

**CONTRIBUTIONS TO IMPROVEMENT
OF LARGE DIAMETER PILE RESISTANCE CALCULATION,
AXIALLY LOADED, BASED ON IN SITU LOAD TESTS**

RESEARCH REPORT

**PROCESSING OF LOAD TESTS MEASUREMENTS ON
INSTRUMENTED PILES, AXIALLY LOADED**

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Contents

1. The purpose of research “Contributions to improvement of large diameter pile resistance calculation, axially loaded, based on in situ load tests”	5
2. Processing of measurements on load tests on instrumented piles, axially loaded	5
2.1. Enlarged base piles performed in Bucharest typical geotechnical conditions	7
2.2. Pile embedded in a layer of semi-rocky rock	20
2.3. Full displacement pile (FDP) in a marly clay complex.....	29
2.4. CFA pile in a sandy layer (PP4)	37
3. Conclusions	47
4. Bibliography	50

Figures list

Figure 1. Scheme of test pile execution technology	7
Figure 2. Reinforcing cage	8
Figure 3. Reinforcing cage ready for installation	8
Figure 4. Axial compression test overview	9
Figure 5. Positioning of the test pile and anchor piles (PP1)	10
Figure 6. Determination of the deformation modulus for reinforced concrete PP1	12
Figure 7. Details of the test pile instrumentation PP1.....	12
Figure 8. Test pile instrumentation PP1	13
Figure 9. Rod extensometer ready for installation in pile PP1	14
Figure 10. Load-settlement-time diagram PP1	15

Figure 11. The variation of the stress on the length of the PP1 pile resulted from the measurements on strain gauges.....	16
Figure 12. Unit shaft resistances mobilized of the PP1 pile determined by strain gauges measurements	17
Figure 13. Mobilized pressure on the enlarged base of the PP1 pile	18
Figure 14. Variation of PP1 test pile displacements and foundation ground from - 0.60 to -60.50 for the loading cycle.....	19
Figure 15. Sketch of PP2 pilot execution technology	20
Figure 16. Axial compression load test overview PP2	21
Figure 17. Positioning of the PP2 test pile and anchor piles.....	22
Figure 18. PP2 pile test instrumentation	24
Figure 19. Determination of the deformation modulus for PP2 pile's reinforced concrete section.....	25
Figure 20. Load-settlement-time diagram PP2.....	26
Figure 21. The variation of the stresses on the length of the PP2 pile resulted from the measurements on strain gauges.....	27
Figure 22. Shaft resistance of the PP2 pile	28
Figure 23. base resistance of PP2 pile	29
Figure 24. Axial compression load test overview PP3	29
Figure 25. Sketch of the FDP construction technology of PP3 test pile	30
Figure 26. Layout of the PP3 pile and anchoring piles	31
Figure 27. Determination of the deformation modulus for PP3 pile reinforced concrete section.....	32
Figure 28. Schematic section of the Ø510 mm PP3 pile.....	33
Figure 29. Load-settlement-time diagram PP3.....	34
Figure 30. The variation of the stresses on the length of the PP3 pile resulted from the measurements on strain gauges.....	35

Figure 31. Mobilized unit shaft resistances of the PP3 pile determined by strain gauges	36
Figure 32. Base resistance pile PP3	37
Figure 33. Sketch of technology for the construction of CFA test pile (PP4)	38
Figure 34. Axial compression load test overview PP4	39
Figure 35. Positioning of the PP4 test pile and anchor piles.....	40
Figure 36. Schematic section of the PP4 $\Phi 620$ mm test pile.....	41
Figure 37. Extended pile section PP4	42
Figure 38. Determination of the deformation modulus of the reinforced concrete section for strain gauges - PP4	43
Figure 39. load-settlement-time diagram - PP4	44
Figure 40. Variation of the stress on the length of the test pile, measured on the PP4 strain gauges.....	45
Figure 41. Shaft resistance of the PP4 pile	46
Figure 42. Base resistance for pile PP4.....	47

1. The purpose of research “Contributions to improvement of large diameter pile resistance calculation, axially loaded, based on in situ load tests”

The general objective of the thesis is improving the resistance analyses of foundation piles based on in-situ load tests and detailed analysis of the static load test procedures to simplify testing instrument piles. The aim of the thesis is at least to achieve the following specific objectives:

- Understanding and quantifying the processes and parameters of concrete that can influence the results of load test piles instrumentation;
- Detailing the calculation for determining the transmission of loads to the foundation ground for axially loaded piles which transmit the load both on the shaft and on their base;
- Detailing interpretation of data collected from instruments used in instrumented load tests for designing of the foundation systems.

2. Processing of measurements on load tests on instrumented piles, axially loaded

Within the research report no. 2, some load tests will be presented on instrumented piles and will be processed based on the equipment and methods for determining the state of stress and strains previously presented in the research report no. 1.

The test loads were performed in accordance with the norm NP 045-2000, normative regarding the field test of the test piles and of the foundation piles.

The static tests were performed by applying controlled loads, which remain constant at certain intervals, with the measurement of movements at the top of the instrumented pilot.

The displacements of the pile's head were measured using analog and / or digital dial gauges, which have a measurement accuracy of 0.01 mm. Additionally, the stability of the reference beams with an optical level located outside the area of influence of the test was verified.

After applying the loading step, recordings of the reading devices (vertical) were made at 0', 2', 5', 10', 15', 20', 25', 30', 40', 50', 60' and where necessary, further every 10 minutes, until conventional stabilization of vertical displacement (settlement) according to NP 045-2000.

Also, for a detailed analysis of the behavior of the piles under the action of loads and to determine the resistance on the lateral surface of the test pile in the different ground layers traveled and the base pressure, the piles were equipped with strain gauges and, where appropriate, extensometers arranged in depth.

The settlement gauges measure the microdeformations that occurred in the pile in the instrumented sections. Knowing the specific deformation at the level of a section and the value of the equivalent deformation modulus of the section of the pile made of concrete and steel reinforcement, the total axial compression force in the respective section of the pilot is obtained. The difference between the forces in two consecutive instrumented sections results in the shaft resistance of the pile between the two sections. ($q_{s,m,i}$).

