PUMICE APPLICATION
FROM GYALI ISLAND
FOR THE CONSTRUCTION OF A LIGHT EMBANKMENT

TECHNICAL REPORT

ATHENS, FEBRUARY 1998

1. Introduction

This report presents the physical, chemical and mechanical properties of pumice from Gyali Island with special emphasis to those properties stated for their use as a light filling material.
The research was performed following an order by «ALPINE HELLAS», while the material was provided by LAVA S.A.
Following a brief goelogical review of the formation of the deposit at Gyali Island, a history of its exploitation is mentioned. The classifications are described through which it is offered in the market along with the mineral properties of the material.
Then, lab and on site test results are presented and evaluated, concerning the inspection of the material's suitability. Lab tests include tests of granular classification, measurements of the relative humidity and bulk density.
On site tests were performed on the 20th and 21st of January, 1998 at the premices of AGET at Kiourka - Attica, where a test embankment was constructed.
Lab tests were performed at the laboratory of EDAFOMECHANIKI Ltd. at Marousi and Thessaloniki. by Prof. K. Demiris.

2. Pumice of Gyali Island

By the term pumice we mean a pore volcanic Lithological mass, formed from the defrosting and freezing of liquid lava coming out of volcanoes, during their activity, and which, as soon as it comes out on ground surface and before it freezes, it expands due to the relief of gases which are dioluted and under pressure in their mass.
Pumice was known in the ancient years as light stone, because it floated on water, and it was used, from time to time, both from Greeks and Romans for the construction of magnificent constructions, many of which still exist.
In Greece, there are pumice deposits, the most significant of which are at Gyali Island of Dodecanese, between the islands of Kos and Nissiros.
According to the experts, these deposits were formed from volcanic lava of Nissiros Island during its activity approximately 200.000 years ago.
Since 1952, these deposits are being exploited by LAVA S.A., which in 1977, was incorporated to IRAKLIS General Cement Company.
For the exploitation of these deposits, LAVA S.A. disposes and uses modern slicing, sorting and loading equipment of products, loaded in large capacity ships ((30000 MT).

During the last years at Gyali Island, pumice production reached 750,000 to 1,000,000 m3 per year, quantities that may be increased, if required, due to the disposed equipment by LAVA S.A.

From the above quantities, the largest part is exported abroad. The countries importing pumice from Gyali Island are mainly the United States, EC countries, countries of the Middle and Far East, as well as the Scandinavian countries.

Both in Greece and abroad, the provided pumice quantities by LAVA S.A. are mainly used in building construction and light structural projects, as well as the construction of thermal insulating and sound insulating structural elements, in Road Construction for the improvement of road sub-layers in areas with doubtful soil and in Port Works, during the construction of quays, as light embankment material.

Depending on the requirements of each application and in order to cover the needs, LAVA S.A. produces and provides to its clients pumice in the form of four granular classifications, i.e. 0-15 mm, 0-18 mm, 5-8 mm and 8-16 mm.

3. Physical and chemical properties

Pumice of Gyali Island has a granular form and, as it was mentioned above, it is provided to the market in usually four granular classifications.

It concerns a natural, stable in respect of deterioration material, which was tested from the goetectonic and atmospheric effects of the area for many thousands of years.

The chemical composition of pumice at Gyali Island is shown on Table 1.

TABLE 1 : TYPICAL CHEMICAL ANALYSIS OF PUMICE AT GYALI ISLAND

SiO_2	70.55%
Al_2O_3	12.24%
Fe_2O_3	0.89%
CaO	2.36%
MgO	0.10%
SO_3	0.03%
K_2O	4.21%
Na_2O	3.49%
Burning loss	5.51%
Other elements	0.62%
	100.00%

Pumice grains have a white up to whitish color. This light color, as also resulting from the chemical analysis of Table 1, occurs due to the fact that pumice mass has more whitish mineral ingredients (SiO_2, Al_2O_3) than the dark ones (Fe_2O_3, MgO), which are included in smaller percentages and provide color to the rocks and geological formations.

From the above chemical analysis of Table 1 and the factor K of the material, it is resulted that pumice of Gyali Island has pozulanic properties.

$$K = \frac{CaO+MgO+K_2O+Na_2O}{SiO_2 + Al_2O_3} \cong 0.12$$

The absolute specific weight of the structural material of pumice grains at Gyali Island is approximate 2350 kg/m^3.

Bulk density of pumice, as also resulted by Table 2, depends directly on its granular composition and varies from 550 kgs/m^3 to 720 kgs/m^3.

Table 2 refers to four typical granular pumice compositions produced and provided to the market by LAVA S.A., as well as to the bulk density of each composition in a dry status of the material.

Vaccum volume, existing both inside the grains and among the grains of pumice, is not stable because it depends directly, as also presented in Table2, on the bulk density, that is the granular composotion of the material.

TABLE 2 : TYPICAL GRANULAR COMPOSITIONS OF PUMICE FROM GYALI ISLAND

Granular Classification	0-5 MM		0-8 MM		5-8 MM		8-18 MM	
	Withheld percentage %							
Size of grain	Ideal	Variation	Ideal	Variation	Ideal	Variation	Ideal	Variation
3/4 IN 9.00MM							0	0
5/8 IN 16.00 MM							1	0-3
½ IN 12.70 MM			0	0	0	0		
12.00 MM							12	8-14
5/18 IN 8.00 MM			0.5	0-1.0	1	0.3	55	50-60
1/4 IN 6.40 MM	0	0						
No 4 MESH 4.76 MM	2	0.5-4	21	17-28	82	78-86		
No 5 MESH 4.00 MM		28-36					24	20-30
No 8 MESH 2.38 MM	32	19-25	25.5	21-30	8	6-10		
No 18 MESH 1.19 MM	22	11-15	17	13-21	0.5	0-2		
No 30 MESH 0.80 MM	13	7-11	11.5	7-15.5	0.5	0-2		
No 50 MESH 0.30 MM	9	5.5-8.5	9	5-13	0.5	0-2		
No 100 MESH 0.15 MM	7	12-17	8.5	5-10.5	1	0-3		
PAN	15		9	7-13	6.5	5-8	8	6-10

Granular Classification	0-5 mm	0-8 mm	5-8 mm	8-16 mm
Bulk density of dry material kgs/m3	720 ± 5%	700 ± 5%	600 ± 5%	550 ± 5%

4. Forms of pumice disposal

After its slicing and basic process at Gyali Island, pumice is available in the market in various standard classifications, as already mentioned on previous paragraphs. For the present research, the following classifications were used :

Classification A : Grain size 0-8 mm (trade name Besser)

Classification B : Grain size 3-8 mm

Classification C : Grain size 8-16 mm (trade name German)

Classifications B and C always include a small percentage of fine grained material.

