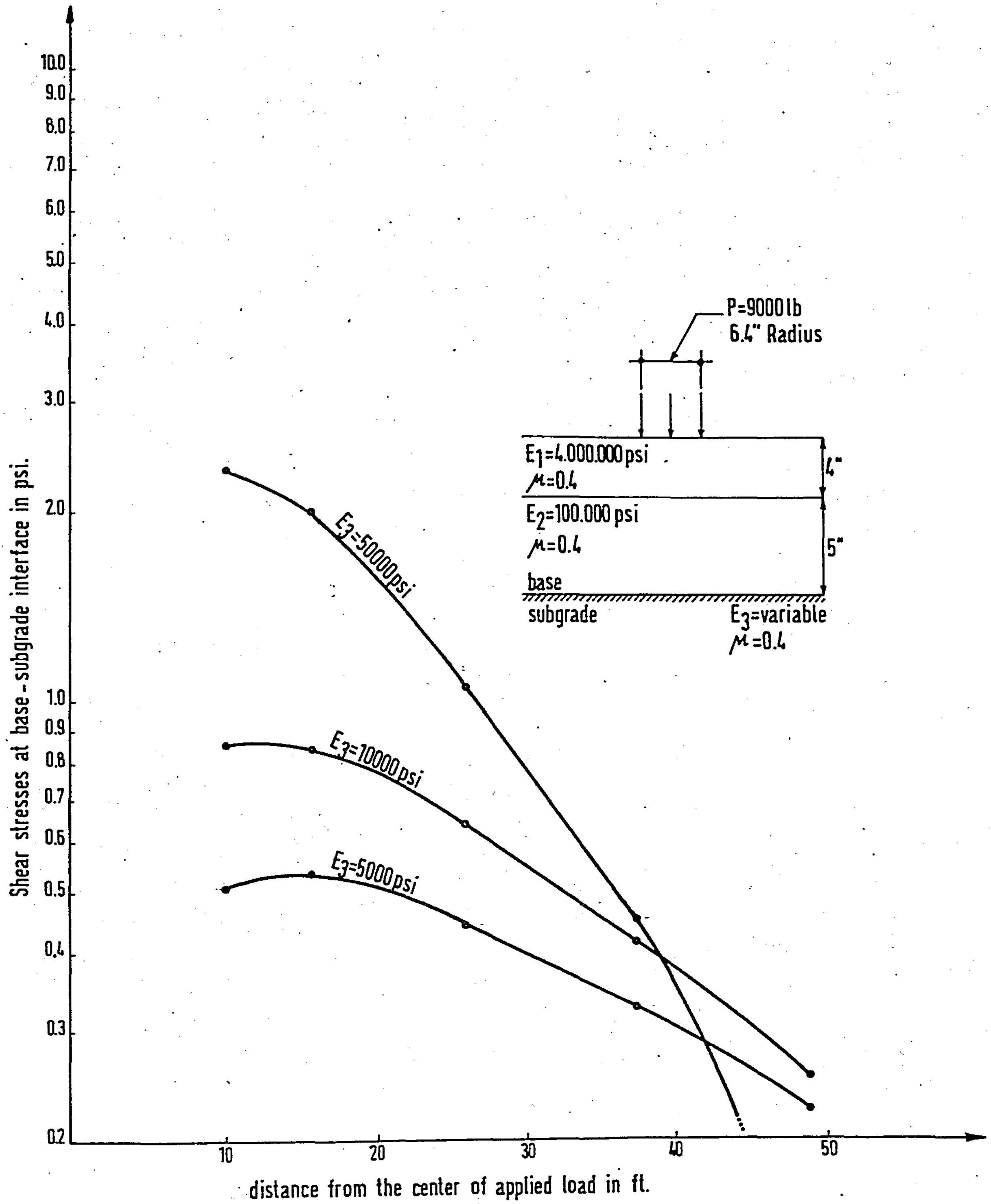


Figure 3.24 _ THE RELATIONSHIP BETWEEN SHEAR STRESS AT BASE_SUBGRADE INTERFACE AND DISTANCE FROM THE CENTER OF APPLIED LOAD WITH DIFFERENT ELASTIC MODULI OF SUBGRADE

IV - AN APPLICATION OF COMPUTER DEFLECTION ANALYSIS TO A HIGHWAY DEFLECTION MEASURING INSTRUMENT - DYNAFLECT

4.1 WHAT IS DYNAFLECT ?

Dynaflect is used for the first time in California State[(1)] - 1966 for the road project to determine the defected sections under the road having asphalt concrete pavement. Dynaflect is later extensively used for moduli determination of pavement structures. Deflections, measured during the operation of Dynaflect , help to determine elastic moduli of pavement structures and defected sections of the existing roads.

Dynaflect[(2)] comprises a dynamic force generator together with a set of motion sensing devices mounted on a small trailer , and a motion measuring system which is normally carried in the towing vehicle . Deflections are measured while the trailer is halted for a brief time at the chosen location . The motion sensors are lowered into contact with the surface and the results are read by the operator in the vehicle .

The force generator , which utilizes a pair of unbalanced flywheels , provides a vertical force which varies sinusoidally at the rate of eight cycles per second . The total downward force applied to the material beneath the trailer consists of the static weight of the apparatus , 1600 pounds , plus the

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(1) Legarra , J.A. , " Evaluation Of The Lane-Wells Dynaflect " ,Highway Research Report , State Of California , Division Of Highways ,October , 1968

(2) Swift , G. , " Dynaflect - A New Highway Deflection Measuring Instrument " , 48 th Annual Tennessee Highway Conference , University Of Tennessee , 1966 "

dynamic force which alternately adds to and subtracts from this weight . Since the total excursion of the dynamic force is 1.000 lb , the actual load on the ground varies between 1.100 and 2.100 lb eight times every second . This load is applied to the ground through a pair of rigid wheels , on which the equipment can be moved to measure at a succession of nearby locations . For high - speed long - distance travel the trailer is transported on its pneumatic tires . All power for the Dynaflect apparatus is obtained from the 12 Volt electrical system of the towing vehicle . Under the influence of the 1.000 lb repetitive force the material on which the trailer rests deflects downward and upward in synchronizing with the force . The amplitude of this induced motion is sensed at five locations , ranging from 10 to 50 inches away from the point of application of the load . These measurements serve to define the shape , as well as the depth , of the deflection basin .

The deflection measurements are read on a meter located on the driver 's seat in the vehicle . Six meter scale ranges are provided for reading deflections from as large as 30 thousandths of an inch to as small as 1 / 100 of a thousandth . This range permits measurements on the stiffest rigid pavements on all flexible pavements , and at construction sites , on any materials which will support the towing vehicle .

Measurements can be made quickly with The Dynaflect system , averaging less than one minute for consecutive locations . The system has been correlated favorably with static deflection measurements made by other more cumbersome methods .

Comparison of the deflections observed at a number of locations is facilitated by plotting the results on semi - log graph paper . The logarithmic axis is used for the deflections , while the linear axis is used for the distance between the point of application of the force and the measuring point .

Using the normal measuring array , shown in Figure 4.1 in which the first measuring point is midway between the load wheels and the other successively spaced at one foot intervals ,the actual slant - range distance 10 , 15.6 , 26 , 37.4 and 49 inches , respectively .

4.2 ESTIMATION OF MATERIAL PROPERTIES FROM DYNAFLECT DEFLECTIONS

The pavement layer stiffness may be back calculated from Dynaflect deflection measurements by using elastic - layered theory as follows(*) ;

1 - Pavement layer thicknesses , initial estimates of the pavement layer moduli , and the loading and deflection measurement configuration are input into the computer program .

2 - The computed deflections at the five geophone positions can be compared with those actually measured in the field.

3 - The layer moduli used in the computer program can now be adjusted to improve the fit of the predicted and actual deflection basins .

4 - This process is repeated until the two deflection basins are virtually the same . The process may have to be repeated several times before a reasonable fit is obtained.

Knowledge of the effects of changes to the various layer moduli on the shape and position of the deflection basin may speed the process considerably . Some of the terms commonly used with deflection basins are as follows : (Figure 4.2)

(*) B.Frank Mc Cullough & Arthur Taute , " Use Of Deflection Measurements For Determining Pavement Material Properties " , Transportation Research Board , Record No 852 , 1982

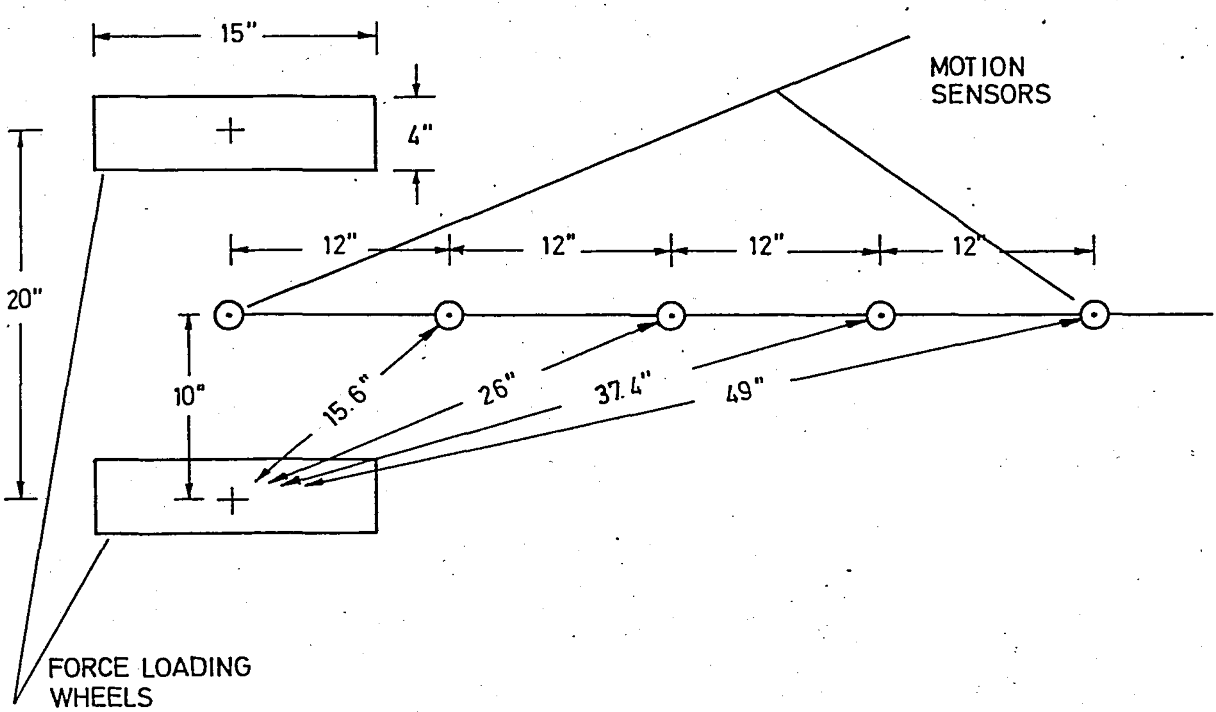

Figure 4.1 _ DYNAFLECT MEASURING ARRAY

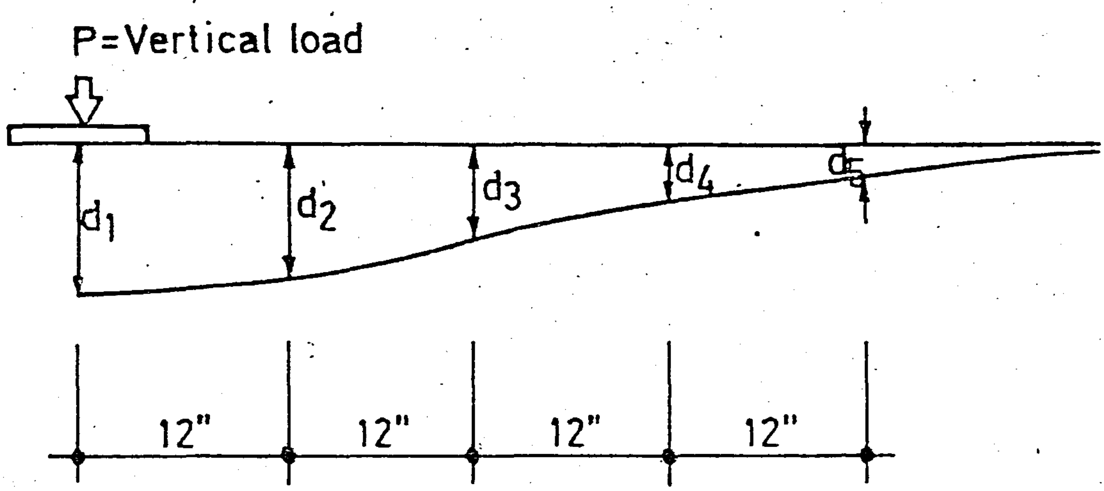

Figure 4.2 _ DEFLECTION BASIN PARAMETERS

1 - Sensor - i deflection , d_i

2 - Surface curvature index (SCI) , $d_1 - d_2$

3 - Base curvature index (BSI) , $d_4 - d_5$

4 - Spreadability , $(d_1 + d_2 + d_3 + d_4 + d_5) / 5 d_1$ and

5 - Slope of the deflection basin , $d_1 - d_5$

Deflection basin parameters at the measuring points and the point of application of the force are presented in Figure 4.2 .

4.3 THE APPLICABILITY OF COMPUTER DEFLECTION ANALYSES TO A DEFLECTION MEASURING INSTRUMENT - DYNAFLECT

The dependent variables in this investigation were the maximum deflection of the deflected basin and spreadability of the deflected basin. The spreadability Sd is the average deflection in percent of the maximum deflection and, in this investigation , was taken as follows ,

$$S_d = \frac{d_1 + d_2 + d_3 + d_4 + d_5}{5 d_1} \times 100 \quad .. (4.1)$$

where d_1 = maximum deflection of the pavement , as measured in the field and dmax , when theoretically calculated and d_2 , d_3 , d_4 and d_5 are deflections at 1 , 2 , 3 and 4 ft away from the center of the applied load .

In the theoretical evaluation , the materials in the layered system were assumed to be elastic , isotropic and homogeneous and it was assumed that there was a perfect bond between the adjacent layers. Computer program Chevron 5L was used for this evaluation. A maximum wheel load of 9.000 lb , as a design load was chosen for use in the investigation . The tire pressure was taken as 70 psi over a circular contact area having a radius of 6.4 inch .

Pavement systems with layers of decreasing strength from the top of the pavement toward the subgrade were taken into consideration . Neither the sandwich layer system nor the case of weaker layers over stronger layers is included in this study of their different behavior .

4.3.1 Theoretical Evaluation Of Subgrade Properties

Based on Boussinesq 's and Terzaghi 's analyses , the following simple relationship for displacements in the deflected basin of the top horizontal surface has been drawn for a semi - infinite single layer system ;

$$d = \frac{P}{E} \frac{(1 - \mu^2)}{f(r)} = \frac{d_{max}}{f(r)} \qquad ..(4.2)$$

where d = Deflection in the deflected basin at a distance r from the load center

P = Applied load

μ = Poisson 's ratio of the subgrade material in the layer

E = Modulus of elasticity of the material in the layer

f(r)= Function of r , the distance from the center of applied load

The deflection values in the deflected basin can be calculated according to Equation 4.2 for various values of E , μ and P . It is known that , for all values of E and μ , the deflections at any point in terms of the maximum deflection dmax were constant . For example , In Two Layered System study , the deflections for a 9.000 lb wheel load , a 70 psi tire pressure having a 6.4 inch load radius at 1 , 2 , 3 and 4 ft away from the center of the applied load are found to be 0.277 d_{max} , 0.134 d_{max} , 0.089 d_{max} and 0.067 d_{max} respectively . (Figure 3.3)

If the subgrade layer is taken as uniform layer , elastic moduli of pavement structures could be back calculated . However , in practice pavements have various layers and subgrade is not uniform therefore there is a need of the analysis of layered system.

4.3.2 Analysis Of Proposed Pavement Structures According To Dynaflect Sensor Distances

The distance from the center of applied load given in some of the figures presented in chapter III, are the distance taken from the Dynaflect sensor distances .

In the study of Two Layered System study , Figures 3.3 , 3.4 and 3.9 presented in chapter III , are drawn according to r distances which are equal to Dynaflect sensor distances.

Similarly, in the study of Three Layered System study , Figures 3.13 , 3.14 , 3.15 , 3.20 and 3.24 are drawn according to Dynaflect sensor distances.

Pavement layers over the subgrade increase the spreadability while reducing the deflection . In some cases it may be possible to determine the amount of decrease in deflection caused by the overlying pavement layers . If this is determined , then the deflection of the subgrade could be calculated by adding this decrease in deflection to the total deflection determined on the top of the pavement . The deflection of the subgrade , along with the spreadability value of the pavement over the subgrade , will make it possible to determine the modulus of elasticity of the subgrade , the thickness index of the pavement and the average modulus of elasticity of the pavement layers .

Spreadability values for Two Layered System are plotted against maximum deflection in Figure 4.3 . Base layer modulus are taken as variable . Each of the curves shown in Figure 4.3 was determined by assuming that there is a uniform modulus of elasticity of the base layer over the subgrade . The spacing among the curves increases very little with an increase in the modulus of elasticity of the base layer over the subgrade .

Similarly, spreadability values for Three Layered System are plotted against maximum deflection in Figure 4.4 . Curves are plotted by taking the subgrade layer modulus as variable. The spacing among the curves increases too much with an increase in the subgrade modulus .