The extensometers consist of a continuous metal rod with an end anchored in concrete at known depths, protected from concreting in a metal pipe.

The determination of the deformation modulus of the composite reinforcement section of the pile was performed according to the method described in the Research Report no. 1 (Fellenius, 2006) based on measurements on strain gauges. The method involves the installation of strain gauges or extensometer on a free length of the pile. Knowing the applied force and the specific deformations of the free section, the deformation modulus of the reinforced concrete section of the pile is determined. This procedure was applied in the section at the piles' head, after which the resulting values of the deformation modulus were processed, obtaining the linear variation diagram of the deformation modulus E with the specific deformation.

2.1. Enlarged base piles performed in Bucharest typical geotechnical conditions

The pile with the enlarged base had a length of about 32 m, the diameter of the base $d_b = 2,640$ mm and the diameter of the shaft $d = 1,060$ mm. The pile was bored under the protection of polymer suspensions and subsequently after concreting was grouted into the base area through 6 grouting points. Four anchor piles were used, which were made in the same conditions and have approximately the same characteristics as the test pile.

Figure 1 shows schematically the steps of making the test pile with the enlarged base.

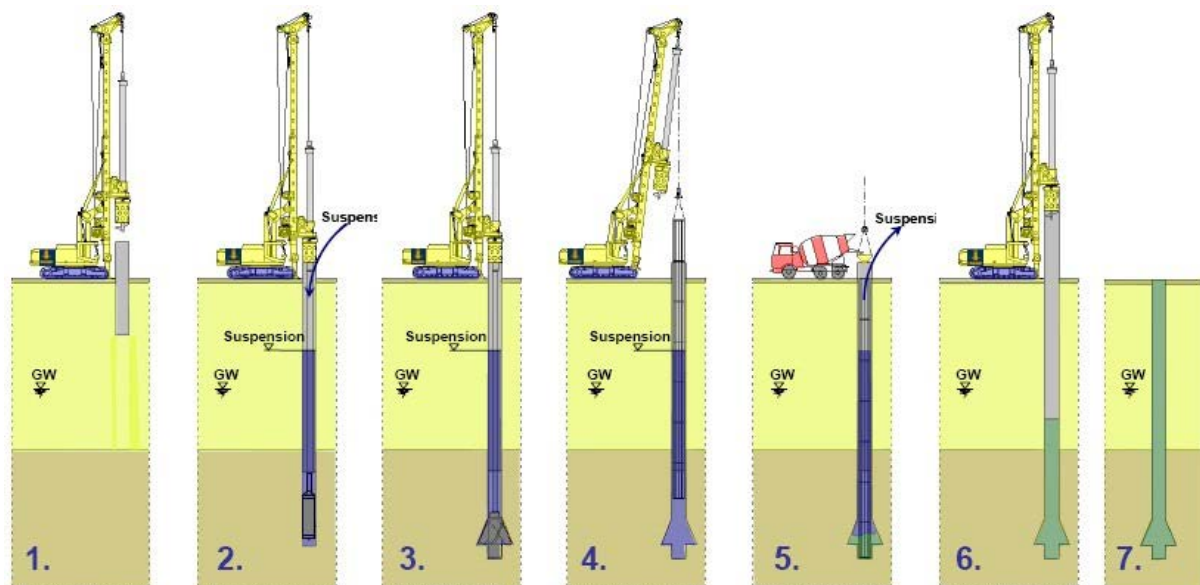


Figure 1. Scheme of test pile execution technology

The materials used in the execution of the test pile with an enlarged base are:

- concrete strength class C50/60, 480 kg cement CEM-I 52,5R, $W/C_{max} = 0.33$, $D_{max} = 16$ mm, exposure classes XC4, XF1, XA1.
- reinforcement class B500C - reinforcement cage with outer diameter of 920 mm, total length of 34.55 m, made of four sections welded together on the longitudinal bars, with an overlapping length between 135-150 cm. Each section consists of 20 longitudinal bars with a diameter of 25 mm, stiffening rings in bars of $\Phi 20$ mm and a spiral of $\Phi 12$ mm with a step of 15 cm.

The pile was made from the level of the natural ground (± 0.00), and in order to reduce the friction on the lateral surface to the lower level of the raft, drillings tangential to it were performed on the contour of the test pile, up to a level of -12.00. The space thus created around the test pile, from the level of the working platform to the level of -12.00, was filled with bentonite slurry. During the load test, the slurry level was maintained at -2.30 level.

To determine the shaft friction in each layer and the base pressure the reinforcing cage of the test pile (fig. 2 and 3) was previously equipped with 18 strain gauges (with vibrating wire) and 3 rod-extensometers, respectively steel pipe $\Phi 159$ mm for the subsequent installation under the pilot base of a rod-extensometer column.

The piles were equipped at the bottom, between the levels -31.20 and -35.50, with 6 injection hoses to consolidate the ground from the base, disturbed by the execution process of the piles with the enlarged base.



Figure 2. Reinforcing cage



Figure 3. Reinforcing cage ready for installation

For the execution of the load test at axial static compression on the test pile described above, a work platform was used at the level ~ -2.00 compared to the level ± 0.00 (fig. 4).

The stratification encountered when drilling the test pile is indicated in table no. 1.

Table 1. Stratification related to the natural ground level

Depth (m)	Stratification
0,00 – 1,50	Fill
1,50 – 8,00	Sand with gravel
8,00 – 10,00	Clayey sand
10,00 – 31,00	Clays
31,00 – 35,50	Sandy clay/ Clayey sand



Figure 4. Axial compression test overview

To apply the compressive force to the pile's head, a 40 mm thick steel load distribution plate was installed so as to avoid cracking of the concrete at high loads.

The force was applied with the help of four hydraulic presses with a capacity of 5,000 kN. The hydraulic presses were operated in parallel using an automatic hydraulic system for putting and maintaining the pressure (pumping equipment).