Bulk density of dry material at a loose status is respectively :

Classification A : $\gamma_a = 790$ Kgr/m^3

Classification B : $\gamma_b = 675$ Kgr/m^3

Classification C : $\gamma_c = 580$ Kgr/m^3

Following immersion in water for 100 hours and then drainage,the material of classification C presented 31% water content.

The natural humidity of the above material, as circulated in the market, varies between 20% and 28%.

The granular composition of classifications A, B and C is presented on the diagram of page 1 of the Annex.

5. Ground - technical researches

Ground - technical researches include lab and on site tests :

4.1. Lab tests

a) Granular analysis of material, threeclassifications.

b) Measurements of dry and wet bulk density.

c) Measurements of water content.

4.2. Open air tests

a) Construction of tests embankment.

b) Inspection of conpaction on site.

c) Plate loading test.

d) Pocket penetrometer test.

6. Lab tests

Lab tests were performed on samples from the accumulated material before laying.

The lab tests were the following :

i. Granular analysis with test sieves, according to E105-86, paragraphs 7-8-9, AASHTO T27 and T86-88 and ASTM C136-84. Granular analyses were performed on three (3) samples before laying. Analysis diagrams are presented on pages 2, 3 and 4 of the Annex.

ii. Dry bulk density of loose material

Material I : 580 kg/m^3

Material II : 620 kg/m^3

Material III : 680 kg/m^3

iii. Water content

Material I : 31%

Material II : 34%

Material III : 34%

7. Construction of test embankment

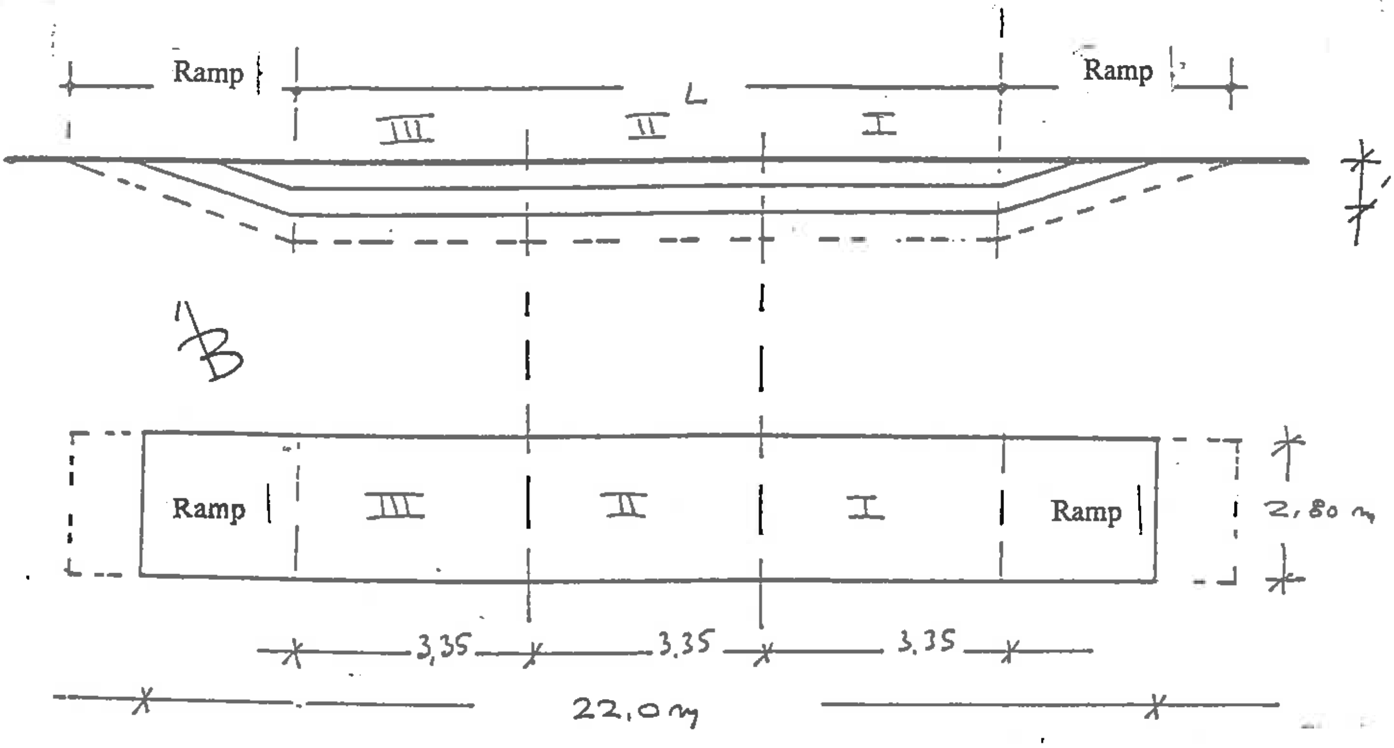
The purpose of the test embankment is to find the behavior of the layed material under actual construction conditions, in order to evaluate the following :

a. Method of compaction

b. Required water content

c. Mechanical strength of embankment.

The geometric form of the test embankment is the following :



The test embankment was layed inside a pit with dimensions 22.0 m X 2.80 m. The embankment was divided into three parts with three different material classifications in order to inspect the suitability of the different classifications.

The classifications of the three materials used, are the following :

Material I : Material classification 8-16 mm.

Material II : Material classification 8-16 mm at 70% and
Material classification 5-8 mm at 30%.

Material III : Material classification 0-8 mm at 40% and
Material classification 8-16 mm at 60%.

Laying was made in layers of mean thickness 30 cm with vibrationg tendem roller DYNAPAC by SOLVA SWEDEN, CC 10 III type. The equivalent static load of the roller was 10 t, while its actual weight (deadweight) was 2.5 t. The speed during compaction waas 4.0 KM/h.
Laying procedure of compaction was the following :

- Static and vibrating compaction of the pit's bottom.
- Laying of three layers with mean thickness 30 cm
- Static compaction with wetting.
- Wetting and vibrational compaction

Weather conditions during the construction of the test embankment were 10-13°C with light rain.
When the rain was heavier and the works were stopped, the embankment was fully covered by a plastic layer. The same applied during work stops and during the night.
During compaction, the layer's thickness was inspected by levelling in order to check if the desired compaction degree had been accomplished.

