

Cupolex Floors: Static Behaviour Analysis

Padua, November 30th, 2003



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1 INTRODUCTION

We report here the results of a study conducted for the Pontarolo Company about the static behaviour of concrete slabs made by employing Cupolex modules.

This research aims at the definition of numerical models as well as their experimental validation with tests in situ. A characteristic attribute of this product is its modular dome made of plastic materials with plan dimensions of about 56x56 cm.

The modules are variously interlinked to create a formwork for successive complete concrete casting.

The slabs, thanks to the distinctive domed shape of the modular elements, provide an internal orthogonal mesh allowing for air-circulation ducts. The project data refers to the concrete over layer and to the level of reinforcement needed, as established according to the soil characteristics and loading types and levels. For a more detailed description of the construction methods employed, please visit the manufacturer's Internet site: www.pontarolo.com.

The main steps used in the experimental and numeric investigations are listed below:

- Bibliography research and definition of analytical-numerical models
- Definition of a validation method and design of the experimental equipment
- Definition of tests and their implementation
- Execution of geotechnical investigations for ground characterization where testing should be conducted
- Numerical simulation of experimental testing by using the results of geotechnical investigations for ground characterization.
- Execution of ultimate load testing.
- Study of the experimental curves obtained:
 - analysis of the experimental data in comparison with the results of the single tests and notation of any anomalies,
 - initial considerations on the geometry of distorted slabs,
 - qualitative evaluation of ultimate load limits
- Comparison of numerical and experimental data along with the consequent validation of the numerical models.

By now, about 24 stress-rupture tests have been conducted on artefacts with various reinforcements, thickness and geometry.

The test is conducted by loading the artefact with a hydraulic jack until a break occurs. The load is applied to the centre of the slab and a steel ribbed plate, 0.56x0.56 m wide, is inserted between piston and concrete. At the interface of steel and CLS, a plastic layer is inserted to ensure a uniform distribution of pressures onto the loaded area (fig.1a, 1b). The jack is countered by a metallic bridge crane anchored to a basin made of reinforced concrete and about 1.5 m deep. The basin is designed to contain a layer of soil of known characteristics. The thickness of the layer of soil and the container size (as a ratio of the test-piece size) ensure that, during stress-rupture tests, the soil is not affected by the restraints provided by the containment walls and by the concrete floor at the bottom.

This statement has been verified through a finite element model in which the soil is represented as a homogeneous material with linear elastic behaviour.

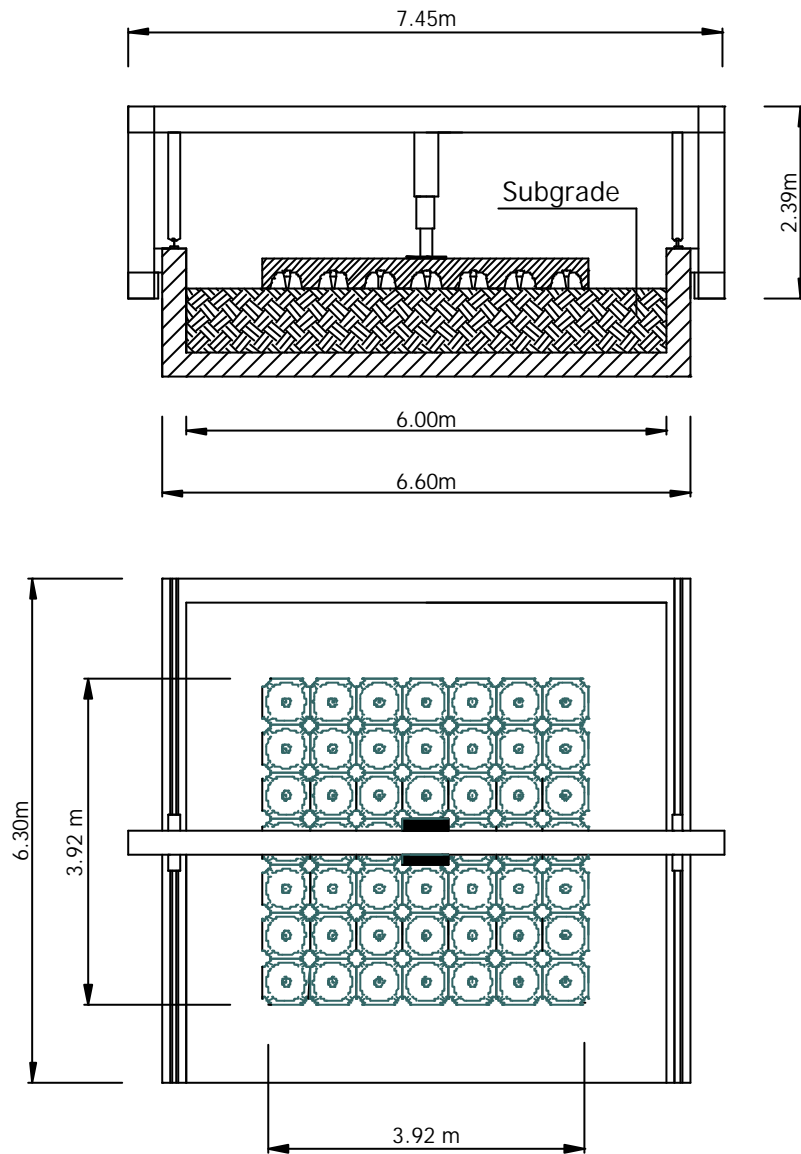
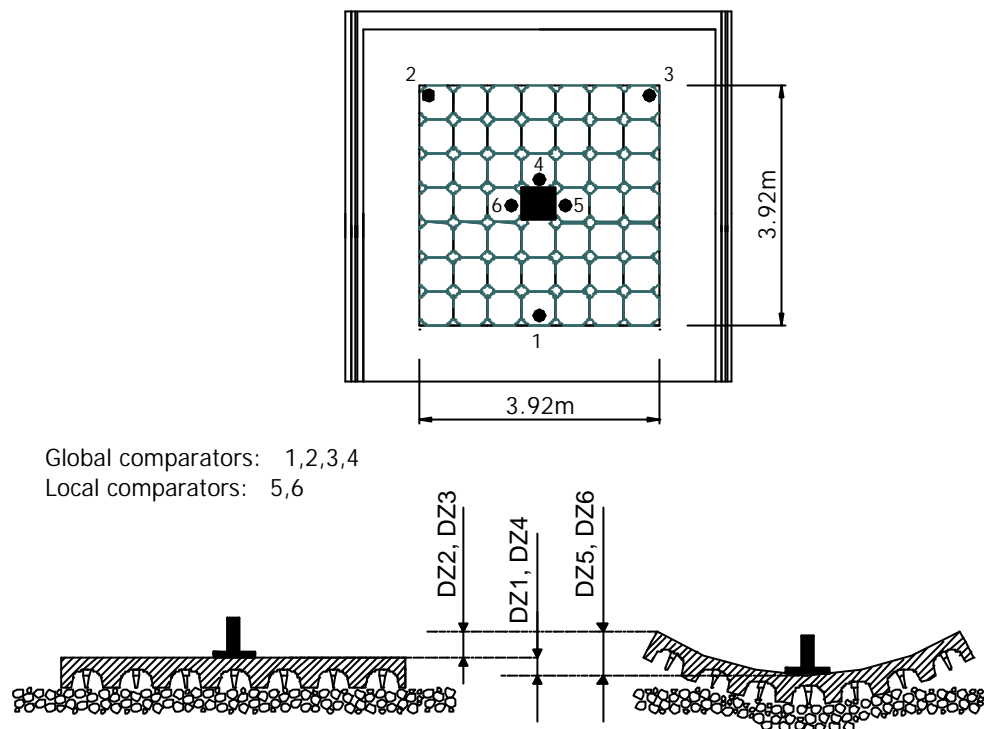


Fig. 1a Plan and cross-section of the testing basin.



Global comparators: 1,2,3,4
Local comparators: 5,6

Fig. 1b Arrangement of comparators .

A typical test piece includes 7×7 Cupolex modules placed side-by-side (fig.1b). During the latest tests (tests 23 and 24 in tab.1), the size was reduced to 5×5 modules for the purpose of conducting two tests on the same type of subsoil at the same time. The dimensional difference is irrelevant since the 7×7 test pieces, used for small slab thickness (50 mm) and centrally loaded, rise at the peripheral modules.

Limited to the cases analysed, these peripheral modules therefore give results that are irrelevant from a static point of view. Results for the '5×5' test piece may be considered equivalent to the results of the similar '7×7' test piece.

The reading of data is performed by using 6 centesimal comparators arranged as shown in figure 1. Comparators 1,2,3, and 4 are linked to the concrete basin and are set to measure absolute vertical displacement. On the other end, comparators 5 and 6 measure the relative displacement (indicated respectively as DZ5 and DZ6), which is calculated as the difference between the lowering of the central point, located immediately beside the area being loaded, and that of the midway point of the test-piece's external border.

Contact between the test piece and the soil occurs at the "feet" of the modular elements. Their plan dimensions are about 12×12 cm at the midpoint zones. Their area decreases respectively to ½ and ¼ along the perimeter and in the corners. The load being applied may be considered short-term.

By way of experimental testing, we wanted to re-create a typical mechanism of slab shear-bending rupture. As a matter of fact, during actual utilization, the most significant load distributions are those that maximize (positive and negative) bending moment; the break generally occurs when exceeding the flexural strength.

The ultimate load varies in relation to slab geometry, quality of concrete, type of soil and any reinforcement levels of the concrete.

The test is devised so that, after an initial loss of stiffness due to the flexural rupture, the load may increase again to trigger other shear/punching rupture mechanisms.

The punching rupture generally follows the flexural one.

Experimentally, the following variables were considered:

- Type of Cupolex
- Thickness of slab
- Levels of reinforcement
- Type of soil

Specifically, the following values were employed:

- *Dome geometry:*
 - H 9.5
 - H 13
 - H 26

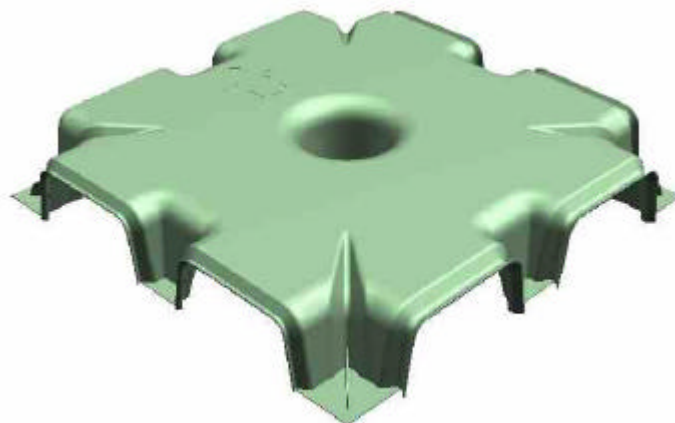


Fig. 2 Cupolex 9.5



Fig. 3 Cupolex 13



Fig. 4 Cupolex 26

- *Slab minimum thicknesses:*

- 50 mm
- 60 mm
- 80 mm
- 120 mm

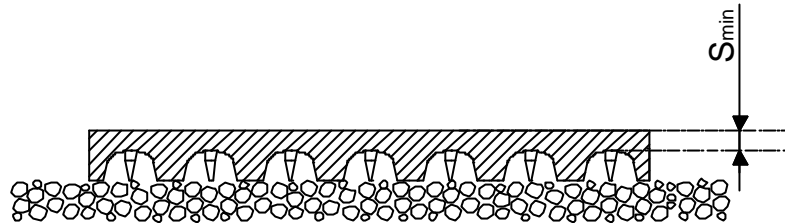


Fig. 5 Slab minimum thickness.

- *Reinforcement:*

- $\phi 6/20 \times 20$ cm electro-welded network
- $\phi 8/20 \times 20$ cm electro-welded network
- Test pieces without reinforcement
- Fibre-reinforced test pieces in concrete (25 kg/m^3 of fibres)

- *Soil:*

- Type 1 soil: surface soil collected in the zone where the tests were conducted
- Type 2 soil: loose stone foundation of compacted granular material
- Type 3 soil: lean concrete for foundations, cast on the type 1 soil
- Type 4 soil: surface soil where tests were conducted (type 1) with a layer of gravel of 10 cm

The loading tests, which were conducted thus far, are described in the table below.

Number of test piece	Type of Cupolex	Type of soil	Slab thickness (mm)	Electro-welded network	Steel fibres
1	H13	1	50	-	-
2	H13	1	50	6/20x20	-
3	H13	1	50	8/20x20	-
4	H26	1	80	-	-
5	H26	1	80	-	25 kg/m ³
6	H26	1	80	6/20x20	-
7	H26	1	80	8/20x20	-
8	-	-	-	-	-
9	H26	1	120	6/20x20	-
10	H26	1	120	8/20x20	-
11	H13	2	50	6/20x20	-
12	H26	2	80	6/20x20	-
13	H26	2	80	-	25 kg/m ³
14	H26	2	120	6/20x20	-
15	H26	3	50	6/20x20	-
16	-	-	-	-	-
17	H26	3	80	6/20x20	-
18	H26	3	120	6/20x20	-
19	H9.5	1	50	-	-
20	H9.5	2	50	6/20x20	-
21	H9.5	3	60	6/20x20	-
22	H9.5	3	80	6/20x20	-
23	H26	1	50	-	-
24	slab	4	75	-	-

Tab. 1 Experimental tests.

From a numerical point of view, the soil was represented by a non-linear spring bed displaying uncoupled behaviour (Winkler). It's a simplified schematisation which allows for a precise enough evaluation of the soil-to-structure interaction effects. The model has proven valid for a large variety of soils. Application limits are widely described in bibliography [1-5]. The schematisation's validity is assured because for the most part of soils, the shear-flexion breaking occurs with soil's differentiated settlements of millimetres and for corresponding tensions still in the elastic field.

2 TEST RESULTS

In this chapter we analyse the results of test n. 23 and n. 24. These tests are particularly important because we can compare directly the behaviour of a full slab (n. 24) with that of a floor Cupolex (n. 23). In both cases the slab are without reinforcements.

In enclosed A there are also the other concise test results.

We established the soil characteristics by employing a test on an ASTM $\phi 30$ cm plate which gave an initial coefficient of subgrade soil reaction of about 0.075 N/mm^3 . In enclosed B there are results of the geotechnic test.

For a more detailed description of the geotechnic tests, see the report of Prof. Simonini of the University of Padova.

The graph (fig.6) shows the patterns of the DZ5 relative displacement. In test piece 23, the first macroscopic rupture occurs at about 80 kN of load, corresponding at a rupture for shear/flexion. Then the curve continues to climb with a lower slope up to about 160 kN, at which load the final rupture occurs due to punching of the damaged area (photo D.27, D.28, D.29).

Test piece 24 (full slab, 75 mm thick) shows an almost constant rigidity up to 170 kN, at which limit an immediate and sudden loss of bearing capacity occurs.

The full slab shows therefore behaviour of the fragile type, while the rupture of the Cupolex slab shows higher ductility. The experimental numeric data referring to two examined cases are shown in enclosed C.

Also, regardless of the fact that the Cupolex slab transfers the load to the soil only spottily, through its feet distant 0.58 m, it displays an initial stiffness similar, if not slightly higher, than that of the full slab on compacted gravel. In both cases, the load/unload curves do not show significant stiffness variations up to loads at the levels of 60-80 kN. The behaviour is different only in the post elastic phase.

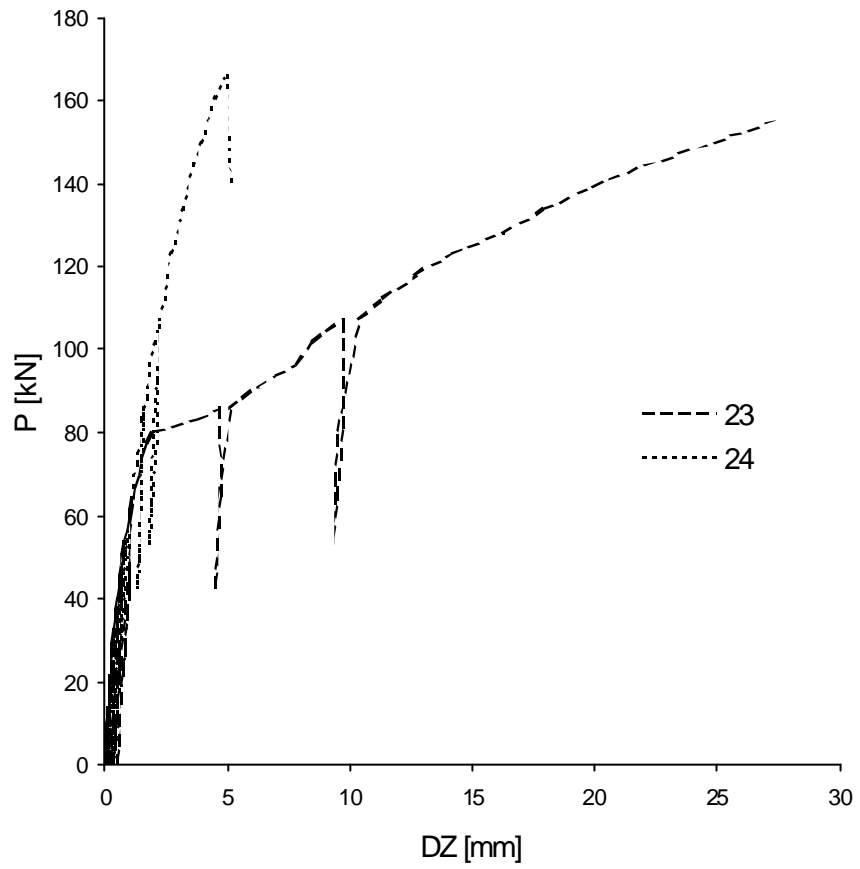


Fig. 6 Load-displacement curves – Tests 23 and 24

3 INTERPRETATION OF COLLAPSE

A linear and non-linear finite-element model was used for the simulation of a load test on the full slab (test no. 24).

Mechanical and geometry characteristics are as follows:

- slab thickness: 75 mm
- material: concrete $R_{ck} > 25$ MPa
- load: 50 kN
- coefficient of reaction: 0.075 N/mm^3

Taking advantage of the double symmetry and applying the appropriate external restraints, only a quarter of the test piece is schematised in the graph.

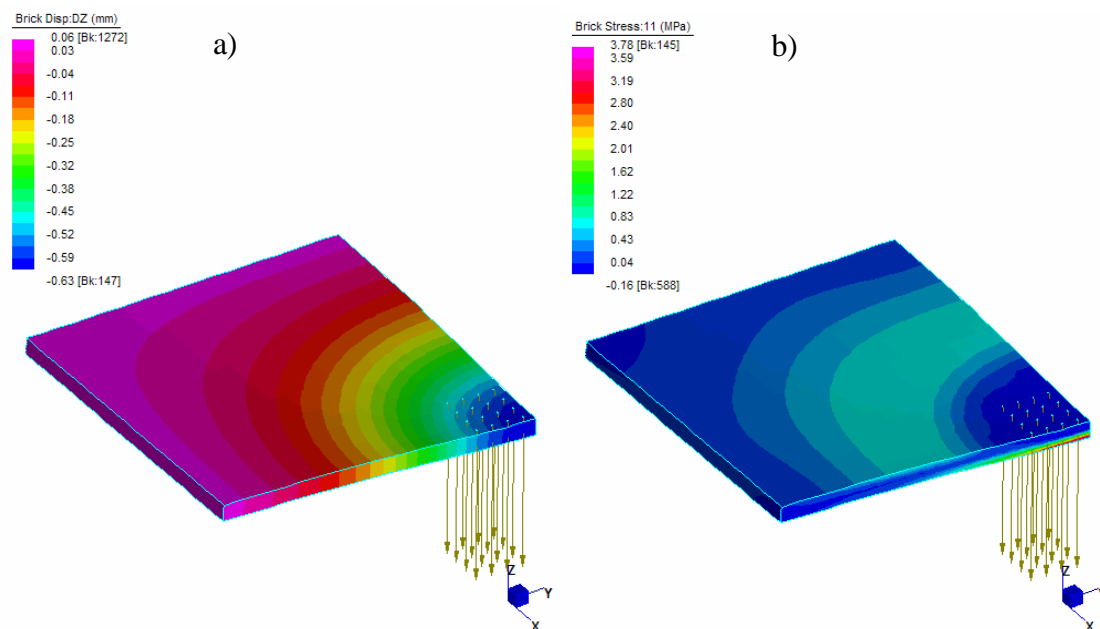


Fig. 7 Test 24: Vertical displacements and main tensile stresses for a reference load of 50 kN

Maximum displacement is 0.68 mm (Fig. 7a). Relative displacement, corresponding to the reading of comparator 5, is $-0.53 - (+0.08) = 0.61$ mm. The load-displacement curve (linear elastic material) is indicated as *fem_24a* in figure 8. In figure 7b, the colour map of the main tensile stress, for the same load of 50 kN, is shown. The maximum value of the main tensile stress is 3.5 MPa ($> f_t = 2.77 \text{ MPa}$) and it occurs at the bottom, in the centre of the indicated area.

The *fem_24b* curve (fig.8) describes the results by using the hypothesis of non-linear elasto-plastic materials (Mohr Coulomb) and non-linear elastic springs with load functions obtained by plate testing. A complete plasticization of the central loaded zone, and consequent final rupture by punching, occurs at a load of 160 kN. The two models, with finite-element grid (beam elements) or with plate (shell elements), show similar results.

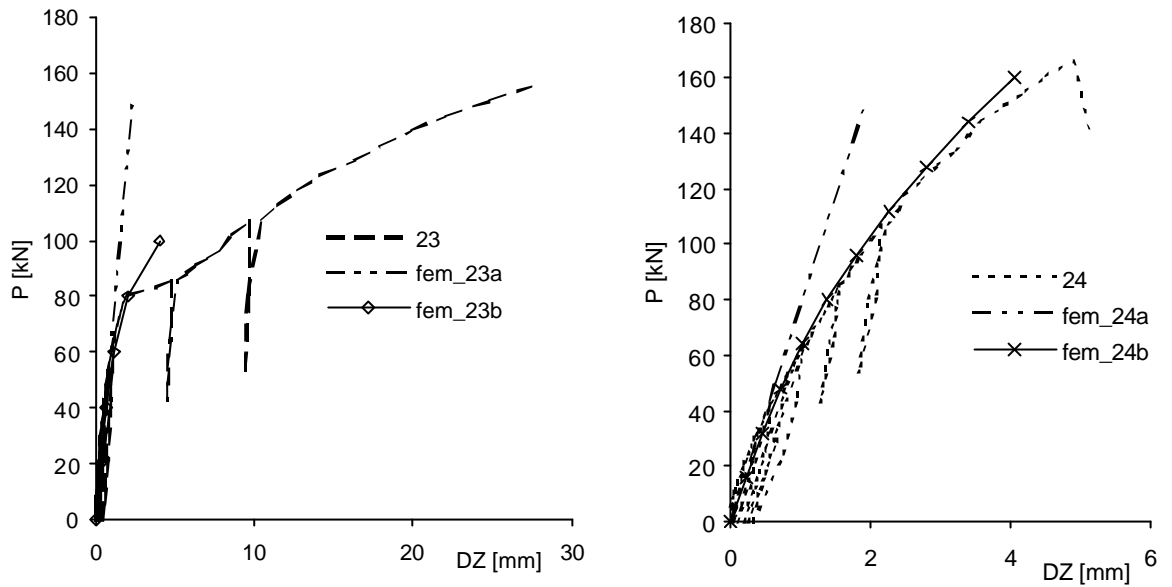


Fig. 8 Tests 23, 24: comparison between numeric and experimental data

The grid models, initially implemented in the Cupolex program, by considering the experimental results, proved excessively conservative. The employment of a flat beam grid, of constant stiffness and equivalent section equal to the minimum section of ribbing, underestimates both the stiffness and ultimate strength of the artefact.