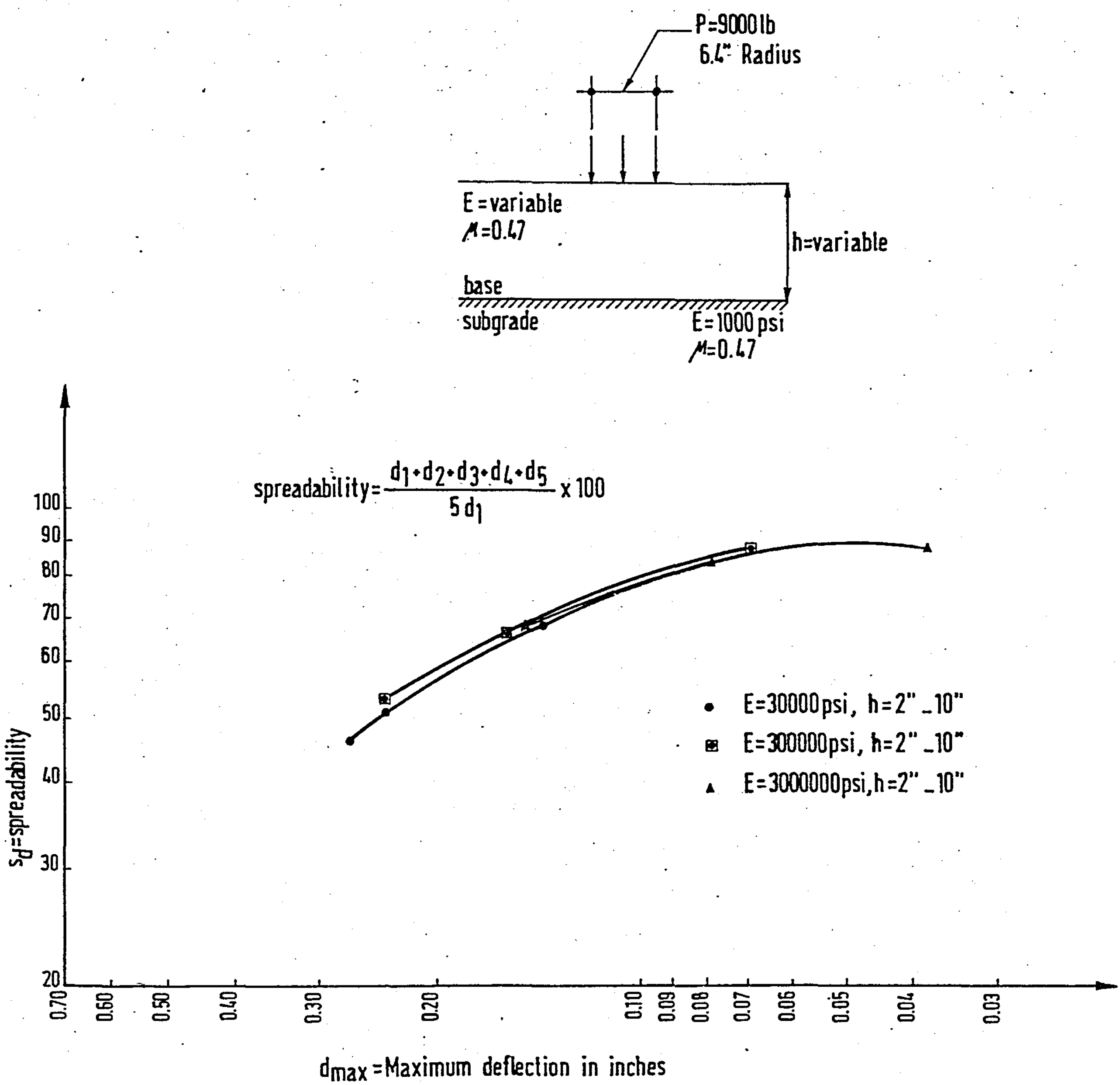

Figure 4. 3 _ SPREADABILITY VALUES FOR TWO LAYERED SYSTEM

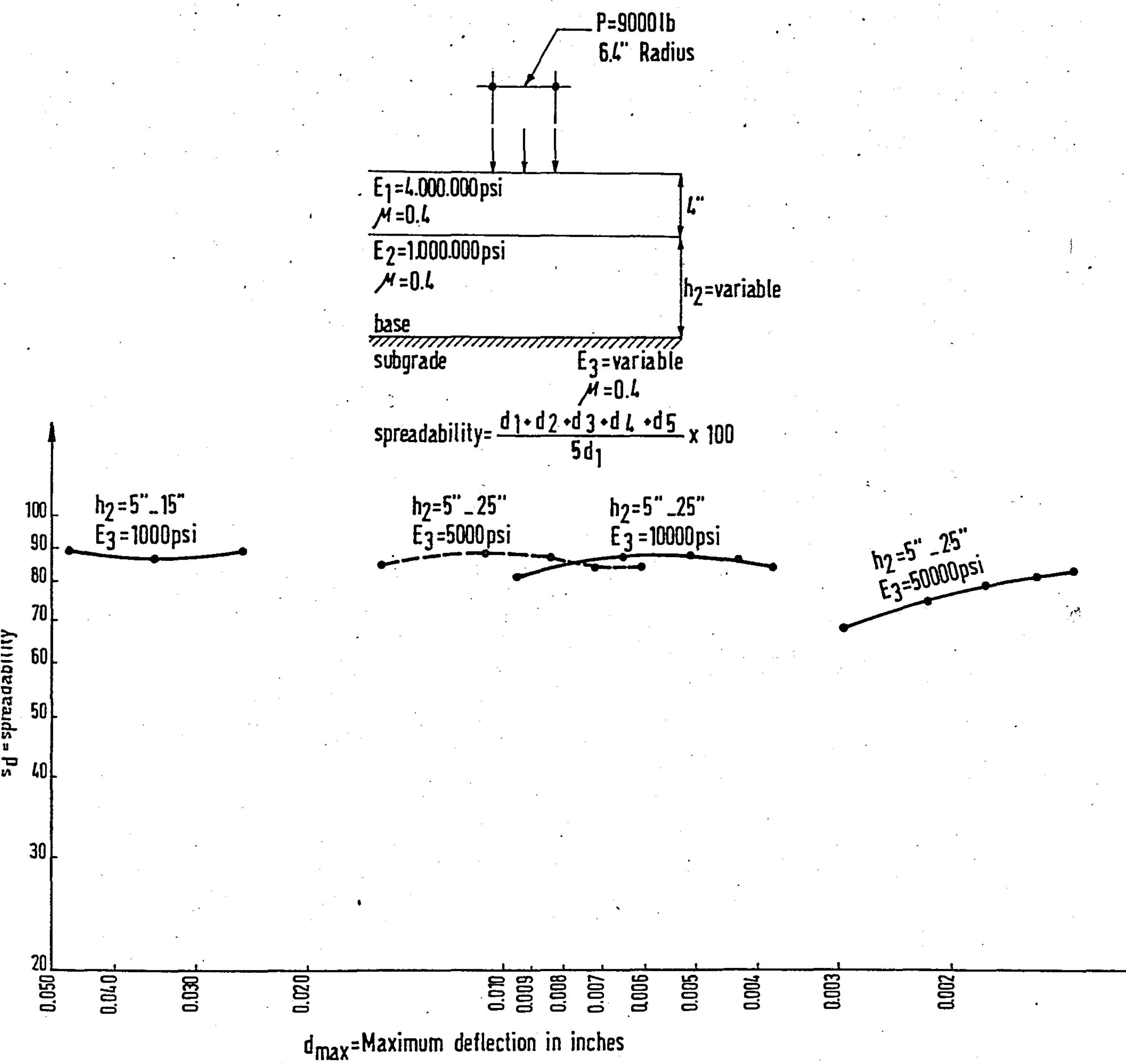

Figure 4.4 _ SPREADABILITY VALUES FOR THREE LAYERED SYSTEM

4.4 SUMMARY AND CONCLUSIONS

A brief description of Dynaflect instrument , estimation of material properties from Dynaflect deflections and on application of computer deflection analysis to a highway deflection instrument - Dynaflect are given in this chapter.

It is possible to back calculate the pavement layer stiffness from Dynaflect deflection measurements by using elastic layered theory. It is also possible to check the quality by comparing measured and calculated deflections. It should be stated that no such measurement have performed in Yeldeğirmeni Project.

The computer program, Chevron 5L can be used to determine the pavement layer stiffness by using iteration process between Dynaflect deflection measurements and computed deflections. Knowledge of the effects of changes to the various layer moduli on the shape and position of the deflection basin may speed the process considerably.

V - CONCLUSIONS

In this thesis , in - situ density and moisture - density relationship of cement - treated base layer of the layered system are tested experimentally and similar layered systems are analyzed by a computer as a parametric study to find the expected solutions for stresses and deflections of the existing layered system under the design loads .

For this purpose , material having 30 % coarse material and 70 % fine material is mixed with 5 % cement in volume to obtain cement - treated base layer material. In - place soil densities of cement - treated base layer are measured with field density test in Kadıköy Yeldeğirmeni region and the results are compared with the compaction test results obtained in the laboratory .

In addition to this experimental study, similar layered systems are analyzed using a multi - layered elastic system computer program determining the various component stresses and strains in a three dimensional ideal elastic layered system with a single vertical circular load at the surface of the system . The expected solutions for stresses and deflections of the elastic layered systems are given in the form of parametric study .

The following results are concluded from the experimental study and the computer solutions.

A - Conclusion Derived From The Experimental Study

1- It is determined from the laboratory test results that, the treatment of the base layer material (30 % coarse + 70 % fine) with 5 % cement in volume gives the required property to the base layer of the proposed pavement structure according to design loads.

2- The relative compaction values calculated from the field density test results according to the standard proctor and modified proctor tests satisfy the design criteria.

3- The mean dry unit weight calculated from the field density test results is almost the same with the maximum dry density obtained from the standard proctor test.

A - Conclusion Derived From The Computer Solutions

1- It is possible to determine the required base thickness for the base layer having specific material properties from the charts given in chapter III according to the design criteria. (stress, strain and deflection)

2- As a vice versa to the above statement, it is also possible to determine the required material properties for the base layer having constant height from the charts given in chapter III according to the design criteria.

3- The effect of modulus of elasticity on stresses and deflections is much greater than the effect of poisson's ratio for the same base thickness of the given layered system.

4- In Three Layered System , the effect of elastic modulus of subgrade layer on stresses and deflections is much greater than the effect of elastic modulus of base layer.

5- If the same increment ratio is used for the base thickness and modulus of elasticity , the effect of modulus of elasticity is much greater than the effect of base thickness for the same layered system in terms of stresses and deflections.

6- It is possible to back calculate the pavement layer stiffness from Dynaflect deflection measurements by using elastic layered theory and the computer program, Chevron 5L can be used to determine the pavement layer stiffness by using iteration process between Dynaflect deflection measurements and computed deflections.

7- The spacing among the spreadability curves increases very little with an increase in the modulus of elasticity of the base layer over the subgrade , but the spacing among the spreadability curves increases too much with an increase in the modulus of elasticity of the subgrade laying under the base layer .

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APPENDIX A

SOIL LABORATORY TEST RESULTS

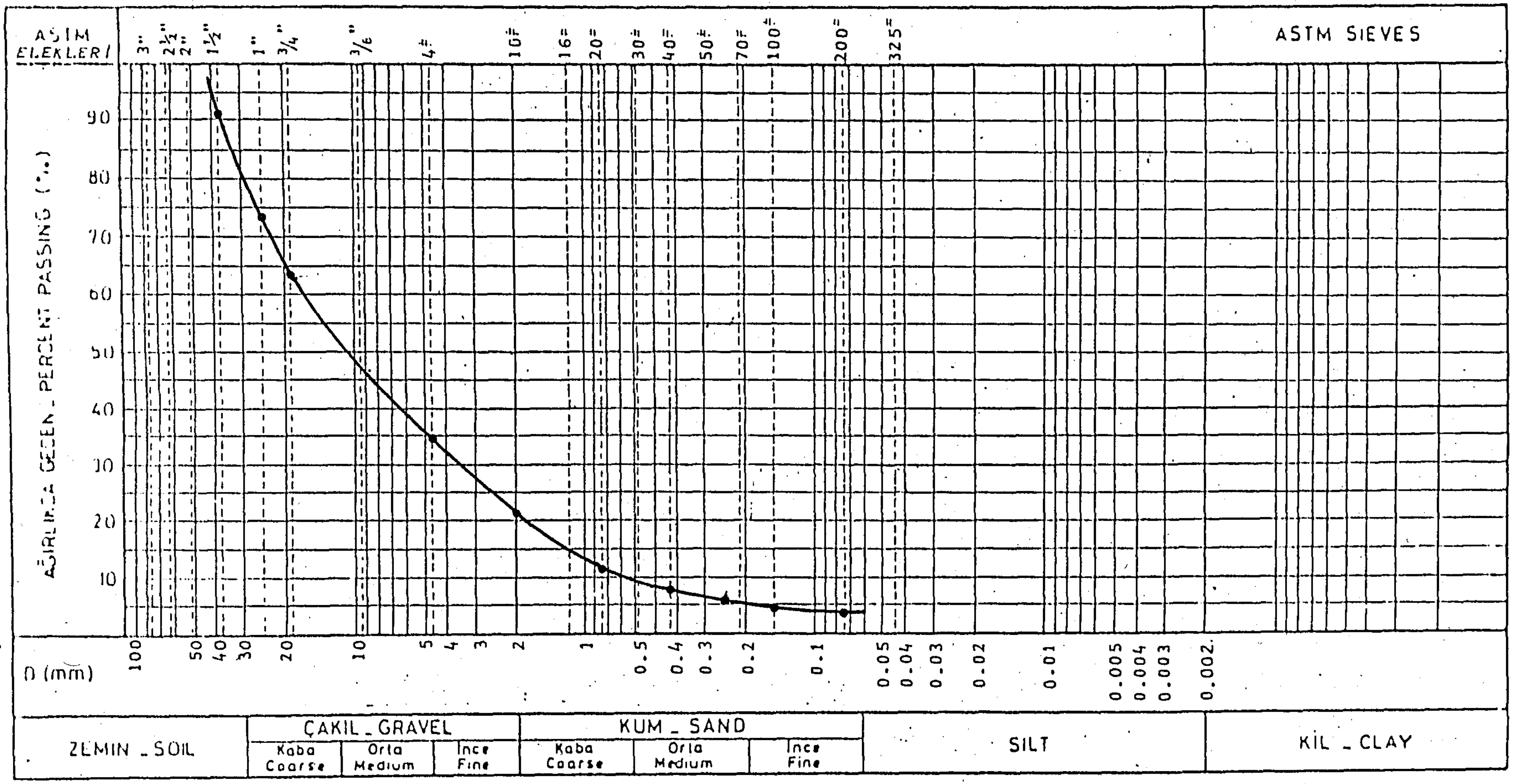
INDEX PROPERTIES OF SUBGRADE

Sample No.	ω_n %	ω_l %	ω_p %	Ip %
1	16.0	28.4	19.8	8.6
2	15.8	36.7	20.9	15.8
3	18.2	43.2	20.4	22.8

ω_n : Natural Water Content
ω_l : Liquid Limit
ω_p : Plastic Limit
Ip : Plasticity Index

Project : KADIKÖY YELDEĞİRMENİ
Sample No : Base Coarse Material

GRANÜLOMETRİ EĞRİSİ _ GRADATION CURVE



Gravel : % 79.0
Sand : % 18.0
Silt }
Clay } % 3.0

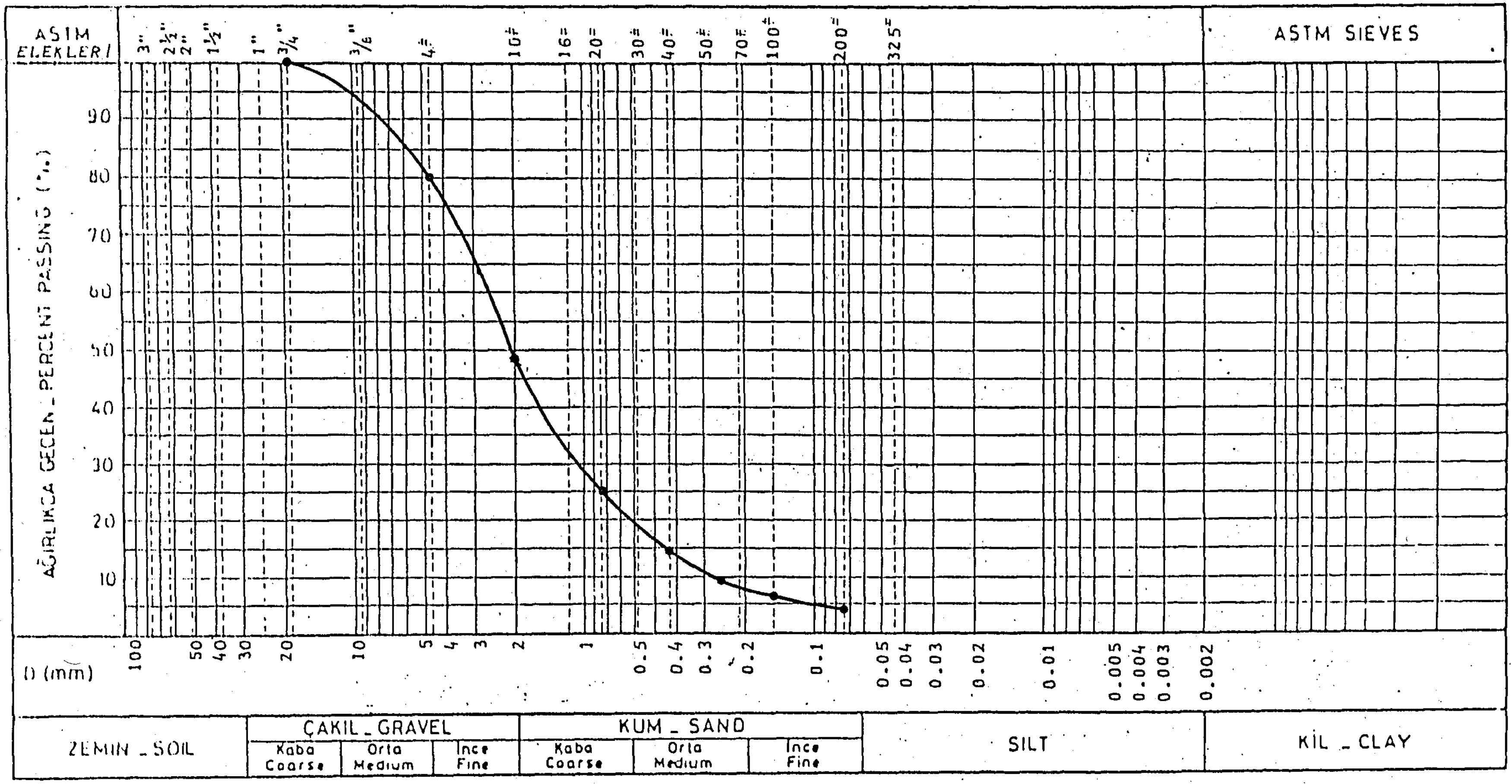
D_{60} : 17.0 mm.
D_{10} : 0.5 mm.
U : 34