8. Inspection of compaction

Inspection of compaction was made as previously mentioned through measuring the settlemnt of the material's level during compaction.
Measurements showed an 8% reduction of material volume.
This concludes that the mean dry density of compacted material is :

Material I

Dry bulk density : 580 . 1.08 = 626 kg/cm^2

Wet bulk density : 626 . 1.31 = 820 kg/cm^2

Material II :

Dry bulk density : 620 . 1.08 = 670 kg/cm^2

Wet bulk density : 670 . 1.34 = 897 kg/cm^2

Material III :

Dry bulk density : 680 . 1.08 = 734 kg/cm^2

Wet bulk density : 734 . 1.34 = 984 kg/cm^2

9. Plate loading test

Aiming to the on site evaluation of deformability factor E, of the material used for the construction of the embankment, three plate loading tests were performed at the center of each surface of the material. Tests were performed according to ASTM 4395-89 specifications and based on the directions of ISRM (Suggested Method for Deformability Determination using Plate Loading Test).

The loads applied on the embankment were imposed through the aid of a hydraulic jack ENERPAC with maximum capacity 60t and piston cross section E = 85.50 cm^2, through an iron plate with diameter d = 200 mm and total area E = 314 cm^2.

On each test, two (2) tensiometers of 0.01 mm precission and total stroke 50 mm. A CATERPILLAR 955L with a dead load of 25t was used as counter loading.

The following table presents test data for each location.

MATERIAL	TEST LOCATION	LOAD CYCLE	AIR PRESS. GAUGE STRESS (BAR)		IMMERSED STRESS (KN/m^3)	
			LOAD	UNLOAD	LOAD	UNLOAD
I	No I	A'	40	8	10.88	2.18
		B'	43	0	11.70	0
II	No II	A'	40	10	10.88	2.72
		B'	40	0	12.00	0
III	No III	A'	40	10	10.88	2.72
		B'	50	0	10.88	0

From the indications of the two tensiometers, the mean value results which corrsponds to sinkings of the plate's center eliminating possible turn. Diagrams of sinkings at the location of each test, depending on the imposed load, are presented in the Annex pages 5,6 and 7.

Ground deformability factor is calculated for loading sector and reloading sector, from the formula :

$$Er = 0.75 * \frac{Dp}{Ds} * d \text{ (in } MN/m^2\text{)}.$$

Where

Dp = Pressure increase in MN/m^2

Ds = Sinking difference in m

d = 0.20 m. Diameter of plate in m.

Thus, the two ground deformability factors are calculated which correspond to loading and reloading. During loading, the deformability factor is also affected by possible surface unevenness and sets of the ground.

The following table presents the relevant calculations :

MATERIAL	TEST LOCATION		P final kgr/cm^2	P initial kgr/cm^2	Dp MN/m^2	S final (mm)	S initial (mm)	Ds (m)	Er, φ Er, a MN/m^2	Er₁ Er₁
I	No I	1st load	10.88	8.70	0.218	3,14	1.72	$14{,}20 * 10^{-4}$	23,0	2,4
		Reload	11.70	2.18	0.952	4,306	1.56	$27{,}46 * 10^{-4}$	52,0	
II	No II	1st load	10.88	9.52	0.136	2.362	1.30	$10.62 * 10^{-4}$	19.2	1.9
		Reload	12.00	2.42	0.928	5.11	1.34	$37.7 * 10^{-4}$	36.92	
III	No III	1st load	10.88	9.52	0.136	2.205	1.31	$8.95 * 10^{-4}$	22.8	2.3
		Reload	10.88	2.72	0.816	3.451	1.12	$23.31 * 10^{-4}$	52.5	

Loading diagrams are presented on pages 5, 6 and 7 of the Annex.

10. Pocket penetrometer test

On the final surface of the test embankment for the execution of tests with pocket penetrometer, the instrument was a GEOTOP ST 308 type with head Φ 6.40 mm.

On all cases, there was refusal of instrument penetration on approximately 15 locations.

11. Proposals

Based on the test results described in the previous paragraphs and the acquired experience from pumice applications on various port works and road construction works it is resulted that pumice from Gyali Island may also be used in the case of Rome airport as a light embankment material, since it complies with all relevant requirements of the study.

Particularly on the use of pumice at the specific project and in reference to the attached cross section of the airport (Figure on page 8 of the Annex), the following are proposed :

a) Base and sub-base asphalt layers of the study (Layers A, B, B', C, D and E of the cross section of the figure on page 8 of the Annex) are constructed as anticipated in the study without asny changes. The same applies for the solid caissons of the asphalt road (E') at the feet of the runway, made of concrete with 35 cm thickness.

b) The layer for the reformation and improvement of the runway embankment is proposed to be constructed with pumice from Gyali Island, instead of expanded clay, of type I (material 8-16 mm) with layers of thickness 40-50 cm and compacted by 8% on the initial volume of each layer.

It concerns a material which has pozulanic properties, it is made condensed and stabilized easily, and after an 8% compaction, it receives a dry bulk density of 626 kg/m^3 and deformability factor Er_1 = 23,0 MN/m^2.The grain size curves of this material may lie in the dashed area of the diagram page 2 of the Annex.

c) The concrete layer (E ', figure on page 8 of the Annex), with 20 cm thickness are proposed to be disregarded and it should be replaced by pumice in a way that the entire embankment is constituted by an integral pumice body. This abolishment is facilitated by the fact that pumice, as compactible material, does not require caissoning for its stability.

d) By the use of pumice, an embankemnt is created from a pore permeable material which allows the free air movement through its mass. Also, the abolishment of the concrete layer facilitates the relief of air in case of seasonal increase or decrease of the level of the underground aquifer without having pressures developing on the airway layer.

e) The thickness of the integral pumice body is proposed to be equal to the sum of the thickness of the two layers of expanded clay and the concrete layer of the embankment, despite what is proven from the inspection of embankment weight (see inspection of embankemnt weight, page 9 of the Annex), that it could be much less. This way, the construction is ensured against any increase of the bulk density of any layer, coming from an eventual overcompaction.

f) The anticipated, by the study, geotextil , which covers the two sides of the embankment remain as specified.