The axial compression load test started on 01.04.2014, 18 days after the pile's execution and was completed on 04.04.2014.

The position of the group of test piles is shown in Figure 5..

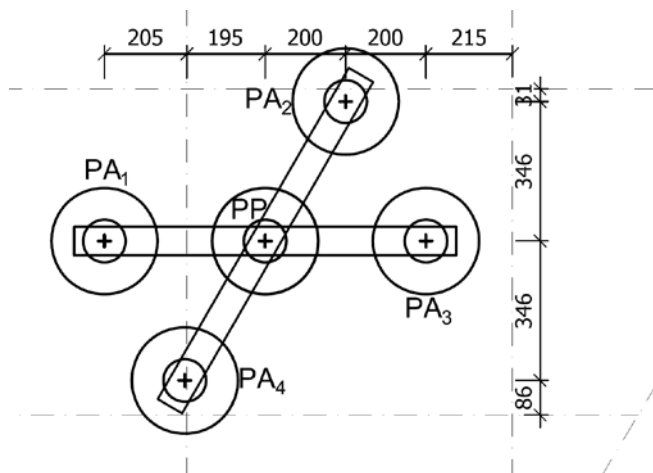


Figure 5. Positioning of the test pile and anchor piles (PP1)

For the axial compression test, the maximum force of 15,500 kN was applied in approximately equal steps according to Table 2 and the evolution over time of the pile displacements was observed, in order to evaluate the bearing capacity.

Table 2. Loading steps for static compression test

Step	Q (kN)	Cycle
1	2.000	Load
2	4.000	
3	6.000	
4	8.000	
5	10.000	
6	12.000	
7	13.500	
8	14.500	
9	15.500	
10	12.500	Unload
11	9.500	
12	6.500	
13	3.500	
14	0	

The strain gauges were positioned on each cross section of the pilot, in 6 sections located at elevations: -4.15, -11.85, -16.65, -21.85, -25.90 and -30.20 from the elevation ± 0.00 (Figure 8).

To verify the measurements on the strain gauges, rod-extensometers were installed located at only 3 levels, namely: -11.85, -30.20 and -35.30 compared to the ± 0.00 level.

Based on the linear variation diagram of the deformation modulus E with the strain shown in figure 6, table 3 shows the values obtained of the deformation modulus at different levels and loading stages.

Table 3. Variation of the deformation modulus calculated on the basis of the measurements on the strain gauges PP1

STEP (kN)	E (MPa) at level:				
	-11,85	-16,65	-21,85	-25,90	-30,20
2.000	38.572	38.835	39.196	39.433	39.593
4.000	36.961	37.367	37.972	38.625	39.120
6.000	35.309	35.834	36.502	37.555	38.439
8.000	33.540	34.158	34.834	36.223	37.488
10.000	31.719	32.408	33.092	34.781	36.396
12.000	29.929	30.681	31.305	33.285	35.290
13.500	27.789	28.507	28.813	30.858	32.762
14.500	26.608	27.266	27.471	29.387	31.162
15.500	25.354	25.978	26.116	27.926	29.583
12.500	26.196	26.561	26.492	28.171	29.743
9.500	28.102	28.068	27.543	28.869	30.146
6.500	30.391	30.151	29.285	30.094	30.932
3.500	33.043	32.688	31.692	31.855	32.099
0	36.906	36.366	35.171	34.575	34.321

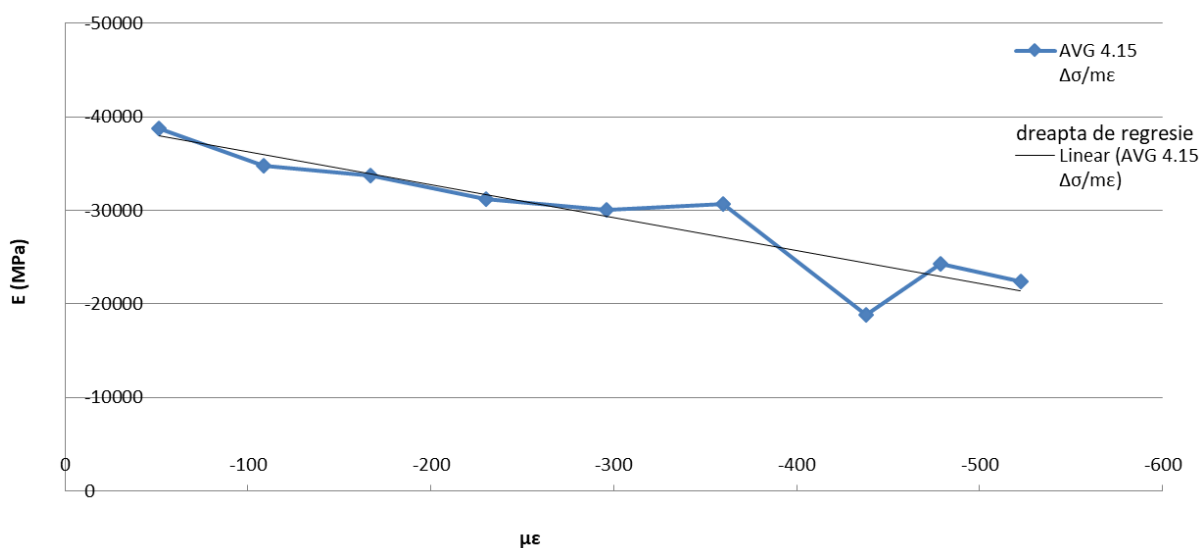
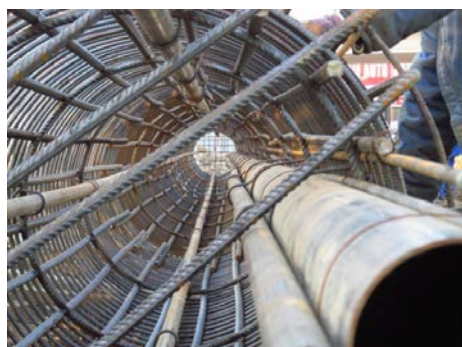