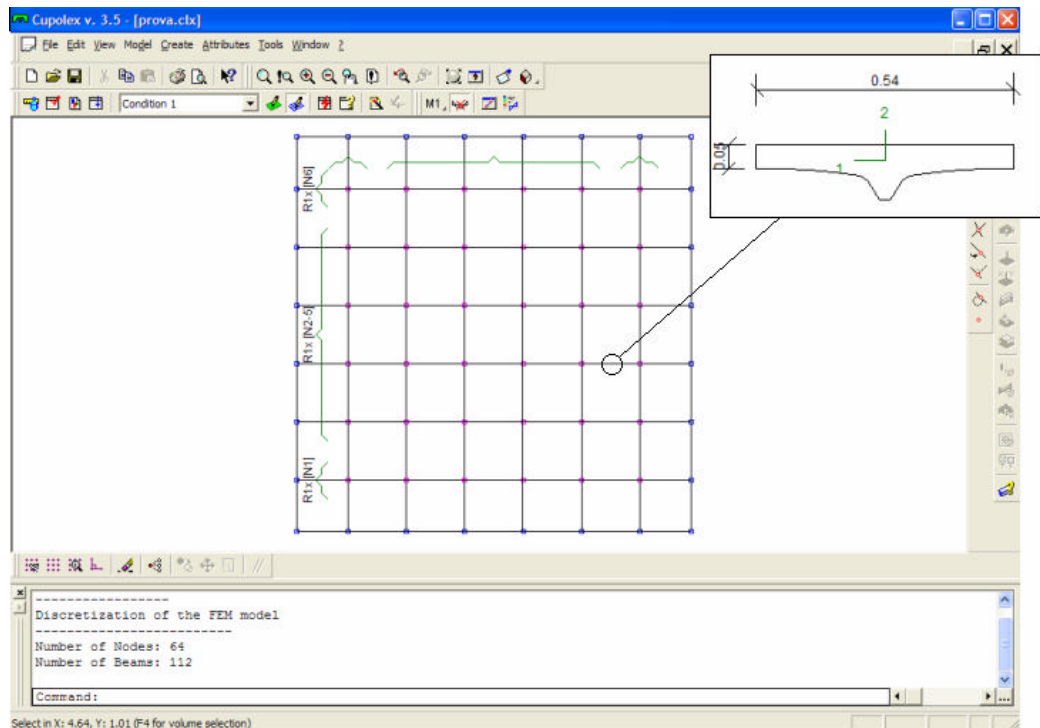


Fig. 9 Grid model (Cupolex program)

Contrary to the previous case (full slab), where the topology of the elements was not particularly relevant, for floor Cupolex a three-dimensional finite-element model seemed to be an almost obvious choice in order to correctly represent the complex geometry of the artefact.

To limit the number of degrees of freedom, by exploiting the various symmetries and imposing restraints by using Lagrange multipliers, only one eighth of the structure was schematised in the graph. We considered the actual load area on the soil ($12 \times 12 = 144.0 \text{ cm}^2$). The coefficient of reaction of the soil related to the actual load area was established by applying a correction factor obtained using an ASTM $\phi 30$ plate test (Terzaghi). The multiplier used is equal to the ratio between the diameters of two plates, and in this case is 2.5. Such assumption was verified experimentally by direct testing on a modified plate of reduced dimensions equal to the dimensions of the foot ($12 \times 12 \text{ cm}$).

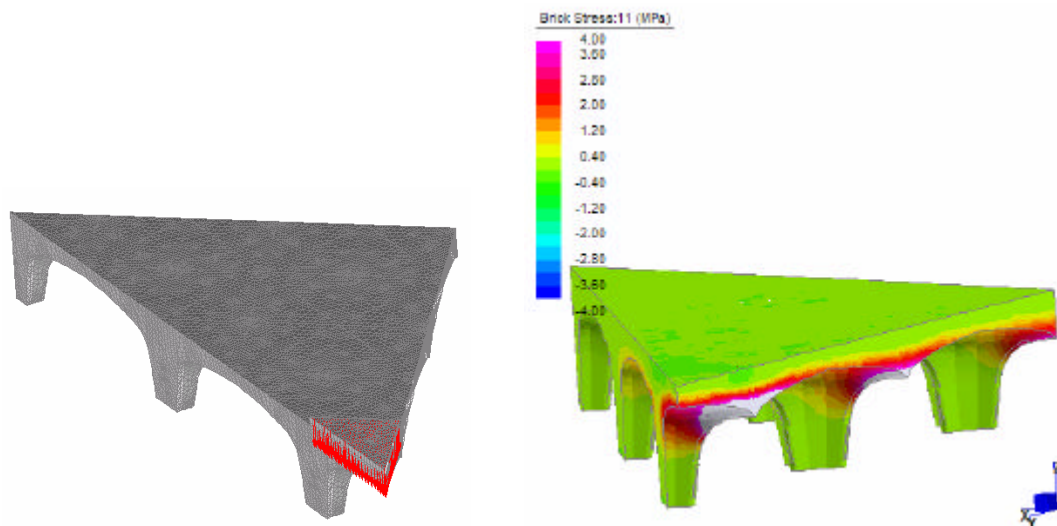


Fig. 10 3D model employed. The representation considers only one eighth of the structure. The red arrows represent the load applied by the jack. Figure 10b shows the colour map of the main tensile stresses for a reference load of 50 kN.

The model has approximately 33,000 nodes and 150,000 4-node isoparametric bricks. The corresponding degrees of freedom are approximately 100,000.

The results of the non-linear model are in good agreement with the experimental ones (Fig. 8a). Without reinforcements the collapse is assumed when the maximum tensile stress of concrete is reached.

With respect to structures without steel reinforcement or weakly reinforced, and in compliance with the European Eurocode, Canadian, Italian D.M. 9.1.96 and Italian CNR DT 103/97 standards, the load which gives concrete stresses equal to the (tensile) limits of the material may be considered the ultimate limit load.

Moreover, for design purposes, it is necessary to divide the limit stress by a coefficient, e.g. $\gamma_n = 1.8$ (EC2 Part-6: structures that are without reinforcement or weakly reinforced).

The ultimate load limit that we see from the load-displacement curve is about of 80 kN, and can be determined by using non-linear material analyses or by making use of the science of fracture mechanics, which is particularly helpful in describing the behaviour of stressed concrete, the fragility of which appears to increase in the absence of reinforcements.

As we can see from numerical analysis the material's limit traction is reached for lower load and is non directly legible in experimental curves.

The elastic-plastic analyses are important only for the purpose of scientific research; as we said, for design purposes, instead, we must consider the elastic limit of material.

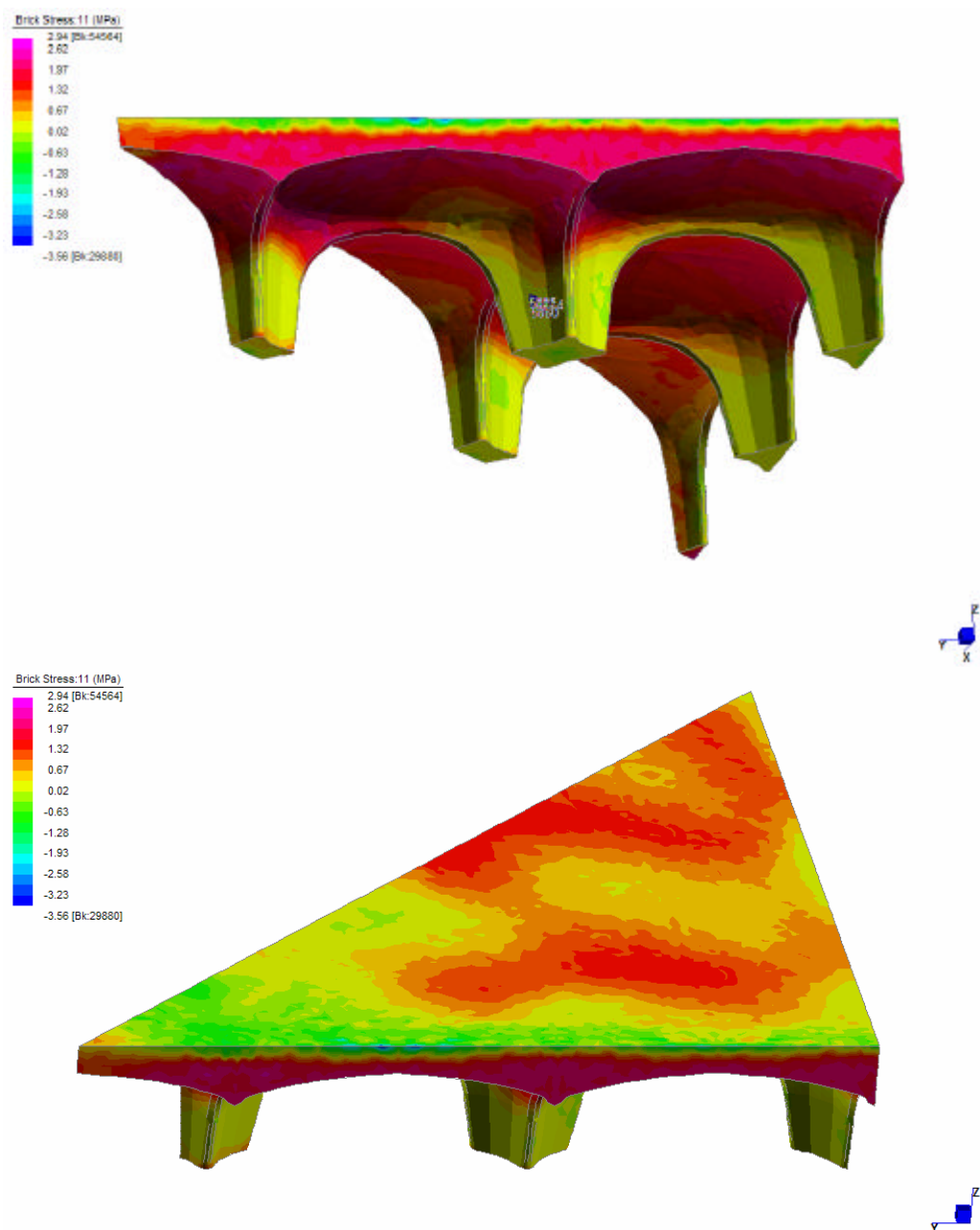


Fig. 11 Colour map of the main tensile stresses for a load of 140 kN. Viewed from below and above.

With respect to the Cupolex slabs, in determining the limits of the crack opening, the secondary concrete ribs corresponding to the stiffeners of the plastic cast may be considered 'non-structural' (fig.12). Those protrusions contribute only to a secondary stiffness and do not constitute crack tips in terms of fracture propagation. In any case, in order to optimise slab performance, anomalies in geometry should be limited so that smooth and cut-free cast surfaces may be obtained.

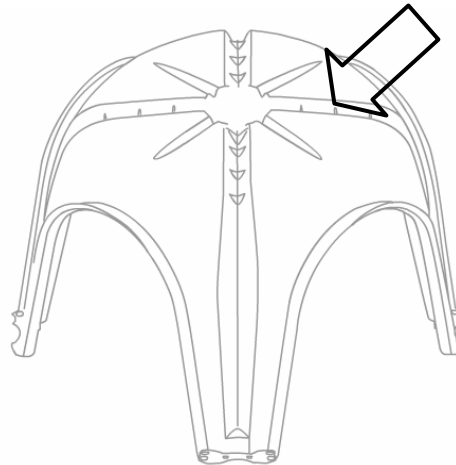


Fig. 12 Secondary ribs not considered during calculation and verification

With regard to the cases of full slabs and Cupolex slabs analysed, limited to the particular load conditions considered, the ultimate stress of the material is exceeded respectively at loads of 40 kN and 30 kN. These values numerically calculated have been obtained considering a characteristic tensile stress ($\gamma_n = 1$).

The resulting working load is, in both cases, much lower than that which may be deduced on the basis of the experimental load-displacement curves only (Fig. 8).

	Full slab	Floor Cupolex
First cracks (*)	40 kN	30 kN
Loss of stiffness	---	80 kN
First crack in extrados		
Break for shear-punching	170 kN	160 kN

(*) Numerically calculated; the first cracks come on the central inferior superficies of plate and are not visible.

3.1 RESULTS OF NUMERICAL ANALYSIS WITH A REDUCED SOIL COEFFICIENT OF ELASTICITY

The numerical analyses have been repeated considering a halved soil coefficient of elasticity ($k_w \cong 0.035 \text{ N/mm}^3$).

The first crack is reduced of 12%, from 30 to 26.8 kN.

4 NUMERICAL MODEL AND VERIFICATION

The numerical model that better suits the experimental results is the one with brick elements in non-linear method.

For the design, in order to accelerate the model elaboration and solution time, we suggest a uniformly distributed plate finite elements model on an independent springs bed (Winkler), with the following coefficient of elasticity:

For subgrade of lean concrete (at least 5 cm for standard houses):

$$k_w = k_{w0}$$

without poor concrete:

$$k_w = k_{w0} \cdot A_p / A_m$$

where:

k_{w0} = calculated from plate tests (ASTM)

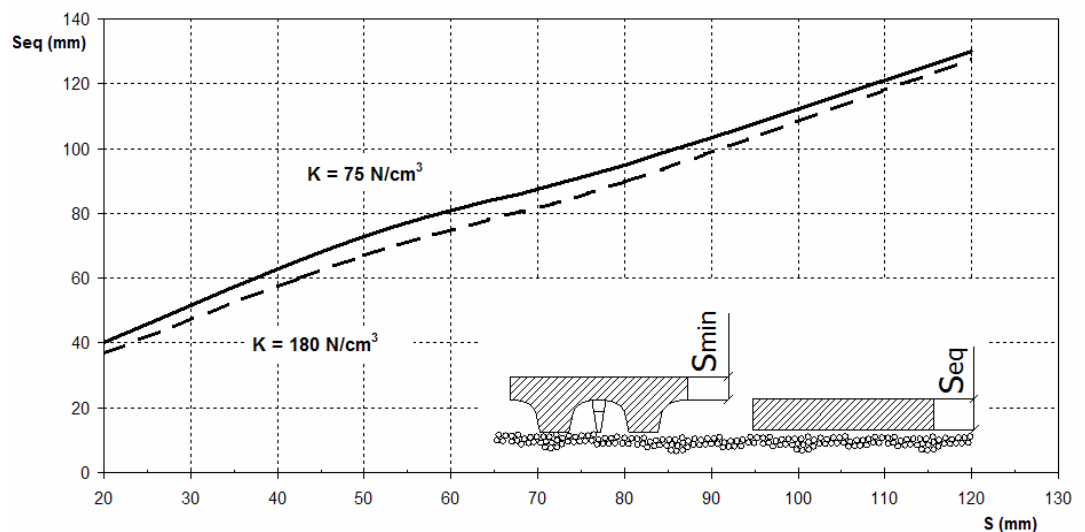
A_p = foot's area (ex. 12x12 cm)

A_m = Modulus's area (ex. 56x56 cm)

The plate numerical model is similar to the brick model if we consider a thickness equivalent S_{eq} greater than S_{min} .

The increasing of the thickness is due to the presence of feet and in general to the three-dimensional geometry of Cupolex. This increasing has been evaluated in terms of displacement equivalence considering several coefficients of soil reaction.

In the following figure the equivalent thickness for $k = 75 \text{ N/cm}^3$ end $k = 180 \text{ N/cm}^3$ is shown:



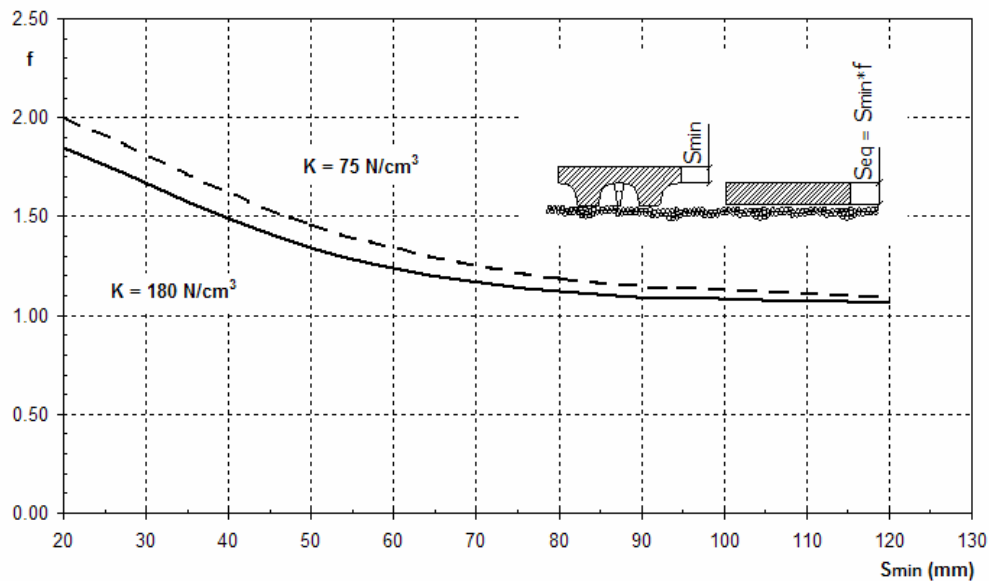


Fig. 13 S_{eq} for plate elements models

Once the displacements and the internal forces are known, considering the real geometry of structure the following tests must be verified:

- bending and shear verification for the most unfavourable conditions load.
- punching for a concentrated load in the central singular Cupolex
- soil stress verification

Moreover, commonly used disposals for traditional slab must be adopted: construction joints, steel reinforcements for shrinking and thermal variations, etc, according the reference standards.

4.1 PUNCHING VERIFICATION

The punching verification can be made according the reference standard. We adopt, for example, the method proposed in the EC2. The verification considers slabs with or without steel reinforcements.

The shear resistance for unit of length is given by:

$$V_{Rd1} = t_{Rd} \cdot k \cdot (1.2 + 40r_1) \cdot d$$

where:

V_{Rd1} = design shear resistance for unit of length for non-prestressed slabs

t_{Rd} = design shear stress resistance

$$t_{Rd} = \frac{0.25 \cdot 0.7 \cdot f_{ctm}}{g_c}$$

f_{ctm} = mean value of the tensile strength of concrete

$$f_{ctm} = 0.27 \cdot \sqrt[3]{R_{ck}^2}$$

R_{ck} = characteristic cubic compressive strength of concrete

$\gamma_c = 1.8$ (material safety coefficient)

d = slab effective height

$k = \max(1, 1.6 - d) \geq 1$ (d in meters)

$$r_1 = \sqrt{r_{1x} \cdot r_{1y}} \leq 0.015$$

r_{1x}, r_{1y} = steel area in direction x and y divided by concrete area

The punching verification is satisfied if:

$$V_{Rd1} \cdot u < N_{sd}$$

Where:

u = critical perimeter

N_{sd} = design load defined in EC2

The critical perimeter for circular or rectangular areas far from free edges is defined as the perimeter of the loaded area at a distance of 1.5 d.

The punching limit, for load area (projected) wider than 30×30 cm, is reached at higher loads than those causing an initial crack. Checks may be conducted locally, at the level of a single module, by placing the load in the most unfavourable position.

5 CONCLUSIONS

The research project has given a general and easy to apply method to calculate and verify Cupolex floors variously loaded.

- The static behaviour of the Cupolex floor depends on the following factors:
 - 1) geometry:
 - dome geometry
 - minimum thickness of the slab
 - 2) type of soil
 - 3) position of loads
- Three different schematisations have been considered:
 - 1) Beam grid model (fig. 9)
 - 2) Plate model (fig. 14)
 - 3) 3D model (fig. 15)

The suggested schematisation for practical applications is that with plate elements with equivalent thickness, ref. §4.

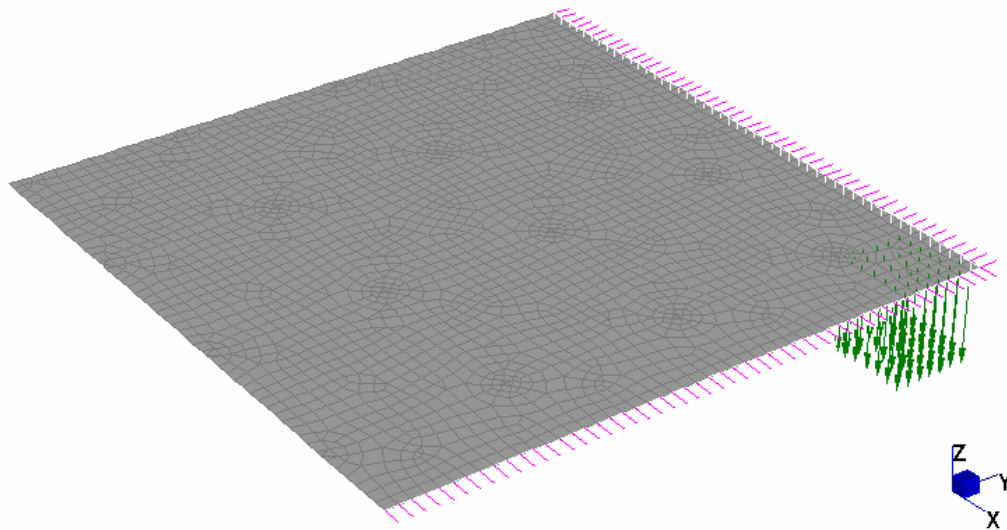


Figure 14 Plate model (1/4).