Athens, February 2nd, 1998

Prepared by

(Signature)
K.DEMIRIS
PROFESSOR

(Signature)
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CIVIL ENGINEER

ANNEX

Classification and physical properties of ground sample

Drilling : **Sample :** **Depth :**

1. Granular composition curve

Clay Silt Sand Gravel Rocks

Diameter (mm)

Content in sand + gravel / silt / clay (%) =

Uniformity factor U =

Uniformity indicator =

2. Plasticity.

Liquid limit LL =

Plasticity limit PL =

Plasticity index PI =

3. Natural humidity

Natural water content Wn =

Consistancy index Ic =

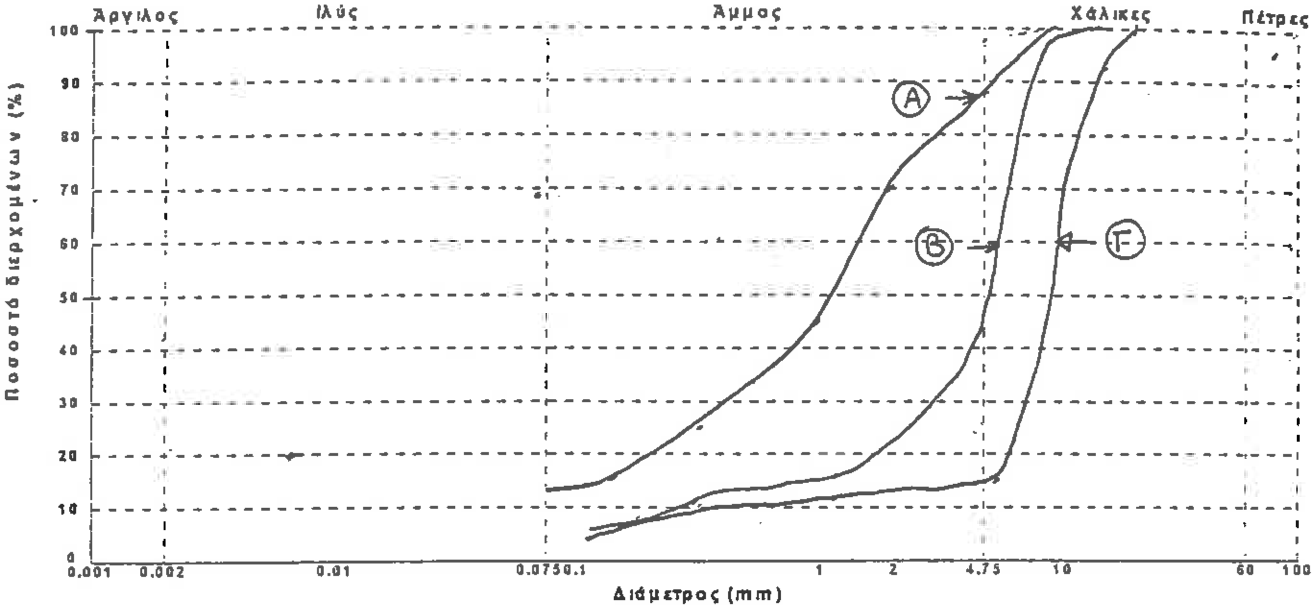
4. Classification according to AUSCS

5. Classification according to AASHTO

Κατάταξη και φυσικές ιδιότητες εδαφικού δείγματος

Γεώτρηση :   **Δείγμα :**   **Βάθος :**

1. Καμπύλη κοκκομετρικής σύνθεσης.



Περιεκτικότητα σε άμμο ÷ χαλίκια / ιλύ ÷ άργιλο (%) =
Συντελεστής ομοιομορφίας U =
Δείκτης ομοιομορφίας =

2. Πλαστικότητα.

Όριο υδαρότητας LL =
Όριο πλαστικότητας PL =
Δείκτης πλαστικότητας PI =

3. Φυσική υγρασία.

Φυσική υγρασία Wn =
Δείκτης συνεκτικότητας Ic =

4. Κατάταξη κατά AUSCS.

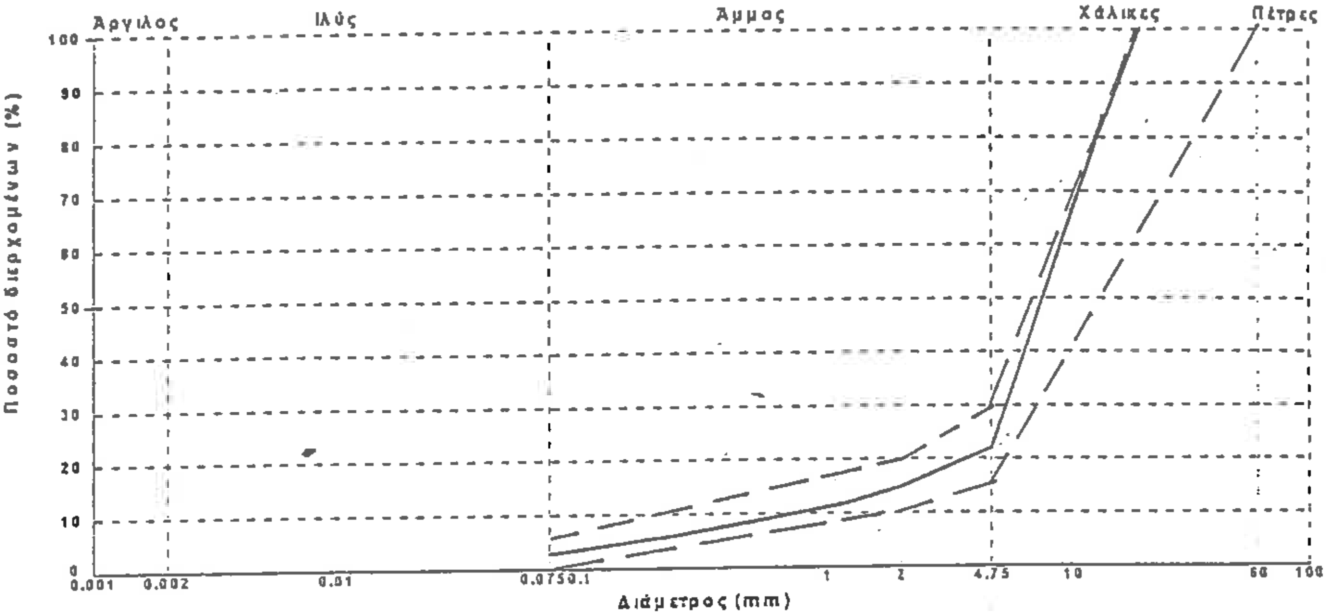
5. Κατάταξη κατά AASHTO.

ΕΔΑΦΟΜΗΧΑΝΙΚΗ ΕΠΕ ΔΕΛΦΩΝ 58 ΜΑΡΟΥΣΙ ΤΗΛ: 6897568, FAX: 6897581

Κατάταξη και φυσικές ιδιότητες εδαφικού δείγματος

Γεώτρηση : Δ1 / υλικο Ι Δείγμα : Δ1 Βάθος : m

1. Καμπύλη κοκκομετρικής σύνθεσης.



Περιεκτικότητα σε άμμο + χαλίκια / ιλύ + άργιλο (%) = 97 / 3
Συντελεστής ομοιομορφίας U = 9.192 / 0.761 = 12.079
Δείκτης ομοιομορφίας = 4.606

2. Πλαστικότητα.