Figure 6. Determination of the deformation modulus for reinforced concrete PP1



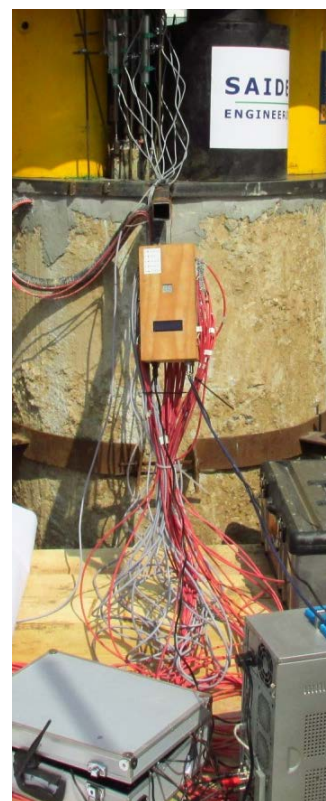
a)



b)



c)



d)

Figure 7. Details of the test pile instrumentation PP1

- a), b) Reinforced cage equipped for installation into the borehole
- c) Electronic displacement transducers for reading rod-extensometers
- d) Central panel for reading the test load instrumentation

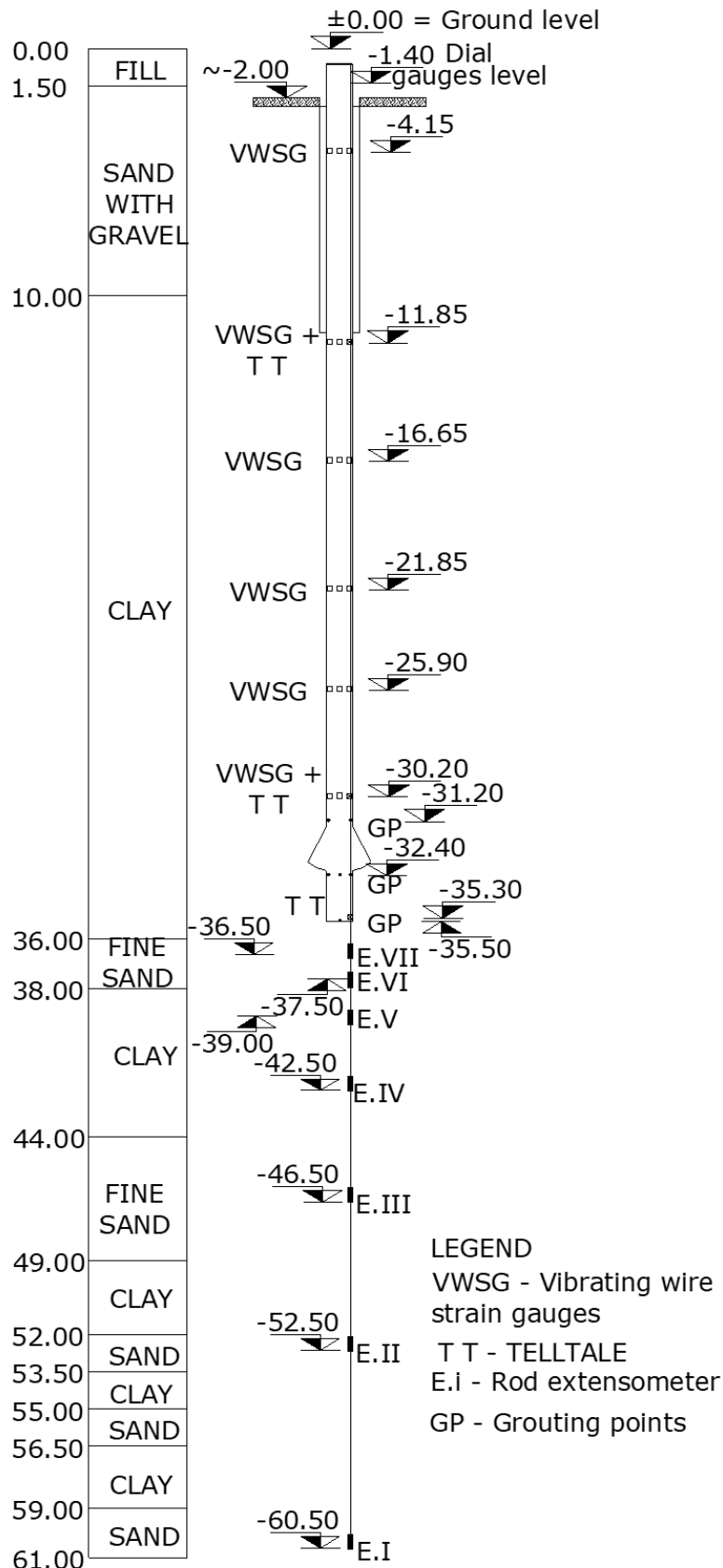


Figure 8. Test pile instrumentation PP1

A Ø159 mm steel pipe was installed on the reinforcement cage of the PP1 test pile, down to the base of the borehole. After concreting the pile, a rod-extensometer with 7 anchors was inserted through the steel pipe up to the level -60.50 and 7 anchors were inserted at the levels -36.50, -37.50, -39.00, -42.50, -46.50, -52.50 and -60.50 (fig. 9).



Figure 9. Rod extensometer ready for installation in pile PP1

The PP1 test pile was loaded in steps applied according to Table 2, up to a maximum stabilised force of 14,500 kN. The step corresponding to the force $Q = 15,500$ kN was maintained for 24 hours without obtaining the conventional condition of stabilization of the settlements, after which according to the norm NP 045 2000 the loading was stopped and the unloading in steps was started. The graphical representation of the displacements is presented in Figure 10.

At the maximum stabilized load of 14,500 kN, the test pile PP1 recorded a settlement at the level of its head of 74.01 mm, and at the maximum applied load of 15,500 kN the pile recorded a settlement at the level of its head of 105.92 mm. After unloading the pile, a residual settlement of 89.77 mm was recorded at the level of its head (Figure 10).