D_{30} : 3.3 mm.
C_c : 1.3

NOTE : USCS : (GW)
Well graded gravel

Project : KADIKÖY YELDEĞİRMENİ
Sample No : Base Fine Material

GRANÜLOMETRİ EĞRİSİ _ GRADATION CURVE



Gravel : % 52.0
Sand : % 44.0
Silt }
Clay } % 4.0

D_{60} : 2.5 mm.
D_{10} : 0.28 mm.
U : 8.9

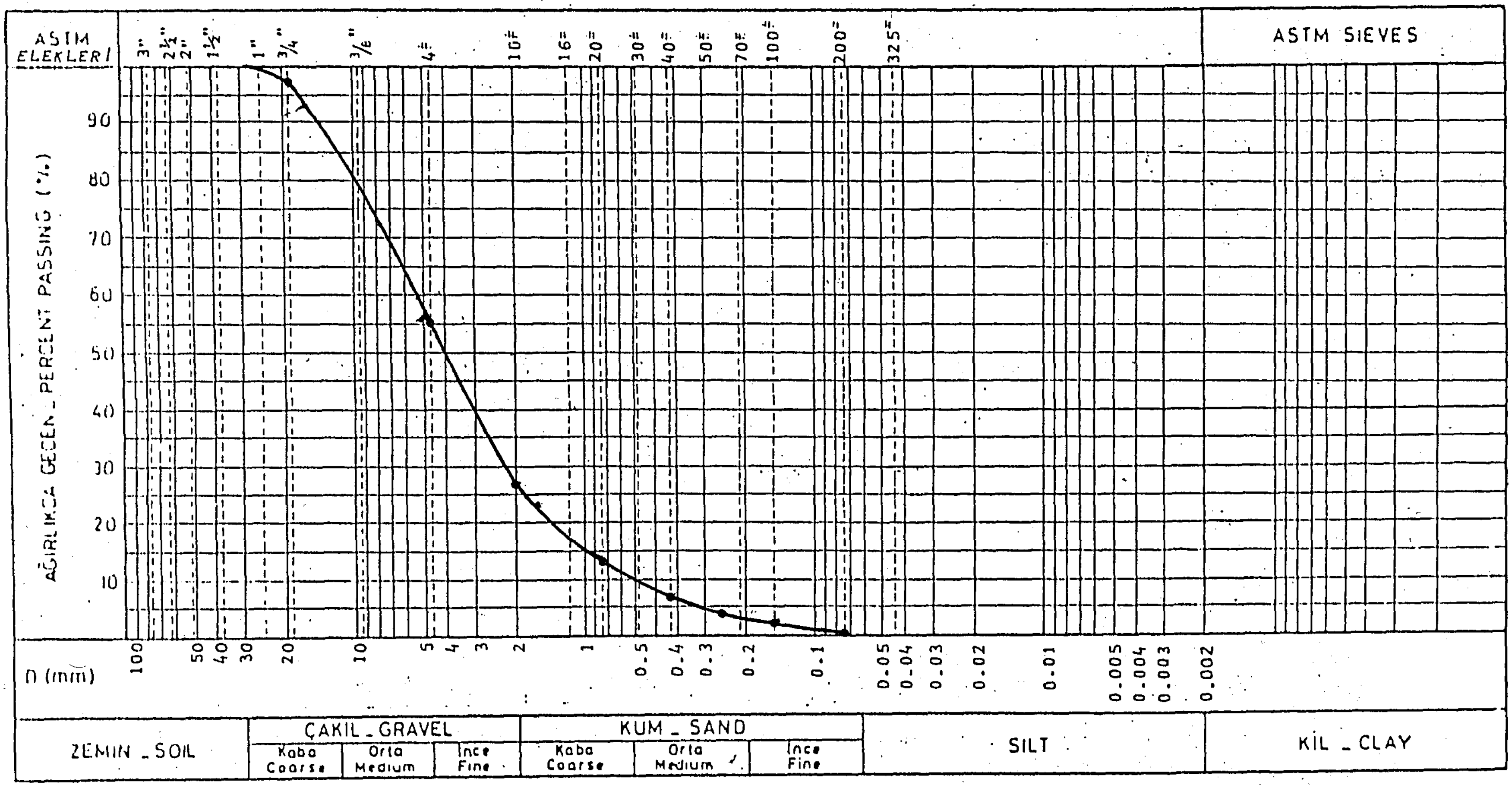
D_{30} : 1.0 mm.
C_c : 1.4

NOTE : USCS : (GW)
Well graded gravel

Project : KADIKOY YELDEGIRMENI

Sample No : Base Material (30 % coarse + 70 % fine)

GRANÜLOMETRİ EĞRİSİ _ GRADATION CURVE



Gravel : % 73.0

Sand : % 27.0

Silt : % 0.0

Clay : % 0.0

D_{60} : 5.3 mm.

D_{10} : 0.53 mm.

U : 10

D_{30} : 2.2 mm.

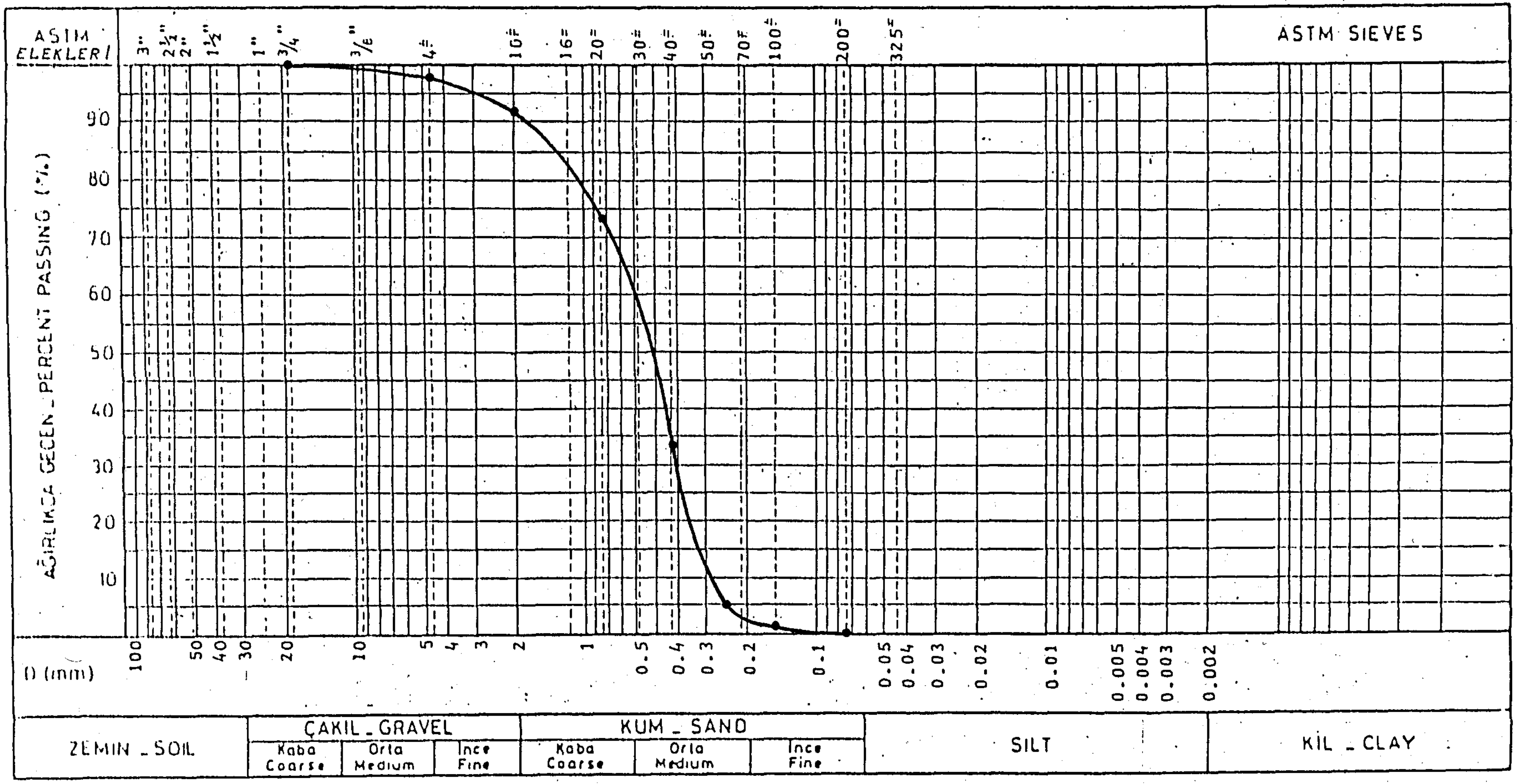
C 1.7

NOTE : USCS : (GW)

Well graded gravel

Project : KADIKÖY YELDEĞİRMENİ
Sample No : Cushioning Sand

GRANÜLOMETRİ EĞRİSİ _ GRADATION CURVE



Gravel : % 9.0
Sand : % 91.0
Silt : % 0.0
Clay : % 0.0

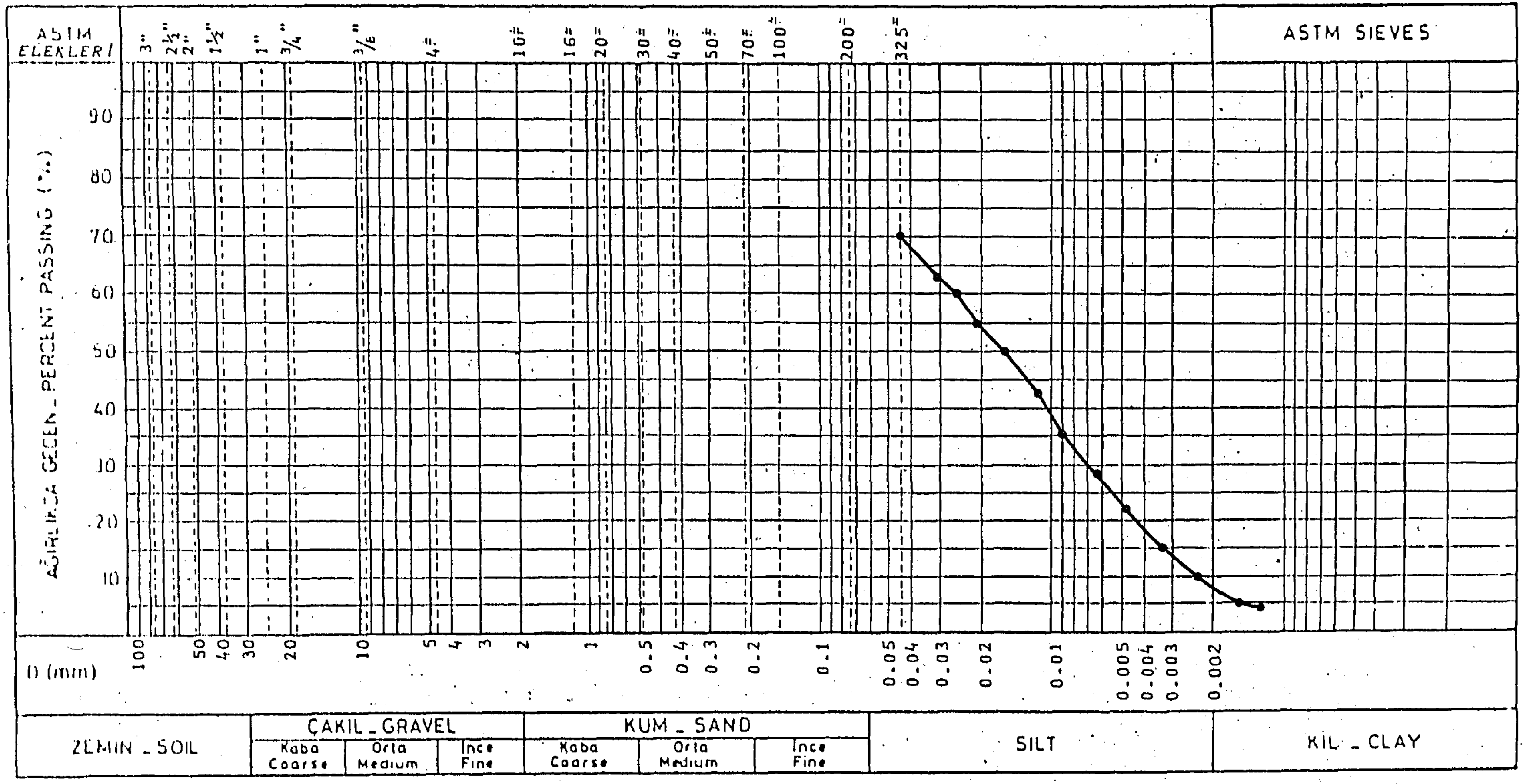
D_{60} : 0.52 mm.
D_{10} : 0.30 mm.
U : 1.7

D_{30} : 0.40 mm.
Cc : 1.03

NOTE : USCS : (SP)
Uniform sand

Project : KADIKÖY YELDEĞİRMENİ
Sample No : Subgrade _ Sample No.1 _ Hydrometer

GRANÜLOMETRİ EĞRİSİ _ GRADATION CURVE



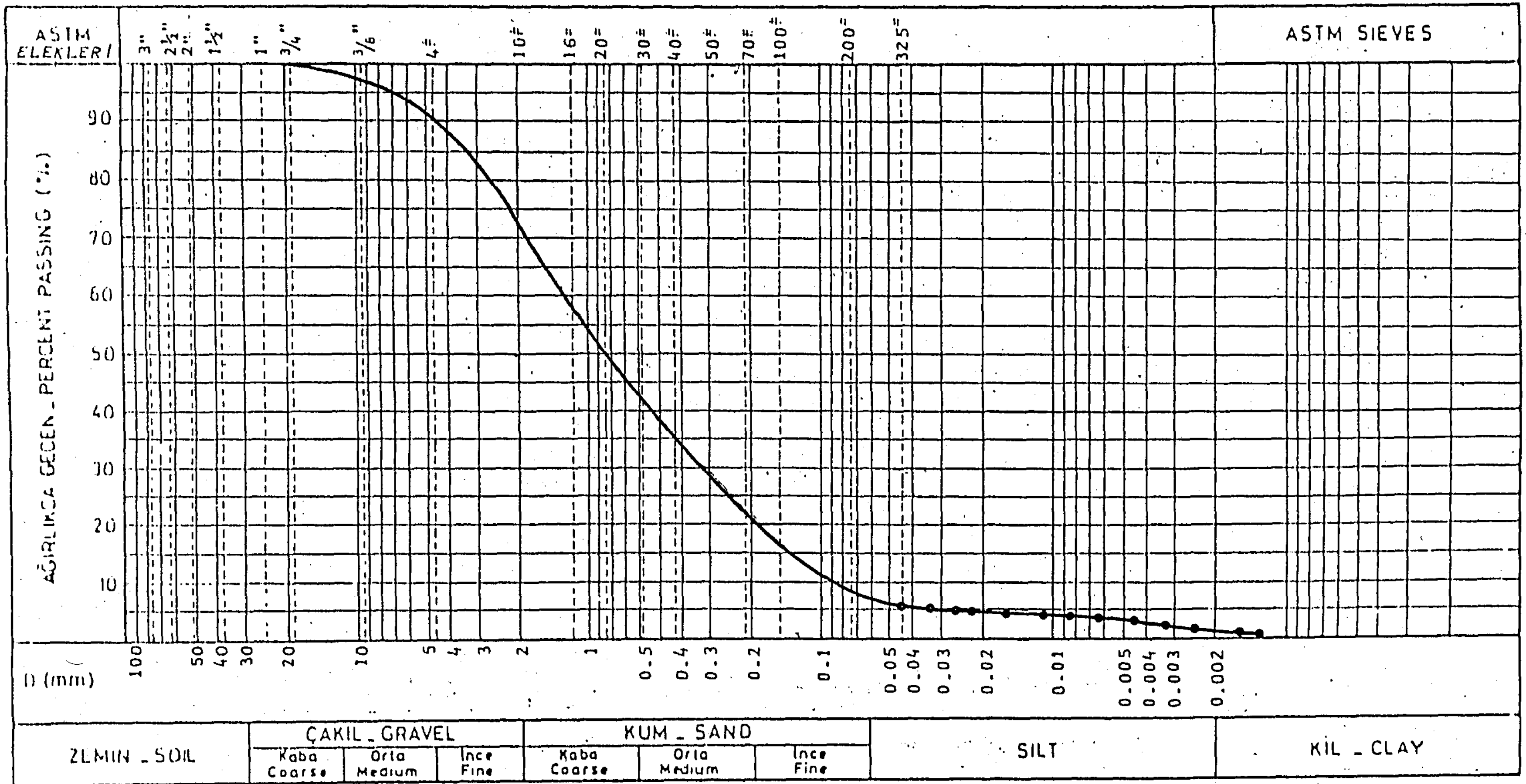
Gravel : %
Sand : %
Silt : %
Clay : %

D_{60} :
D_{10} :
U :

NOTE : Based on material passing No. 200 sieve

Project : KADIKÖY YELDEĞİRMENİ
Sample No : Subgrade_Sample No.1

GRANÜLOMETRİ EĞRİSİ _ GRADATION CURVE



Gravel : %

Sand : %

Silt : %

Clay : %

D_{60} :

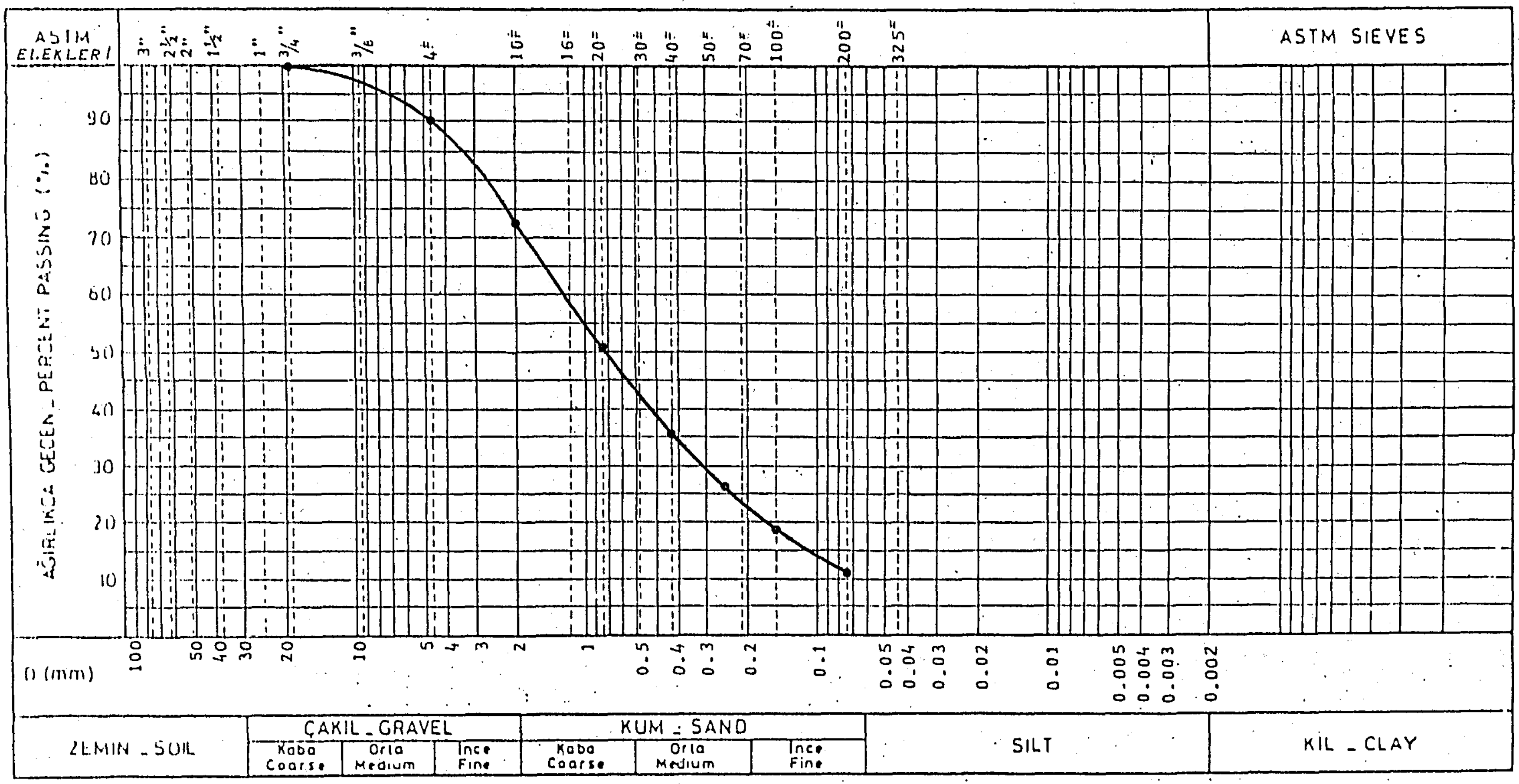
D_{10} :