Όριο υδαρότητας LL = -
Όριο πλαστικότητας PL = -
Δείκτης πλαστικότητας PI = -

3. Φυσική υγρασία.

Φυσική υγρασία Wn = 31.8 %
Δείκτης συνεκτικότητας Ic = -

4. Κατάταξη κατά AUSCS.

-

5. Κατάταξη κατά AASHTO.

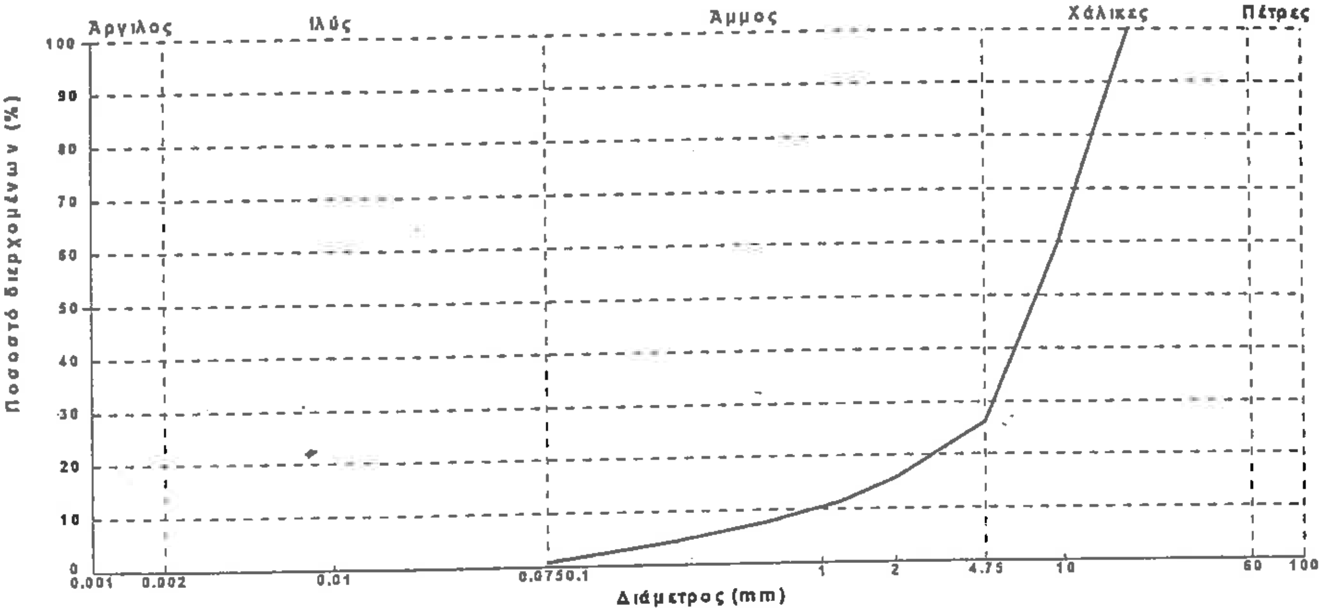
-

ΕΔΑΦΟΜΗΧΑΝΙΚΗ ΕΠΕ ΔΕΛΦΩΝ 58 ΜΑΡΟΥΣΙ ΤΗΛ: 6897568, FAX: 6897581

Κατάταξη και φυσικές ιδιότητες εδαφικού δείγματος

Γεώτρηση : Δ2 / υλικο II Δείγμα : Δ2 Βάθος : m

1. Καμπύλη κοκκομετρικής σύνθεσης.



Περιεκτικότητα σε άμμο + χαλίκια / ιλύ + άργιλο (%) = 99 / 1
Συντελεστής ομοιομορφίας U = 9.629 / 0.960 = 10.030
Δείκτης ομοιομορφίας = 3.023

2. Πλαστικότητα.

Όριο υδαρότητας LL = -
Όριο πλαστικότητας PL = -
Δείκτης πλαστικότητας PI = -

3. Φυσική υγρασία.

Φυσική υγρασία Wn = 30.2 %
Δείκτης συνεκτικότητας Ic = -

4. Κατάταξη κατά AUSCS.

-

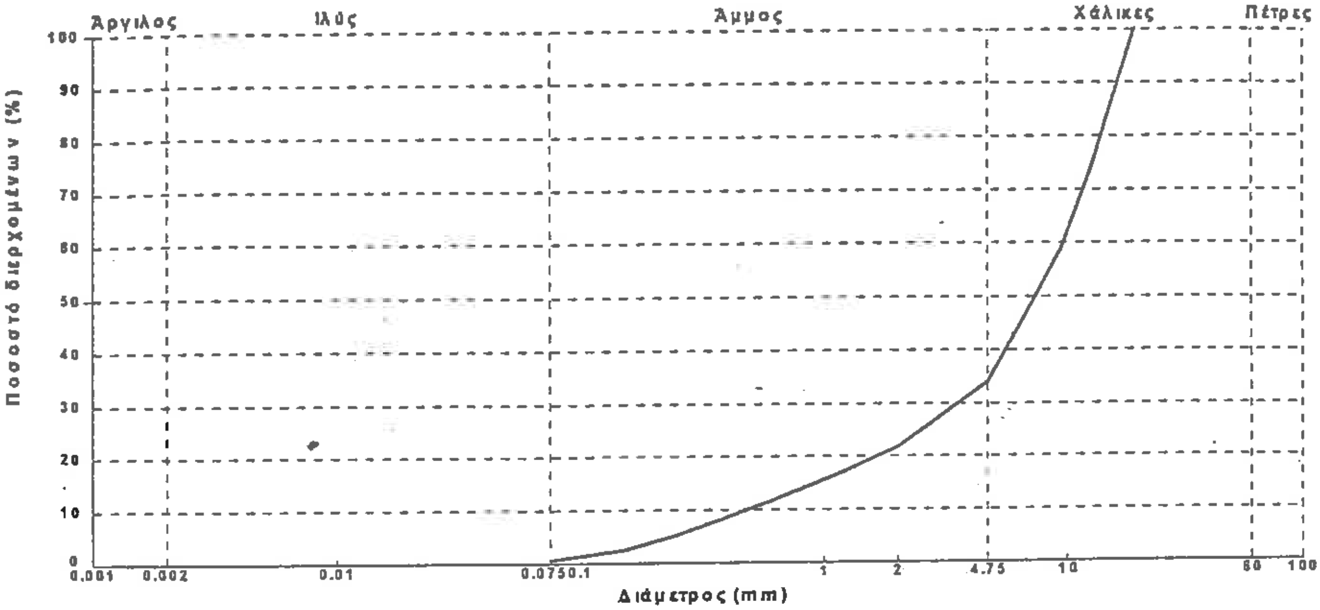
5. Κατάταξη κατά AASHTO.