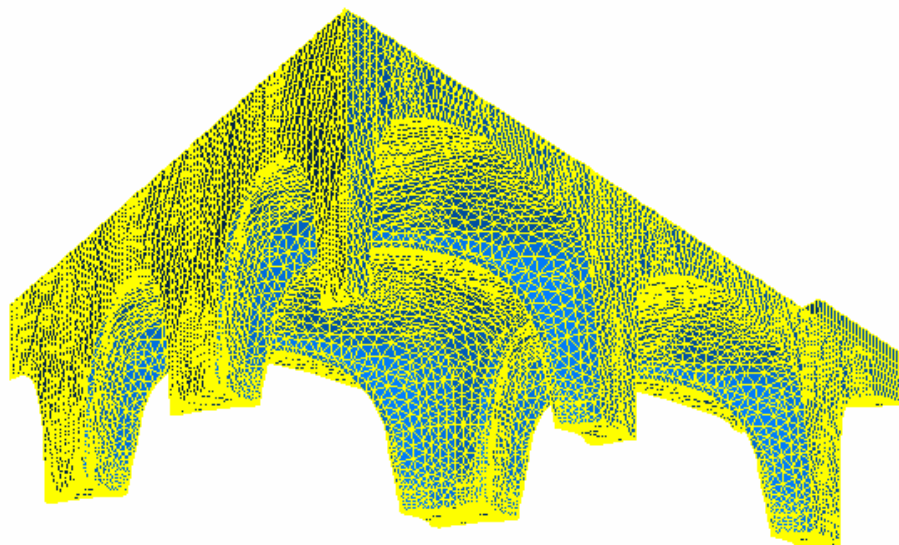


Figure 15 Modello 3D-H26 (1/8)

- The results of the loading tests on ASTM plate show that the soil coefficient of elasticity of mean size gravel is greater than that of silt and sand found in situ. The tests show also that, for the same slab, the results with a soil type 1 are not very different from those with soil type 2. The size of the gravel, of about 1 cm, does not permit a uniform and stable support of the 12 cm wide feet. The instability is lower for wider load areas (ex. for ASTM test: plate of 30 cm).
Gravel subgrade may give good results if grains are fixed with cement. Otherwise better results will be obtained adopting lean concrete foundations (5-10 cm) or opportunely mixed 'tout venant'.
- The rupture behaviour of the Cupolex slabs shows an unexpected and useful structural ductility regardless of the absence of reinforcements. Such feature may be explained only by considering the statically indeterminate effect provided by the supporting feet; the useful effect is proportionately greater according to a greater degree of restraint to horizontal shifting on the feet themselves. Performance is greatly enhanced, both in terms of strength and stiffness, if the subgrade consists of lean concrete. A partial penetration of the feet into the fresh lean concrete would further enhance the structure's behaviour, which would take characteristics similar to those of a full slab with dimensions slightly smaller than the element itself (20-25 cm).
- The soil coefficient of elasticity to use for the slab verification can be found out with loading tests in situ with standard plate or, better, with a 12×12 cm plate, wide as the Cupolex feet. Where loading tests are not possible, the value of k_{w0} can be assumed on the base of experience or technical literature. In table 4.1 some characteristic values for different types of soil are shown.

Soil	k_{w0} (N/cm ³)
Loose sand	4.8-16
Meanly compacted sand	9.6-80
Compacted sand	64-128
Meanly compacted clayey sand	32-80
Meanly compacted silt sand	24-48
Clay:	
$q_u \leq 200$ kPa	12-24
$200 < q_u \leq 400$ kPa	24-48
$q_u > 400$ kPa	>48

Table 2 Bowles, J.E.(1998), *Foundation Analysis and Design*. Ed.McGraw-Hill, New York.

In the presence of a layer of compacted silt sand the value of k_{w0} can be assumed from 30 N/cm³ to 50 N/cm³, independently from the underlying layer.

- Also a non-uniform contact with the soil has been taken into account (for example different yielding) preparing the test slabs out from the test basin. The results are reported in A.

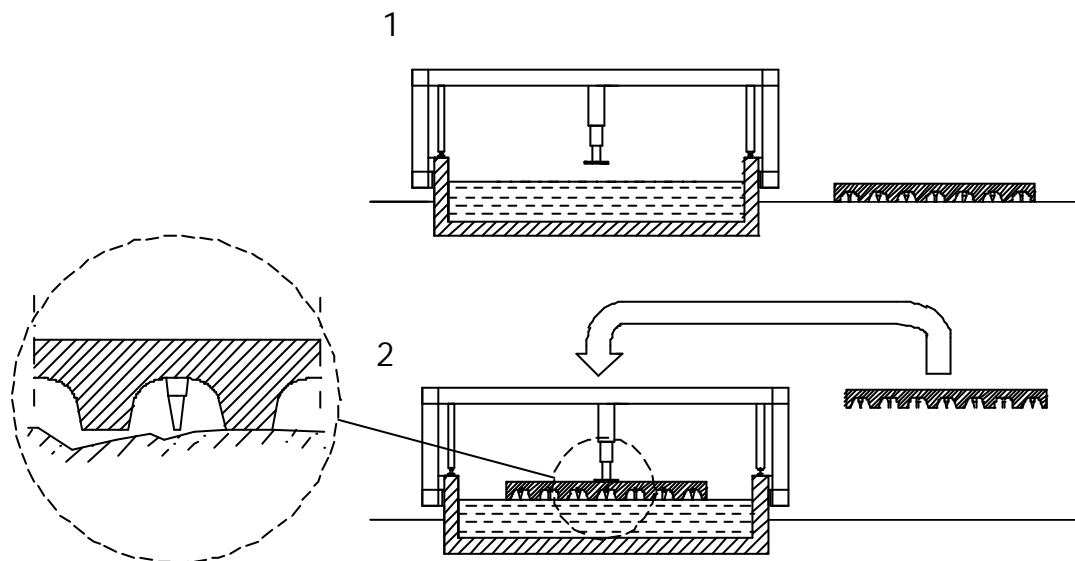


Figure 16 Preparation of test slabs 1-22.

- According to the experimental results, for the types of soil taken into account (silt sand, gravel, lean concrete), the Cupolex slab, with a minimum thickness of 50 mm, satisfies the Italian standard D.M 16/9/96 for category 1 (vertical uniformly distributed loads of 2 kN/m² and concentrated vertical loads of 2 kN). Steel reinforcement shall be calculated for shrinkage and thermal load only.



- For loads of greater intensity we suggest to find out the stress, strain, displacements and pressure on the soil from the 'plate' model described in §4. Verifications shall be carried out according to the reference standards.



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ENCLOSED A: BREAKING TESTS RESULTS

In the following figures the graphs of the displacements (DZ5) for some test slabs are reported. A direct comparison of the different bending stiffness of the slabs can be made.

The test slabs 23 and 24 have been made in situ. The test slabs 1-22 have been instead made out of the basin test. After 28 days each slab has been lifted and put on the basin for the braking test. The experimental results show, with respect to slabs 23 and 24, a decrease of the bearing load.

The cause is that the contact with the soil is not perfect for each foot of these slabs, with a consequent decrease of the first crack load.

Also numerical results show that a gap of some millimetres between a foot and the soil, in particular on soils of good mechanical characteristics, strongly decreases the bearing load of the artefact.

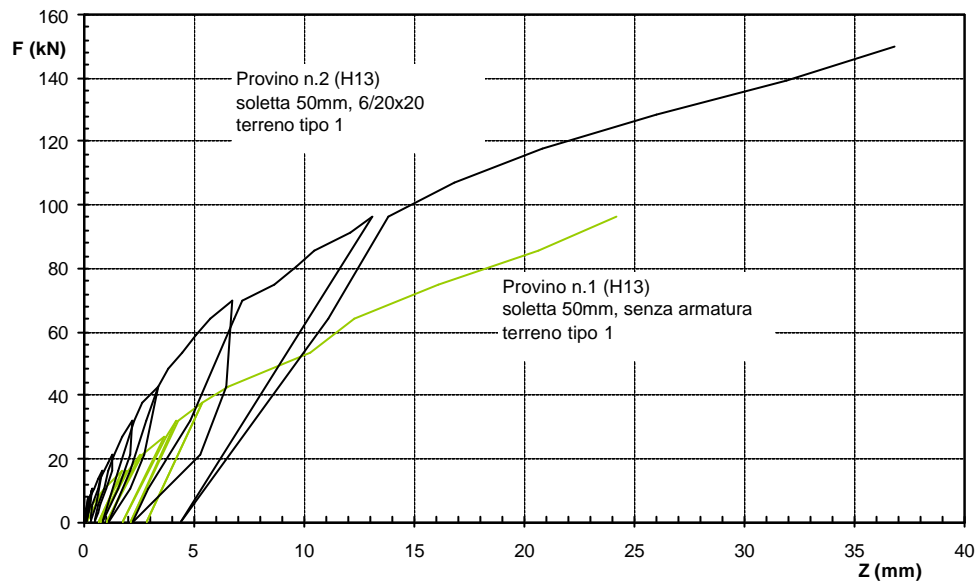


Fig. A.1 Comparison between the results of test 1 and test 2.

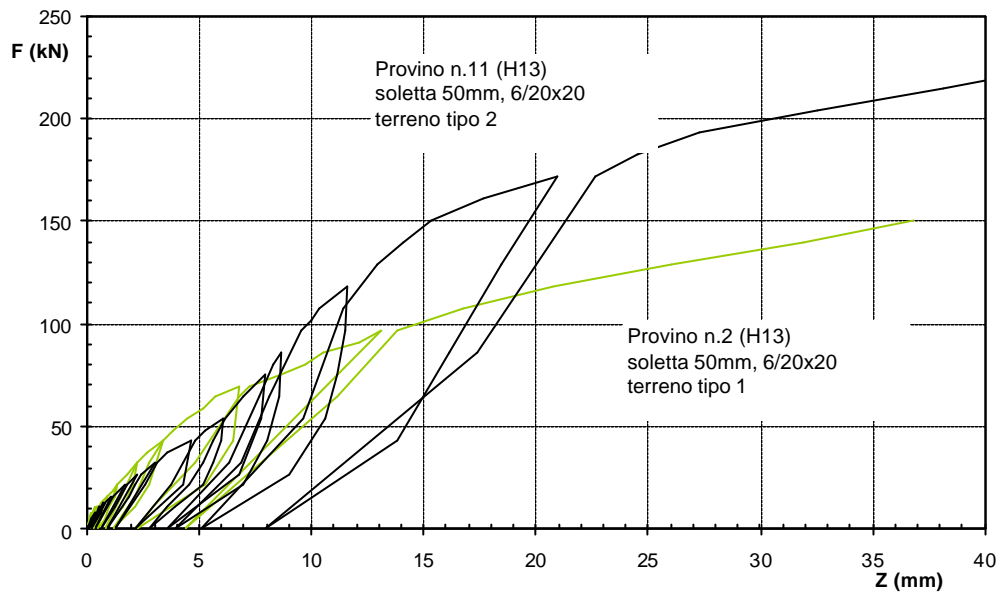


Fig. A.2 Comparison between the results of test 2 and test 11.

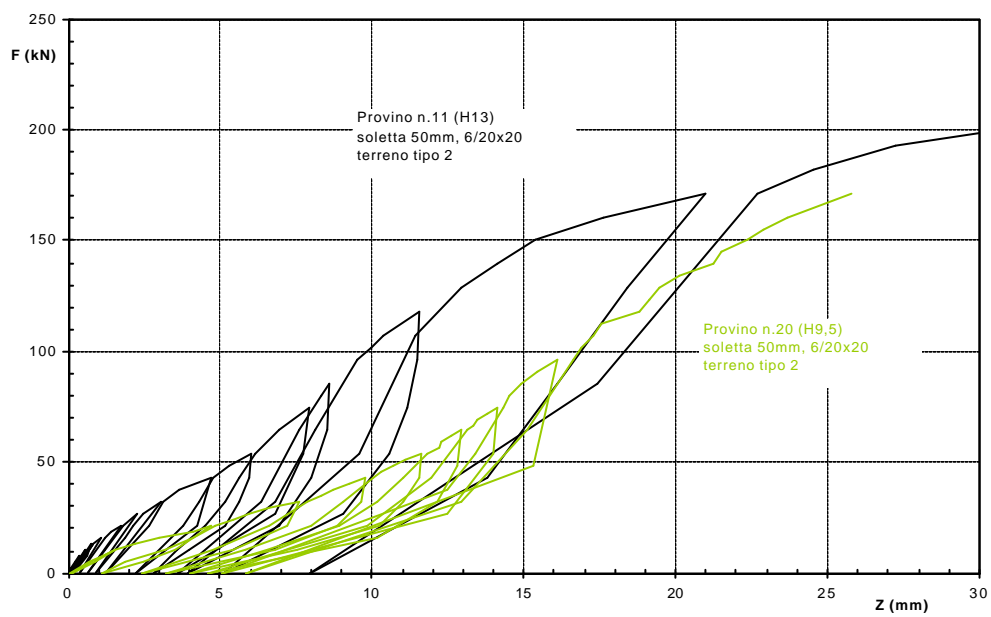


Fig. A.3 Comparison between the results of test 11 and test 20.

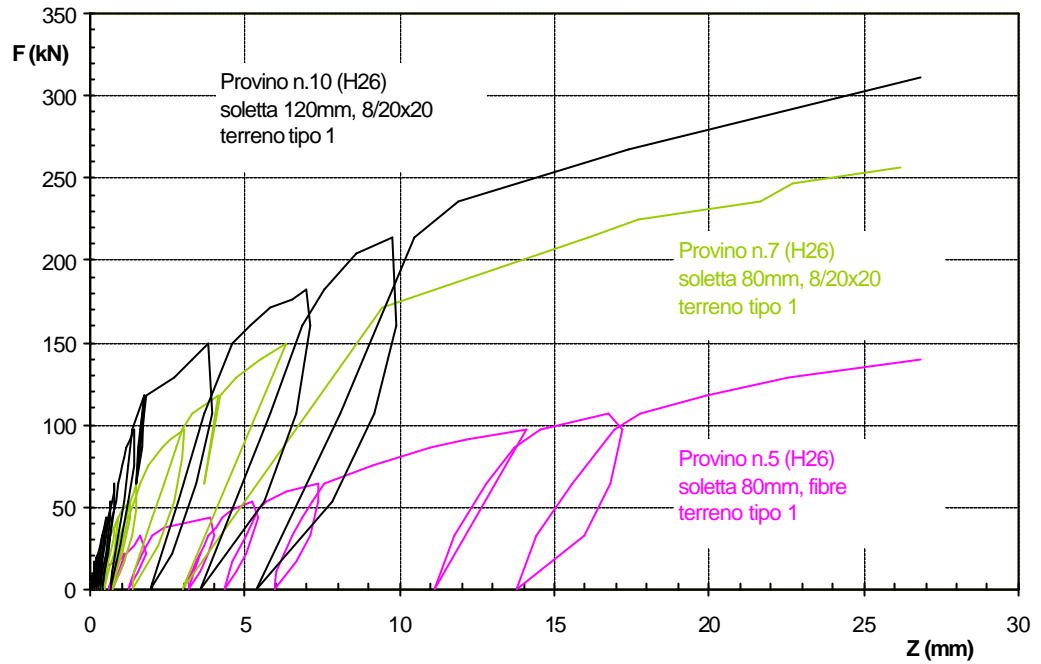


Fig. A.4 Comparison between the results of test 5, 7 and test 10.

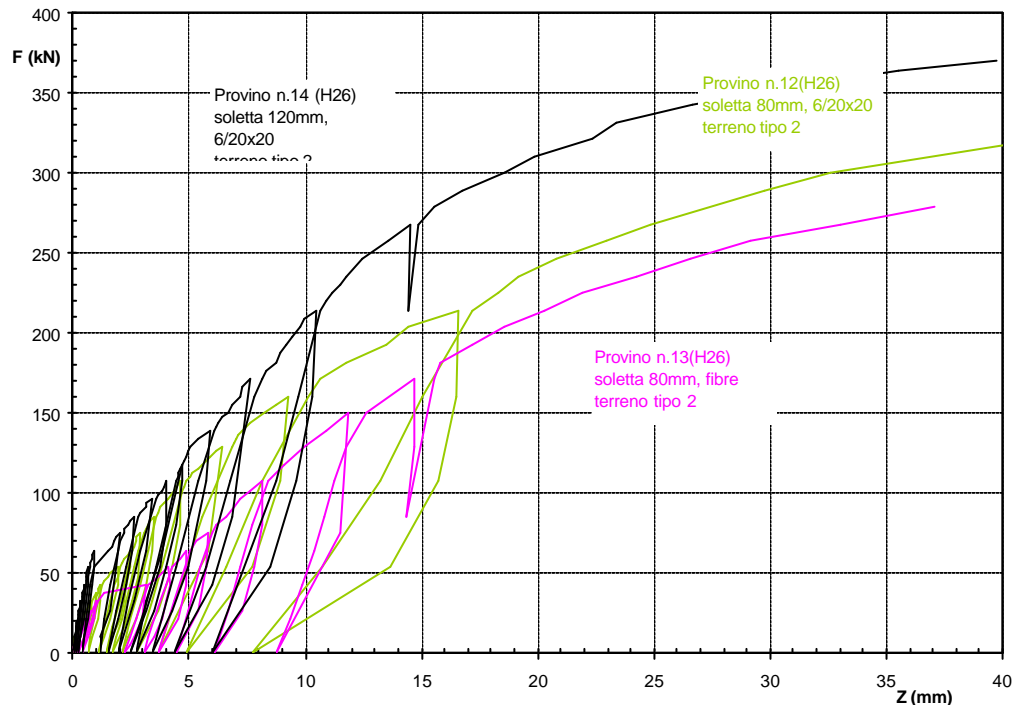


Fig. A.5 Comparison between the results of test 12, 13 and test 14.

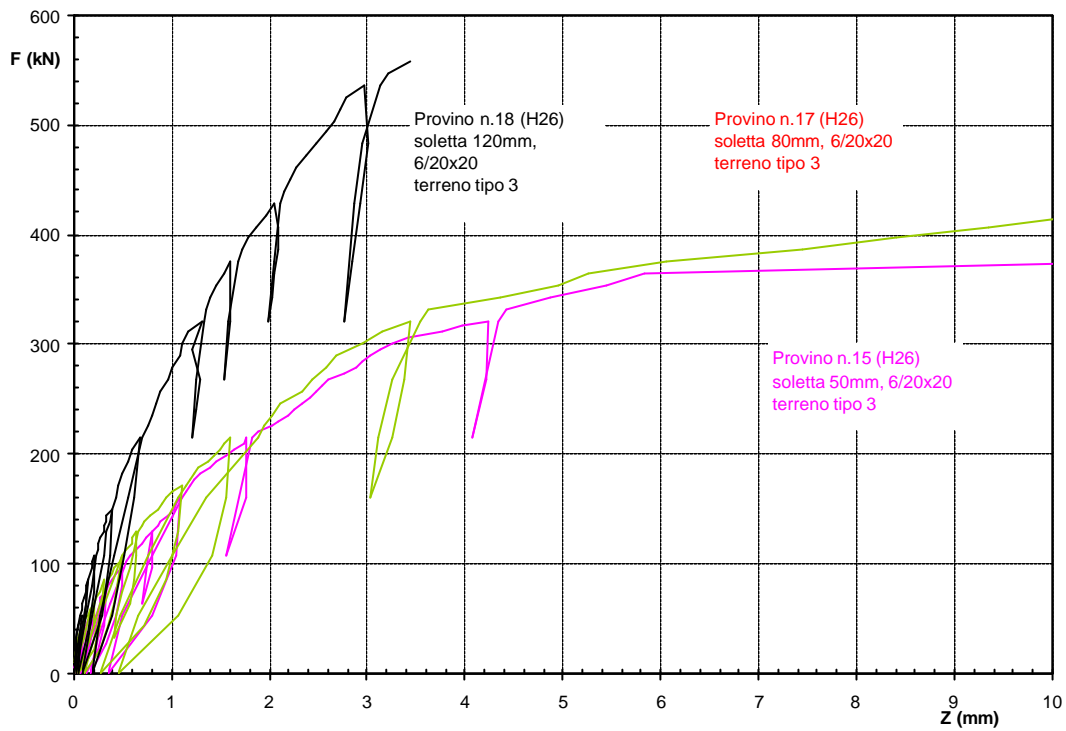


Fig. A.6 Comparison between the results of test 15, 17 and test 18.

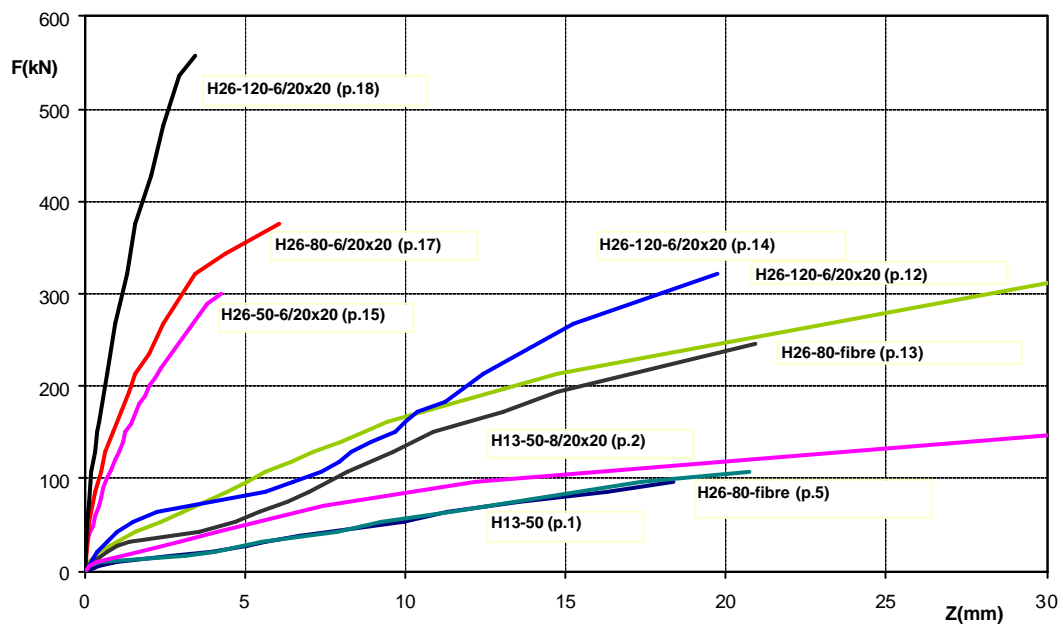


Fig. A.7 Experimental results comparison (DZ4).

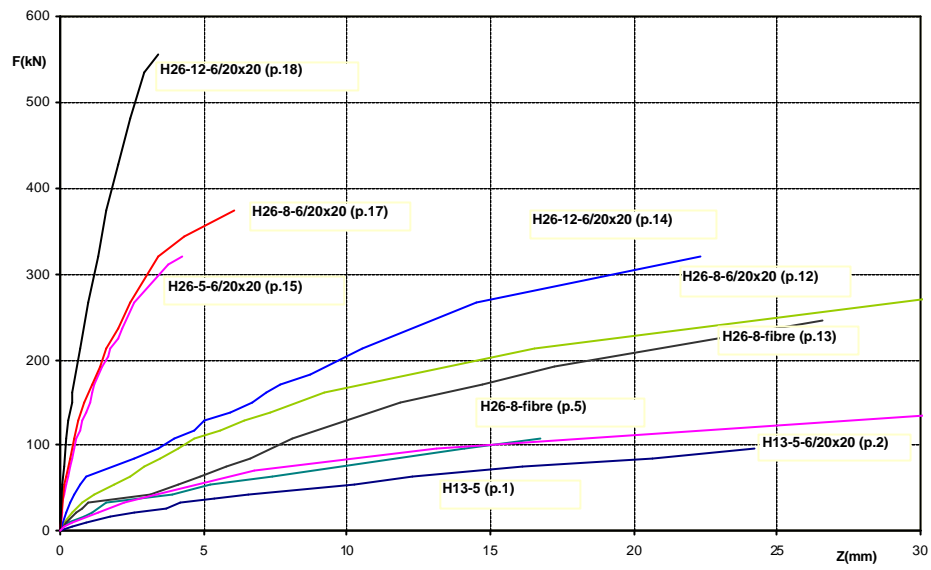


Figura A.8 Experimental results comparison (DZ5).



ENCLOSED B: GEOTECHNICAL REPORT - TEST REPORTS



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Via Ognissanti, 39, 35129 Padova – ITALY – tel. +39-049-8277980 – fax. +39-049-8277988

GEOTECHNICAL CHARACTERIZATION OF THE SUBGRADES SUPPORTING THE ELEMENTS CUPOLEX

TEST REPORT

Scientific Coordinator

(Prof. Paolo Simonini)

Handwritten signature of Paolo Simonini in black ink.