U :

NOTE : Based on main material

Project : KADIKOY YELDEGIRMENI
Sample No ; Subgrade _ Sample No. 2

GRANÜLOMETRİ EĞRİSİ _ GRADATION CURVE



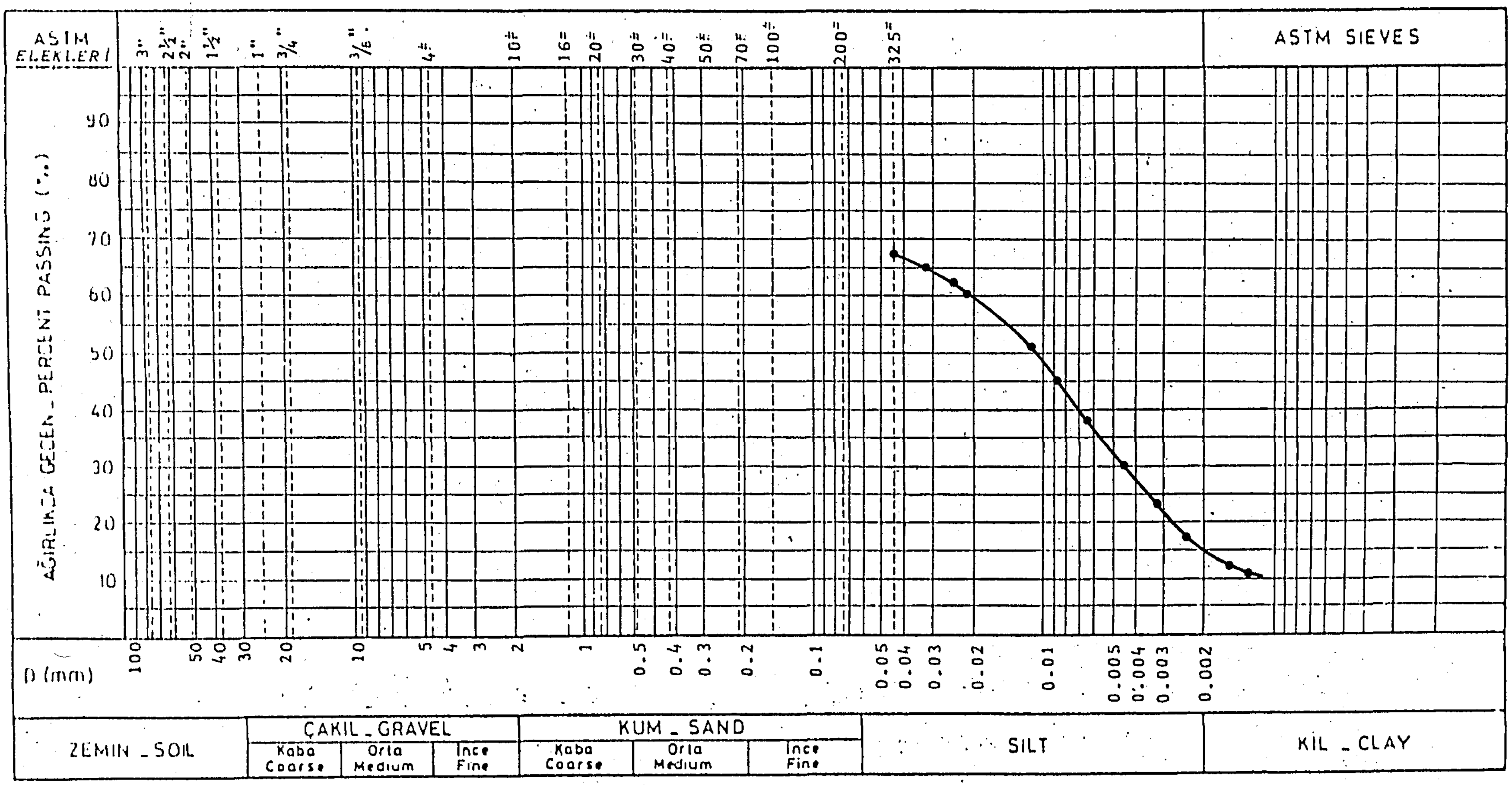
Gravel : % 27.0
Sand : % 61.0
Silt }
Clay } % 12.0

D_{60} : 1.3 mm.
D_{10} : 0.06 mm.
U : 21.7

NOTE :

Project : KADIKÖY YELDEĞİRMENİ
Sample No : Subgrade _ Sample No. 2 _ Hydrometer

GRANÜLOMETRİ EĞRİSİ _ GRADATION CURVE



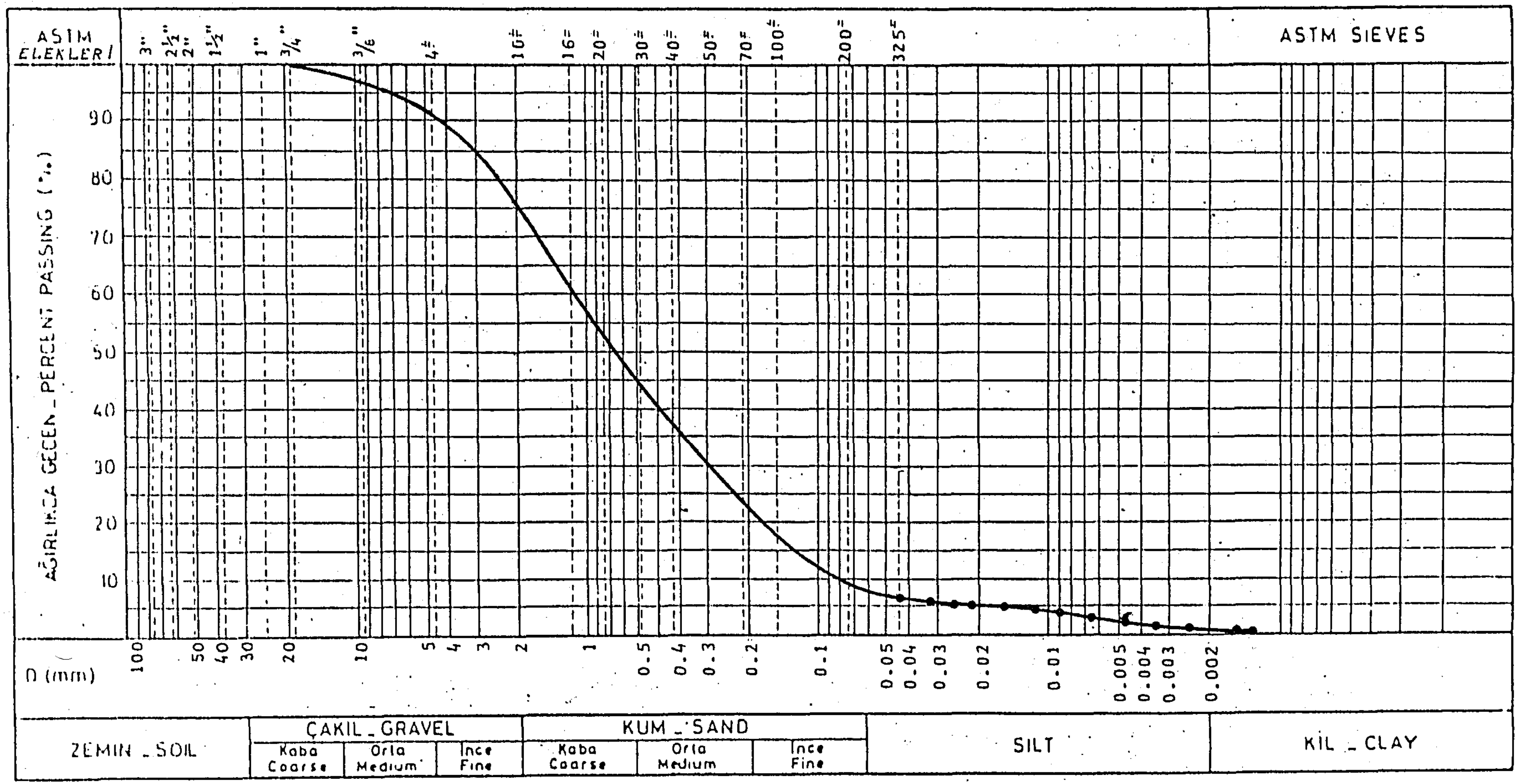
Gravel : %
Sand : %
Silt : %
Clay : %

D_{60} :
D_{10} :
U :

NOTE : Based on material passing No. 200 sieve

Project : KADIKÖY YELDEĞİRMENİ
Sample No : Subgrade _ Sample No. 2

GRANÜLOMETRİ EĞRİSİ _ GRADATION CURVE



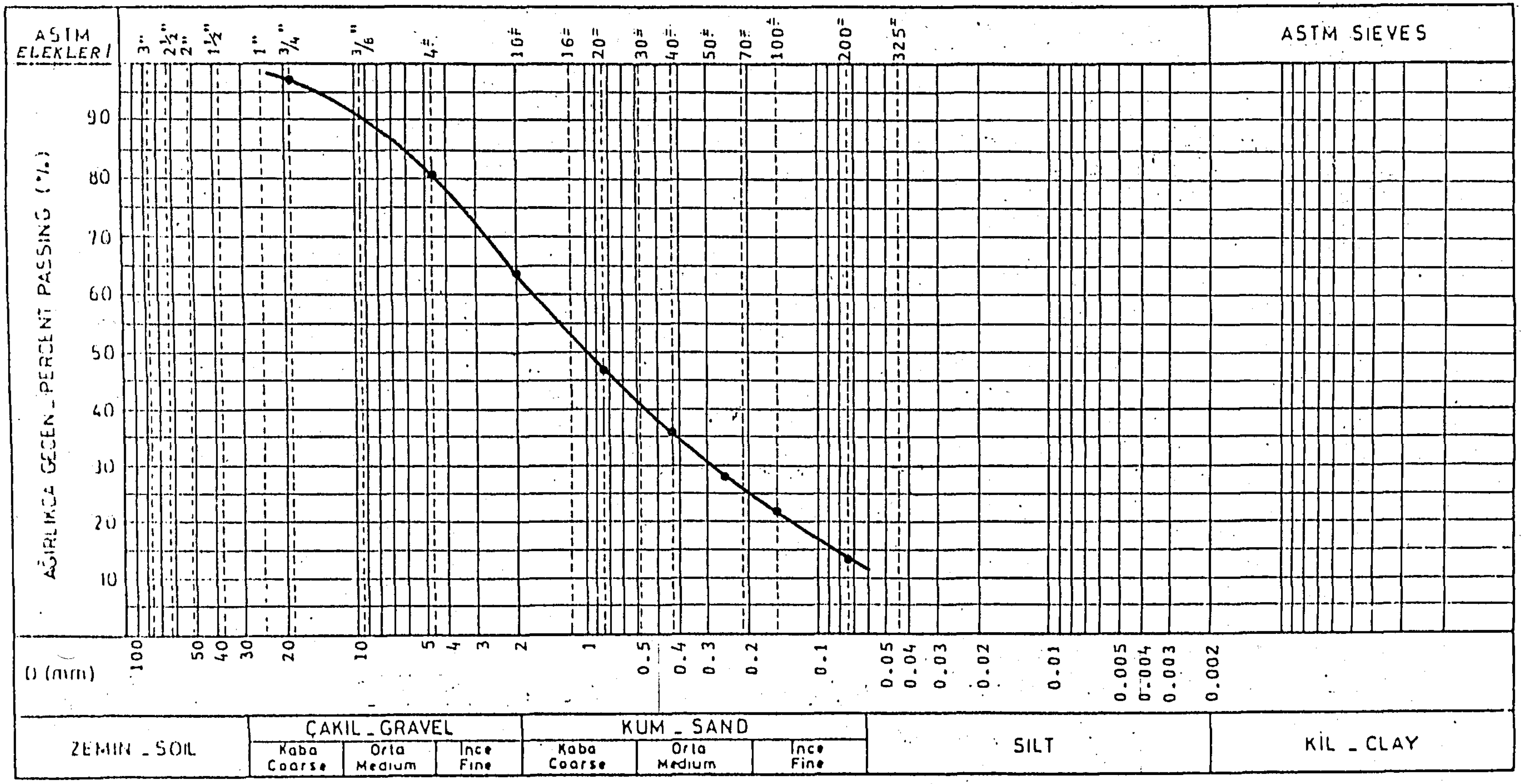
Gravel : %
Sand : %
Silt : %
Clay : %

D_{60} :
D_{10} :
U :

NOTE : Based on main material

Project : KADIKOY YELDEGIRMENI
Sample No : Subgrade_Sample No. 3

GRANÜLOMETRİ EĞRİSİ _ GRADATION CURVE



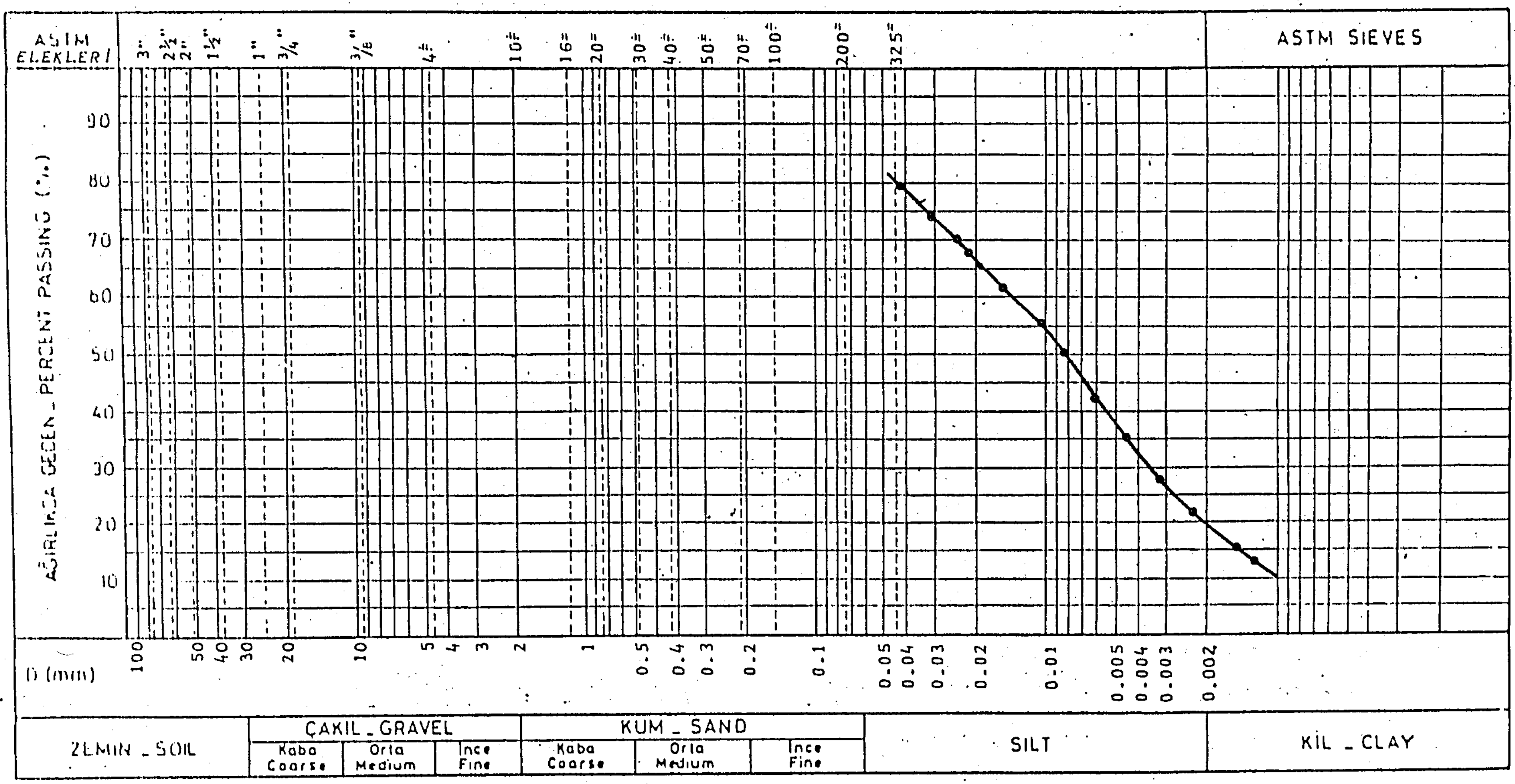
Gravel : % 34.0
Sand : % 53.0
Silt
Clay
} % 13.0

D_{60} : 1.7 mm
D_{10} : 0.05mm.
U : 34

NOTE :

Project : KADIKÖY YELDEĞİRMENİ
Sample No : Subgrade _ Sample No. 3 _ Hydrometer

GRANÜLOMETRİ EĞRİSİ _ GRADATION CURVE



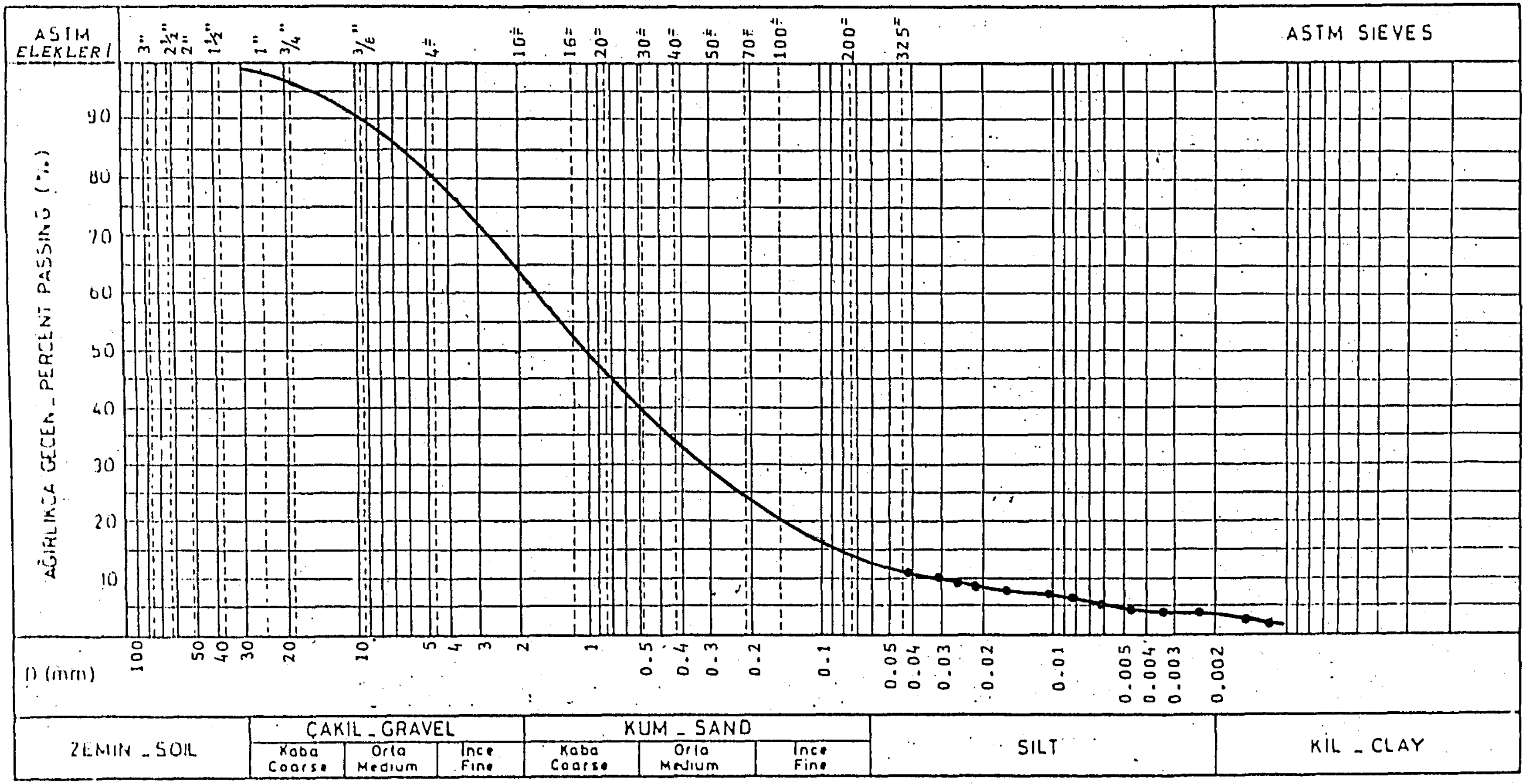
Gravel : %
Sand : %
Silt : %
Clay : %

D_{60} :
D_{10} :
U :

NOTE : Based on material passing No. 200 sieve

Project : KADIKOY YELDEGIRMENI
Sample No : Subgrade_Sample No. 3

GRANÜLOMETRİ EĞRİSİ _ GRADATION CURVE



Gravel : %
Sand : %
Silt : %
Clay : %

D_{60} :
D_{10} :
U :

NOTE : Based on main material

SOIL CLASSIFICATION

Sample No. 2 - Kadıköy - Ayrılıkçeşme Sokak - km 0 + 210

Sieve No.	4	10	40	200
% Passing	90.53	73.06	35.63	11.72

ω_l = 36.69 % , ω_p = 20.93 % , I_p = 15.76

THE UNIFIED SOIL CLASSIFICATION SYSTEM

1 - Less than 50 % passes the No.200 sieve; therefore,the soil is coarse grained.