-

Κατάταξη και φυσικές ιδιότητες εδαφικού δείγματος

Γεώτρηση : Δ3 / υλικό III Δείγμα : Δ3 Βάθος : m

1. Καμπύλη κοκκομετρικής σύνθεσης.



Περιεκτικότητα σε άμμο + χαλίκια / ιλύ + άργιλο (%) = 99 / 1
Συντελεστής ομοιομορφίας U = 9.760 / 0.509 = 19.175
Δείκτης ομοιομορφίας = 2.981

2. Πλαστικότητα.

Όριο υδαρότητας LL = -
Όριο πλαστικότητας PL = -
Δείκτης πλαστικότητας PI = -

3. Φυσική υγρασία.

Φυσική υγρασία Wn = 27.5 %
Δείκτης συνεκτικότητας Ic = -

4. Κατάταξη κατά AUSCS.

-

5. Κατάταξη κατά AASHTO.

-

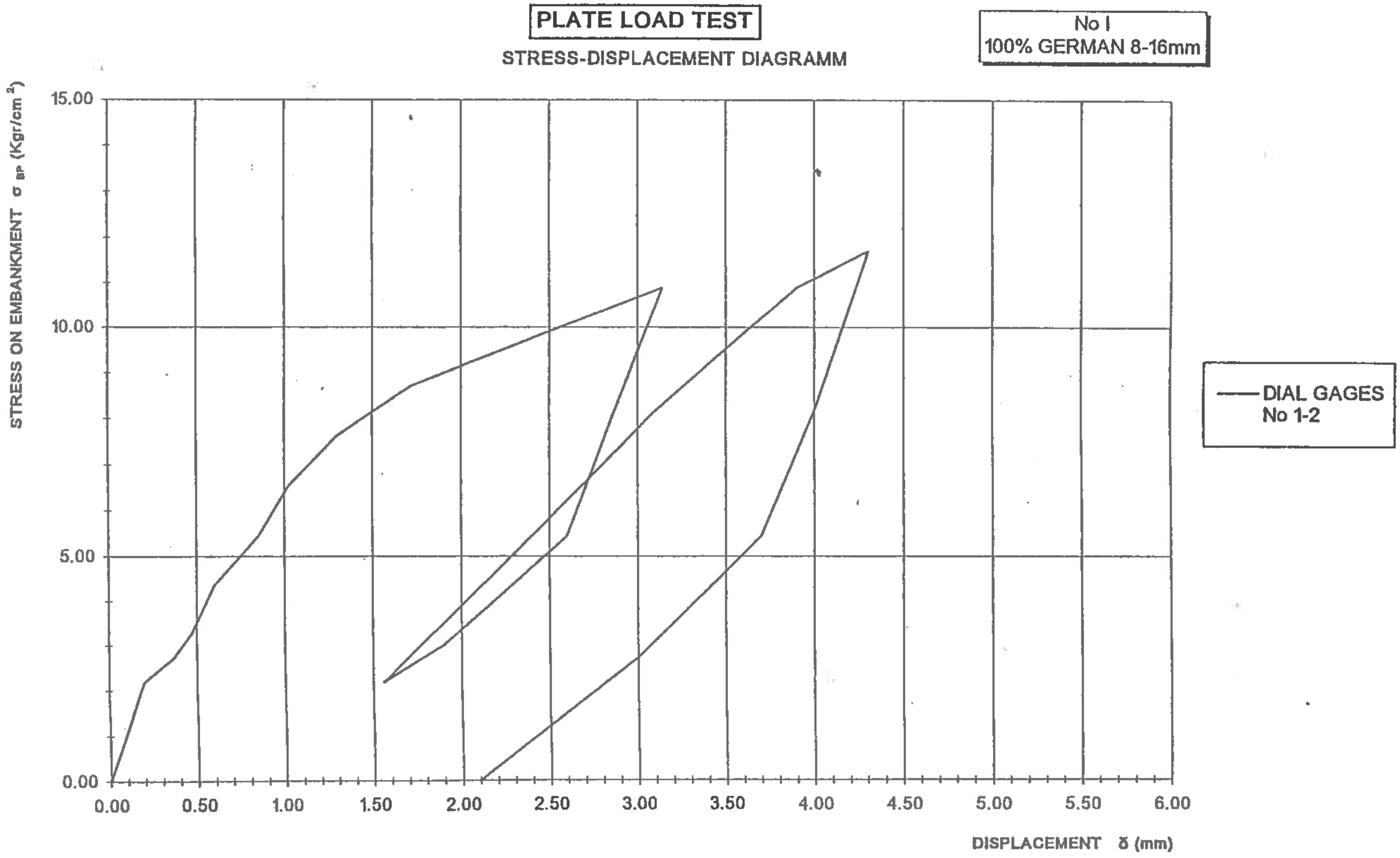


PLATE LOAD TEST
STRESS-DISPLACEMENT DIAGRAMM
No I
100% GERMAN 8-16mm
STRESS ON EMBANKMENT σ BP (Kgr/cm 2)
15.00
10.00
5.00
0.00
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
5.50
6.00
DISPLACEMENT δ (mm)
DIAL GAGES
No 1-2