Department Director

(Prof. Giuseppe Matteotti)

Handwritten signature of Giuseppe Matteotti in black ink.

Padova, September 2003



University of Padova – Faculty of Engineering Science

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Via Ognissanti, 39, 35129 Padova – ITALY – tel. +39-049-8277980 – fax. +39-049-8277988

FOREWORD

This study deals with the geotechnical characterization of the soils forming the subgrades supporting the elements CUPOLEX.

The in-situ and laboratory tests, necessary to characterize the soil properties and described in the following, have been carried out according to the requirements of the Pontarolo Engineering.

Three types of soil have been selected and referred as soil subgrade N. 1, 2 and 4. An additional subgrade N. 3, consisting of an unreinforced concrete slab has been also prepared and tested.

The three soil subgrades have been prepared by moist compaction in a test tank by the Pontarolo Engineering.

On the subgrades 1, 2, 3 and 4 the geotechnical tests reported below have been performed (in parenthesis the ASTM standard practice and test methods assumed as reference methods) :

- Tests for Particle-Size Analysis of Soil (D421-85; D422-90; D1140-92);
- Test for Laboratory Compaction Characteristics of Soil using Modified Effort (D 1557-91);
- Test for Water Content by Direct Heating Method (D4959);
- Density and Unit Weight of Soil in Place by the Sand-Cone Method (D1556-90);
- Nonrepetitive Static Plate Load Tests of Soil Flexible Pavement Components (D1196-93);
- N. 1 Special Static Plate Load Test.

The Static Plate Load Tests have been carried out by using a rigid circular steel plate of 300 mm diameter and 25 mm thickness. The load has been applied through a 100 kN hydraulic jack and the vertical displacements of the plate have been measured using three mechanical dial gauges located at the vertexes of an equilateral triangle. The pressure readings have been taken from a manometer connected at the pressure generator. The load has been applied in steps (50 or 100 kPa); after each step the load has been maintained

constant not less than 15 min and/or when the measured settlement rate was less than 0.03 mm in 3 minutes.

In addition, special plate tests have been carried out to reproduce as close as possible the interaction between the base of the elements Cupolex and the soil. To this purpose a small stiff square steel plate (width = 120 mm) have been prepared and subjected to vertical load transmitted through an hydraulic jack. The test procedure is the same used for the standard static plate load tests, except that the vertical pressure was driven to higher value.

In the following sections the results of the in-situ and laboratory tests are reported.



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CHARACTERISTICS OF SUBGRADE N. 1

Subgrade N. 1 is composed by a unique layer of natural medium-fine silty sand, coming from a site close to the test area. It has been placed in the test tank and compacted reaching a height of 80 cm.

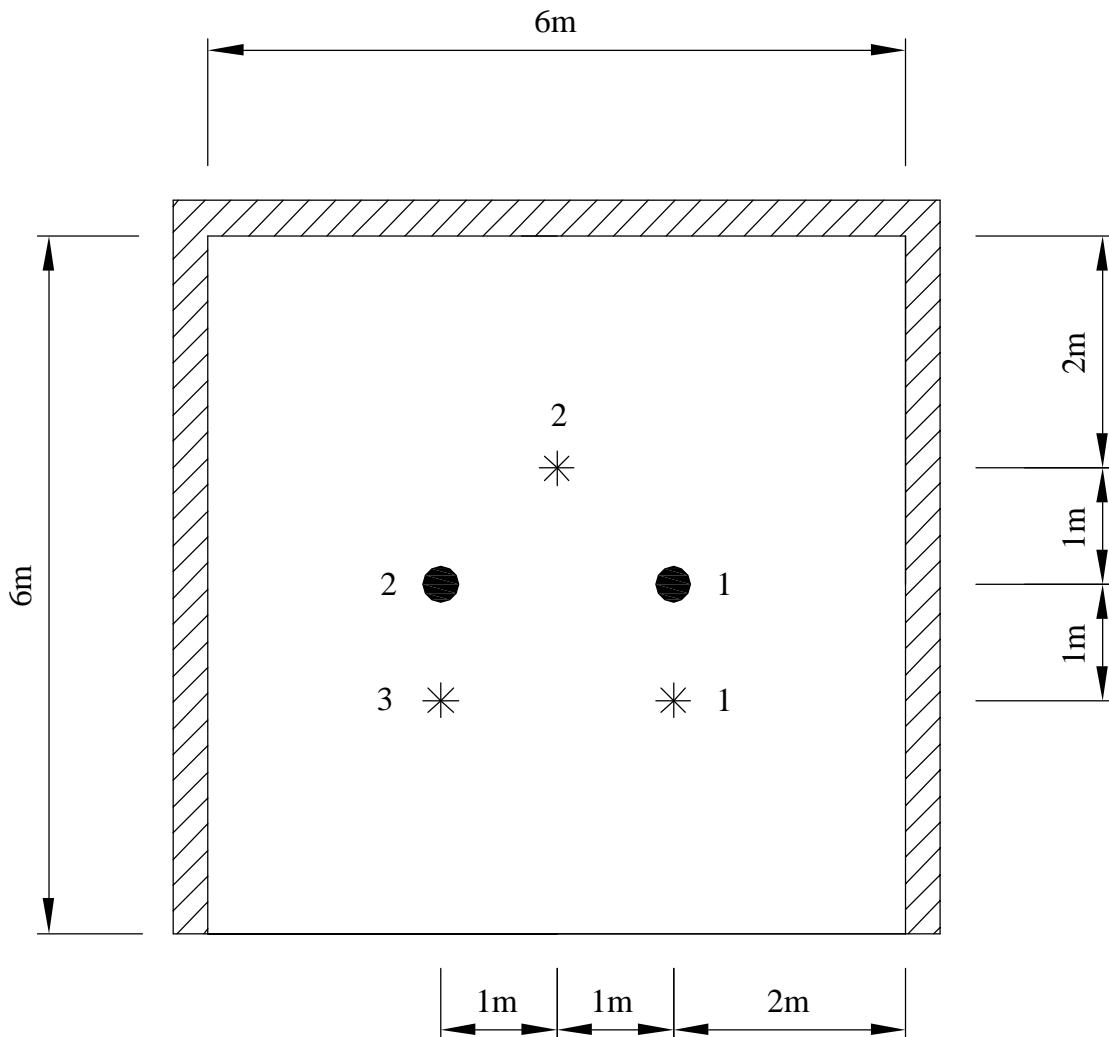
On the material forming the soil bed the following tests have been carried out:

- N. 1 Test for Particle-Size Analysis of Soil (D421-85; D422-90; D1140-92);
- N. 1 Test for Laboratory Compaction Characteristics of Soil using Modified Effort (D 1557-91);
- N. 3 Tests for Water Content by Direct Heating Method (D4959);
- N. 3 Tests for Density and Unit Weight of Soil in Place by the Sand-Cone Method (D1556-90);
- N. 2 Tests for Nonrepetitive Static Plate Load Tests of Soil and Flexible Pavement Components (D1196-93)

A photographic view of test tank with the 300 mm diameter plate resting on the subgrade is reported at the end of this section.



TEST LOCATION



● Plate Load test (circular steel bearing plate diameter 300mm)

* In situ density



Density and Unit Weight of Soil in Place by the Sand-Cone method (D1556-90)

Date: 20 / 05 / 2003
Client: Pontarolo Engineering
Site : S.Vito al Tagliamento
Soil: Subgrade 1
Test N° 1-2-3

		Position N°		
		1	2	3
Test hole volume	(cm ³)	969,4	941,1	881,8
Net weight of soil	(g)	1653,0	1591,3	1539,5
In place wet unit weight γ_n	(g/cm ³)	1,705	1,691	1,746
Water weight	(g)	159,9	187,9	155,6
Water content w	(%)	10,71	13,39	11,24
In place dry unit weight γ_d	(g/cm ³)	1,540	1,491	1,569

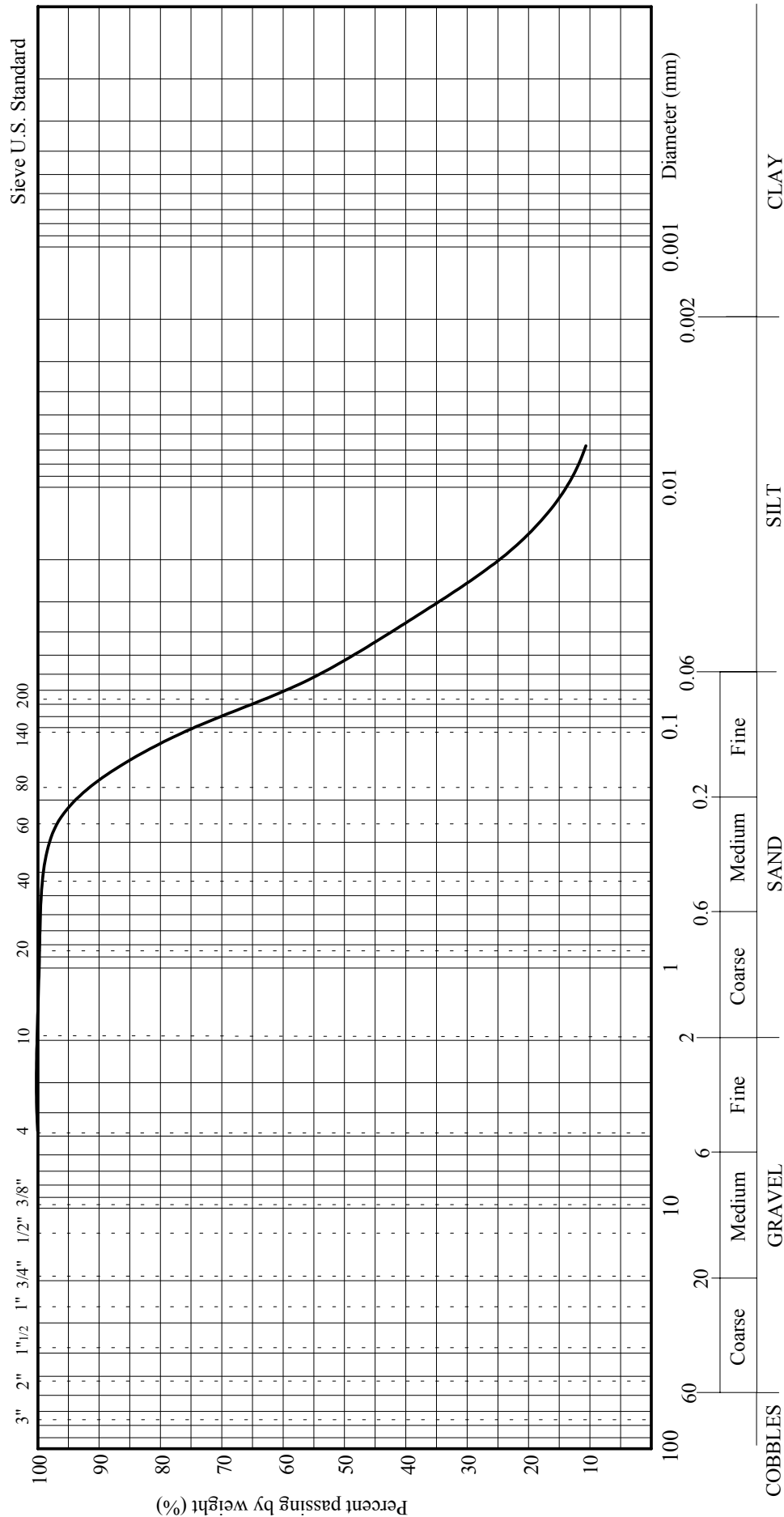
In place wet unit weight γ_n	(KN/m ³)	16,73	16,59	17,13
In place dry unit weight γ_d	(KN/m ³)	15,11	14,63	15,40
Water content w	(%)	10,71	13,39	11,24



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Client Site Pontarolo Engineering S.Vito al Tagliamento	Date 22/05/2003	Dry <input type="checkbox"/> Wet <input checked="" type="checkbox"/>	<table border="1" style="width: 100%; border-collapse: collapse;"> <tr><td>Gross weight g.</td><td style="text-align: center;">450,0</td></tr> <tr><td>Tare weight g.</td><td style="text-align: center;">150,0</td></tr> <tr><td>Net weight g.</td><td style="text-align: center;">300,0</td></tr> </table>	Gross weight g.	450,0	Tare weight g.	150,0	Net weight g.	300,0
Gross weight g.	450,0								
Tare weight g.	150,0								
Net weight g.	300,0								
Borehole <input type="text"/>	Sample <input type="text" value="Subgrade 1"/>	Depth <input type="text"/>	Description of depth: 						
PARTICLE-SIZE ANALYSIS									
ASTM Sieve n.	Diameter	Net weight (g)	% Passing						
4"	101,6		100,00						
3"	76,2		100,00						
2"	50,8		100,00						
1" 1/2	38,1		100,00						
1"	25,4		100,00						
3/4"	19,1		100,00						
1/2"	12,7		100,00						
3/8"	9,52		100,00						
4	4,76	0,0	100,00						
10	2	0,3	99,90						
20	0,84	0,6	99,70						
40	0,42	1,4	99,23						
60	0,25	7,3	96,80						
80	0,177	25,5	88,30						
140	0,105	35,8	76,37						
200	0,074	23,1	68,67						



Sample	Depth	CLASSIFICATION SUBGRADE 1														
		GRAVEL			SAND			SILT			CLAY					
		Coarse	Medium	Fine	Coarse	Medium	Fine	w %	w_L %	w_p %	I_p %	Pen. (kPa)	qu^1 (kPa)	qu^2 (kPa)		
		Medium fine sand with silt.														
GRAIN SIZE DISTRIBUTIONS		Client Site		Pontarolo Engineering S. Vito al Tagliamento											BOREHOLE	



Test for Laboratory Compaction Characteristics of Soil using Modified Effort (D 1557-91)

Date: 26 / 5 / 2003

Client: Pontarolo Engineering

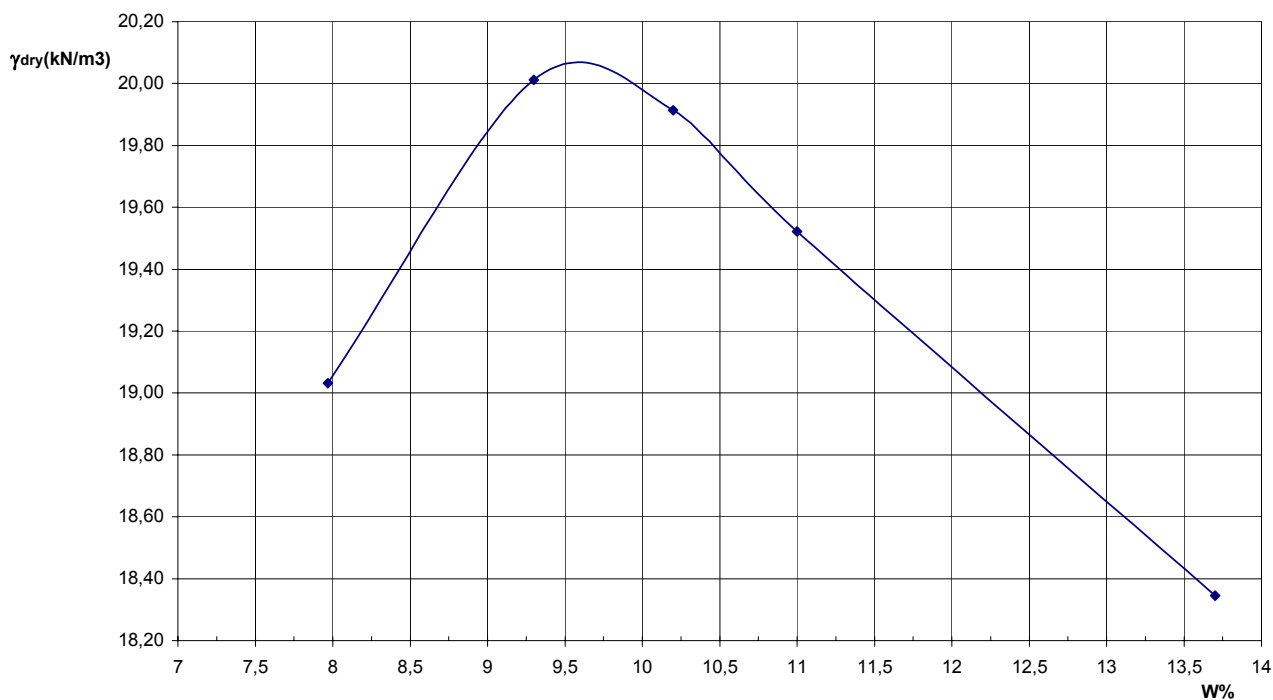
Site : S.Vito al Tagliamento

Soil: Subgrade 1

Test N° 1

Water content w (%)	Dry Unit Weight γ_d (kN/m ³)
7.97	19.03
9.3	20.01
10.2	19.91
11.0	19.52
13.7	18.34

$$W_{\text{optimum}} = 9.6 \%$$
$$\gamma_{\text{dry,optimum}} = 20.04 \text{ kN/m}^3$$





**Test for Nonrepetitive Static Plate Load Tests of Soils
and Flexible Pavement Components
(D 1196-93)**

Date: 20 / 05 / 2003

Client: Pontarolo Engineering

Site : S.Vito al Tagliamento

Soil: Subgrade 1

Test N° 1

Circular steel plate – diameter 300 mm

p = vertical pressure

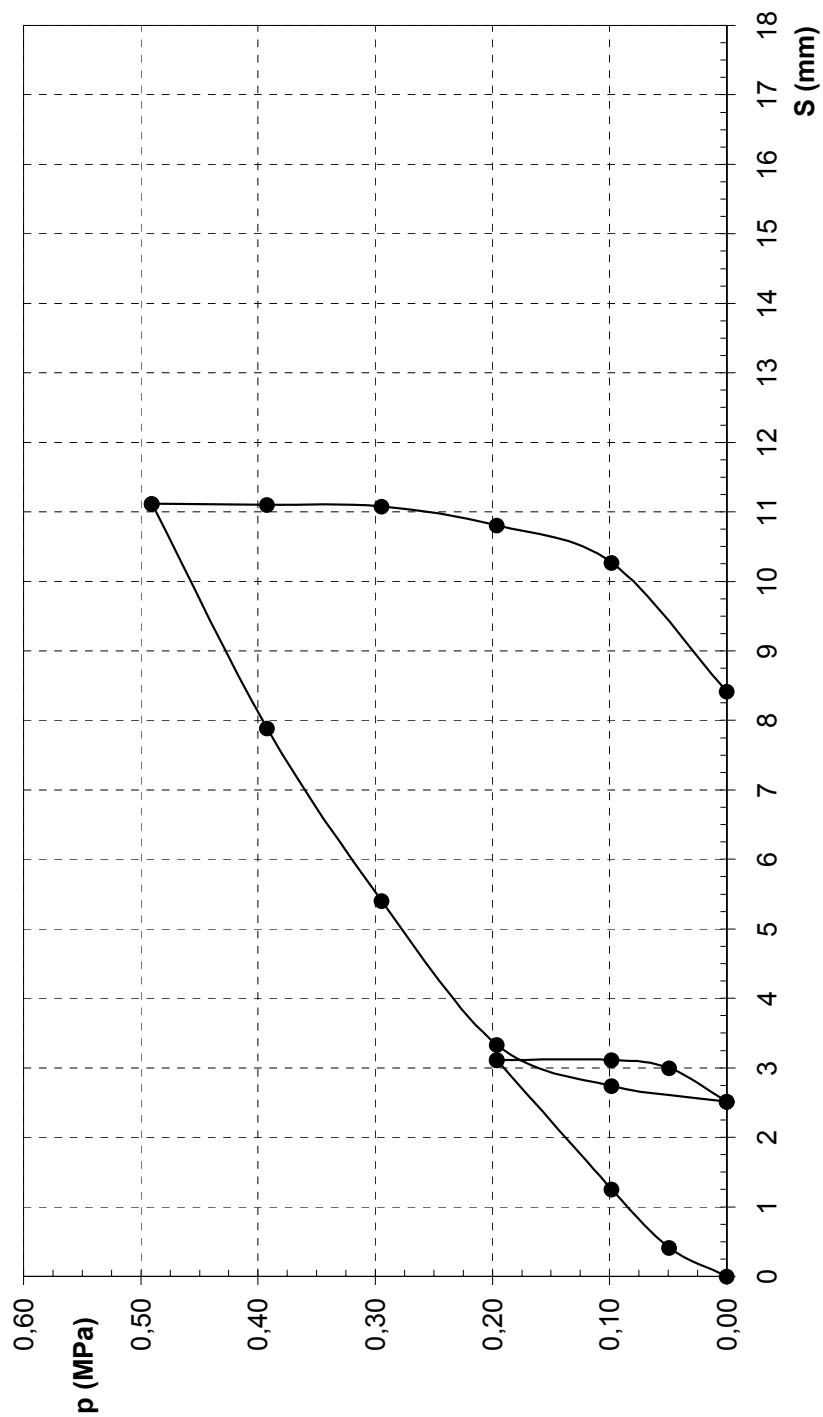
S = vertical settlement

p (MPa)	S (mm)
0,00	0,00
0,05	0,41
0,10	1,26
0,20	3,11
0,10	3,12
0,05	3,00
0,00	2,51
0,10	2,74
0,20	3,34
0,29	5,40
0,39	7,88
0,49	11,12
0,39	11,10
0,29	11,08
0,20	10,81
0,10	10,27
0,00	8,42



Soil: Subgrade 1

Test N° 1





**Test for Nonrepetitive Static Plate Load Tests of Soils
and Flexible Pavement Components
(D 1196-93)**

Date: 20 / 05 / 2003

Client: Pontarolo Engineering

Site : S.Vito al Tagliamento

Soil: Subgrade 1

Test N° 2

Circular steel plate – diameter 300 mm

p = vertical pressure

S = vertical settlement

p (MPa)	S (mm)
0,00	0,00
0,05	0,21
0,10	1,01
0,20	3,19
0,10	3,18
0,05	2,96
0,00	2,32
0,10	2,67
0,20	3,38
0,29	5,81
0,39	9,69
0,49	14,29
0,39	14,31
0,29	14,29
0,20	13,95
0,10	13,36
0,00	11,63



Soil: Subgrade 1

Test N° 2





Subgrade 1





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CHARACTERISTICS OF SUBGRADE N. 2