Applying the linear variation of the deformation module E of the composite section was obtained the variation curves of the stress along the pile shown in figure 11.

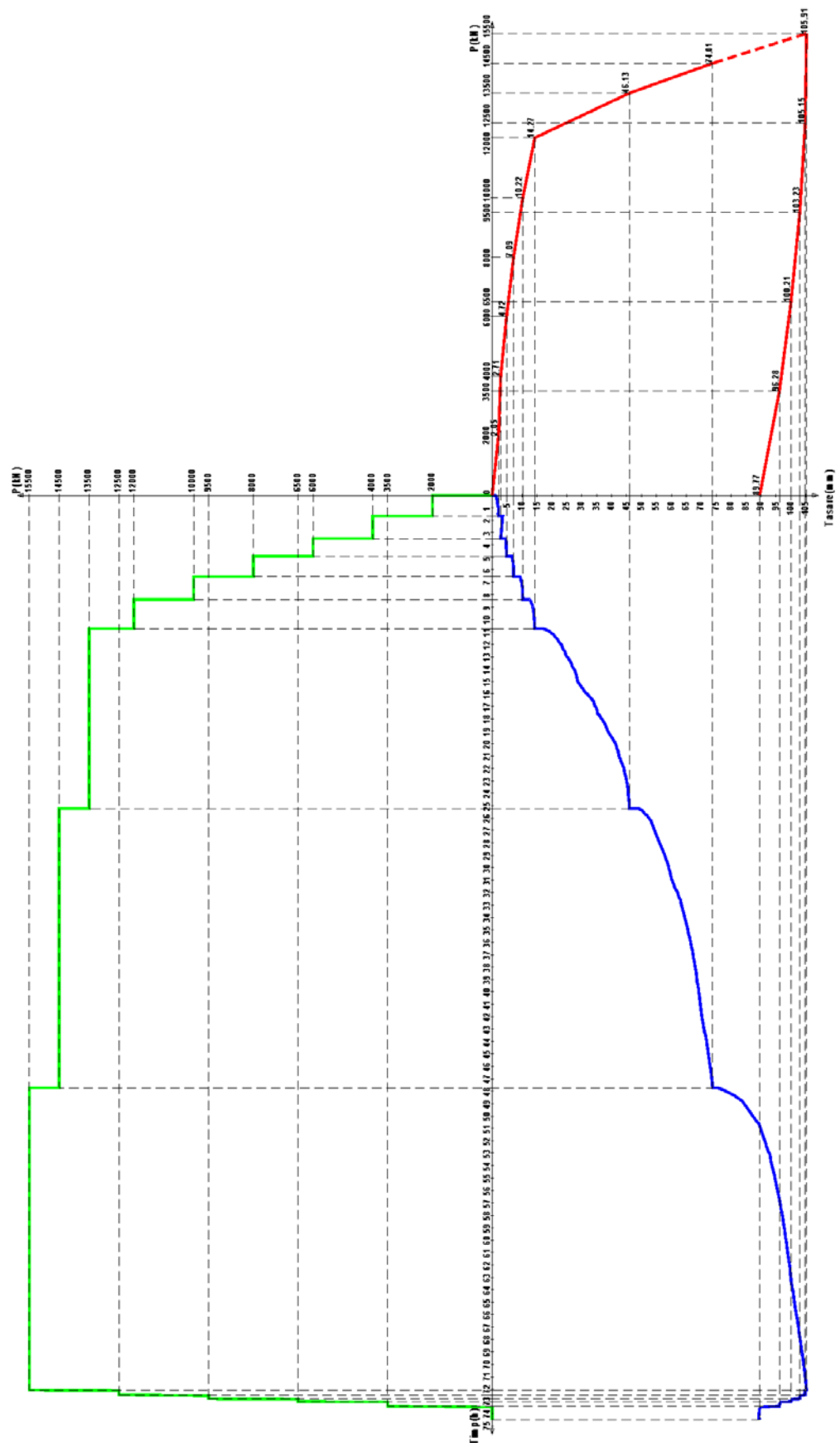


Figure 10. Load-settlement-time diagram PP1

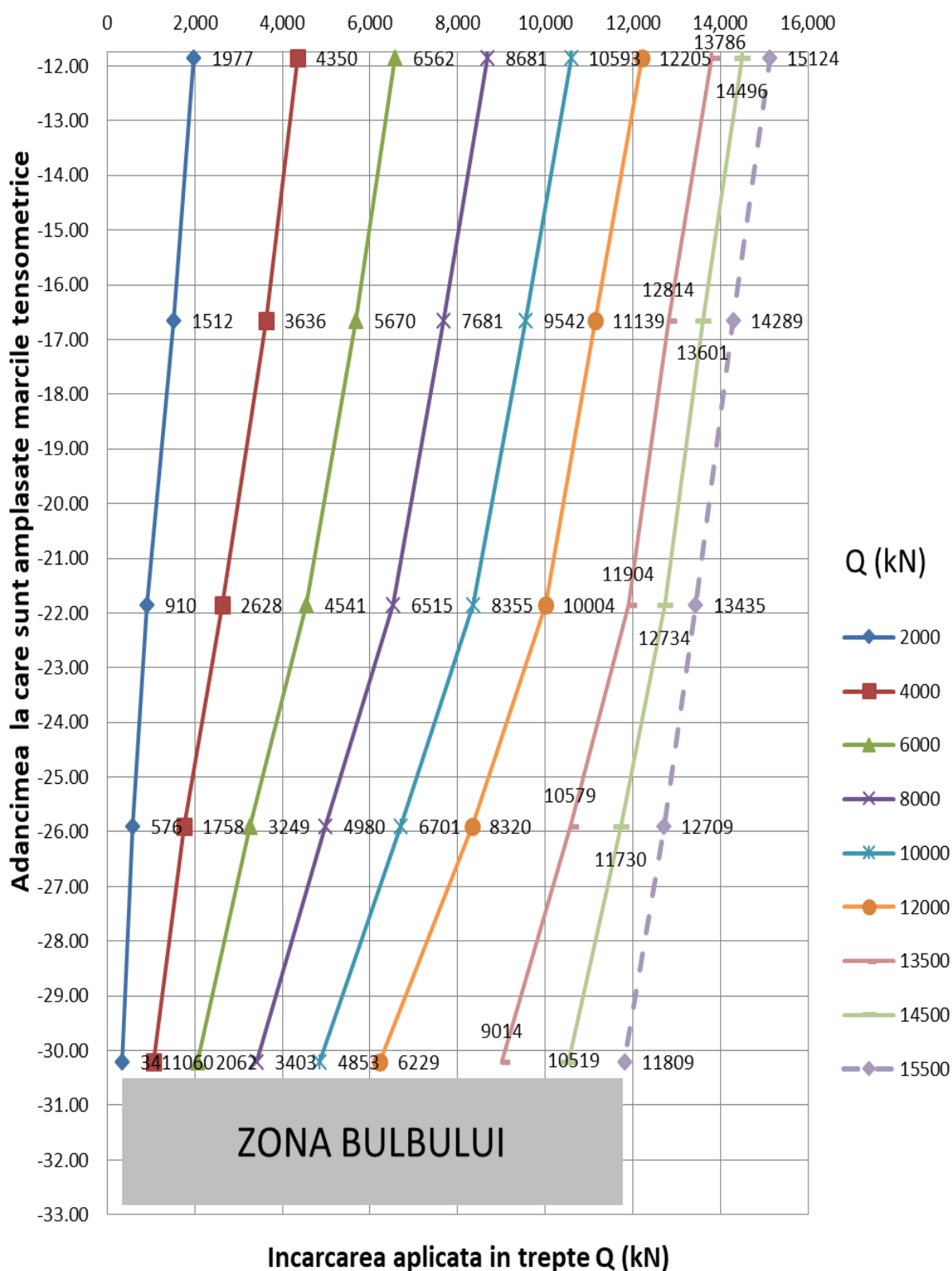


Figure 11. The variation of the stress on the length of the PP1 pile resulted from the measurements on strain gauges

In the test on the instrumented pile with the enlarged base PP1, the values of the shaft resistance resulting from the processing of the data recorded on the basis of strain gauges are presented in Table 4.

Table 4. The shaft resistance values between two instrumented sections by strain gauges PP1