2 - More than 50 % passes the No.4 sieve; therefore, the soil is sand.

3 - Less than 12 % passes the No.200 sieve and more than 5 % passes the No.200 sieve.

4 - Considering the location of the ω_l = 36.69 % and I_p = 15.76 on the A chart , we find CL.

5 - From the preceding four observations , soil is SM-SC

THE AASHTO SOIL CLASSIFICATION SYSTEM

1 - Proceeding from left to right in Table (AASHTO soil classification system), the soil will be either on A-1 , A-3 or A-2 , since only 11.72 % passes the No.200 sieve.

2 - Based on I_p = 15.76 , we eliminate A-1 and A-3

3 - With ω_l = 36.69 % and I_p = 15.76 , the soil fits the A-2-6 classification.

4 - The group index can be computed as

$$GI = 0.2 \times a + 0.005 \times a \times c + 0.01 \times b \times d$$

$$a = 0 \; , \; b = 0 \; , \; c = 0 \; , \; d = 5.76$$

$$GI = 0.2 \times 0 + 0.005 \times 0 \times 0 + 0.01 \times 0 \times 5.76 = 0$$

5 - From inspection of the sieve analysis data and the classification data, soil is A-2-6 (0)

SOIL CLASSIFICATION

Sample No. 3 - Kadıköy - Ayrılıkçeşme Sokak - km 0 + 395

Sieve No.	4	10	40	200
% Passing	80.32	63.79	35.35	13.02

$\omega_l = 43.19$ % , $\omega_p = 20.37$ % , $I_p = 22.82$

THE UNIFIED SOIL CLASSIFICATION SYSTEM

1 - Less than 50 % passes the No.200 sieve; therefore,the soil is coarse grained.

2 - More than 50 % passes the No.4 sieve; therefore, the soil is sand.

3 - Less than 12 % passes the No.200 sieve

4 - Considering the location of the $\omega_l = 43.19$ % and $I_p = 22.82$ on the A chart , we find CL.

5 - From the preceding four observations , soil is SC

THE AASHTO SOIL CLASSIFICATION SYSTEM

1 - Proceeding from left to right in Table (AASHTO soil classification system), the soil can only be on A-1 , A-3 or A-2 , since 13.02 % passes the No.200 sieve.

2 - Based on $I_p = 22.82$, the soil can be only on A-2

3 - With $\omega_l = 43.19$ % and $I_p = 22.82$, the soil is on A-2-7

4 - The group index is

$$GI = 0.2 \times a + 0.005 \times a \times c + 0.001 \times b \times d$$

$$a = 0 , b = 0 , c = 3.19 , d = 12.82$$

$$GI = 0.2 \times 0 + 0.005 \times 0 \times 3.19 + 0.001 \times 0 \times 12.82 = 0$$

5 - Soil is A-2-7 (0)

COMPACTION TEST — STANDARD PROCTOR — Data Sheet

Project: Kadıköy Yeldeğirmeni — Job No

Location of Project: Ayrılıkçeşme sokak — Boring No — Sample No.

Description of Soil: Sample No. 3 - Km 0+395

Test Performed By: Faruk Yanık — Date of Test

Blows/Layer: 25/3 — No. of Layers: 3 — Wt. of Hammer: 2.5 kg

Mold dimensions: Diam. 50.8 mm. Ht. 30.5 cm. Vol. 944 cm³

Water Content Determination

Sample no.	1		2		3		4		5	
Moisture can no.	104	105	107	124	130	126	134	101	117	133
Wt. of can + wet soil	70.78	62.63	81.40	74.80	69.38	64.79	74.82	72.58	76.18	76.83
Wt. of can + dry soil	66.60	58.93	76.44	69.94	64.60	59.81	67.70	66.18	68.75	68.76
Wt. of water	4.18	3.70	4.96	4.86	4.78	4.98	7.12	6.40	7.43	8.07
Wt. of can	32.00	28.60	42.10	35.30	35.60	29.10	30.70	31.10	32.00	30.20
Wt. of dry soil	34.60	30.33	34.34	34.64	29.00	30.71	37.0	35.08	36.75	38.56
Water content, w%	12.08	12.20	14.44	14.03	16.48	16.22	19.24	18.24	20.22	20.93

Density Determination

Assumed water content	10	12	14	16	18	
Water content, w%	12.14	14.24	16.35	18.74	20.58	
Wt. of soil + mold	3695	3800	3860	3895	3895	
Wt. of mold	1990	1990	1990	1990	1990	
Wt. of soil in mold	1705	1810	1870	1905	1905	
Wet density, gr/cm³	1.771	1.880	1.943	1.979	1.979	
Dry density γ, gr/cm³	1.579	1.646	1.670	1.667	1.641	

Optimum moisture = 16.4 % Maximum dry density = 1.670 gr/cm³

COMPACTION TEST

STANDARD PROCTOR

Data Sheet 9

Project: Kadıköy Yeldeğirmeni — Job No. ____

Location of Project: 30% coarse material — Boring No. ____ Sample No. ____

Description of Soil: 70% fine material without cement

Test Performed By: Faruk Yanık — Date of Test: 20.7.1985

Blows/Layer: 25/3 — No. of Layers: 3 — Wt. of Hammer: 2,5 kg

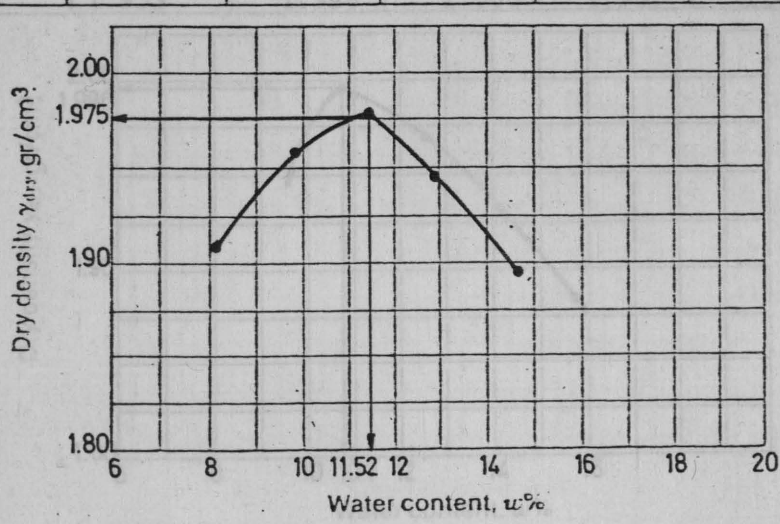
Mold dimensions: Diam. 50.8 mm. Ht. 30.5 cm. Vol. 944 cm³

Water Content Determination

Sample no.	1		2		3		4		5	
Moisture can no.	127	114	119	128	111	109	120	101	103	105
Wt. of can + wet soil	65.31	71.06	86.12	64.74	65.32	65.57	73.22	66.6	77.35	86.18
Wt. of can + dry soil	63.01	68.52	81.69	61.40	61.50	61.76	69.10	62.48	70.54	78.82
Wt. of water	2.30	2.54	4.43	3.34	3.82	3.81	4.12	4.12	6.81	7.36
Wt. of can	34.0	37.5	37.0	27.0	29.0	28.0	37.1	31.1	24.8	28.6
Wt. of dry soil	29.01	31.02	44.69	34.40	32.5	33.76	32.0	31.38	45.74	50.22
Water content, w%	7.93	8.19	9.91	9.71	11.75	11.29	12.88	13.13	14.89	14.66

Density Determination

Assumed water content	% 8	%10	% 12	% 14	% 16	
Water content, w%	8.06	9.81	11.52	13.01	14.78	
Wt. of soil + mold	3915	4000	4050	4040	4020	
Wt. of mold	1970	1970	1970	1970	1970	
Wt. of soil in mold	1945	2030	2080	2070	2050	
Wet density, gr/cm³	2.060	2.150	2.203	2.193	2.172	
Dry density γ, gr/cm³	1.906	1.958	1.975	1.941	1.892	



Optimum moisture = 11.52 % — Maximum dry density = 1.975 gr/cm³

STANDARD PROCTOR

COMPACTION TEST

Data Sheet 9

Project Kadıköy Yeldeğirmeni Job No.

Location of Project 30 % coarse material Boring No. Sample No.

Description of Soil 70 % fine material, 5% cement in volume

Test Performed By Faruk Yanık Date of Test 20.7.1985

Blows/Layer 25/3 No. of Layers 3 Wt. of Hammer 2.5 kg.

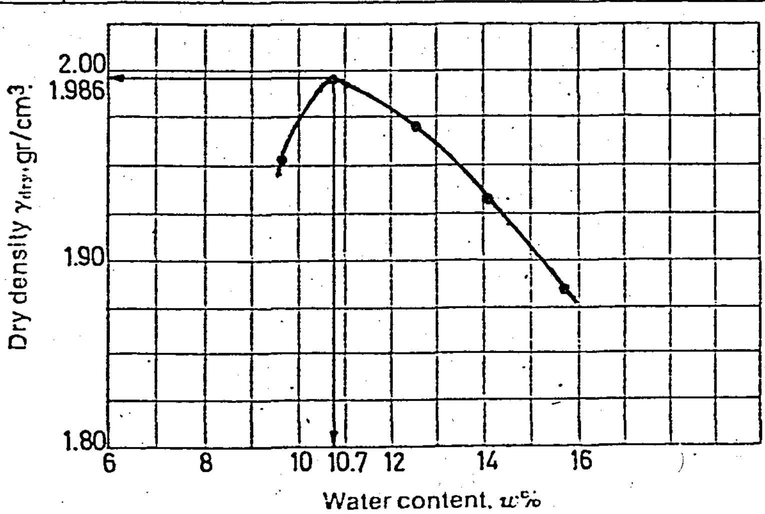
Mold dimensions: Diam. 50.8 mm. Ht. 30.5 cm. Vol. 944 cm3.

Water Content Determination

Sample no.	1		2		3		4		5	
Moisture can no.	105	109	101	111	114	133	119	128	103	136
Wt. of can + wet soil	55.68	55.42	63.28	61.29	74.27	69.56	79.21	73.79	70.77	80.21
Wt. of can + dry soil	53.37	52.98	60.20	58.14	70.24	65.07	73.97	68.07	64.55	73.26
Wt. of water	2.31	2.44	3.08	3.15	4.03	4.49	5.24	5.72	6.22	6.95
Wt. of can	28.6	28.0	31.10	29.0	37.5	30.2	37.0	27.0	24.8	28.4
Wt. of dry soil	24.77	24.98	29.10	29.14	32.74	34.87	36.97	41.07	39.75	44.86
Water content, w%	9.33	9.77	10.58	10.81	12.31	12.88	14.17	13.93	15.65	15.49

Density Determination

Assumed water content	% 8	% 10	% 12	%14	% 16	
Water content, w%	9.55	10.7	12.60	14.05	15.77	
Wt. of soil + mold	3990	4045	4060	4050	4030	
Wt. of mold	1970	1970	1970	1970	1970	
Wt. of soil in mold	2020	2075	2090	2080	2060	
Wet density, gr/cm3	2.140	2.198	2.214	2.203	2.182	
Dry density γ, gr/cm3.	1.953	1.986	1.966	1.932	1.888	



Optimum moisture = 10.7 % Maximum dry density = 1.986 gr/cm3

COMPACTION TEST MODIFIED PROCTOR Data Sheet 9

Project Kadıköy Yeldeğirmeni Job No.

Location of Project 30% coarse material Boring No. Sample No.

Description of Soil 70% fine material without cement

Test Performed By Faruk Yanık Date of Test 24.7.1985

Blows/Layer 25/5 No. of Layers 5 Wt. of Hammer 4.45 kg

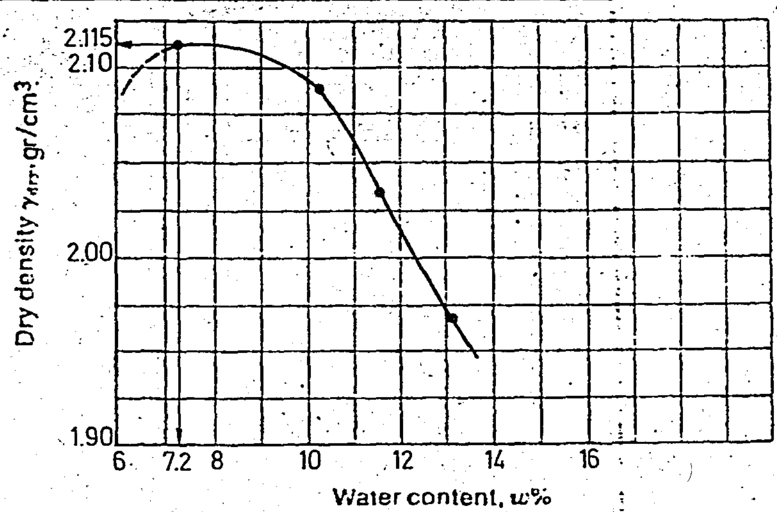
Mold dimensions: Diam. 50.8 mm. Ht. 46 cm. Vol. 944 cm³

Water Content Determination

Sample no.	1		2		3		4		5	
Moisture can no.	125	107	117	109	128	119	126	105		
Wt. of can + wet soil	75.22	78.47	62.82	57.26	70.98	73.84	70.13	72.87		
Wt. of can + dry soil	72.70	76.01	59.92	54.53	66.45	70.07	65.41	67.76		
Wt. of water	2.52	2.46	2.90	2.73	4.53	3.77	4.72	5.11		
Wt. of can	37.2	42.1	32.0	28.0	27.0	37.0	29.1	28.6		
Wt. of dry soil	35.50	33.91	27.92	26.53	39.45	33.07	36.31	39.16		
Water content, w%	7.1	7.3	10.4	10.3	11.5	11.4	13.0	13.05		

Density Determination

Assumed water content	% 8	% 10	% 12	% 14		
Water content, w%	7.2	10.35	11.45	13.03		
Wt. of soil + mold	4110	4150	4110	4070		
Wt. of mold	1970	1970	1970	1970		
Wt. of soil in mold	2140	2180	2140	2100		
Wet density, gr/cm³	2.267	2.309	2.267	2.225		
Dry density γ, gr/cm³	2.115	2.092	2.030	1.968		



Optimum moisture = 7.2 % Maximum dry density = ~~2.115~~ gr/cm³

MODIFIED PROCTOR

COMPACTION TEST

Data Sheet 9

Project Kadıköy Yeldeğirmeni Job No.

Location of Project 30 % coarse material Boring No. Sample No.

Description of Soil +70% fine material,5% cement in volume

Test Performed By Faruk Yanık Date of Test 24.7.1985

Blows/Layer 25/5 No. of Layers 5 Wt. of Hammer 4.45kg

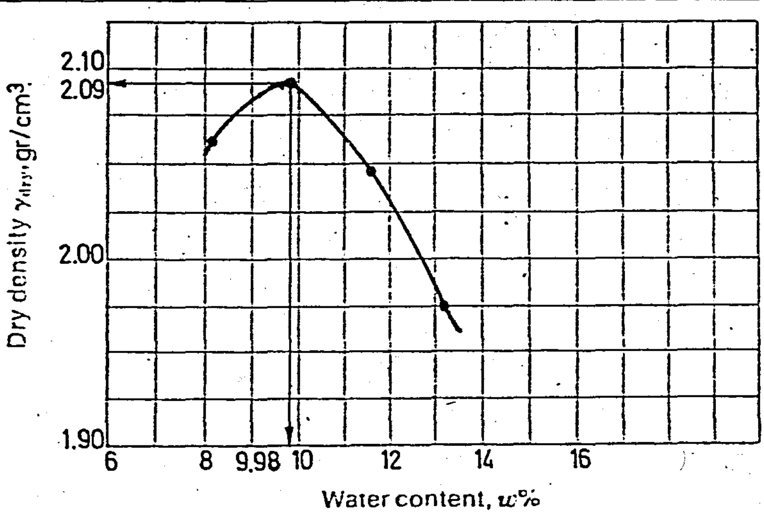
Mold dimensions: Diam. 50.8 mm. Ht. 46 cm. Vol. 944 cm3.