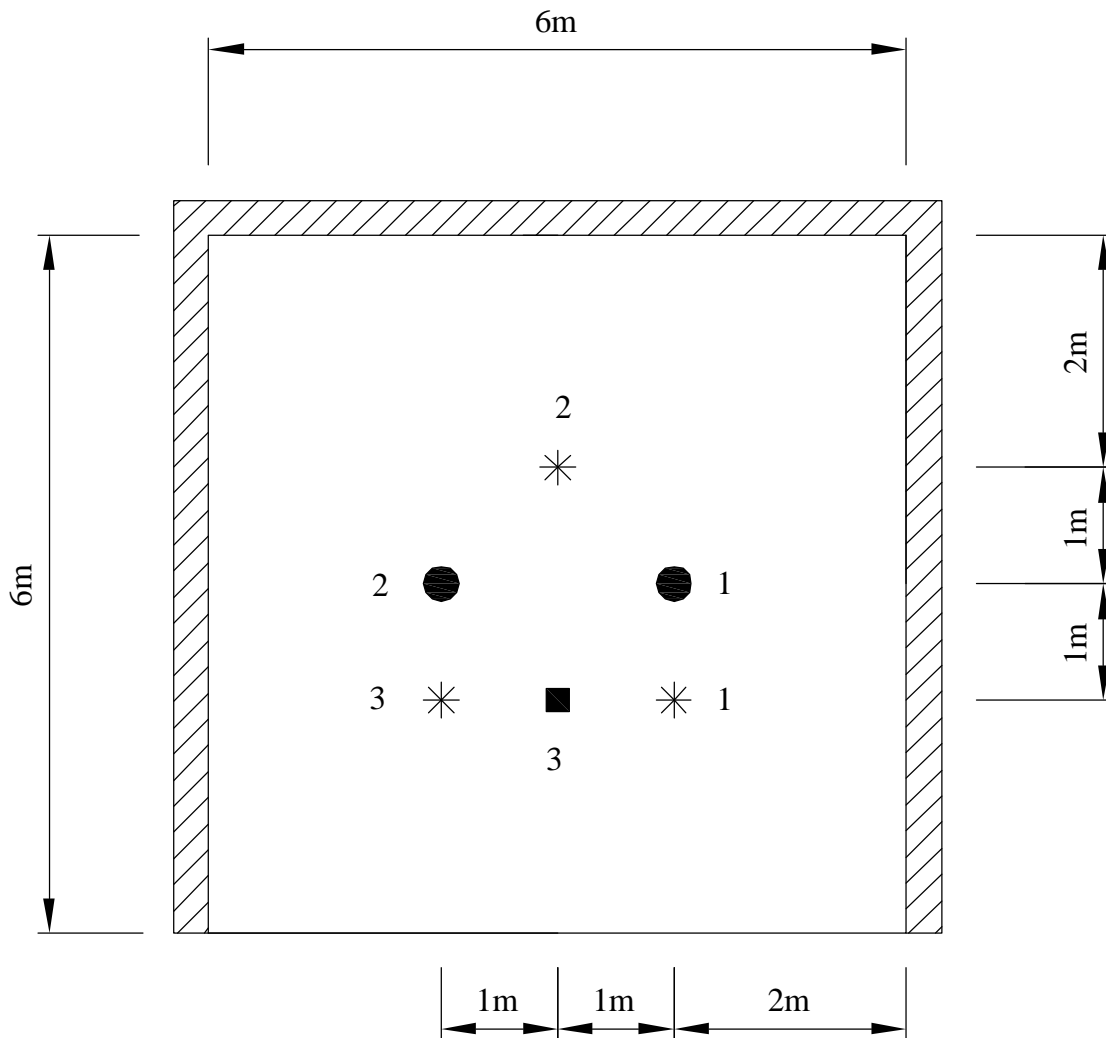
Subgrade N. 2 was placed on subgrade N. 1. The layer is composed by a medium fine sandy gravel, compacted to reach a thickness of 30 cm. The total thickness of both layers is 110 cm. On the soil bed the following tests have been carried out:

- N. 1 Test for Particle-Size Analysis of Soil (D421-85; D422-90; D1140-92);
- N. 1 Test for Laboratory Compaction Characteristics of Soil using Modified Effort (D 1557-91);
- N. 3 Tests for Water Content by Direct Heating Method (D4959);
- N. 3 Tests for Density and Unit Weight of Soil in Place by the Sand-Cone Method (D1556-90);
- N. 2 Tests for Nonrepetitive Static Plate Load Tests of Soil and Flexible Pavement Components (D1196-93);
- N. 1 Special Static Plate Load Test with the square steel plate (width = 120 mm).

A photographic view of test tank with the 300 mm diameter plate resting on the subgrade is reported at the end of this section.



TEST LOCATION



- Plate Load test (circular steel plate diameter 300mm)
- Plate Load test (square steel plate side 120mm)
- * In situ density



Density and Unit Weight of Soil in Place by the Sand-Cone method (D1556-90)

Date: 04 / 06 / 2003
Client: Pontarolo Engineering
Site : S.Vito al Tagliamento
Soil: Subgrade 2
Test N° 1-2-3

		Position N°		
		1	2	3
Test hole volume	(cm ³)	622,9	756,4	819,2
Net weight of soil	(g)	1338,5	1557,8	1749,0
In place wet unit weight γ_n	(g/cm ³)	2,149	2,060	2,135
Water weight	(g)	43,6	43,9	45,0
Water content w	(%)	3,37	2,90	2,64
In place dry unit weight γ_d	(g/cm ³)	2,079	2,002	2,080

In place wet unit weight γ_n	(KN/m ³)	21,08	20,20	20,94
In place dry unit weight γ_d	(KN/m ³)	20,39	19,63	20,41
Water content w	(%)	3,37	2,90	2,64



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Client Site Pontarolo Engineering S.Vito al Tagliamento	Date 12/06/2003	Dry <input checked="" type="checkbox"/>	Wet <input type="checkbox"/>	
Soil <input type="text" value=" >3/4"/>	Sample <input type="text" value=" Subgrade 2"/>	Depth <input type="text"/>		
DESCRIPTION OF DEPTH:				
PARTICLE-SIZE ANALYSIS				
ASTM Sieve n.	Diameter	Net weight (g)	% Passing	
4"	101,6		100,00	
3"	76,2		100,00	
2"	50,8	613,9	98,68	
1" 1/2	38,1	176,8	98,30	
1"	25,4	2788,5	92,30	
3/4"	19,1	2016,8	87,97	
1/2"	12,7		87,97	
3/8"	9,52		87,97	
4	4,76		87,97	
10	2		87,97	
20	0,84		87,97	
40	0,42		87,97	
60	0,25		87,97	
80	0,177		87,97	
140	0,105		87,97	
200	0,074		87,97	
		Gross weight g.	56800,0	
		Tare weight g.	10300,0	
		Net weight g.	46500,0	



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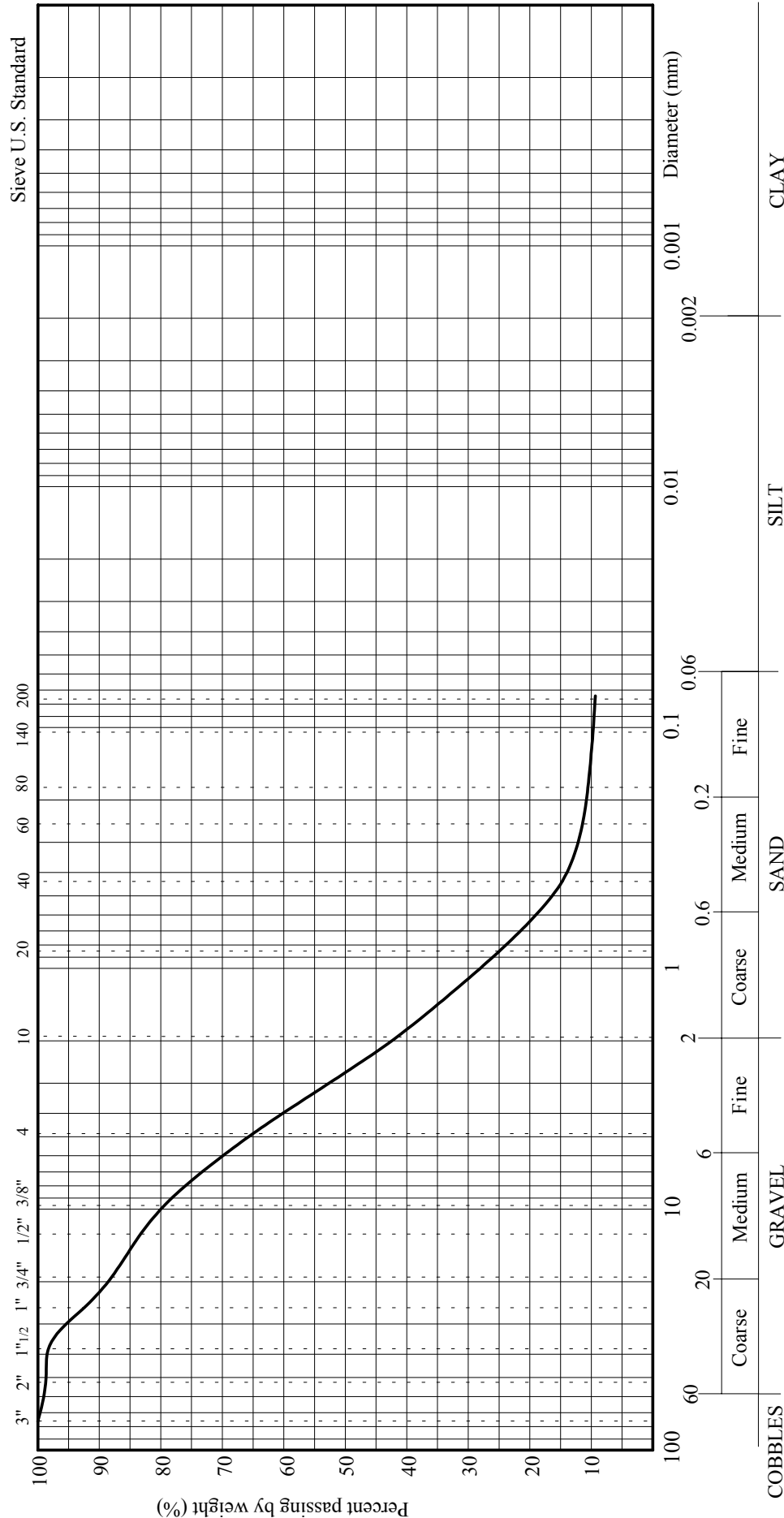
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Client Site Pontarolo Engineering S.Vito al Tagliamento	Date 12/06/2003	Dry <input type="checkbox"/> Wet <input checked="" type="checkbox"/>	<table border="1" style="width:100%; border-collapse: collapse;"> <tr> <td style="width:33%;">Gross weight g.</td> <td style="width:33%; text-align: center;">3100,0</td> <td style="width:33%;"></td> </tr> <tr> <td>Tare weight g.</td> <td style="text-align: center;">100,0</td> <td></td> </tr> <tr> <td>Net weight g.</td> <td style="text-align: center;">3000,0</td> <td></td> </tr> </table>	Gross weight g.	3100,0		Tare weight g.	100,0		Net weight g.	3000,0	
Gross weight g.	3100,0											
Tare weight g.	100,0											
Net weight g.	3000,0											
Soil <input type="text" value=" <3/4"/>	Sample <input type="text" value=" Subgrade 2"/>	Depth <input type="text"/>	Description of depth:									
PARTICLE-SIZE ANALYSIS												
ASTM Sieve n.	Diameter	Net weight (g)	% Passing									
4"	101,6		100,00									
3"	76,2		100,00									
2"	50,8		100,00									
1" 1/2	38,1		100,00									
1"	25,4		100,00									
3/4"	19,1		100,00									
1/2"	12,7	158,8	94,71									
3/8"	9,52	139,8	90,05									
4	4,76	499,7	73,39									
10	2	754,4	48,24									
20	0,84	603,0	28,14									
40	0,42	354,1	16,34									
60	0,25	101,5	12,96									
80	0,177	29,2	11,98									
140	0,105	27,8	11,06									
200	0,074	13,2	10,62									



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Sample	Depth	CLASSIFICATION SUBGRADE 2	γ_s (kN/m ³)	G _s	w %	w _L %	w _p %	I _p %	Pen. (kPa)	qu ¹ (kPa)	qu ² (kPa)	BOREHOLE

GRAIN SIZE DISTRIBUTIONS

Client Site
Pontarolo Engineering
S. Vito al Tagliamento



Test for Laboratory Compaction Characteristics of Soil using Modified Effort (D 1557-91)

Date: 12 / 06 / 2003

Client: Pontarolo Engineering

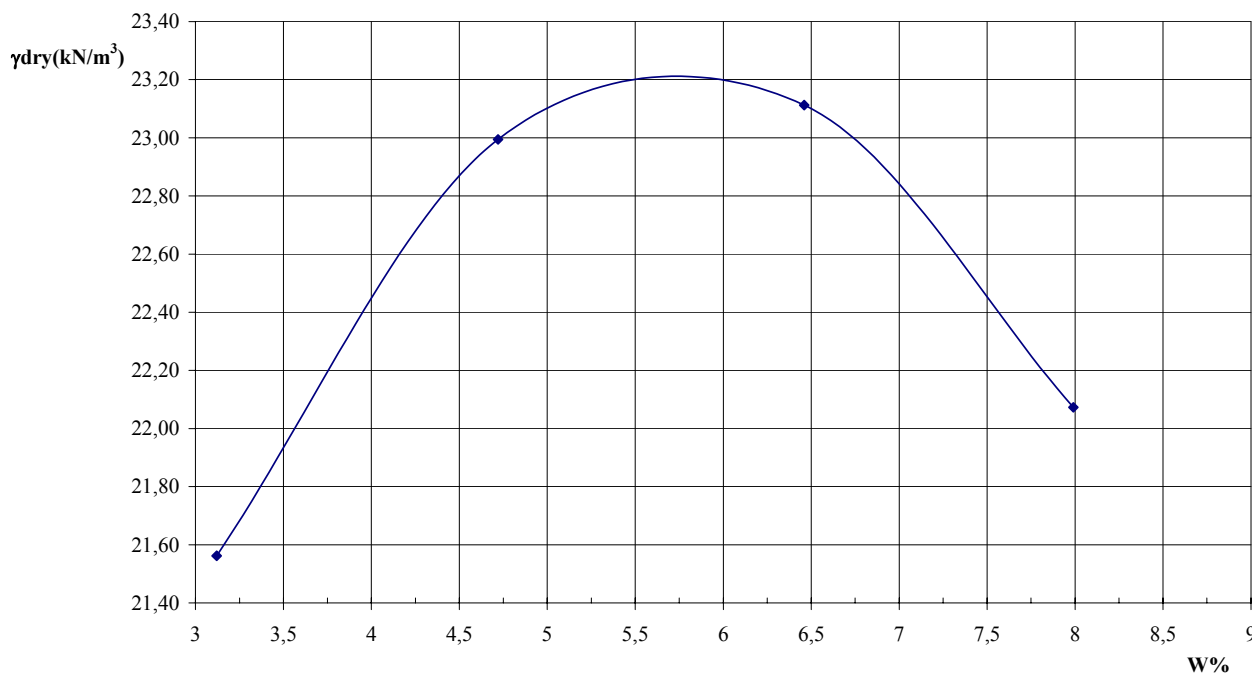
Site : S.Vito al Tagliamento

Soil: Subgrade 2

Test N° 1

Water content w (%)	Dry Unit Weight γ_d (kN/m ³)
3,12	21,56
4,72	22,99
6,46	23,11
7,99	22,07

$$W_{\text{optimum}} = 5.75 \%$$
$$\gamma_{\text{dry,optimum}} = 23.21 \text{ kN/m}^3$$





**Test for Nonrepetitive Static Plate Load Tests of Soils
and Flexible Pavement Components
(D 1196-93)**

Date: 04 / 06 / 2003

Client: Pontarolo Engineering

Site : S.Vito al Tagliamento

Soil: Subgrade 2

Test N° 1

Circular steel plate – diameter 300 mm

p = vertical pressure

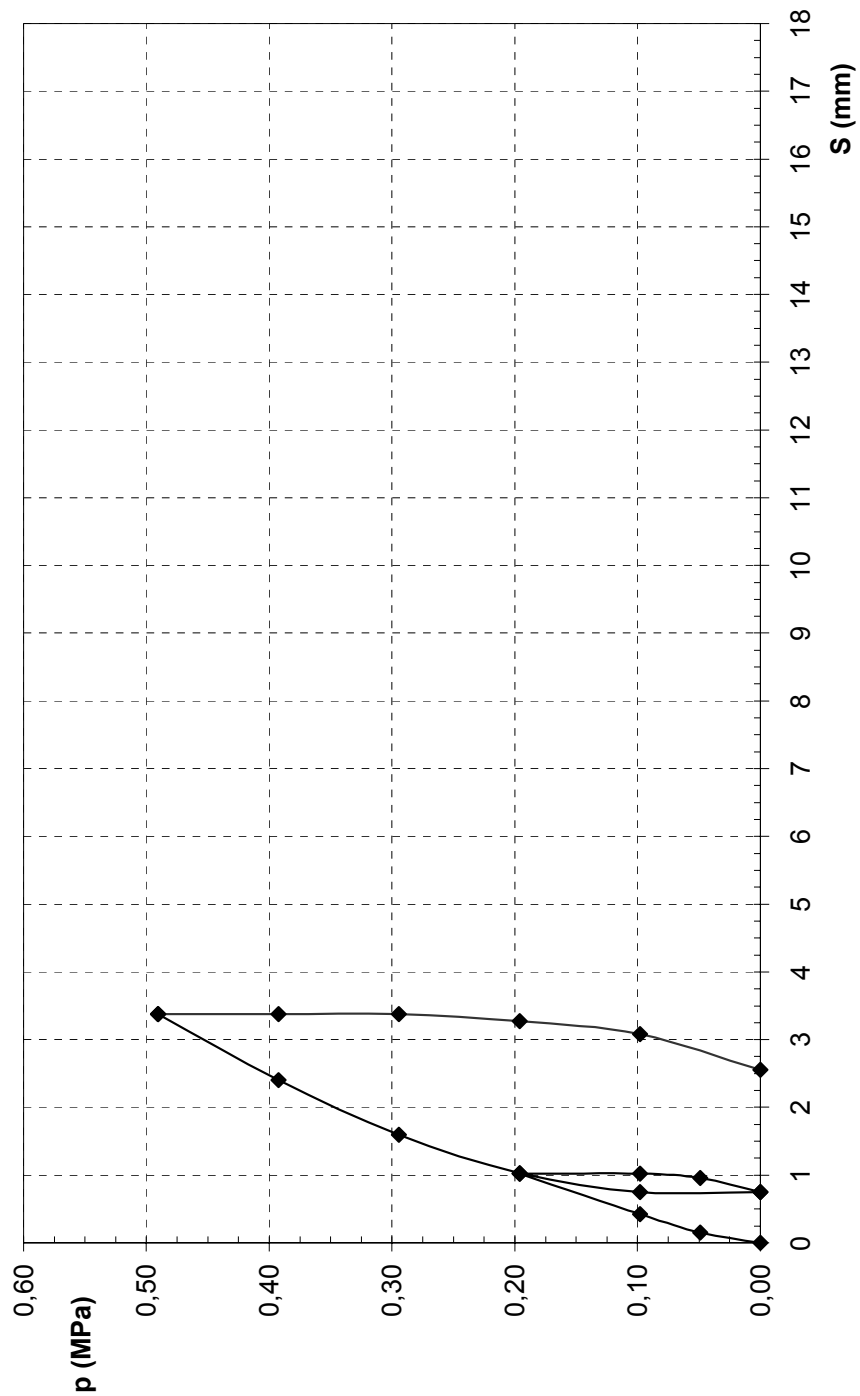
S = vertical settlement

p (MPa)	S (mm)
0,00	0,00
0,05	0,15
0,10	0,42
0,20	1,02
0,10	1,02
0,05	0,96
0,00	0,75
0,10	0,75
0,20	1,03
0,29	1,60
0,39	2,40
0,49	3,37
0,39	3,37
0,29	3,37
0,20	3,27
0,10	3,08
0,00	2,55



Soil: Subgrade 2

Test N° 1





**Test for Nonrepetitive Static Plate Load Tests of Soils
and Flexible Pavement Components
(D 1196-93)**

Date: 04 / 06 / 2003

Client: Pontarolo Engineering

Site : S.Vito al Tagliamento

Soil: Subgrade 2

Test N° 2

Circular steel plate – diameter 300 mm

p = vertical pressure

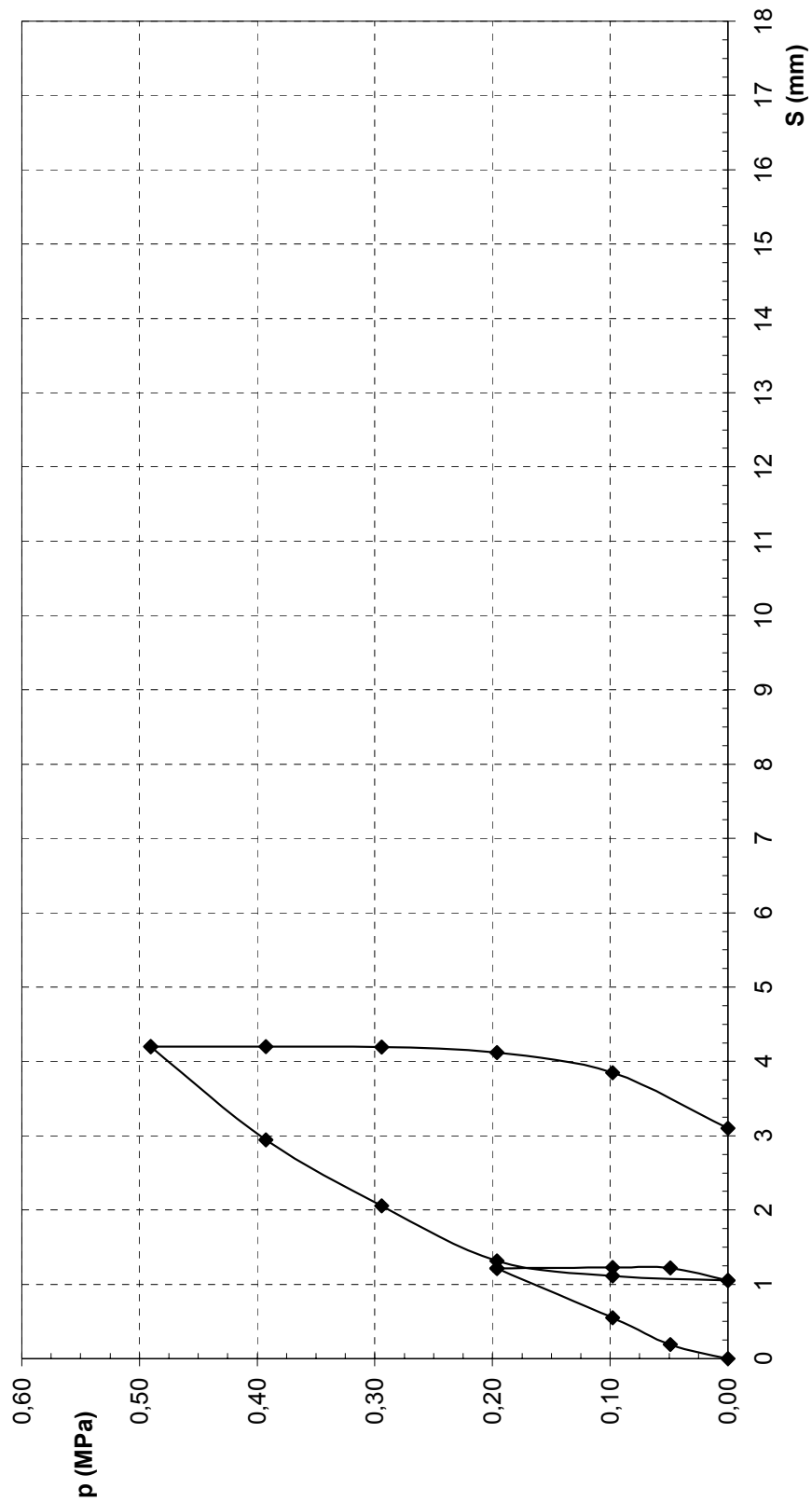
S = vertical settlement

p (MPa)	S (mm)
0,00	0,00
0,05	0,19
0,10	0,55
0,20	1,21
0,10	1,23
0,05	1,22
0,00	1,05
0,10	1,11
0,20	1,32
0,29	2,06
0,39	2,95
0,49	4,20
0,39	4,20
0,29	4,19
0,20	4,12
0,10	3,85
0,00	3,10