Depths of areas traversed by the test pile [m]	Mobilized shaft resistance, maximum value $q_{s,m}$ [kPa]
from -11,85 to -16,65	66
from -16,65 to -21,85	70
from -21,85 to -25,90	126
from -25,90 to -30,20	146

Figure 12 also shows the shaft resistance mobilization curves.

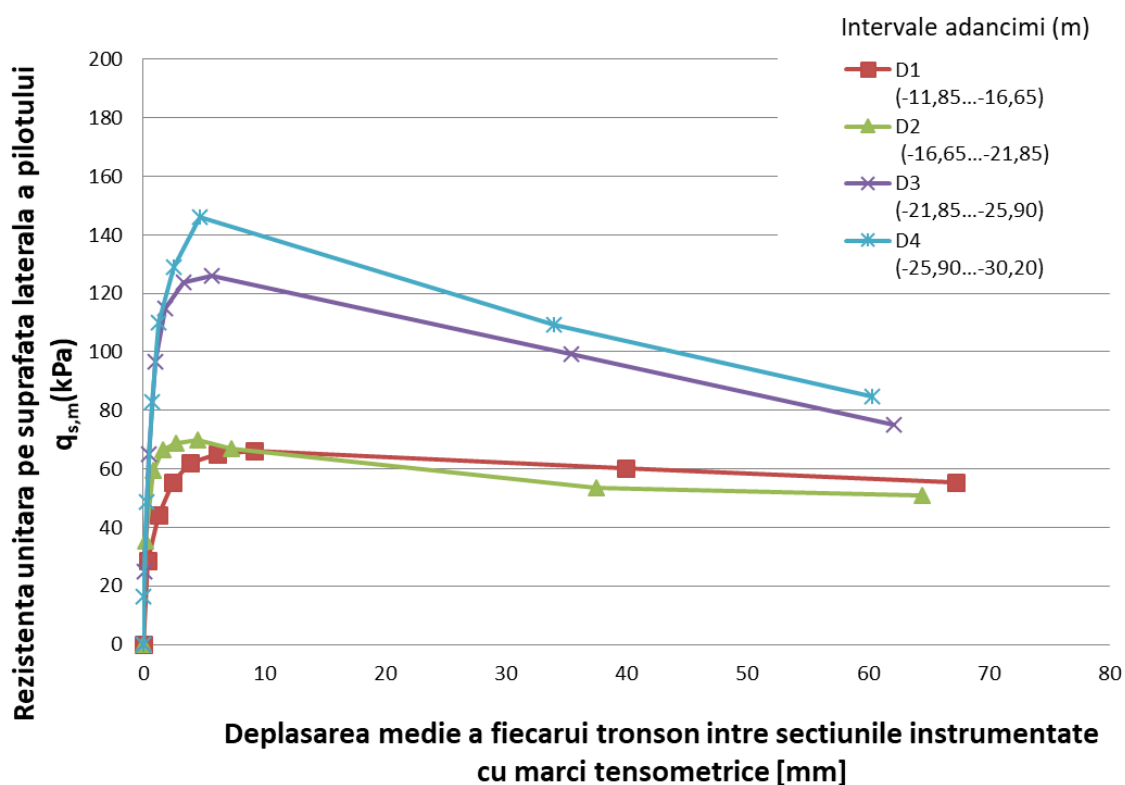


Figure 12. Unit shaft resistances mobilized of the PP1 pile determined by strain gauges measurements

The maximum value of the unit base pressure on the pile enlarged base (bulb area) for the last stabilized loading step $Q = 14.5$ MN, defined as the ratio between the force transmitted to the ground below -30.20 and the area of the bulb base (having diameter $d_b = 2.64$ m) resulted in $q_b \approx 2$ MPa. The graph of mobilization of the base pressure can be found in Figure 13.