Water Content Determination

Sample no.	1		2		3		4		5	
Moisture can no.	136	101	127	120	103	114	133	108		
Wt. of can + wet soil	66.63	74.27	75.73	75.13	73.00	71.82	75.52	59.02		
Wt. of can + dry soil	63.75	70.94	71.90	71.72	68.07	68.16	70.30	54.96		
Wt. of water	2.88	3.33	3.83	3.41	4.93	3.66	5.22	4.06		
Wt. of can	28.4	31.1	34.0	37.1	24.8	37.5	30.2	24.0		
Wt. of dry soil	35.35	39.84	37.90	34.62	43.27	30.66	40.10	30.96		
Water content, w%	8.15	8.36	10.11	9.85	11.39	11.94	13.02	13.11		

Density Determination

Assumed water content	% 8	% 10	% 12	% 14		
Water content, w%	8.26	9.98	11.67	13.07		
Wt. of soil + mold	4080	4140	4130	4075		
Wt. of mold	1970	1970	1970	1970		
Wt. of soil in mold	2110	2170	2160	2105		
Wet density, gr/cm3	2.235	2.299	2.288	2.230		
Dry density γ, gr/cm3.	2.065	2.090	2.049	1.972		

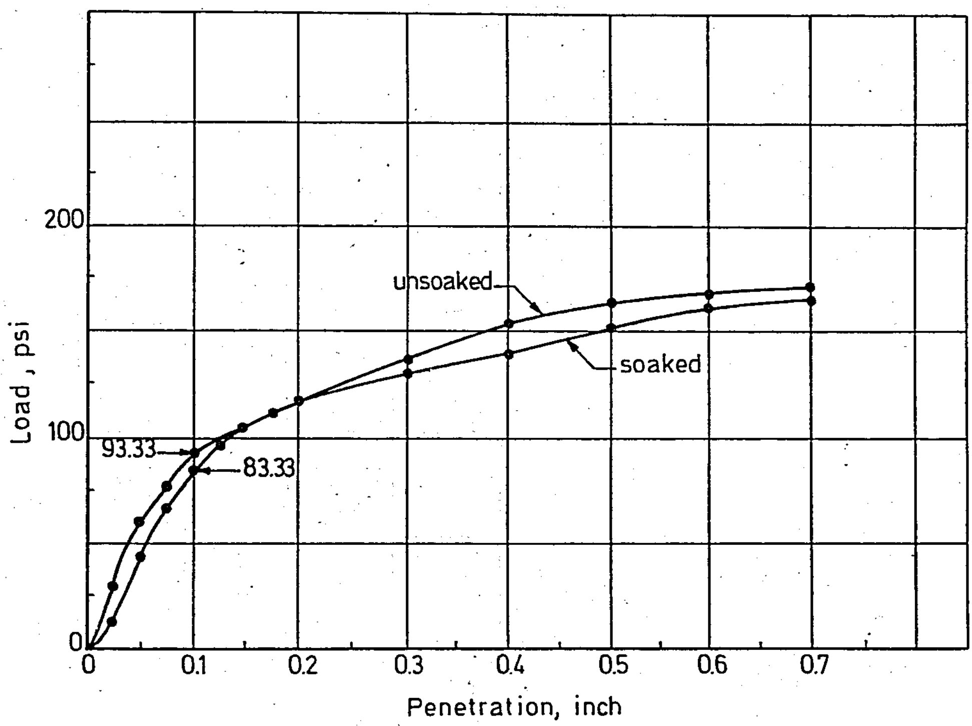


Optimum moisture = 9.98 % Maximum dry density = 2.09 gr/cm3

BEARING RATIO TEST _ CBR

Subgrade _ Sample No. 3

Kadıköy Ayrılıkçeşme Sokak _ Km. 0+395

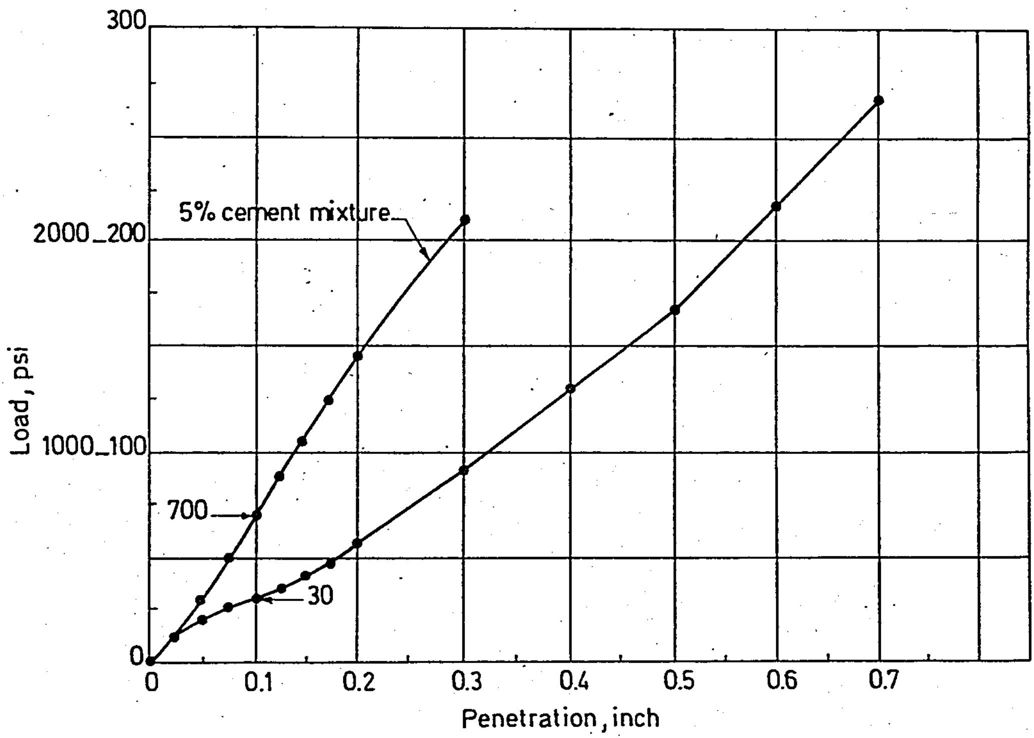


$$CBR = \frac{83.33\,(100)}{1000} = 8.3 \qquad \text{(for unsoaked)}$$

$$CBR = \frac{93.33\,(100)}{1000} = 9.3 \qquad \text{(for soaked)}$$

BEARING RATIO TEST _ CBR

Base Material (30% Coarse+70% Fine)



$$CBR = \frac{30\ (100)}{1000} = 3$$

$$CBR = \frac{700\ (100)}{1000} = 70$$

Field Density Test

Sand Cone Method

Volume of Mold :

D : 10.2 cm

h : 11.6 cm

$$V = \pi r^2 h = 3.14 (5.1)^2 11.6$$

$$V = 947.4 \text{ cm3}$$

Weight of Mold + Base Plate : 4240 gr.

	1	2	3
Wt. of (Mold + Base Plate + Sand)	5665 gr.	5687 gr.	5677 gr.

Average the results of two readings in good agreement (Within about 10 gr.)

$$\frac{5687 + 5677}{2} = 5682 \text{ gr.}$$

Wt. of Sand in the Mold : 5682 - 4240 = 1442 gr.

$$\gamma_{sand} = \frac{1442}{947.4} = 1.52 \text{ gr / cm3}$$

	1	2
Jug + Cone + Sand	6630 gr.	6877 gr.
Jug + Cone + Sand - Sand in Cone	4850 gr.	5093 gr.
Wt. of Sand in Cone (From Calibration)	1780 gr.	1784 gr.

$$\text{Average} = \frac{1780 + 1784}{2} = 1782 \text{ gr.}$$

SAMPLE - 1

h: 3.0 - 3.5 cm

FIELD DENSITY TEST (Sand cone, Balloon) Data Sheet 10

Project ______ Job. No ______

Location of Project Düz Sokak

Description of Soil ______

Test Performed By ______ Date of Test 12.7.1985

Laboratory Data from Field Test

Sand-cone method		Balloon method	
Wt. of wet soil + can	2985 gr.	Wt. of wet soil + can	
Wt. of can	1160 gr.	Wt. of can	
Wt. of wet soil, W'	1825 gr.	Wt. of wet soil, W'	
Wt. of wet soil + pan	2400 gr.	Wt. of wet soil + pan	
Wt. of dry soil + pan	2325 gr.	Wt. of dry soil + pan	
Wt. of pan	575 gr.	Wt. of pan	
Wt. of dry soil	1750 gr.	Wt. of dry soil	
Water content, w%	75/1750 : 4.3 %	Water content, w%	

Field Data

Sand-cone method		Balloon method	
Type of sand used	Ottawa	Correction factor CF =	
Unit wt. of sand, γ_{sand} =	1.52 gr/cm3	Final scale reading	
Wt. of jug + cone before use	6945 gr.	Initial scale reading	
Wt. of jug + cone after use	3835 gr.	Vol. of hole, V_h'	
Wt. of sand used (hole + cone)	3110 gr.	Vol. of hole = V_h' (CF)	
Wt. of sand in cone (from calibration)	1782 gr.		
Wt. of sand in hole, W	1328 gr.		
Vol. of hole, $V_h = W/\gamma_{sand}$ =	873.68 cm3		

Density of Soil

Wet density $\gamma_{wet} = W'/V_h$ = 2.09 gr/cm3 Dry density $\gamma_{dry} = \gamma_{wet}/(1 + w)$ = 2.00 gr/cm3

SAMPLE - 2
h: 7.5 -8 cm.

FIELD DENSITY TEST (Sand cone, Balloon) Data Sheet 10

Project ______ Job. No ______

Location of Project Düz Sokak

Description of Soil ______

Test Performed By ______ Date of Test 12.7.1985

Laboratory Data from Field Test

Sand-cone method

Wt. of wet soil + can 3520 gr.

Wt. of can 1160 gr.

Wt. of wet soil, W' 2360 gr.

Wt. of wet soil + pan 2940 gr.

Wt. of dry soil + pan 2835 gr.

Wt. of pan 580 gr.

Wt. of dry soil 2255 gr.

Water content, w% 105/2255 : 4.7 %

Balloon method

Wt. of wet soil + can ______

Wt. of can ______

Wt. of wet soil, W' ______

Wt. of wet soil + pan ______

Wt. of dry soil + pan ______

Wt. of pan ______

Wt. of dry soil ______

Water content, w% ______

Field Data

Sand-cone method

Type of sand used Ottawa

Unit wt. of sand, γ_{sand} = 1.52 gr/cm3

Wt. of jug + cone before use 7100 gr.

Wt. of jug + cone after use 3470 gr.

Wt. of sand used (hole + cone) 3630 gr.

Wt. of sand in cone (from calibration) 1782 gr.

Wt. of sand in hole, W 1848 gr.

Vol. of hole, $V_h = W/\gamma_{sand}$ = 1215.79 cm3

Balloon method

Correction factor CF = ______

Final scale reading ______

Initial scale reading ______

Vol. of hole, V_h' ______

Vol. of hole = V_h' (CF) ______

Density of Soil

Wet density $\gamma_{wet} = W'/V_h$ = 1.94 gr/cm3 Dry density $\gamma_{dry} = \gamma_{wet}/(1+w)$ = 1.85 gr/cm3

SAMPLE - 3
h: 7,5 cm

FIELD DENSITY TEST (Sand cone, Balloon) Data Sheet 10

Project ______ Job. No ______

Location of Project : Düz Sokak

Description of Soil ______

Test Performed By ______ Date of Test 12.7.1985

Laboratory Data from Field Test

Sand-cone method		Balloon method	
Wt. of wet soil + can	4440 gr.	Wt. of wet soil + can	
Wt. of can	1160 gr.	Wt. of can	
Wt. of wet soil, W'	3280 gr.	Wt. of wet soil, W'	
Wt. of wet soil + pan	4030 gr.	Wt. of wet soil + pan	
Wt. of dry soil + pan	3905 gr.	Wt. of dry soil + pan	
Wt. of pan	750 gr.	Wt. of pan	
Wt. of dry soil	3155 gr.	Wt. of dry soil	
Water content, w%	125/3155: 3.96 %	Water content, w%	

Field Data

Sand-cone method		Balloon method	
Type of sand used	Ottawa	Correction factor CF =	
Unit wt. of sand, γ_{sand} =	1.52 gr/cm3	Final scale reading	
Wt. of jug + cone before use	7265 gr.	Initial scale reading	
Wt. of jug + cone after use	3000 gr.	Vol. of hole, V_h'	
Wt. of sand used (hole + cone)	4265 gr.	Vol. of hole = V_h' (CF)	
Wt. of sand in cone (from calibration)	1782 gr.		
Wt. of sand in hole, W	2483 gr.		
Vol. of hole, $V_h = W/\gamma_{sand}$ =	1633.55 cm3		

Density of Soil

Wet density $\gamma_{wet} = W'/V_h$ = 2.01 gr/cm3 Dry density $\gamma_{dry} = \gamma_{wet}/(1 + w)$ = 1,93 gr/cm3

SAMPLE 4
h = 4cm.

FIELD DENSITY TEST (Sand cone, Balloon) Data Sheet 10

Project ______ Job. No ______

Location of Project Dua Tepe

Description of Soil ______

Test Performed By ______ Date of Test 26.7.1985

Laboratory Data from Field Test

Sand-cone method		Balloon method	
Wt. of wet soil + can	3100 gr.	Wt. of wet soil + can	
Wt. of can	1150 gr.	Wt. of can	
Wt. of wet soil, W'	1950 gr.	Wt. of wet soil, W'	
Wt. of wet soil + pan	2520 gr.	Wt. of wet soil + pan	
Wt. of dry soil + pan	2425 gr.	Wt. of dry soil + pan	
Wt. of pan	580 gr.	Wt. of pan	
Wt. of dry soil	1845 gr.	Wt. of dry soil	
Water content, w%	5.15	Water content, w%	

Field Data

Sand-cone method		Balloon method	
Type of sand used	Ottawa	Correction factor CF =	
Unit wt. of sand, γ_{sand} =	1.52 gr/cm3	Final scale reading	
Wt. of jug + cone before use	6740 gr.	Initial scale reading	
Wt. of jug + cone after use	3505 gr.	Vol. of hole, V_h'	
Wt. of sand used (hole + cone)	3235 gr.	Vol. of hole = V_h' (CF)	
Wt. of sand in cone (from calibration)	1782 gr.		
Wt. of sand in hole, W	1453 gr.		
Vol. of hole, $V_h = W/\gamma_{sand}$ =	956 cm3		

Density of Soil

Wet density $\gamma_{wet} = W'/V_h$ = 2.04 gr/cm3 Dry density $\gamma_{dry} = \gamma_{wet}/(1 + w)$ = 1.94 gr/cm3

SAMPLE 5
h = 4 cm.

FIELD DENSITY TEST (Sand cone, Balloon) Data Sheet 10

Project ______ Job. No ______

Location of Project Dua Tepe

Description of Soil ______

Test Performed By ______ Date of Test 26.7.1985

Laboratory Data from Field Test

Sand-cone method		Balloon method	
Wt. of wet soil + can	3110 gr.	Wt. of wet soil + can	
Wt. of can	1150 gr.	Wt. of can	
Wt. of wet soil, W'	1960 gr.	Wt. of wet soil, W'	
Wt. of wet soil + pan	2710 gr.	Wt. of wet soil + pan	
Wt. of dry soil + pan	2620 gr.	Wt. of dry soil + pan	
Wt. of pan	750 gr.	Wt. of pan	
Wt. of dry soil	1870 gr.	Wt. of dry soil	
Water content, w%	4.81	Water content, w%	

Field Data

Sand-cone method		Balloon method	
Type of sand used	Ottawa	Correction factor CF =	
Unit wt. of sand, γ_{sand} =	1.52 gr/cm3	Final scale reading	
Wt. of jug + cone before use	6760 gr.	Initial scale reading	
Wt. of jug + cone after use	3545 gr.	Vol. of hole, V_h'	
Wt. of sand used (hole + cone)	3215 gr.	Vol. of hole = V_h' (CF)	
Wt. of sand in cone (from calibration)	1782 gr.		
Wt. of sand in hole, W	1433 gr.		
Vol. of hole, $V_h = W/\gamma_{sand}$ =	942.8 cm3		

Density of Soil

Wet density $\gamma_{wet} = W'/V_h$ = 2.08 gr/cm3 Dry density $\gamma_{dry} = \gamma_{wet}/(1 + w)$ = 1.985 gr/cm3

SAMPLE 6
$h = 4-4,5$ cm.

FIELD DENSITY TEST (Sand cone, Balloon) Data Sheet 16

Project ______ Job. No ______

Location of Project Düz sokağı

Description of Soil ______

Test Performed By ______ Date of Test 31.7.1985

Laboratory Data from Field Test

Sand-cone method

Wt. of wet soil + can 1720 gr.

Wt. of can 10 gr.

Wt. of wet soil, W'' 1710 gr.

Wt. of wet soil + pan 2460 gr.

Wt. of dry soil + pan 2365 gr.

Wt. of pan 750 gr.

Wt. of dry soil 1615 gr.

Water content, w% 5.88

Balloon method

Wt. of wet soil + can ______

Wt. of can ______

Wt. of wet soil, W'' ______

Wt. of wet soil + pan ______

Wt. of dry soil + pan ______

Wt. of pan ______

Wt. of dry soil ______

Water content, w% ______

Field Data

Sand-cone method

Type of sand used Ottawa

Unit wt. of sand, $\gamma_{sand} =$ 1.52 gr/cm3

Wt. of jug + cone before use 6890 gr.

Wt. of jug + cone after use 3840 gr.

Wt. of sand used (hole + cone) 3050 gr.

Wt. of sand in cone (from calibration) 1782 gr.

Wt. of sand in hole, W' 1268 gr.

Vol. of hole, $V_h = W'/\gamma_{sand} =$ 834.21 cm3

Balloon method

Correction factor CF = ______

Final scale reading ______

Initial scale reading ______

Vol. of hole, V_h' ______

Vol. of hole = V_h' (CF) ______

Density of Soil

Wet density $\gamma_{wet} = W''/V_h =$ 2.05 gr/cm3

Dry density $\gamma_{dry} = \gamma_{wet}/(1 + w) =$ 1.94 gr/cm3

SAMPLE 7

h= 4.5 - 5 cm.

FIELD DENSITY TEST (Sand cone, Balloon) Data Sheet 10

Project ______ Job. No ______

Location of Project Yeldeğirmeni sok.

Description of Soil ______

Test Performed By ______ Date of Test 31.7.1985

Laboratory Data from Field Test

Sand-cone method		Balloon method	
Wt. of wet soil + can	1730 gr.	Wt. of wet soil + can	
Wt. of can	10 gr.	Wt. of can	
Wt. of wet soil, W'	1720 gr.	Wt. of wet soil, W'	
Wt. of wet soil + pan	2300 gr.	Wt. of wet soil + pan	
Wt. of dry soil + pan	2230 gr.	Wt. of dry soil + pan	
Wt. of pan	580 gr.	Wt. of pan	
Wt. of dry soil	1650 gr.	Wt. of dry soil	
Water content, w%	4.24	Water content, w%	

Field Data

Sand-cone method		Balloon method	
Type of sand used	Ottawa	Correction factor CF =	
Unit wt. of sand, γ_{sand} =	1.52 gr/cm3	Final scale reading	
Wt. of jug + cone before use	6815 gr.	Initial scale reading	
Wt. of jug + cone after use	3735 gr.	Vol. of hole, V_h'	
Wt. of sand used (hole + cone)	3080 gr.	Vol. of hole = V_h' (CF)	
Wt. of sand in cone (from calibration)	1782 gr.		
Wt. of sand in hole, W'	1298 gr.		
Vol. of hole, $V_h = W'/\gamma_{sand}$ =	853.95 cm3		

Density of Soil

Wet density $\gamma_{wet} = W'/V_h$ = 2.01 gr/cm3 Dry density $\gamma_{dry} = \gamma_{wet}/(1+w)$ = 1.93 gr/cm3

SAMPLE 8
h= 5 - 5.5 cm.