Soil: Subgrade 2

Test N° 2





**Test for Nonrepetitive Static Plate Load Tests of Soils
and Flexible Pavement Components
(D 1196-93)**

Date: 04 / 06 / 2003

Client: Pontarolo Engineering

Site : S.Vito al Tagliamento

Soil: Subgrade 2

Test N° 3

Square steel plate – side 120 mm

p = vertical pressure

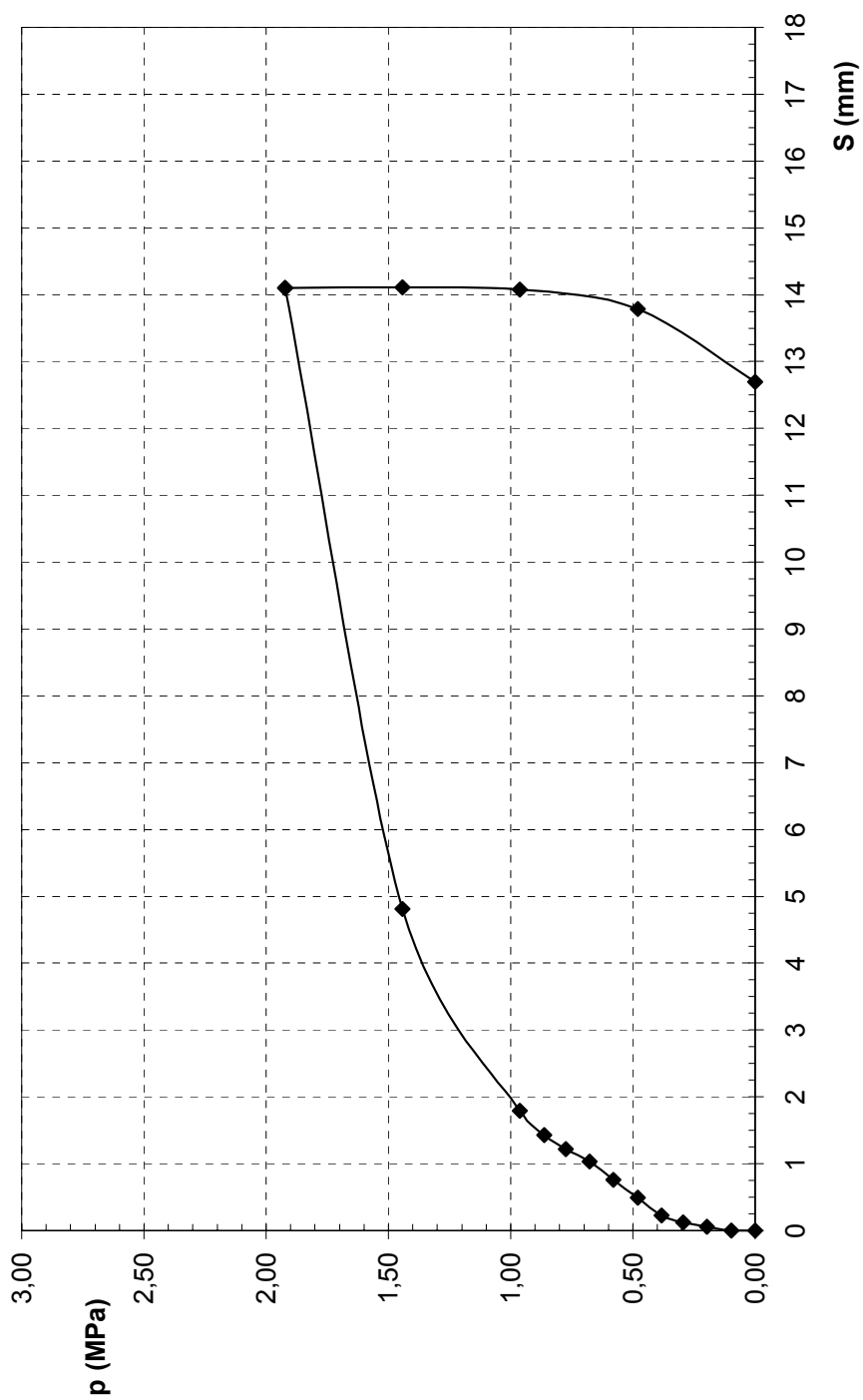
S = vertical settlement

p (MPa)	S (mm)
0,00	0,00
0,10	0,00
0,20	0,05
0,29	0,12
0,38	0,23
0,48	0,49
0,58	0,76
0,68	1,03
0,77	1,22
0,86	1,43
0,96	1,79
1,44	4,81
1,92	14,10
1,44	14,11
0,96	14,08
0,48	13,79
0,00	12,70



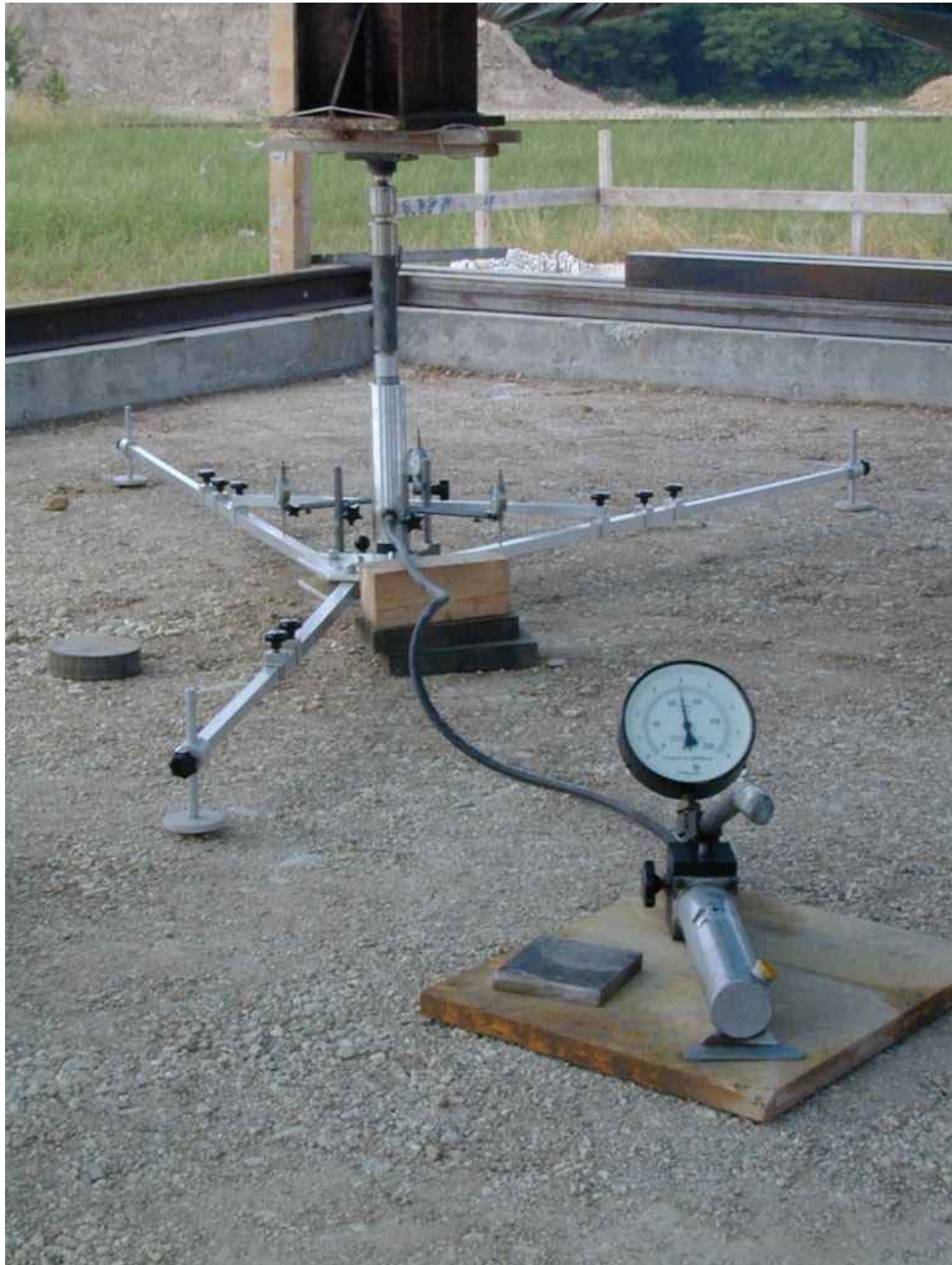
Soil: Subgrade 2

Test N° 3





Subgrade 2





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CHARACTERISTICS OF SUBGRADE N. 3

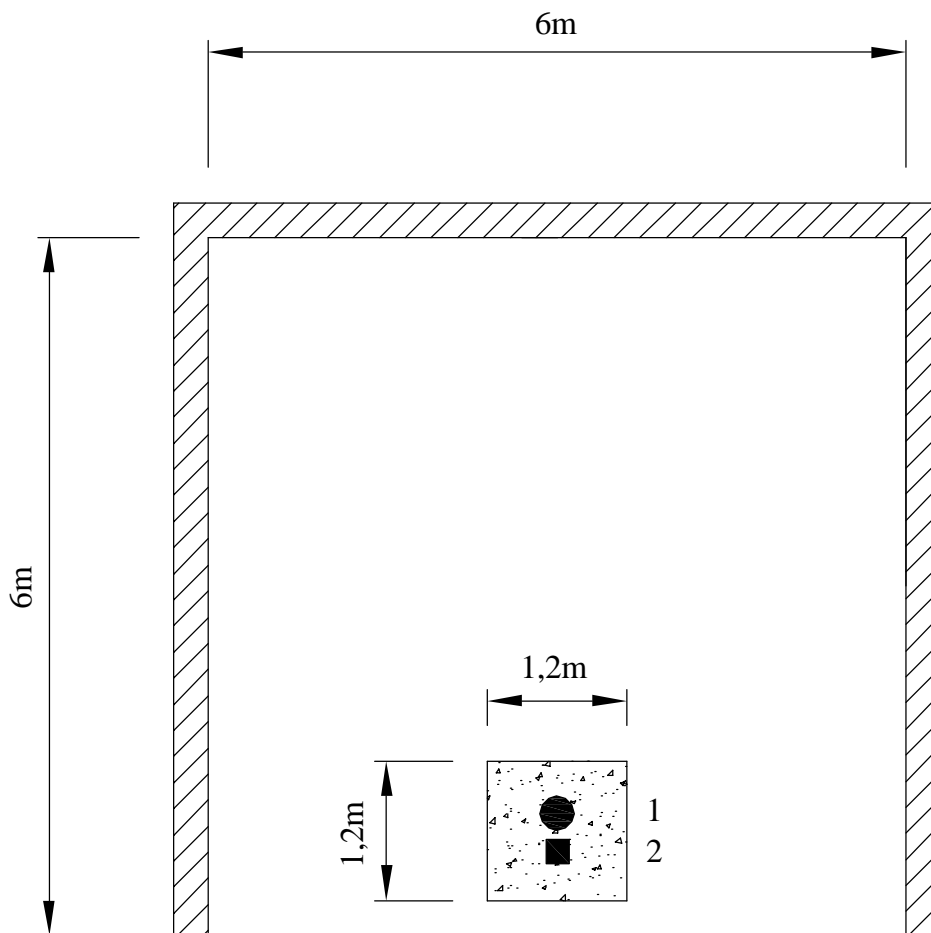
The layer forming the subgrade N. 2 was removed and then an unreinforced concrete slab having a thickness of 10 cm was realized. On the concrete slab the following tests have been carried out:

- N. 1 Test for Nonrepetitive Static Plate Load Tests of Soil and Flexible Pavement Components (D1196-93)
- N. 1 Special Static Plate Load Test with the square steel plate (width = 120 mm)

A photographic view of test tank with the 300mm diameter plate resting on the subgrade is reported at the end of this section.



TEST LOCATION



● Plate Load test (circular steel plate diameter 300mm)

■ Plate Load test (square steel plate side 120mm)



**Test for Nonrepetitive Static Plate Load Tests of Soils
and Flexible Pavement Components
(D 1196-93)**

Date: 19 / 06 / 2003

Client: Pontarolo Engineering

Site : S.Vito al Tagliamento

Soil: Subgrade 3

Test N° 1

Circular steel plate – diameter 300 mm

p = vertical pressure

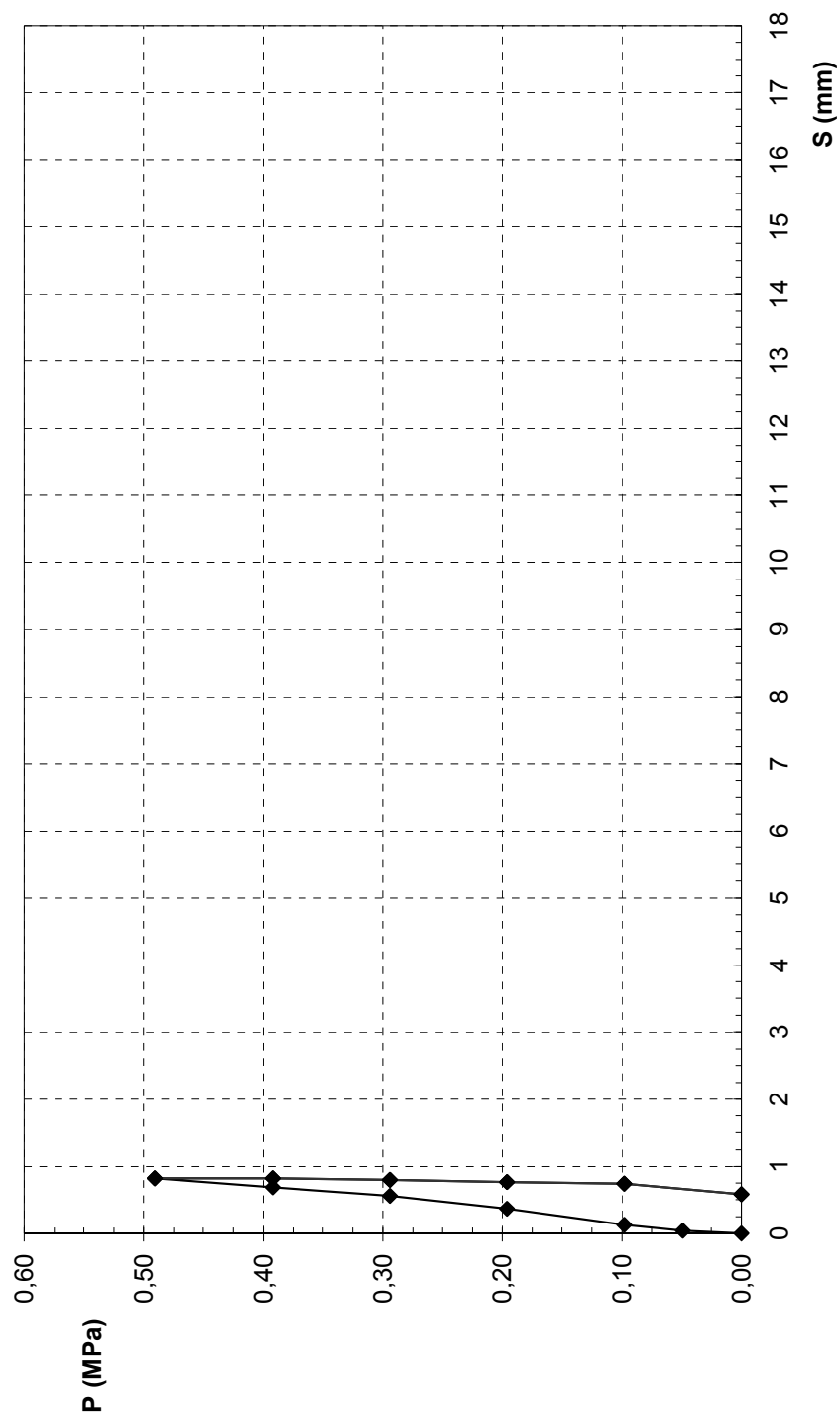
S = vertical settlement

p (MPa)	S (mm)
0,00	0,00
0,05	0,04
0,10	0,13
0,20	0,37
0,29	0,56
0,39	0,69
0,49	0,82
0,39	0,82
0,29	0,80
0,20	0,77
0,10	0,74
0,00	0,58



Soil: Subgrade 3

Test N° 1





**Test for Nonrepetitive Static Plate Load Tests of Soils
and Flexible Pavement Components
(D 1196-93)**

Date: 19 / 06 / 2003

Client: Pontarolo Engineering

Site : S.Vito al Tagliamento

Soil: Subgrade 3

Test N° 2

Square steel plate – side 120 mm

p = vertical pressure

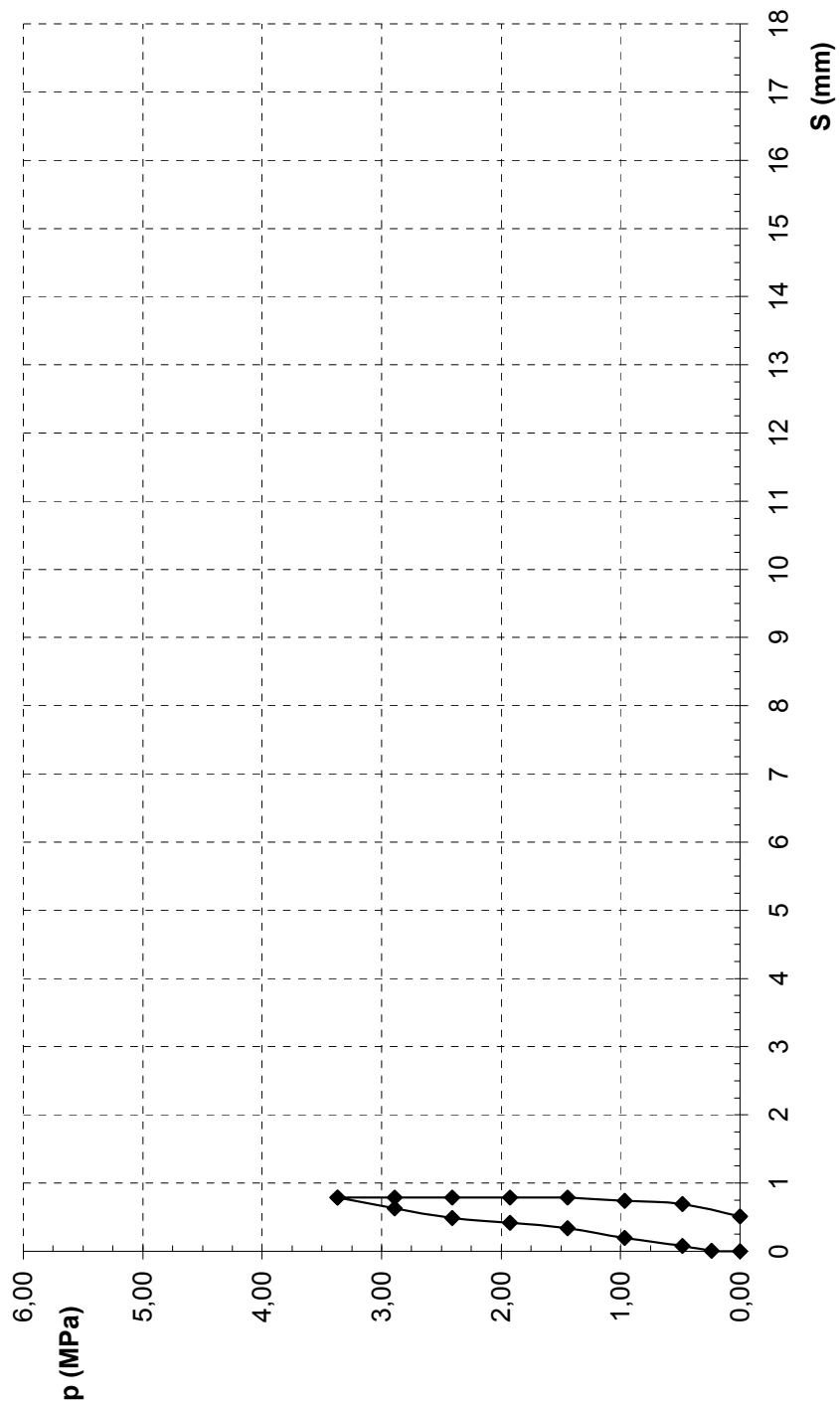
S = vertical settlement

p (MPa)	S (mm)
0,00	0,00
0,24	0,01
0,48	0,08
0,96	0,20
1,45	0,34
1,93	0,42
2,41	0,49
2,89	0,63
3,37	0,79
2,89	0,79
2,41	0,79
1,93	0,79
1,45	0,79
0,96	0,74
0,48	0,69
0,00	0,51



Soil: Subgrade 3

Test N° 2





Subgrade 3





University of Padova – Faculty of Engineering Science

DEPARTMENT OF HYDRAULIC, MARITIME, ENVIRONMENTAL AND GEOTECHNICAL ENGINEERING
Via Ognissanti, 39, 35129 Padova – ITALY – tel. +39-049-8277980 – fax. +39-049-8277988

CHARACTERISTICS OF SUBGRADE N. 4

After removing the concrete slab, the test tank was prepared for the new series of tests. A square zone of the tank area (3.3 m x 3.3 m) was prepared by compacting 10 cm of medium gravel (this soil bed is referred as subgrade N. 4). On the resting part of the tank area, the subgrade for testing was maintained as in the first series of tests (subgrade N. 1), but re-compacted.