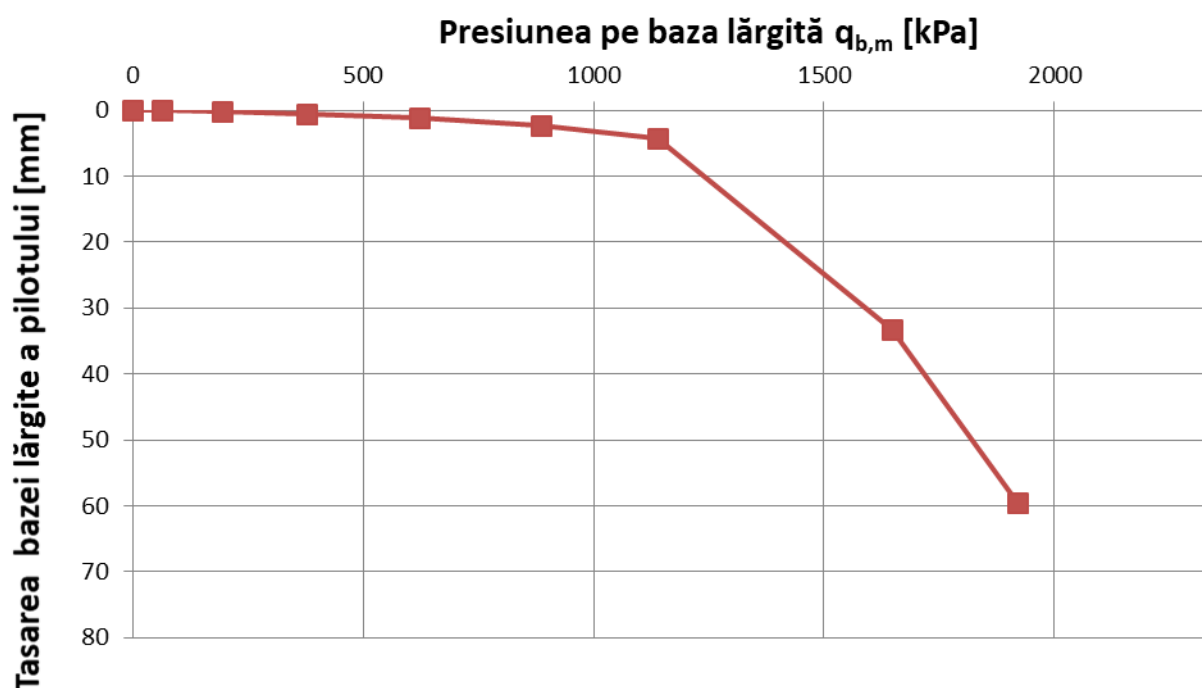


Figure 13. Mobilized pressure on the enlarged base of the PP1 pile

Following the processing of the records in the rod-extensometer column made during the test, Figure 14 shows the vertical displacements of the test pile and the foundation ground below its base. The low influence of vertical stress on the deep layers can be observed. The behavior is typical for a single pile. In the case of group work of the pile in the foundation system, the influence of vertical efforts will extend in depth.