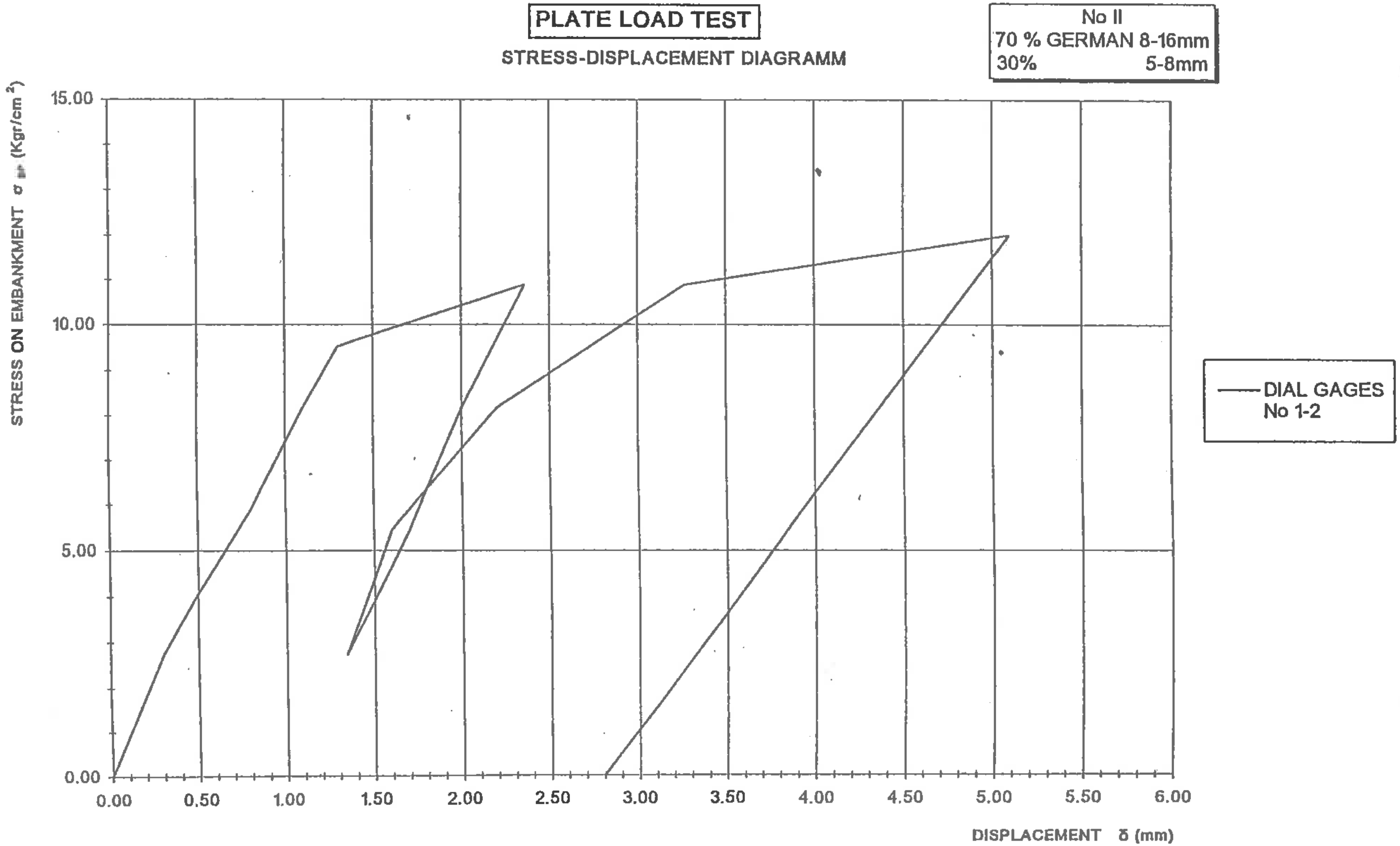


PLATE LOAD TEST
STRESS-DISPLACEMENT DIAGRAMM
No II
70 % GERMAN 8-16mm
30% 5-8mm
STRESS ON EMBANKMENT σ (Kgr/cm²)
15.00
10.00
5.00
0.00
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
5.50
6.00
DISPLACEMENT δ (mm)
DIAL GAGES
No 1-2