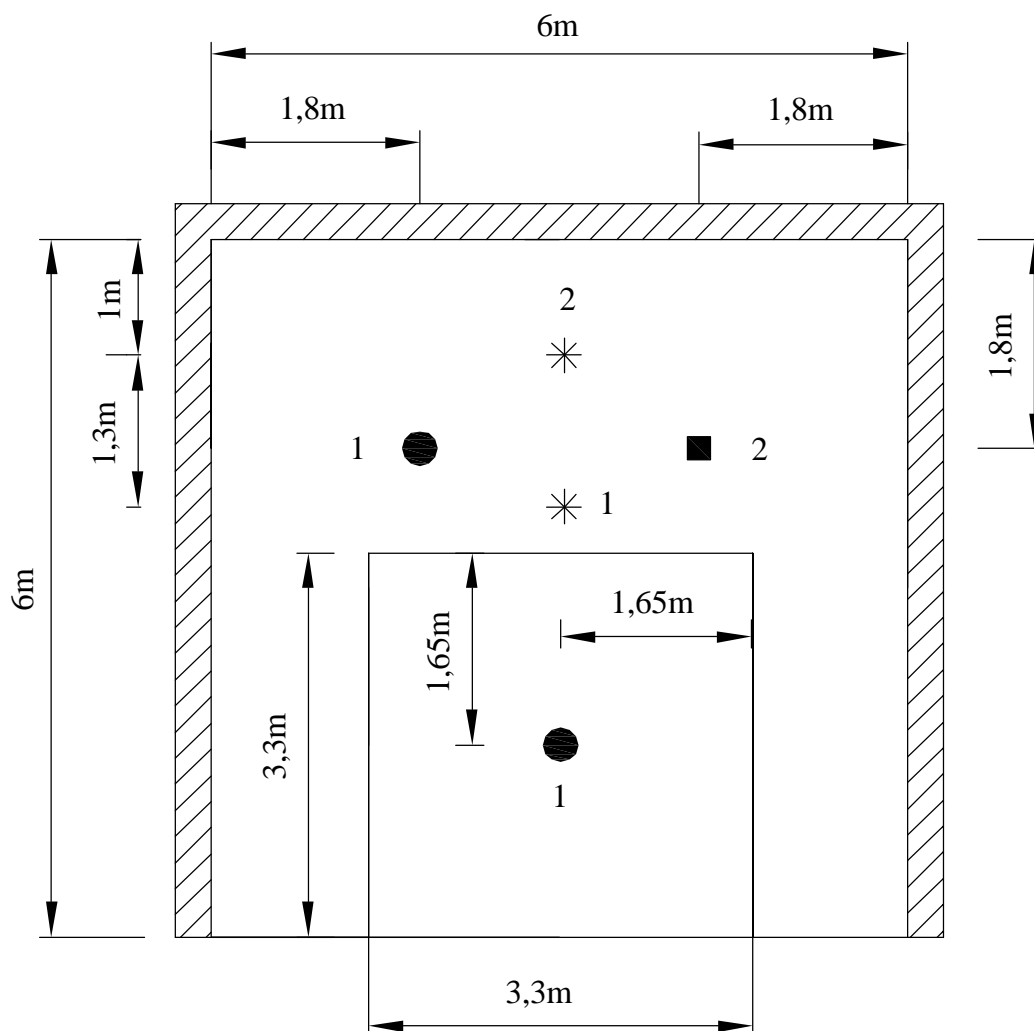
On the two soil areas the following tests have been carried out:

- N. 1 Test for Particle-Size Analysis of Soil (D421-85; D422-90; D1140-92);
- N. 2 Tests for Density and Unit Weight of Soil in Place by the Sand-Cone Method (D1556-90);
- N. 2 Tests for Nonrepetitive Static Plate Load Tests of Soil and Flexible Pavement Components (D1196-93)
- N. 1 Special Static Plate Load Test with the square steel plate (width = 120 mm)

A photographic view of the subgrade N. 4, prepared in the 3,3 m x 3,3 m area, is also provided.



TEST LOCATION



- Plate Load test (circular steel plate diameter 300mm)
- Plate Load test (square steel plate side 120mm)
- * In situ density



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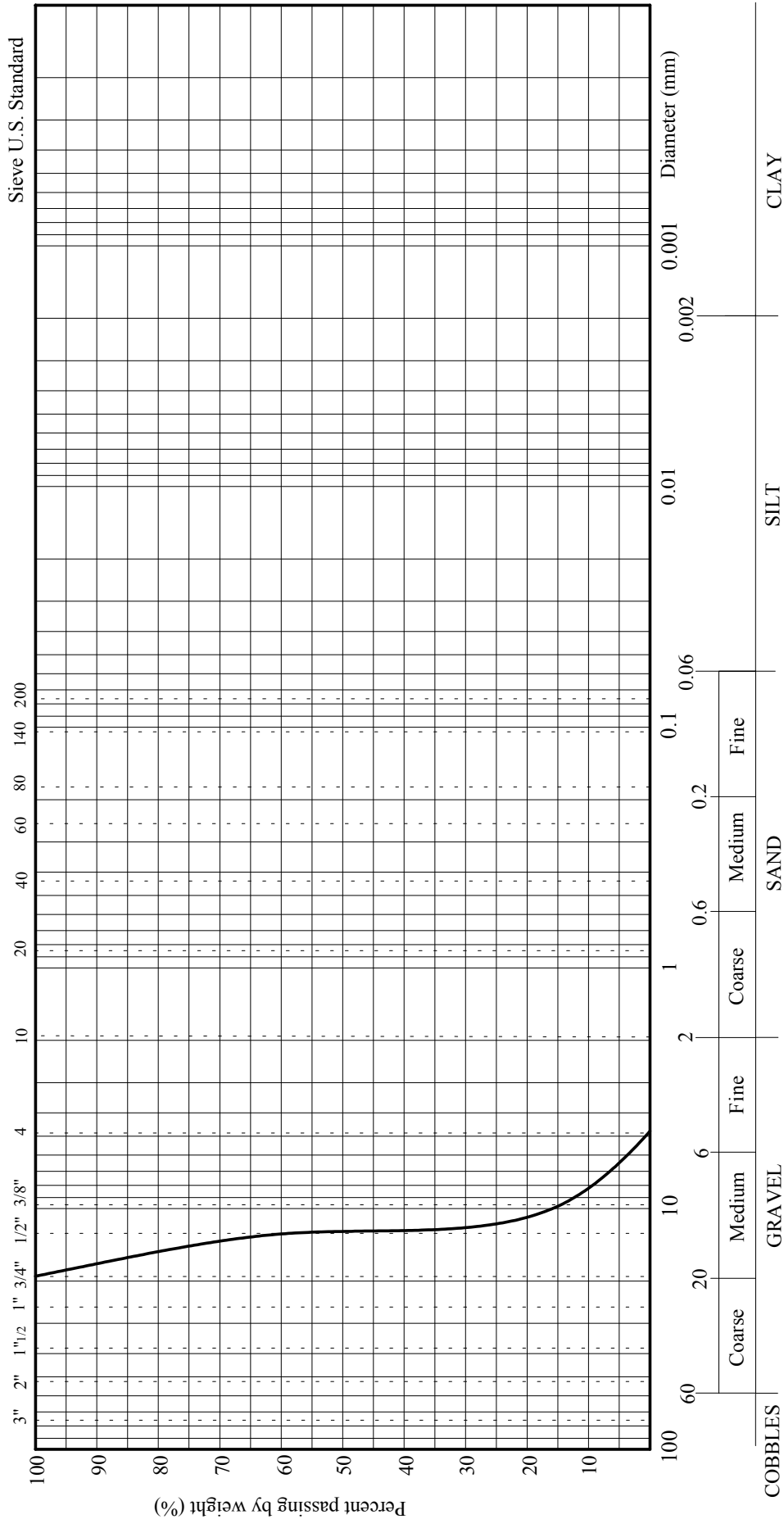
DEPARTMENT OF HYDRAULIC, MARITIME, ENVIRONMENTAL AND GEOTECHNICAL ENGINEERING
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Client Pontarolo Engineering Site S.Vito al Tagliamento Borehole <input type="text"/>	Date 09/07/2003 Sample Subgrade 4 Depth <input type="text"/>	Dry <input checked="" type="checkbox"/> Wet <input type="checkbox"/>	<table border="1" style="width:100%; border-collapse: collapse;"> <tr> <td style="width:33%;">Gross weight g.</td> <td style="width:33%; text-align: center;">1650,0</td> <td style="width:33%;"></td> </tr> <tr> <td>Tare weight g.</td> <td style="text-align: center;">150,0</td> <td></td> </tr> <tr> <td>Net weight g.</td> <td style="text-align: center;">1500,0</td> <td></td> </tr> </table>	Gross weight g.	1650,0		Tare weight g.	150,0		Net weight g.	1500,0	
Gross weight g.	1650,0											
Tare weight g.	150,0											
Net weight g.	1500,0											
PARTICLE-SIZE ANALYSIS												
Description of depth:												
Subgrade 4												
Depth												
ASTM Sieve n.	Diameter	Net weight (g)	% Passing									
4"	101,6		100,00									
3"	76,2		100,00									
2"	50,8		100,00									
1" 1/2	38,1		100,00									
1"	25,4		100,00									
3/4"	19,1		100,00									
1/2"	12,7	610,6	59,29									
3/8"	9,52	678,2	14,08									
4	4,76	211,2	0,00									
10	2		0,00									
20	0,84		0,00									
40	0,42		0,00									
60	0,25		0,00									
80	0,177		0,00									
140	0,105		0,00									
200	0,074		0,00									



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Sample	Depth	CLASSIFICATION SUBGRADE 4				γ_s (kN/m ³)	G_s	w %	w _L %	w _p %	I _p %	Pen. (kPa)	qu ¹ (kPa)	qu ² (kPa)
		Medium gravel.												
GRAIN SIZE DISTRIBUTIONS		Client Site		Pontarolo Engineering S. Vito al Tagliamento		BOREHOLE								



**Test for Nonrepetitive Static Plate Load Tests of Soils
and Flexible Pavement Components
(D 1196-93)**

Date: 08 / 07 / 2003

Client: Pontarolo Engineering

Site : S.Vito al Tagliamento

Soil: Subgrade 4

Test N° 1

Circular steel plate – diameter 300 mm

p = vertical pressure

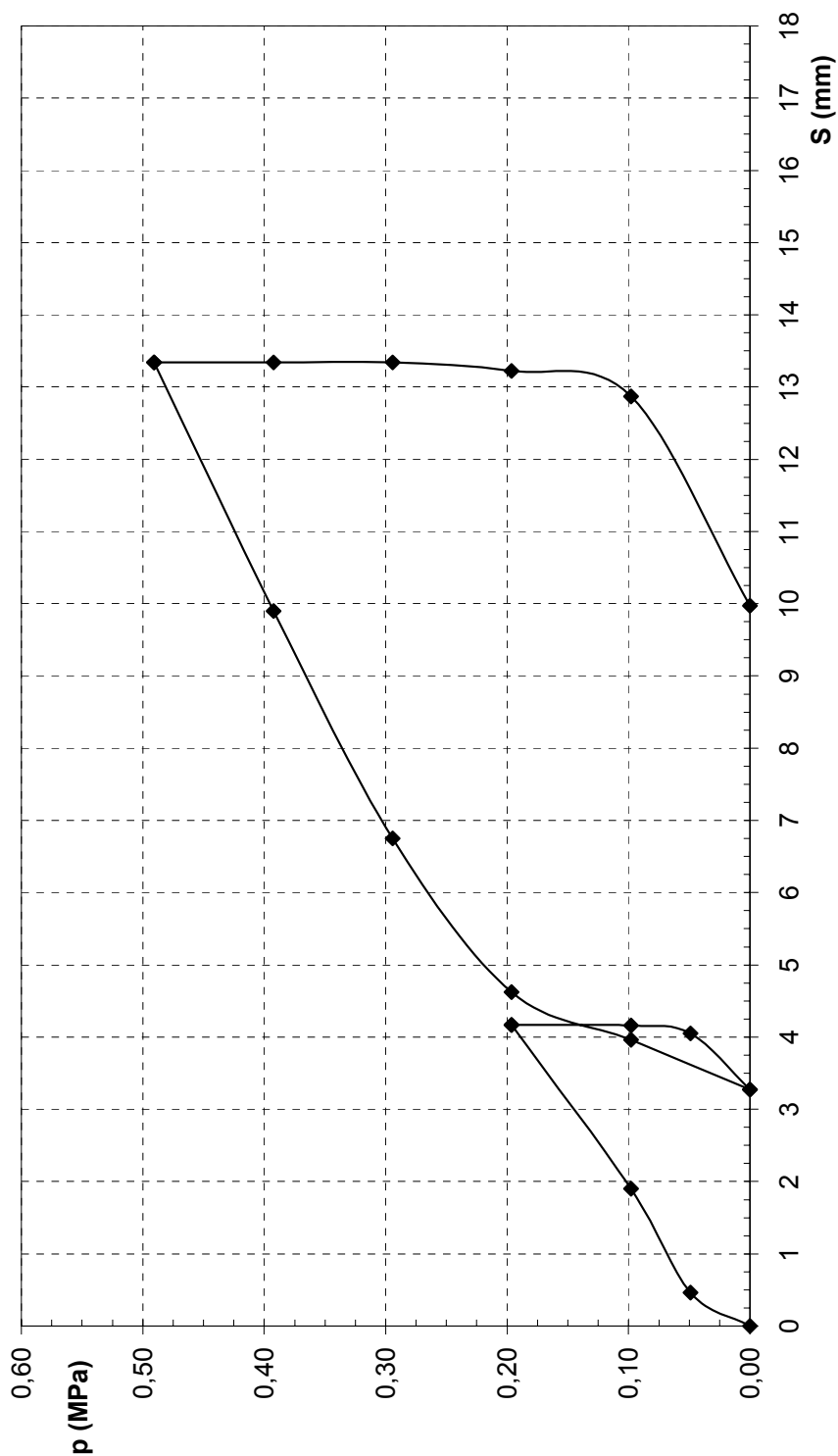
S = vertical settlement

p (MPa)	S (mm)
0,00	0,00
0,05	0,46
0,10	1,90
0,20	4,17
0,10	4,16
0,05	4,05
0,00	3,27
0,10	3,96
0,20	4,62
0,29	6,75
0,39	9,90
0,49	13,34
0,39	13,34
0,29	13,34
0,20	13,22
0,10	12,87
0,00	9,97



Soil: Subgrade 4

Test N° 1





Density and Unit Weight of Soil in Place by the Sand-Cone method (D1556-90)

Date: 08 / 07 / 2003
Client: Pontarolo Engineering
Site : S.Vito al Tagliamento
Soil: Subgrade 1A
Test N° 1-2

		Position N°	
		1	2
Test hole volume	(cm ³)	916,8	1061,1
Net weight of soil	(g)	1681,9	1783,3
In place wet unit weight γ_n	(g/cm ³)	1,835	1,681
Water weight	(g)	156,6	146,7
Water content w	(%)	10,27	8,96
In place dry unit weight γ_d	(g/cm ³)	1,664	1,542

In place wet unit weight γ_n	(KN/m ³)	18,00	16,49
In place dry unit weight γ_d	(KN/m ³)	16,32	15,13
Water content w	(%)	10,27	8,96



**Test for Nonrepetitive Static Plate Load Tests of Soils
and Flexible Pavement Components
(D 1196-93)**

Date: 08 / 07 / 2003

Client: Pontarolo Engineering

Site : S.Vito al Tagliamento

Soil: Subgrade 1A

Test N° 1

Circular steel plate – diameter 300 mm

p = vertical pressure

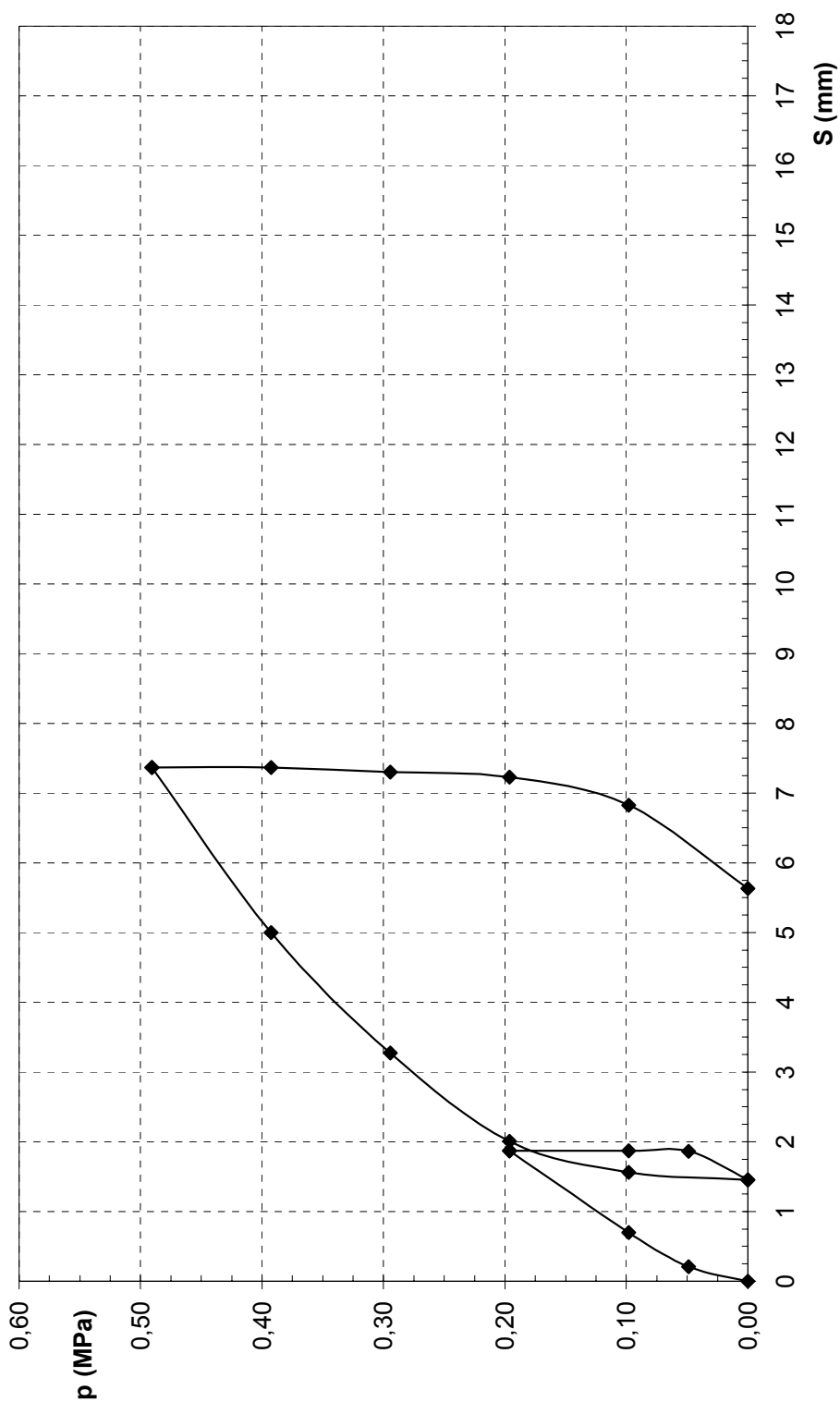
S = vertical settlement

p (MPa)	S (mm)
0,00	0,00
0,05	0,21
0,10	0,70
0,20	1,87
0,10	1,87
0,05	1,86
0,00	1,45
0,10	1,56
0,20	2,01
0,29	3,27
0,39	5,00
0,49	7,37
0,39	7,37
0,29	7,30
0,20	7,23
0,10	6,83
0,00	5,63



Soil: Subgrade 1A

Test N° 1





**Test for Nonrepetitive Static Plate Load Tests of Soils
and Flexible Pavement Components
(D 1196-93)**

Date: 08 / 07 / 2003

Client: Pontarolo Engineering

Site : S.Vito al Tagliamento

Soil: Subgrade 1A

Test N° 2

Square steel plate – side 120 mm

p = vertical pressure

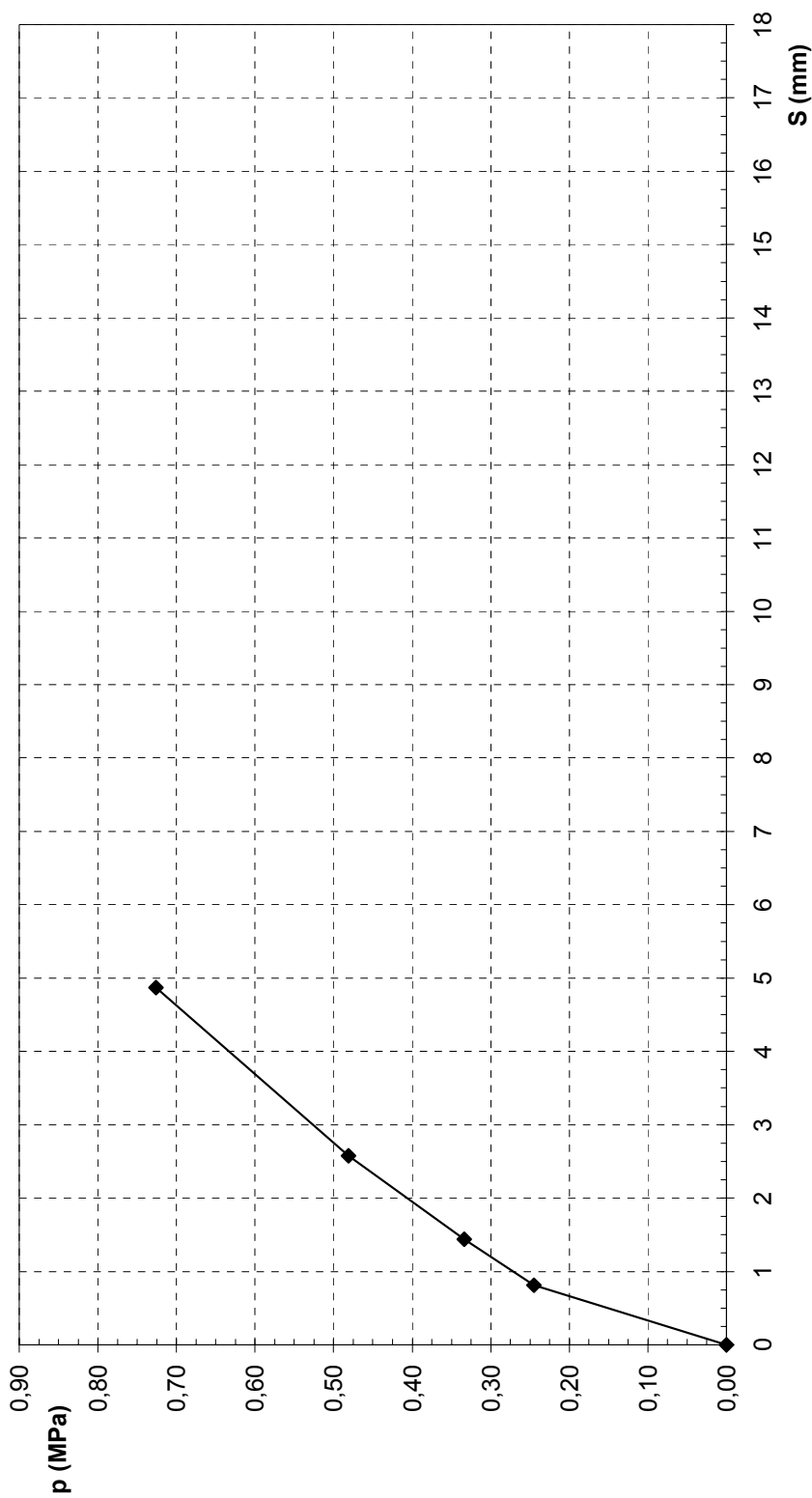
S = vertical settlement

p (MPa)	S (mm)
0,00	0,00
0,25	0,81
0,33	1,44
0,48	2,58
0,73	4,87



Soil: Subgrade 1A

Test N° 2





Subgrade 4





ENCLOSED C: SPERIMENTAL TEST RESULT (tests 23 and 24)