FIELD DENSITY TEST (Sand cone, Balloon) Data Sheet 10

Project ____________ Job. No ____________

Location of Project Dua Tepe sok.

Description of Soil ____________

Test Performed By ____________ Date of Test 31.7.1985

Laboratory Data from Field Test

Sand-cone method		Balloon method	
Wt. of wet soil + can	2150 gr.	Wt. of wet soil + can	
Wt. of can	10 gr.	Wt. of can	
Wt. of wet soil, W'	2140 gr.	Wt. of wet soil, W'	
Wt. of wet soil + pan	2775 gr.	Wt. of wet soil + pan	
Wt. of dry soil + pan	2685 gr.	Wt. of dry soil + pan	
Wt. of pan	635 gr.	Wt. of pan	
Wt. of dry soil	2050 gr.	Wt. of dry soil	
Water content, w%	4.39	Water content, w%	

Field Data

Sand-cone method		Balloon method	
Type of sand used	Ottawa	Correction factor CF =	
Unit wt. of sand, γ_{sand} =	1.52 gr/cm3	Final scale reading	
Wt. of jug + cone before use	6780 gr.	Initial scale reading	
Wt. of jug + cone after use	3360 gr.	Vol. of hole, V_h'	
Wt. of sand used (hole + cone)	3420 gr.	Vol. of hole = V_h' (CF)	
Wt. of sand in cone (from calibration)	1782 gr.		
Wt. of sand in hole, W	1638 gr.		
Vol. of hole, $V_h = W/\gamma_{sand}$ =	1077,63 cm3		

Density of Soil

Wet density $\gamma_{wet} = W'/V_h$ = 1.99 gr/cm3 Dry density $\gamma_{dry} = \gamma_{wet}/(1+w)$ = 1.91 gr/cm3

SAMPLE 9

h = 6 - 6.5 cm.

FIELD DENSITY TEST (Sand cone, Balloon) Data Sheet 10

Project ______ Job. No ______

Location of Project Dua Tepe (2.kısım)

Description of Soil ______

Test Performed By ______ Date of Test 1.8.1985

Laboratory Data from Field Test.

Sand-cone method		Balloon method	
Wt. of wet soil + can	2200 gr.	Wt. of wet soil + can	
Wt. of can	10 gr.	Wt. of can	
Wt. of wet soil, W'	2190 gr.	Wt. of wet soil, W'	
Wt. of wet soil + pan	2940 gr.	Wt. of wet soil + pan	
Wt. of dry soil + pan	2840 gr.	Wt. of dry soil + pan	
Wt. of pan	750 gr.	Wt. of pan	
Wt. of dry soil	2090 gr.	Wt. of dry soil	
Water content, w%	4.78	Water content, w%	

Field Data

Sand-cone method		Balloon method	
Type of sand used	Ottawa	Correction factor CF =	
Unit wt. of sand, γ_{sand} =	1.52 gr/cm3	Final scale reading	
Wt. of jug + cone before use	6600 gr.	Initial scale reading	
Wt. of jug + cone after use	3290 gr.	Vol. of hole, V_h'	
Wt. of sand used (hole + cone)	3310 gr.	Vol. of hole = V_h' (CF)	
Wt. of sand in cone (from calibration)	1782 gr.		
Wt. of sand in hole, W	1528 gr.		
Vol. of hole, $V_h = W'/\gamma_{sand}$ =	1005,26 cm3		

Density of Soil.

Wet density $\gamma_{wet} = W'/V_h$ = 2.17 gr/cm3 Dry density $\gamma_{dry} = \gamma_{wet}/(1+w)$ = 2.07 gr/cm3

SAMPLE 10
h = 6 - 7 cm.

FIELD DENSITY TEST (Sand cone, Balloon)

Data Sheet 10

Project ______ Job. No ______

Location of Project: Dua Tepe (2.kısım)

Description of Soil ______

Test Performed By ______ Date of Test: 1.8.1985

Laboratory Data from Field Test

Sand-cone method		Balloon method	
Wt. of wet soil + can	2700 gr.	Wt. of wet soil + can	
Wt. of can	10 gr.	Wt. of can	
Wt. of wet soil, W'	2690 gr.	Wt. of wet soil, W'	
Wt. of wet soil + pan	3325 gr.	Wt. of wet soil + pan	
Wt. of dry soil + pan	3245 gr.	Wt. of dry soil + pan	
Wt. of pan	635 gr.	Wt. of pan	
Wt. of dry soil	2610 gr.	Wt. of dry soil	
Water content, w%	3.07	Water content, w%	

Field Data

Sand-cone method		Balloon method	
Type of sand used	Ottawa	Correction factor CF =	
Unit wt. of sand, γ_{sand} =	1.52 gr/cm3	Final scale reading	
Wt. of jug + cone before use	6870 gr.	Initial scale reading	
Wt. of jug + cone after use	3150 gr.	Vol. of hole, V_h'	
Wt. of sand used (hole + cone)	3720 gr.	Vol. of hole = V_h' (CF)	
Wt. of sand in cone (from calibration)	1782 gr.		
Wt. of sand in hole, W	1983 gr.		
Vol. of hole, $V_h = W/\gamma_{sand}$ =	1275 cm3		

Density of Soil.

Wet density $\gamma_{wet} = W'/V_h$ = 2.11 gr/cm3 Dry density $\gamma_{dry} = \gamma_{wet}/(1 + w)$ = 2.05 gr/cm3

SAMPLE 11
h = 6.5-7 cm.

FIELD DENSITY TEST (Sand cone, Balloon) Data Sheet 10

Project ______ Job. No ______

Location of Project Taşlıbayır

Description of Soil ______

Test Performed By ______ Date of Test 19.8.1985

Laboratory Data from Field Test

Sand-cone method		Balloon method	
Wt. of wet soil + can	2300 gr.	Wt. of wet soil + can	
Wt. of can	10 gr.	Wt. of can	
Wt. of wet soil, W'	2290 gr.	Wt. of wet soil, W'	
Wt. of wet soil + pan	2930 gr.	Wt. of wet soil + pan	
Wt. of dry soil + pan	2805 gr.	Wt. of dry soil + pan	
Wt. of pan	640 gr.	Wt. of pan	
Wt. of dry soil	2165 gr.	Wt. of dry soil	
Water content, w%	5.77	Water content, w%	

Field Data

Sand-cone method		Balloon method	
Type of sand used	Ottawa	Correction factor CF =	
Unit wt. of sand, γ_{sand} =	1.52 gr/cm3	Final scale reading	
Wt. of jug + cone before use	6760 gr.	Initial scale reading	
Wt. of jug + cone after use	3250 gr.	Vol. of hole, V'_h	
Wt. of sand used (hole + cone)	3510 gr.	Vol. of hole = V'_h (CF)	
Wt. of sand in cone (from calibration)	1782 gr.		
Wt. of sand in hole, W	1728 gr.		
Vol. of hole, $V_h = W/\gamma_{sand}$ =	1136.84 cm3		

Density of Soil.

Wet density $\gamma_{wet} = W'/V_h$ = 2.014 gr/cm3 Dry density $\gamma_{dry} = \gamma_{wet}/(1 + w)$ = 1.904 gr/cm3

SAMPLE 12

h = 5 cm.

FIELD DENSITY TEST (Sand cone, Balloon)

Data Sheet 10

Project ______ Job. No ______

Location of Project Taşlıbayır

Description of Soil ______

Test Performed By ______ Date of Test 19.8.1985

Laboratory Data from Field Test

Sand-cone method		Balloon method
Wt. of wet soil + can	1930 gr.	Wt. of wet soil + can ______
Wt. of can	10 gr.	Wt. of can ______
Wt. of wet soil, W'	1920 gr.	Wt. of wet soil, W' ______
Wt. of wet soil + pan	2390 gr.	Wt. of wet soil + pan ______
Wt. of dry soil + pan	2290 gr.	Wt. of dry soil + pan ______
Wt. of pan	460 gr.	Wt. of pan ______
Wt. of dry soil	1830 gr.	Wt. of dry soil ______
Water content, w%	5.46	Water content, w% ______

Field Data

Sand-cone method		Balloon method
Type of sand used	Ottawa	Correction factor CF = ______
Unit wt. of sand, γ_{sand} =	1.52 gr/cm3	Final scale reading ______
Wt. of jug + cone before use	6795 gr.	Initial scale reading ______
Wt. of jug + cone after use	3675 gr.	Vol. of hole, V_h' ______
Wt. of sand used (hole + cone)	3120 gr.	Vol. of hole = V_h' (CF) ______
Wt. of sand in cone (from calibration)	1782 gr.	
Wt. of sand in hole, W	1338 gr.	
Vol. of hole, $V_h = W/\gamma_{sand}$ =	880.26 cm3	

Density of Soil.

Wet density $\gamma_{wet} = W'/V_h$ = 2.18 gr/cm3 Dry density $\gamma_{dry} = \gamma_{wet}/(1 + w)$ = 2.07 gr/cm3

SAMPLE 13
h= 7 cm.

FIELD DENSITY TEST (Sand cone, Balloon) Data Sheet 10

Project ______ Job. No ______

Location of Project Taşlıbayır

Description of Soil ______

Test Performed By ______ Date of Test 19.8.1985

Laboratory Data from Field Test

Sand-cone method		Balloon method	
Wt. of wet soil + can	2000 gr.	Wt. of wet soil + can	
Wt. of can	10 gr.	Wt. of can	
Wt. of wet soil, W'	1990 gr.	Wt. of wet soil, W'	
Wt. of wet soil + pan	2760 gr.	Wt. of wet soil + pan	
Wt. of dry soil + pan	2635 gr.	Wt. of dry soil + pan	
Wt. of pan	750 gr.	Wt. of pan	
Wt. of dry soil	1885 gr.	Wt. of dry soil	
Water content, w%	6.63	Water content, w%	

Field Data

Sand-cone method		Balloon method	
Type of sand used	Ottawa	Correction factor CF =	
Unit wt. of sand, γ_{sand} =	1.52 gr/cm3	Final scale reading	
Wt. of jug + cone before use	6680 gr.	Initial scale reading	
Wt. of jug + cone after use	3470 gr.	Vol. of hole, V_h'	
Wt. of sand used (hole + cone)	3210 gr.	Vol. of hole = V_h' (CF)	
Wt. of sand in cone (from calibration)	1782 gr.		
Wt. of sand in hole, W	1428 gr.		
Vol. of hole, $V_h = W/\gamma_{sand}$ =	939.47 cm3		

Density of Soil

Wet density $\gamma_{wet} = W'/V_h$ = 2.12 gr/cm3 Dry density $\gamma_{dry} = \gamma_{wet}/(1 + w)$ = 1.988 gr/cm3

FIELD DENSITY TEST (Sand cone, Balloon) Data Sheet 10

Project ______ Job. No ______

Location of Project Uzun Hafız

Description of Soil ______

Test Performed By ______ Date of Test 20.9.1985

Laboratory Data from Field Test

Sand-cone method		Balloon method	
Wt. of wet soil + can	1540 gr.	Wt. of wet soil + can	
Wt. of can	10 gr.	Wt. of can	
Wt. of wet soil, W'	1530 gr.	Wt. of wet soil, W'	
Wt. of wet soil + pan	2090 gr.	Wt. of wet soil + pan	
Wt. of dry soil + pan	2000 gr.	Wt. of dry soil + pan	
Wt. of pan	560 gr.	Wt. of pan	
Wt. of dry soil	1440 gr.	Wt. of dry soil	
Water content, w%	6.25	Water content, w%	

Field Data

Sand-cone method		Balloon method	
Type of sand used	Ottawa	Correction factor CF =	
Unit wt. of sand, γ_{sand} =	1.52 gr/cm3	Final scale reading	
Wt. of jug + cone before use	6540 gr.	Initial scale reading	
Wt. of jug + cone after use	3680 gr.	Vol. of hole, V'_h	
Wt. of sand used (hole + cone)	2860 gr.	Vol. of hole = V'_h (CF)	
Wt. of sand in cone (from calibration)	1782 gr.		
Wt. of sand in hole, W	1068 gr.		
Vol. of hole, $V_h = W/\gamma_{sand}$ =	702.63 cm3		

Density of Soil.

Wet density $\gamma_{wet} = W'/V_h$ = 2.178 gr/cm3 Dry density $\gamma_{dry} = \gamma_{wet}/(1+w)$ = 2.05 gr/cm3

FIELD DENSITY TEST (Sand cone, Balloon) Data Sheet 10

Project ______ Job. No ______

Location of Project Uzun Hafız

Description of Soil ______

Test Performed By ______ Date of Test 20.9.1985

Laboratory Data from Field Test

Sand-cone method		Balloon method	
Wt. of wet soil + can	1750 gr.	Wt. of wet soil + can	
Wt. of can	10 gr.	Wt. of can	
Wt. of wet soil, W'	1740 gr.	Wt. of wet soil, W'	
Wt. of wet soil + pan	2300 gr.	Wt. of wet soil + pan	
Wt. of dry soil + pan	2190 gr.	Wt. of dry soil + pan	
Wt. of pan	560 gr.	Wt. of pan	
Wt. of dry soil	1630 gr.	Wt. of dry soil	
Water content, w%	6.75	Water content, w%	

Field Data

Sand-cone method		Balloon method	
Type of sand used	Ottawa	Correction factor CF =	
Unit wt. of sand, γ_{sand} =	1.52 gr/cm3	Final scale reading	
Wt. of jug + cone before use	6700 gr.	Initial scale reading	
Wt. of jug + cone after use	3680 gr.	Vol. of hole, V_h'	
Wt. of sand used (hole + cone)	3020 gr.	Vol. of hole = V_h' (CF)	
Wt. of sand in cone (from calibration)	1782 gr.		
Wt. of sand in hole, W	1238 gr.		
Vol. of hole, $V_h = W/\gamma_{sand}$ =	814.47 cm3		

Density of Soil.

Wet density $\gamma_{wet} = W'/V_h$ = 2.136 gr/cm3 Dry density $\gamma_{dry} = \gamma_{wet}/(1+w)$ = 2.00 gr/cm3

FIELD DENSITY TEST (Sand cone, Balloon) Data Sheet 10

Project ______ Job. No ______

Location of Project Uzun Hafız

Description of Soil ______

Test Performed By ______ Date of Test 20.9.1985

Laboratory Data from Field Test

Sand-cone method		Balloon method	
Wt. of wet soil + can	1850 gr.	Wt. of wet soil + can	
Wt. of can	10 gr.	Wt. of can	
Wt. of wet soil, W'	1840 gr.	Wt. of wet soil, W'	
Wt. of wet soil + pan	2400 gr.	Wt. of wet soil + pan	
Wt. of dry soil + pan	2310 gr.	Wt. of dry soil + pan	
Wt. of pan	560 gr.	Wt. of pan	
Wt. of dry soil	1750 gr.	Wt. of dry soil	
Water content, w%	5.14	Water content, w%	

Field Data

Sand-cone method		Balloon method	
Type of sand used	Ottawa	Correction factor CF =	
Unit wt. of sand, γ_{sand} =	1.52 gr/cm3	Final scale reading	
Wt. of jug + cone before use	6600 gr.	Initial scale reading	
Wt. of jug + cone after use	3420 gr.	Vol. of hole, V_h'	
Wt. of sand used (hole + cone)	3180 gr.	Vol. of hole = V_h' (CF)	
Wt. of sand in cone (from calibration)	1782 gr.		
Wt. of sand in hole, W	1398 gr.		
Vol. of hole, $V_h = W/\gamma_{sand}$ =	919,74 cm3		

Density of Soil.

Wet density $\gamma_{wet} = W'/V_h$ = 2.00 gr/cm3 Dry density $\gamma_{dry} = \gamma_{wet}/(1 + w)$ = 1.902 gr/cm3

SAMPLE 17

FIELD DENSITY TEST (Sand cone, Balloon)

Data Sheet 10

Project ______ Job. No ______

Location of Project Uzun Hafız

Description of Soil ______

Test Performed By ______ Date of Test 20.9.1985

Laboratory Data from Field Test

Sand-cone method			Balloon method	
Wt. of wet soil + can	1900	gr.	Wt. of wet soil + can	
Wt. of can	10	gr.	Wt. of can	
Wt. of wet soil, W'	1890	gr.	Wt. of wet soil, W'	
Wt. of wet soil + pan	2450	gr.	Wt. of wet soil + pan	
Wt. of dry soil + pan	2370	gr.	Wt. of dry soil + pan	
Wt. of pan	560	gr.	Wt. of pan	
Wt. of dry soil	1810	gr.	Wt. of dry soil	
Water content, w%	4.42		Water content, w%	

Field Data

Sand-cone method			Balloon method	
Type of sand used	Ottawa		Correction factor CF =	
Unit wt. of sand, γ_{sand} =	1.52	gr/cm3	Final scale reading	
Wt. of jug + cone before use	6450	gr.	Initial scale reading	
Wt. of jug + cone after use	3310	gr.	Vol. of hole, V_h'	
Wt. of sand used (hole + cone)	3140	gr.	Vol. of hole = V_h' (CF)	
Wt. of sand in cone (from calibration)	1782	gr.		
Wt. of sand in hole, W	1358	gr.		
Vol. of hole, $V_h = W/\gamma_{sand}$ =	893.42	cm3		

Density of Soil.

Wet density $\gamma_{wet} = W'/V_h$ = 2.116 gr/cm3 Dry density $\gamma_{dry} = \gamma_{wet}/(1 + w)$ = 2.03 gr/cm3

FIELD DENSITY TEST (Sand cone, Balloon) Data Sheet 10

Project ______ Job. No ______

Location of Project ~~Uzun Hafız~~

Description of Soil ______

Test Performed By ______ Date of Test 20.9.1985

Laboratory Data from Field Test

Sand-cone method		Balloon method	
Wt. of wet soil + can	1990 gr.	Wt. of wet soil + can	
Wt. of can	10 gr.	Wt. of can	
Wt. of wet soil, W'	1980 gr.	Wt. of wet soil, W'	
Wt. of wet soil + pan	2540 gr.	Wt. of wet soil + pan	
Wt. of dry soil + pan	2425 gr.	Wt. of dry soil + pan	
Wt. of pan	560 gr.	Wt. of pan	
Wt. of dry soil	1865 gr.	Wt. of dry soil	
Water content, w%	6.17	Water content, w%	

Field Data

Sand-cone method		Balloon method	
Type of sand used	Ottawa	Correction factor CF =	
Unit wt. of sand, γ_{sand} =	1.52 gr/cm3	Final scale reading	
Wt. of jug + cone before use	6640 gr.	Initial scale reading	
Wt. of jug + cone after use	3400 gr.	Vol. of hole, V_h'	
Wt. of sand used (hole + cone)	3240 gr.	Vol. of hole = V_h' (CF)	
Wt. of sand in cone (from calibration)	1782 gr.		
Wt. of sand in hole, W	1458 gr.		
Vol. of hole, $V_h = W/\gamma_{sand}$ =	959.21 cm3		

Density of Soil.