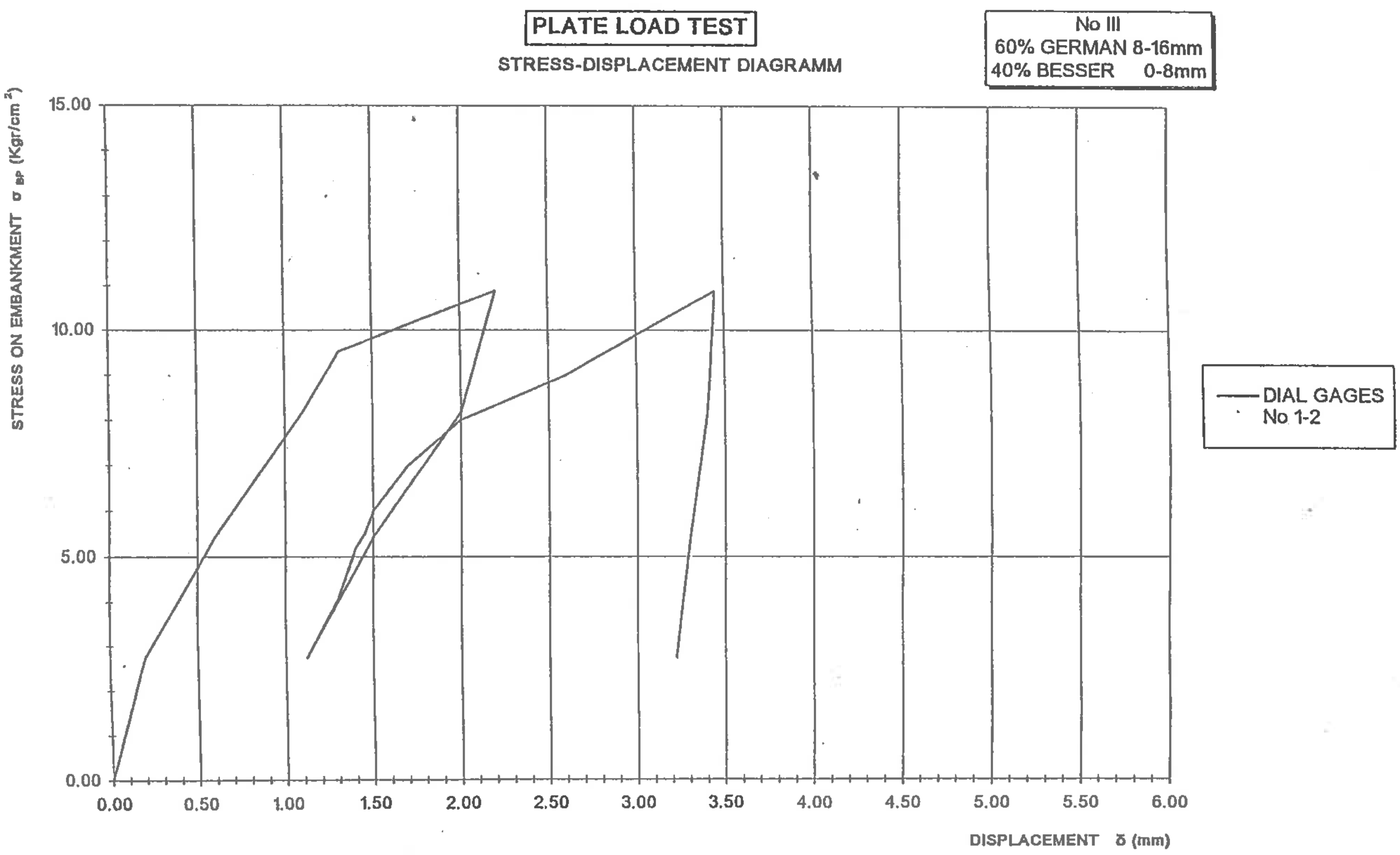
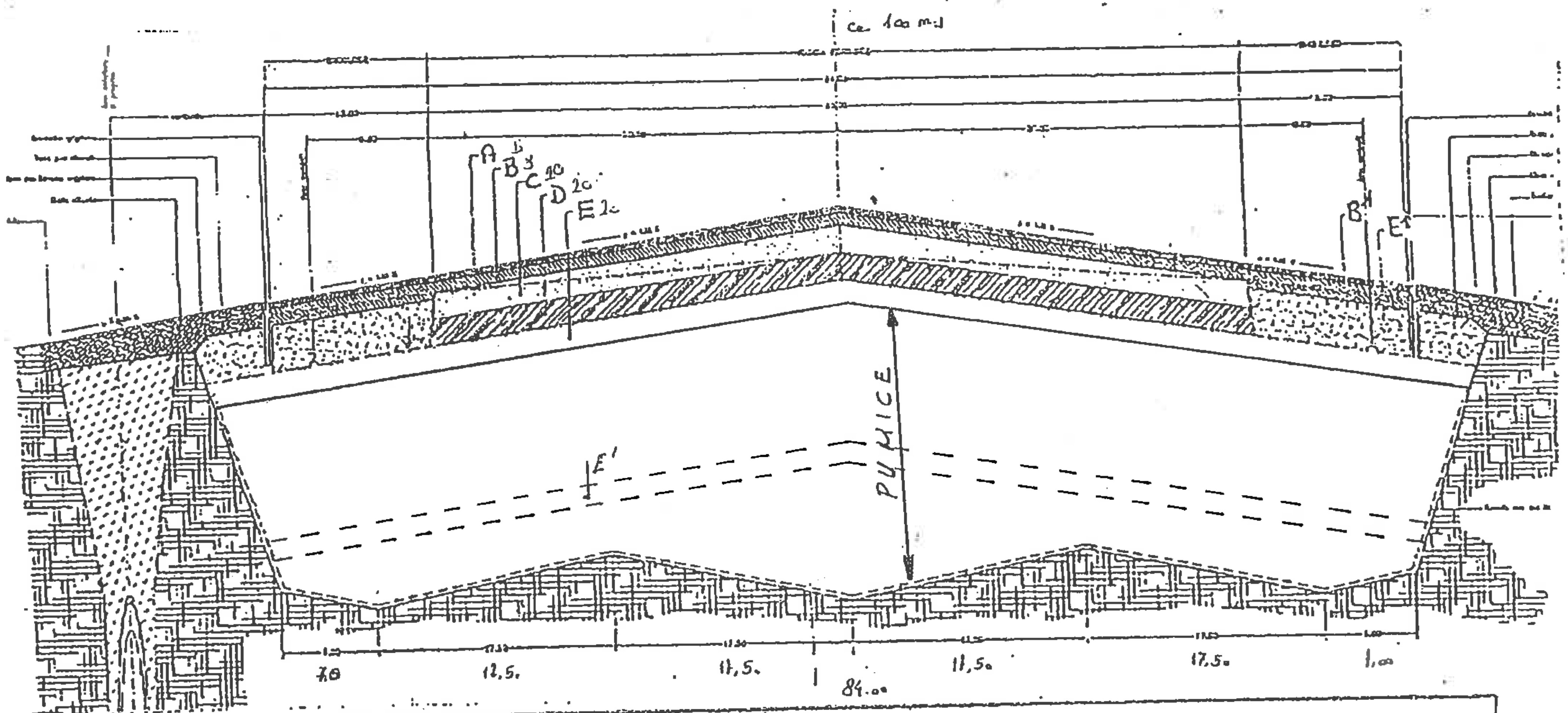


PLATE LOAD TEST
STRESS-DISPLACEMENT DIAGRAMM
No III
60% GERMAN 8-16mm
40% BESSER 0-8mm
STRESS ON EMBANKMENT σ BP (Kgr/cm²)
15.00
10.00
5.00
0.00
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
5.50
6.00
DISPLACEMENT δ (mm)
DIAL GAGES
No 1-2

I/



LEGENDA

		Materiali della sovrastruttura	Spessore degli strati (cm)	ORDINE LAVORAZIONE
6010.130	(A)	Strato di usura in conglomerato bituminoso confezionato con inerti in argilla espansa (1.55 t/m³)	5	6
6010.120	(B)	Strato di collegamento in conglomerato bituminoso confezionato con inerti in argilla espansa (1.7 t/m³)	8	5
6010.120	(B')	Strato di collegamento in conglomerato bituminoso confezionato con inerti in argilla espansa (1.7 t/m³)	13	5
6010.110	(C)	Strato di base in conglomerato bituminoso confezionato con inerti in argilla espansa (1.75 t/m³)	20	3
6005.100	(D)	Strato di base in argilla espansa legata a cemento (1.2 t/m³)	20	2
	(E)	Strato di fondazione in misto granulare stabilizzato (2.1 t/m³) (primo strato)	23	1

CHECK OF THE EMBANKMENT WEIGHT

	Pumice	Expanded Clay
Specific gravity (Kg/m^3)	2350	2550
Dry bulk density, loose	580	400
Dry bulk density, compacted	626	500
Wet bulk density of compacted mat.	11500	1250
Specific weight of water		1000kg/cm³
Bulk density of layer E'		2100kg/cm³

A. Saturated materials-Total stresses

Loads anticipated by the study

Load of compacted laying 0.20. 2100 kg/m^3 = 420 kg/m^2

Weight of condensed expanded clay = 500 kg/m^3

Weight of water (1 -500/2550) = 804 kg/m^3

1304 kg/m^3

Loads from expanded clay saturated with water

(1.05 m+ 0.50 m) X 1304 kg/m^3 = 2021 kg/m^2

Total load for embankment thickness 1.75 m 2441 kg/m^2

Loads developed with the use of pumice

Weight of compacted pumice = 626 kg/m^3

Weight of water (1-626/2350) = 734kg/m^3

1360 kg/m^3

Load from compacted pumice saturated with water

1,75m X 1360 kg/m^3 = 2380 kg/m^2

B.Wet material, compacted

Loads anticipated by the study

Load of concrete laying 0,20.2100 kg/cm^3 = 420 kg/m^3

Weight of saturated expanded clay 1055.1150 = 1782 kg/m^3

Total weight using expanded clay 2202 kg/m^3

Loads developed with the use of pumice

Weights of compacted pumice 1,75.1250= 2187 kg/m^3