PROVA 23							
DY1	DY2	DY3	DY4	DY5	DY6	P [kN]	Osservazioni
0.00	0.00	-0.17	0.00	0.01	0.00	2.68	
-0.01	0.02	-0.34	0.00	0.02	0.02	5.36	
-0.01	0.01	-0.38	0.01	0.02	0.04	8.04	
-0.01	0.01	-0.58	0.04	0.06	0.06	10.71	
-0.01	0.02	-0.60	0.04	0.02	0.05	5.36	
-0.01	0.00	-0.63	0.04	0.02	0.03	2.68	
-0.01	0.00	-0.67	0.02	0.02	0.03	0.00	
-0.01	0.00	-0.72	0.02	0.02	0.03	5.36	
-0.02	0.01	-0.88	0.06	0.08	0.07	10.71	
-0.03	0.02	-0.88	0.10	0.09	0.07	13.39	
-0.03	0.02	-0.96	0.09	0.06	0.06	8.04	
-0.03	0.00	-0.74	0.02	0.02	0.03	0.00	
-0.03	0.00	-0.77	0.02	0.04	0.04	5.36	
-0.03	0.00	-0.83	0.06	0.09	0.07	10.71	
-0.06	0.03	-0.88	0.12	0.13	0.10	16.07	
-0.07	0.04	-0.94	0.15	0.15	0.14	18.75	
-0.06	0.04	-0.96	0.18	0.16	0.16	21.43	
-0.06	0.06	-0.98	0.19	0.15	0.14	16.07	
-0.03	0.05	-0.69	0.15	0.13	0.12	10.71	
-0.03	0.04	-0.76	0.11	0.10	0.07	5.36	
-0.03	0.02	-0.85	0.06	0.08	0.06	0.00	
-0.04	0.04	-0.90	0.09	0.13	0.09	10.71	
-0.07	0.04	-0.96	0.15	0.15	0.14	16.07	
-0.09	0.04	-1.00	0.19	0.20	0.16	21.43	
-0.07	0.06	-0.99	0.22	0.22	0.19	24.11	
-0.10	0.07	-0.98	0.25	0.25	0.24	26.79	
-0.10	0.08	-0.98	0.30	0.27	0.26	29.46	
-0.12	0.08	-1.05	0.33	0.31	0.33	32.14	
-0.06	0.08	-0.61	0.33	0.29	0.27	21.43	
-0.06	0.07	-0.76	0.24	0.22	0.19	10.71	
-0.08	0.07	-1.01	0.14	0.15	0.10	0.00	
-0.12	0.08	-0.85	0.17	0.20	0.16	10.71	
-0.17	0.10	-0.73	0.28	0.28	0.23	21.43	
-0.19	0.14	-0.52	0.39	0.35	0.35	32.14	
-0.19	0.14	-0.55	0.42	0.39	0.38	34.82	
-0.19	0.15	-0.60	0.46	0.42	0.42	37.50	leggero calo di pres.
-0.19	0.17	-0.60	0.51	0.47	0.46	40.18	
-0.20	0.18	-0.61	0.58	0.53	0.50	42.86	leggero calo di pres.
-0.17	0.18	-0.61	0.59	0.48	0.45	32.14	
-0.15	0.17	-0.63	0.47	0.42	0.40	21.43	
-0.16	0.15	-0.92	0.36	0.33	0.27	10.71	
-0.15	0.15	-0.18	0.26	0.24	0.18	0.00	
-0.20	0.20	-0.38	0.39	0.36	0.34	21.43	
-0.29	0.24	-0.42	0.66	0.55	0.52	42.86	
-0.30	0.24	-0.48	0.70	0.56	0.58	45.54	
-0.30	0.24	-0.56	0.75	0.64	0.64	48.21	
-0.30	0.24	-0.58	0.78	0.68	0.67	50.89	
-0.30	0.26	-0.58	0.87	0.74	0.75	53.57	
-0.18	0.24	-0.04	0.71	0.58	0.59	26.79	



-0.20	0.24	-0.72	0.37	0.33	0.26	0.00	
-0.30	0.24	-0.58	0.58	0.51	0.47	26.79	
-0.39	0.31	0.32	0.95	0.77	0.79	53.57	calo di pressione
-0.40	0.31	0.22	1.02	0.86	0.87	56.25	
-0.41	0.33	0.57	1.11	0.93	0.94	58.93	calo di pressione
-0.42	0.31	0.39	1.18	0.98	0.98	61.61	calo di pressione
-0.44	0.31	0.11	1.27	1.07	1.07	64.29	calo di pressione
-0.37	0.31	0.17	1.21	0.96	0.99	42.86	
-0.30	0.30	0.20	0.96	0.77	0.76	21.43	
-0.26	0.27	-0.29	0.59	0.46	0.40	0.00	
-0.36	0.31	-0.16	0.90	0.75	0.71	32.14	
-0.46	0.35	-0.15	1.39	1.15	1.16	64.29	calo di pressione
-0.46	0.36	-0.13	1.44	1.23	1.24	66.96	
-0.46	0.37	0.39	1.57	1.33	1.34	69.64	
-0.47	0.37	0.82	1.67	1.43	1.44	72.32	calo di pressione
-0.47	0.37	0.32	1.82	1.55	1.54	75.00	calo di pressione
-0.48	0.36	-0.06	1.96	1.71	1.73	77.68	
-0.46	0.31	-0.88	2.23	2.00	2.03	80.36	calo di pres. 2 bar
-0.30	-0.32	-0.52	3.51	3.79	3.72	83.04	calo di pres. 3 bar
-0.29	-0.65	-0.98	4.20	4.70	4.54	85.71	calo di pressione
-0.26	-0.69	-1.85	4.24	4.72	4.58	64.29	
-0.19	-0.68	-1.05	4.02	4.47	4.33	42.86	
-0.19	-0.65	-1.66	4.07	4.59	4.45	64.29	
-0.26	-0.77	-1.13	4.54	5.14	4.93	85.71	calo di pressione
-0.26	-0.95	-0.14	4.95	5.72	5.47	88.39	
-0.26	-1.19	-1.64	5.42	6.27	5.97	91.07	fessurato
-0.26	-1.40	-0.70	5.96	6.99	6.65	93.75	
-0.26	-1.69	-0.30	6.59	7.78	7.39	96.43	
-0.26	-2.00	-1.01	7.21	8.56	8.13	101.79	lettura instabile
-0.26	-2.52	-1.71	8.13	9.69	9.08	107.14	
-0.14	-2.57	-1.81	8.19	9.69	9.10	80.36	
-0.09	-2.55	-1.79	7.85	9.36	8.75	53.57	
-0.10	-2.52	-1.63	7.88	9.51	8.92	80.36	
-0.15	-2.74	-1.64	8.72	10.44	9.72	107.14	
-0.15	-3.12	-1.21	9.41	11.41	10.57	112.50	calo di pressione
-0.04	-3.74	-1.26	10.44	12.72	11.70	117.86	calo di pres. di 2.5 bar
-0.01	-4.24	0.00	11.47	14.13	12.93	123.21	calo di pres. di 3 bar
0.12	-5.24	0.00	13.21	16.33	14.78	128.57	calo di pres. di 5 bar
0.19	-5.89	0.00	14.39	17.89	16.17	133.93	
0.34	-6.80	0.00	16.01	19.90	17.83	139.29	calo di pres. di 5 bar
0.39	-7.74	0.00	17.67	22.04	19.64	144.64	
0.44	-9.24	0.00	20.07	24.82	22.23	150.00	calo di pres. di 5 bar
0.48	-10.05	0.00	22.14	27.42	24.63	155.36	rottura a taglio



PROVA 24						P [kN]	Osservazioni
DY1	DY2	DY4	DY5	DY6			
0.00	0.00	0.00	0.00	0.02	5.36		
0.00	0.00	0.02	0.03	0.02	8.04		
0.00	0.00	0.04	0.05	0.04	10.71		
0.00	0.00	0.03	0.03	0.02	5.36		
0.00	0.00	0.00	0.00	0.00	0.00		
0.01	0.00	0.00	0.03	0.02	5.36		
0.02	0.00	0.04	0.06	0.03	10.71		
0.01	0.00	0.07	0.09	0.07	13.39		
0.02	0.00	0.08	0.12	0.10	16.07		
0.01	0.02	0.11	0.17	0.14	18.75		
0.01	0.02	0.12	0.20	0.16	21.43		
0.00	0.00	0.08	0.13	0.11	10.71		
0.00	0.00	0.01	0.04	0.02	0.00		
0.10	-0.04	0.13	0.11	0.07	10.71		
0.12	-0.03	0.17	0.17	0.13	16.07		
0.13	-0.01	0.21	0.22	0.16	21.43		
0.13	0.00	0.23	0.25	0.21	24.11		
0.10	0.00	0.23	0.29	0.25	26.79		
0.11	0.02	0.24	0.32	0.31	29.46		
0.08	0.04	0.26	0.38	0.35	32.14		
0.04	0.03	0.21	0.32	0.31	21.43		
0.03	0.00	0.14	0.23	0.19	10.71		
0.02	-0.03	0.08	0.10	0.05	0.00		
0.04	-0.01	0.12	0.20	0.14	10.71		
0.07	0.00	0.19	0.29	0.23	21.43		
0.10	0.04	0.28	0.40	0.36	32.14		
0.11	0.06	0.31	0.45	0.39	34.82		
0.11	0.06	0.35	0.48	0.44	37.50		
0.11	0.09	0.39	0.54	0.49	40.18		
0.11	0.10	0.39	0.57	0.52	42.86		
0.06	0.09	0.37	0.54	0.50	32.14		
0.04	0.04	0.28	0.47	0.42	21.43		
0.03	0.00	0.20	0.32	0.29	10.71		
0.04	-0.05	0.14	0.20	0.15	0.00		
0.08	0.00	0.24	0.35	0.33	21.43		
0.15	0.10	0.43	0.58	0.55	42.86		
0.16	0.13	0.46	0.65	0.61	45.54		
0.17	0.15	0.48	0.70	0.65	48.21		
0.16	0.16	0.50	0.78	0.71	50.89		
0.17	0.19	0.53	0.81	0.73	53.57		
0.06	0.11	0.41	0.64	0.58	26.79		
0.06	-0.05	0.17	0.25	0.17	0.00		
0.11	0.05	0.33	0.50	0.44	26.79		
0.17	0.00	0.53	0.87	0.76	53.57		
0.16	0.21	0.56	0.89	0.80	56.25		
0.17	0.22	0.58	0.94	0.83	58.93		
0.17	0.24	0.63	1.00	0.89	61.61		
0.17	0.26	0.66	1.05	0.92	64.29		
0.05	0.20	0.56	0.94	0.83	42.86		
0.04	0.09	0.44	0.72	0.64	21.43		



0.09	-0.05	0.23	0.32	0.27	0.00	
0.16	0.05	0.46	0.65	0.58	32.14	
0.18	0.26	0.70	1.08	0.98	64.29	
0.17	0.29	0.73	1.16	1.01	66.96	
0.18	0.31	0.75	1.17	1.05	69.64	
0.15	0.34	0.79	1.26	1.11	72.32	
0.17	0.37	0.80	1.32	1.17	75.00	
0.22	0.38	0.88	1.40	0.00	77.68	
0.22	0.38	0.89	1.44	0.00	80.36	
0.21	0.42	0.89	1.50	0.00	83.04	
0.20	0.45	0.94	1.55	0.00	85.71	
0.09	0.42	0.86	1.48	0.00	64.29	
0.08	0.31	0.73	1.28	0.00	42.86	
0.20	0.36	0.84	1.41	0.00	64.29	
0.21	0.45	0.96	1.58	0.00	85.71	
0.21	0.46	0.99	1.69	0.00	88.39	
0.21	0.48	1.02	1.70	0.00	91.07	
0.21	0.51	1.05	1.80	0.00	93.75	
0.19	0.53	1.10	1.86	0.00	96.43	
0.20	0.62	1.17	2.01	0.00	101.79	
0.18	0.70	1.26	2.15	0.00	107.14	
0.05	0.67	1.13	2.08	0.00	80.36	
0.06	0.53	0.98	1.83	0.00	53.57	
0.19	0.58	1.13	1.97	0.00	80.36	
0.18	0.73	1.29	2.24	0.00	107.14	
0.16	0.78	1.36	2.41	0.00	112.50	
0.15	0.83	1.41	2.49	0.00	117.86	leggero calo di pres.
0.12	0.93	1.50	2.74	0.00	123.21	
0.07	1.05	1.63	2.96	0.00	128.57	
0.04	1.12	1.72	3.21	0.00	133.93	
0.01	1.24	1.82	3.40	0.00	139.29	
0.00	1.33	1.91	3.59	0.00	144.64	
-0.06	1.51	2.07	3.92	0.00	150.00	
-0.11	1.60	2.18	4.22	0.00	155.36	
-0.16	1.77	2.30	4.50	0.00	160.71	
-0.24	2.00	2.44	4.91	0.00	166.07	calo di pres. 30 b

ENCLOSED D: PHOTOGRAF GALLERY

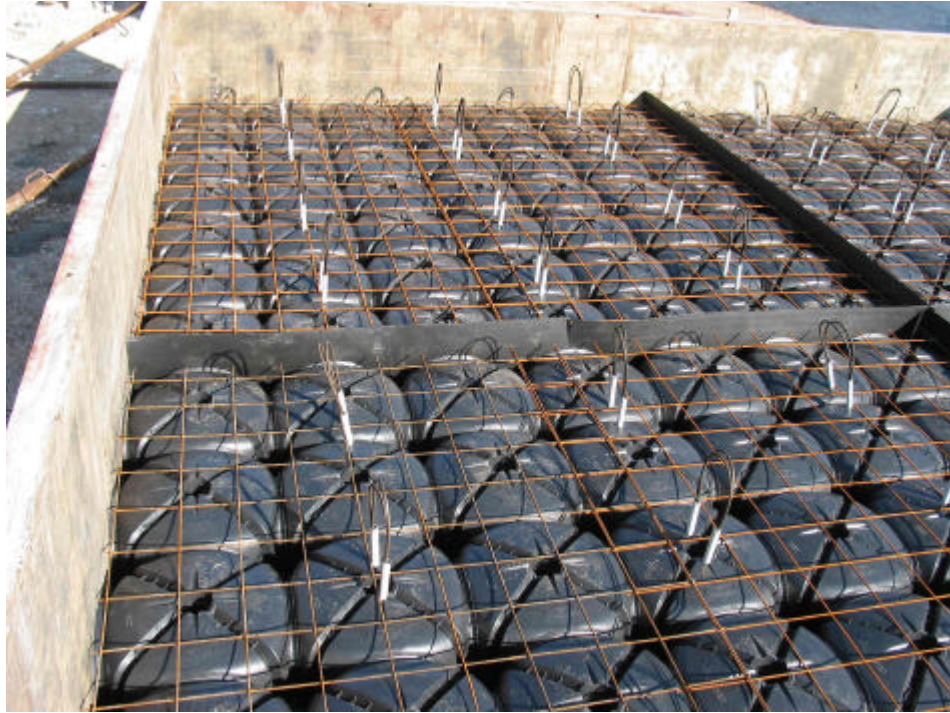


Fig.D.1 Layout Cupolex elements with steel reinforcement



Fig. D.2 Concrete casting with steel lifting rope



Fig. D.3 Complete concrete tests



Fig. D.4 Detail of the top of concrete tests



Fig. D.5 Frontal detail of concrete tests



Fig. D.6 Frontal detail of concrete tests



Fig. D.7 The preparing of the Natural soil test



Fig. D.8 Natural soil test



Fig. D.9: Lifting of concrete tests



Fig. D.10: Detail of concrete tests lifting



Fig. D.11 Crack line on the concrete test n°1



Fig. D.12 Crack line detail on the concrete test n°1



Fig. D.13 Crack line detail on the concrete test n°1



Fig. D.14 Crack line and instruments detail on the concrete test n°4



Fig. D.15 Prints on the soil of concrete test n°4

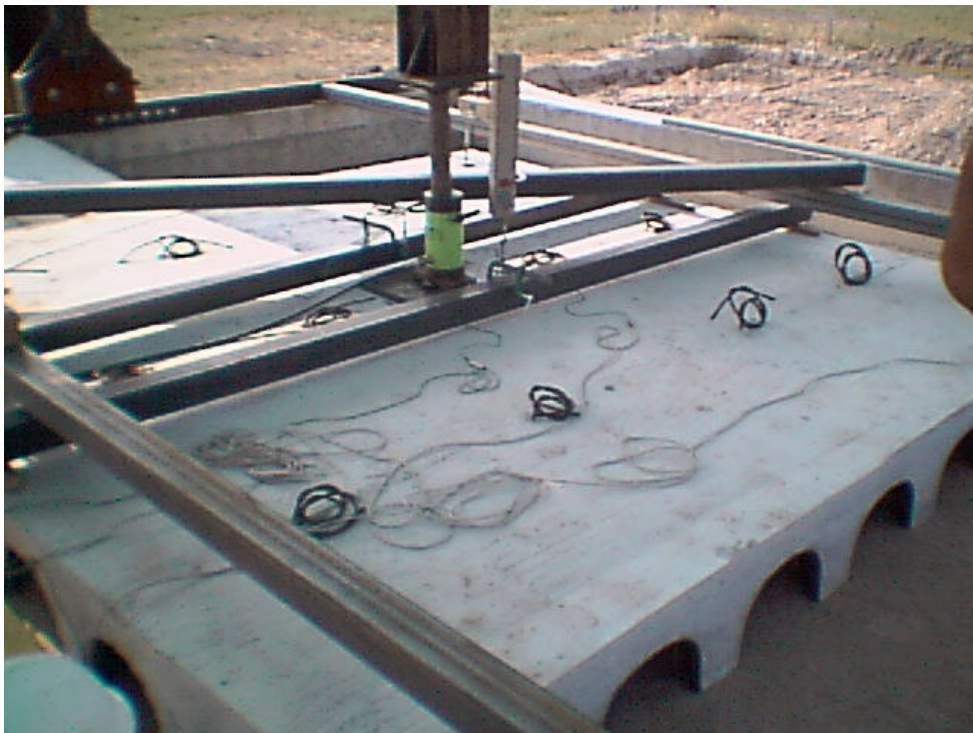


Fig. D.16 Instrument layout of concrete test n°6

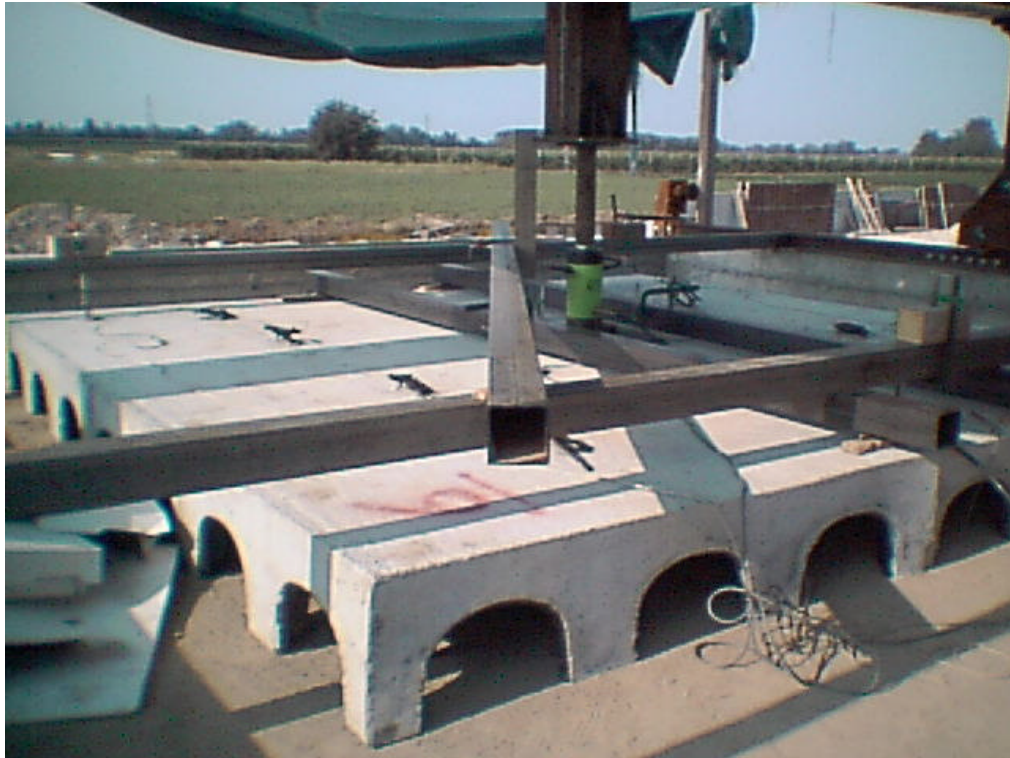


Fig. D.17 Instrument layout of concrete test n°6



Fig. D.18 Crack line detail on the concrete test n°6



Fig. D.19 Details of lifting the column of the concrete test n°7



Fig. D.20 Crack line detail on the concrete test n°7



Fig. D.21 Punching Crack on the concrete test n°7



Fig. D.22 Concrete test n°11 on gravel subgrade



Fig. D.23 Details of lifting the column of the concrete test n°11



Fig. D.24 Instruments for the test



Fig. D.25 Punching Crack on the concrete test n°12



Fig. D.26 Crack line detail on the concrete test n°12



Fig. D.27 Layout tests Cupolex-slab



Fig. D.28 Crack line on the concrete slab



Fig. D.29 Crack line on the Cupolex concrete test

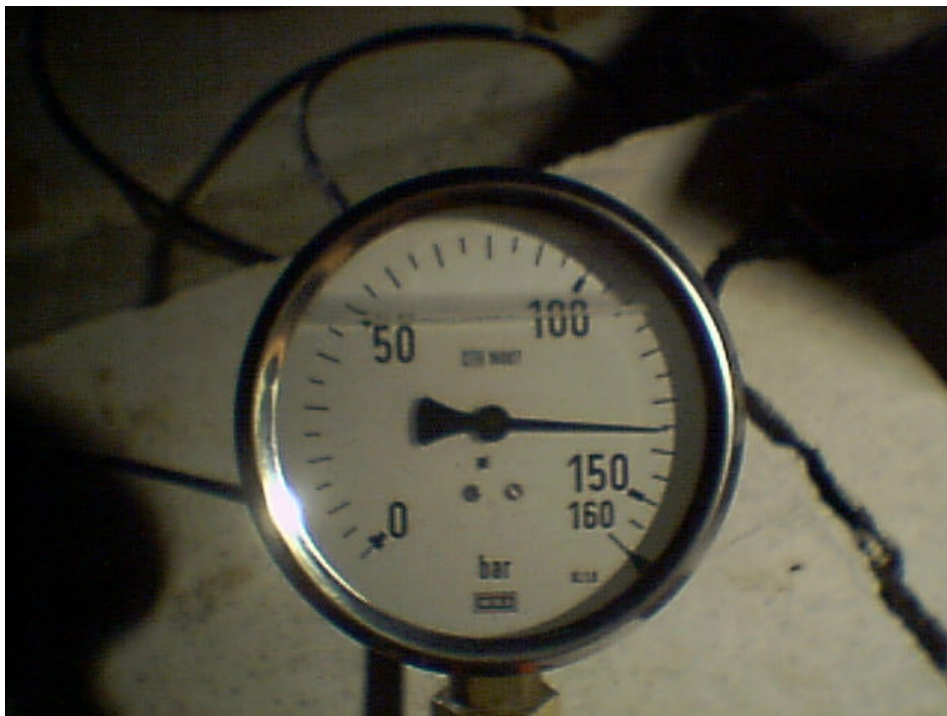


Fig. D.30 The Instrument before Cupolex crack



Fig. D.31 Crack line detail on the concrete slab



Fig. D.32 Punching Crack on the concrete slab