Wet density $\gamma_{wet} = W'/V_h$ = 2.06 gr/cm3 Dry density $\gamma_{dry} = \gamma_{wet}/(1 + w)$ = 1.94 gr/cm3

FIELD DENSITY TEST (Sand cone, Balloon) Data Sheet 10

Project ______ Job No ______

Location of Project İzzettin sok.

Description of Soil ______

Test Performed By ______ Date of Test 10.10.1985

Laboratory Data from Field Test

Sand-cone method		Balloon method	
Wt. of wet soil + can	1960 gr.	Wt. of wet soil + can	
Wt. of can	10 gr.	Wt. of can	
Wt. of wet soil, W'	1950 gr.	Wt. of wet soil, W'	
Wt. of wet soil + pan	2525 gr.	Wt. of wet soil + pan	
Wt. of dry soil + pan	2360 gr.	Wt. of dry soil + pan	
Wt. of pan	575 gr.	Wt. of pan	
Wt. of dry soil	1785 gr.	Wt. of dry soil	
Water content, w%	9.24	Water content, w%	

Field Data

Sand-cone method		Balloon method	
Type of sand used	Ottawa	Correction factor CF =	
Unit wt. of sand, γ_{sand} =	1.52 gr/cm3	Final scale reading	
Wt. of jug + cone before use	6490 gr.	Initial scale reading	
Wt. of jug + cone after use	3320 gr.	Vol. of hole, V_h'	
Wt. of sand used (hole + cone)	3170 gr.	Vol. of hole = V_h' (CF)	
Wt. of sand in cone (from calibration)	1782 gr.		
Wt. of sand in hole, W	1388 gr.		
Vol. of hole, $V_h = W/\gamma_{sand}$ =	913.16 cm3		

Density of Soil.

Wet density $\gamma_{wet} = W'/V_h$ = 2.14 gr/cm3 Dry density $\gamma_{dry} = \gamma_{wet}/(1+w)$ = 1.96 gr/cm3

SAMPLE 20

FIELD DENSITY TEST (Sand cone, Balloon) Data Sheet 10

Project ______ Job. No ______

Location of Project İzzettin Sokak

Description of Soil ______

Test Performed By ______ Date of Test 10.10.1985

Laboratory Data from Field Test

Sand-cone method		Balloon method	
Wt. of wet soil + can	2100 gr.	Wt. of wet soil + can	
Wt. of can	10 gr.	Wt. of can	
Wt. of wet soil, W'	2090 gr.	Wt. of wet soil, W'	
Wt. of wet soil + pan	2730 gr.	Wt. of wet soil + pan	
Wt. of dry soil + pan	2545 gr.	Wt. of dry soil + pan	
Wt. of pan	640 gr.	Wt. of pan	
Wt. of dry soil	1905 gr.	Wt. of dry soil	
Water content, w%	9.71	Water content, w%	

Field Data

Sand-cone method		Balloon method	
Type of sand used	Ottawa	Correction factor CF =	
Unit wt. of sand, γ_{sand} =	1.52 gr/cm3	Final scale reading	
Wt. of jug + cone before use	6700 gr.	Initial scale reading	
Wt. of jug + cone after use	3570 gr.	Vol. of hole, V_h'	
Wt. of sand used (hole + cone)	3130 gr.	Vol. of hole = V_h' (CF)	
Wt. of sand in cone (from calibration)	1782 gr.		
Wt. of sand in hole, W	1348 gr.		
Vol. of hole, $V_h = W/\gamma_{sand}$ =	886.84 cm3		

Density of Soil.

Wet density $\gamma_{wet} = W'/V_h$ = 2.36 gr/cm3 Dry density $\gamma_{dry} = \gamma_{wet}/(1+w)$ = 2.15 gr/cm3

SAMPLE 21

FIELD DENSITY TEST (Sand cone, Balloon) Data Sheet 10

Project ________ Job. No ________

Location of Project İzzettin sokak

Description of Soil ________

Test Performed By ________ Date of Test 10.10.1985

Laboratory Data from Field Test

Sand-cone method			Balloon method	
Wt. of wet soil + can	1850	gr.	Wt. of wet soil + can	
Wt. of can	10	gr.	Wt. of can	
Wt. of wet soil, W'	1840	gr.	Wt. of wet soil, W'	
Wt. of wet soil + pan	2260	gr.	Wt. of wet soil + pan	
Wt. of dry soil + pan	2120	gr.	Wt. of dry soil + pan	
Wt. of pan	420	gr.	Wt. of pan	
Wt. of dry soil	1700	gr.	Wt. of dry soil	
Water content, w%	8.24		Water content, w%	

Field Data

Sand-cone method			Balloon method	
Type of sand used	Ottawa		Correction factor CF =	
Unit wt. of sand, γ_{sand} =	1.52	gr/cm3	Final scale reading	
Wt. of jug + cone before use	6585	gr.	Initial scale reading	
Wt. of jug + cone after use	3550	gr.	Vol. of hole, V_h'	
Wt. of sand used (hole + cone)	3035	gr.	Vol. of hole = V_h' (CF)	
Wt. of sand in cone (from calibration)	1782	gr.		
Wt. of sand in hole, W	1253	gr.		
Vol. of hole, $V_h = W/\gamma_{sand}$ =	824.34	cm3		

Density of Soil.

Wet density $\gamma_{wet} = W'/V_h =$ 2.23 gr/cm3 Dry density $\gamma_{dry} = \gamma_{wet}/(1+w) =$ 2.06 gr/cm3

SAMPLE 22

FIELD DENSITY TEST (Sand cone, Balloon) Data Sheet 10

Project Osmanağa Job. No

Location of Project Neşet Ömer

Description of Soil

Test Performed By Date of Test 28.10.1985

Laboratory Data from Field Test

Sand-cone method

Wt. of wet soil + can 2250 gr.

Wt. of can 10 gr.

Wt. of wet soil, W' 2240 gr.

Wt. of wet soil + pan 2660 gr.

Wt. of dry soil + pan 2400 gr.

Wt. of pan 420 gr.

Wt. of dry soil 1980 gr.

Water content, w% 13.13

Balloon method

Wt. of wet soil + can

Wt. of can

Wt. of wet soil, W'

Wt. of wet soil + pan

Wt. of dry soil + pan

Wt. of pan

Wt. of dry soil

Water content, w%

Field Data

Sand-cone method

Type of sand used Ottawa

Unit wt. of sand, γ_{sand} = 1.52 gr/cm3

Wt. of jug + cone before use 6600 gr.

Wt. of jug + cone after use 3250 gr.

Wt. of sand used (hole + cone) 3350 gr.

Wt. of sand in cone (from calibration) 1782 gr.

Wt. of sand in hole, W 1568 gr.

Vol. of hole, $V_h = W/\gamma_{sand}$ = 1031.6 cm3

Balloon method

Correction factor CF =

Final scale reading

Initial scale reading

Vol. of hole, V_h'

Vol. of hole = V_h' (CF)

Density of Soil.

Wet density $\gamma_{wet} = W'/V_h$ = 2.17 gr/cm3

Dry density $\gamma_{dry} = \gamma_{wet}/(1 + w)$ = 1.92 gr/cm3

SAMPLE 23

FIELD DENSITY TEST (Sand cone, Balloon) Data Sheet 10

Project Osmanağa Job. No

Location of Project Neşet Ömer

Description of Soil

Test Performed By Date of Test 28.10.1982

Laboratory Data from Field Test

Sand-cone method		Balloon method	
Wt. of wet soil + can	2230 gr.	Wt. of wet soil + can	
Wt. of can	10 gr.	Wt. of can	
Wt. of wet soil, W'	2220 gr.	Wt. of wet soil, W'	
Wt. of wet soil + pan	2955 gr.	Wt. of wet soil + pan	
Wt. of dry soil + pan	2770 gr.	Wt. of dry soil + pan	
Wt. of pan	735 gr.	Wt. of pan	
Wt. of dry soil	2035 gr.	Wt. of dry soil	
Water content, w%	9.09	Water content, w%	

Field Data

Sand-cone method		Balloon method	
Type of sand used	Ottawa	Correction factor CF =	
Unit wt. of sand, γ_{sand} =	1.52 gr/cm3	Final scale reading	
Wt. of jug + cone before use	6350 gr.	Initial scale reading	
Wt. of jug + cone after use	3150 gr.	Vol. of hole, V_h'	
Wt. of sand used (hole + cone)	3200 gr.	Vol. of hole = V_h' (CF)	
Wt. of sand in cone (from calibration)	1782 gr.		
Wt. of sand in hole, W	1418 gr.		
Vol. of hole, $V_h = W/\gamma_{sand}$ =	932.89 cm3		

Density of Soil

Wet density $\gamma_{wet} = W'/V_h$ = 2.38 gr/cm3 Dry density $\gamma_{dry} = \gamma_{wet}/(1+w)$ = 2.18 gr/cm3

SAMPLE 24

FIELD DENSITY TEST (Sand cone, Balloon)

Data Sheet 10

Project: Osmanağa   Job. No: ____

Location of Project: Gülşen sokak

Description of Soil: ____

Test Performed By: ____   Date of Test: 1.11.1985

Laboratory Data from Field Test

Sand-cone method		Balloon method	
Wt. of wet soil + can	1610 gr.	Wt. of wet soil + can	
Wt. of can	10 gr.	Wt. of can	
Wt. of wet soil, W'	1600 gr.	Wt. of wet soil, W'	
Wt. of wet soil + pan	2155 gr.	Wt. of wet soil + pan	
Wt. of dry soil + pan	2015 gr.	Wt. of dry soil + pan	
Wt. of pan	555 gr.	Wt. of pan	
Wt. of dry soil	1460 gr.	Wt. of dry soil	
Water content, w%	9.59	Water content, w%	

Field Data

Sand-cone method		Balloon method	
Type of sand used	Ottawa	Correction factor CF =	
Unit wt. of sand, γ_{sand} =	1.52 gr/cm3	Final scale reading	
Wt. of jug + cone before use	6250 gr.	Initial scale reading	
Wt. of jug + cone after use	3440 gr.	Vol. of hole, V_h'	
Wt. of sand used (hole + cone)	2810 gr.	Vol. of hole = V_h' (CF)	
Wt. of sand in cone (from calibration)	1782 gr.		
Wt. of sand in hole, W	1028 gr.		
Vol. of hole, $V_h = W/\gamma_{sand}$ =	676.32 cm3		

Density of Soil

Wet density $\gamma_{wet} = W'/V_h$ = 2.37 gr/cm3 Dry density $\gamma_{dry} = \gamma_{wet}/(1+w)$ = 2.16 gr/cm3

SAMPLE 25

FIELD DENSITY TEST (Sand cone, Balloon)

Data Sheet 10

Project: Osmanağa — Job. No: ______

Location of Project: Gülşen sokak

Description of Soil: ______

Test Performed By: ______ — Date of Test: 1.11.1985

Laboratory Data from Field Test

Sand-cone method		Balloon method	
Wt. of wet soil + can	1410 gr.	Wt. of wet soil + can	
Wt. of can	10 gr.	Wt. of can	
Wt. of wet soil, W'	1400 gr.	Wt. of wet soil, W'	
Wt. of wet soil + pan	1840 gr.	Wt. of wet soil + pan	
Wt. of dry soil + pan	1715 gr.	Wt. of dry soil + pan	
Wt. of pan	440 gr.	Wt. of pan	
Wt. of dry soil	1275 gr.	Wt. of dry soil	
Water content, w%	9.80	Water content, w%	

Field Data

Sand-cone method		Balloon method	
Type of sand used	Ottawa	Correction factor CF =	
Unit wt. of sand, γ_{sand} =	1.52 gr/cm3	Final scale reading	
Wt. of jug + cone before use	6355 gr.	Initial scale reading	
Wt. of jug + cone after use	3600 gr.	Vol. of hole, V_h'	
Wt. of sand used (hole + cone)	2755 gr.	Vol. of hole = V_h' (CF)	
Wt. of sand in cone (from calibration)	1782 gr.		
Wt. of sand in hole, W	973 gr.		
Vol. of hole, $V_h = W/\gamma_{sand}$ =	840.13 cm3		

Density of Soil

Wet density $\gamma_{wet} = W'/V_h$ = 2.19 gr/cm3 Dry density $\gamma_{dry} = \gamma_{wet}/(1 + w)$ = 1.99 gr/cm3

APPENDIX B

COMPUTER PROGRAM FOR ANALYSIS OF A MULTI - LAYERED ELASTIC SYSTEM WITH A SINGLE VERTICAL LOAD

B.1 DESCRIPTION

The multi - layered elastic system computer program (*) will determine the various component stresses and strains in a three dimensional ideal elastic layered system with a single vertical uniform circular load at the surface of the system .

The solutions for stresses and deflections of elastic layered systems are based on the assumption that all the layers are homogeneous , isotropic and elastic. The solutions for stresses and deflections are based on the formulas derived from Boussinesq's and Terzaghi's analyses.

Influence coefficients for stresses are computed using Bessel functions and Bessel function constants are determined using Legendre - Gauss iteration. Influence coefficients for stresses and deflections are determined according to four parameters (H , a_1 , k_1 and k_2).

In three layered system study , parameters are defined as ;

$$H = \frac{h_1}{h_2} , \quad a_1 = \frac{a}{h_2} , \quad k_1 = \frac{E_1}{E_2} \quad \text{and} \quad k_2 = \frac{E_2}{E_3}$$

(*) Michelow J., "Analysis Of Stresses and Displacements In An N - Layered Elastic System Under A Load Uniformly Distributed On A Circular Area", Chevron Research Comp.1963 where h_1 = First layer thickness

h_2 = Second layer thickness

a = Load radius

E_1 = Elastic modulus of first layer

E_2 = Elastic modulus of second layer

E_3 = Elastic modulus of third layer

According to these parameters, stress influence coefficients are calculated and stresses can be expressed simply as ;

$$\sigma_z = q \times I_{\sigma_z} \;,\quad \sigma_r = q \times I_{\sigma_r} \;,\quad \sigma_\theta = q \times I_{\sigma_\theta} \quad \text{and} \quad \tau_{rz} = q \times I_{\tau_{rz}}$$

where σ_z = Vertical compressive stress

σ_r = Radial (Horizontal) stress

σ_θ = Tangential stress

τ_{rz} = Shear stress

q = Tire pressure

I_{σ_z} = Influence coefficient for vertical stress

I_{σ_r} = Influence coefficient for radial stress

I_{σ_θ} = Influence coefficient for tangential stress

$I_{\tau_{rz}}$ = Influence coefficient for shear stress

Deflections are computed as;

$$d = \frac{a \times q}{E1} \times I_d$$

where d = Settlement of the center of the loaded area

a = Load radius

q = Tire pressure

E_1 = Elastic modulus of first layer

I_d = Influence coefficient for deflection determined using same parameters (H , a_1, k_1 and k_2)

Strains can be computed as;

$$\varepsilon_{h_1} = \frac{0.5 \times (\sigma_{r_1} - \sigma_{z_1})}{E_1}$$

where ε_{h_1} = Horizontal strain at the base of first layer

E_1 = Elastic modulus of first layer

σ_{r1} = Horizontal stress at the base of first layer

σ_{z_1} = Vertical compressive stress at the base of first layer

The bottom layer of the system is semi - infinite with all other layers of uniform thickness. All layers extend infinitely in the horizontal direction . The top surface of the system is free of shear and all interfaces between layers have full continuity of stresses and displacements .

With a vertical uniform circular load , the system is axi - symmetric with the z - axis perpendicular to the layers and extending through the center of the load . Using cylindrical coordinates , any point in the system may be described by an R and z . R is the horizontal distance out from the center of the load and z is the depth of the point measured vertically from the surface of the system .

The load is described by the total vertical load in pounds and the tire pressure in psi . The load radius computed by the program . Each layer of the system is described by modulus of elasticity , Poisson 's ratio and thickness in inches . Each layer is numbered with the top layer as 1 and numbering each layer consecutively downward .

B.2 PROGRAM OPERATING NOTES

The program operates with the various given R and z values as follows : For every R value a complete set of characterizing function is developed for all layers , then the stresses and strains are computed at those points represented by that R and each of the given z values . The program then steps to the next R value and computes the stresses and strains at those points represented by each of the given z values and continues until all combinations of R and z values are used .

When a given z value is directly on an interface between two layers , the program will first compute the stresses and strains at this point using the functions for the upper of the two layers then will recompute the stresses and strains at this same point using the functions from the lower of the two layers. In the output of the program a negative z value indicates that the stresses and strains have been computed at an interface and that the characteristics of the upper layer have been used .

B.3 LIMITATIONS

The following are limitations of the program and / or method ,

1 - Number of layers in the system ; minimum of two and a maximum of five .

2 - Number of points in the system where stresses and strains are to be determined ; minimum of one (one R and one z) to a maximum of 121 (maximum of eleven R and eleven z) .

3 - All data are positive , no negative values .

4 - Poisson 's ratio must not have a value of one

B.4 INPUT DATA

Several values of layer thickness or modulus may be specified for each layer and the program will calculate results for the various possible combination of layer thickness and modulus . The required data cards are listed below .

A - Title Card (8 A 10)

Columns 1 - 72 Any desired description

B - Load Card (2 F 10.0)

Columns 1 - 10 Total load in pound (WGT)
11 - 20 Tire pressure in psi (PSI)

C - Control Card (6 I 5)

Columns 1 - 5 Number of layers in system (NS) - Max. 5
6 - 10 Number of values to be specified for thickness or modulus of the top layer (N1) - Max. 5
11 - 15 Number of values to be specified for thickness or modulus of second layer (N2)
Etc.

D - Layer Thickness and material Property Cards (3 F 10.0)

Columns 1 - 10 Layer thickness in inches (HHH)
11 - 20 Young 's modulus in psi (EE)
21 - 30 Poisson 's ratio (VV)

N1 cards for top layer , N2 cards for second layer , etc . For bottom layer , which is semi - infinite , put thickness equal to zero .

E – Coordinate Cards (I 5 , 11 F 5.0)

Columns	1 - 5	Number of values to be specified (IR)
	5 - 10	First R value in inches
	11 - 15	Second R value in inches
	Etc.	

Columns	1 - 5	Number of values to be specified (IZ)
	5 - 10	First z value in inches
	Etc.	

Only one load and one set of values of R and z may be specified for each data set , but as many data sets as desired may be run by repeating cards A to E . The program will end an error number 65 when the last data set has been processed .

B.5 SAMPLE DATA

1. Card	EXAMPLE DATA					(8A10)
2. Card	20000.		125.			(2F10.0)
3. Card	3	1	1	1		(6I5)
4. Card		2.5	490000.		.45	(3F10.0)
5. Card		10.	42000.		.52	(3F10.0)
6. Card		0.	31000.		.5	(3F10.0)
7. Card	2	0.	9.			(I5 , 11F5.0)
8. Card	3	1.	2.5	11.		(I5 , 11F5.0)