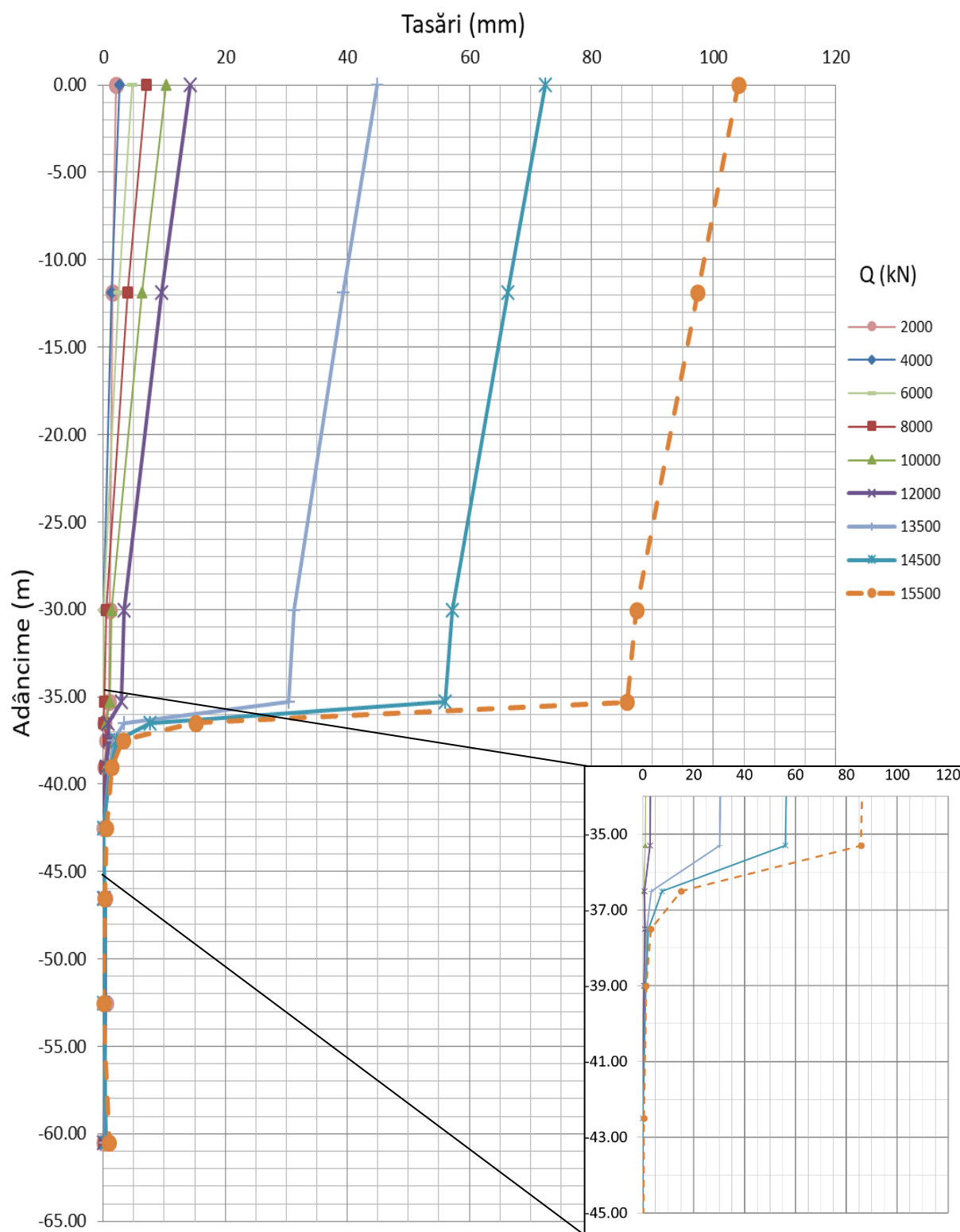


Figure 14. Variation of PP1 test pile displacements and foundation ground from -0.60 to -60.50 for the loading cycle

2.2. Pile embedded in a layer of semi-rocky rock

The PP2 test pile has a diameter of 600 mm, a length of 16.50 m (after excavation for the tests) and a embedding in the rock layer of 2.8 m. The working platform level for the PP2 pile is approximately 50 -70 cm below natural ground (NGL).

The test pile was made on 22.02.2013 and was bored in the ground without supporting the borehole walls. Figure 15 shows schematically the pilot execution technology.

Four anchor piles were used, which were made in similar conditions and have approximately the same characteristics as the test pile.

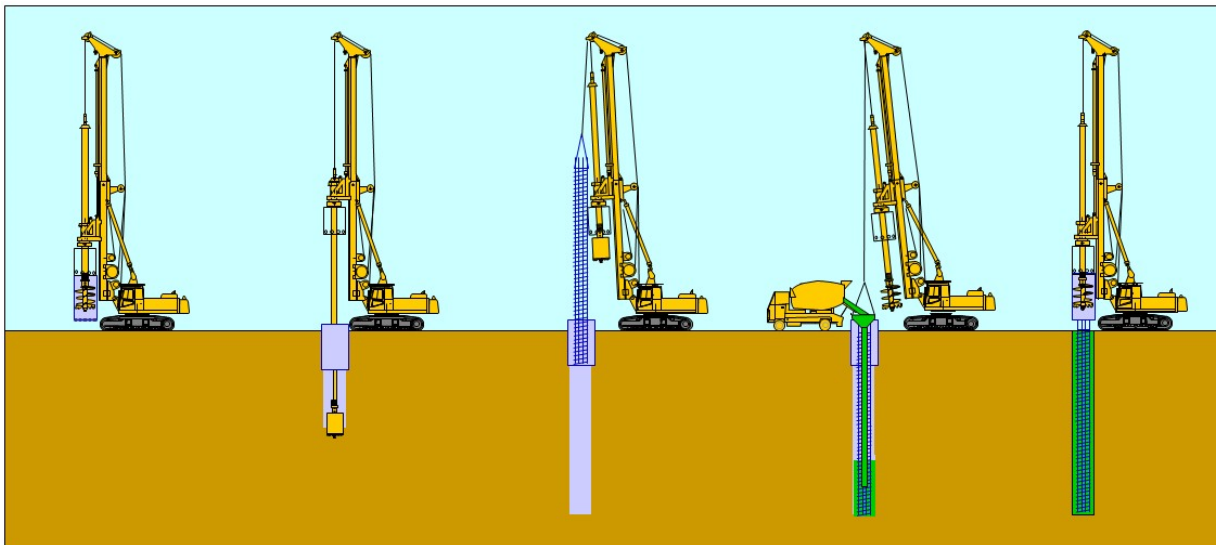


Figure 15. Sketch of PP2 pilot execution technology

The materials used in the execution of the PP2 pile are:

- concrete strength class C45/55, 480 kg cement CEM-II A-V 42.5R, W/Cmax = 0.35, Dmax = 16 mm, exposure classes XC4, XF1, XA1.
- reinforcement class B500B - cylindrical steel cage with an outer diameter of 448 mm and a total length of 18.60 m, made of two sections welded together on the longitudinal bars, with an overlapping length of 170 cm. Each section consists of 12 longitudinal bars with a diameter of 32 mm and a spiral $\Phi 10$ mm with a step of 50 mm on the area of the pile's head, and 75 mm respectively.

For the application of the compression load of 12 MN, an extension of the pile's head was made in the form of a truncated cone or capital, so that 3 presses of 5000 kN with a diameter of 400 mm each could be installed. A steel formwork previously made and installed at the same time as the reinforcement was used to preserve the shape of the extension during concreting (Figure 16).

For the execution of the load test at axial static compression loads on the test pilot PP2, a platform was arranged at -1.80 level compared to the ± 0.00 level of the test (level of the working platform for the construction of the test pile). The ± 0.00 level of the tests is located at a depth of 50-70 cm below the natural ground level (NGL).



Figure 16. Axial compression load test overview PP2

The stratification determined on the basis of the geotechnical investigations carried out on the site of the test pile PP2 is indicated in table 5.

Table 5. Stratification relative to natural ground level (NGL)

Depth (m)	Stratification
0,00 – 0,40	Vegetal soil
0,40 – 8,30	Clayey silt
8,30 – 13,50	Reddish silty clay
13,50 – 16,00	Silty clay with weathered schist fragments
16,00 – 16,50	Green schist fragments in brown clay
below 16,50	Weathered green schists

Pile toe level: -19,30 related to NGL

-18,80 related to $\pm 0,00$ for this test (working platform level for PP2 pile)

The axial compression load test was performed on 08.03.2013, 14 days after the pile's execution.

The position of the group of tested piles is shown in Figure 17.

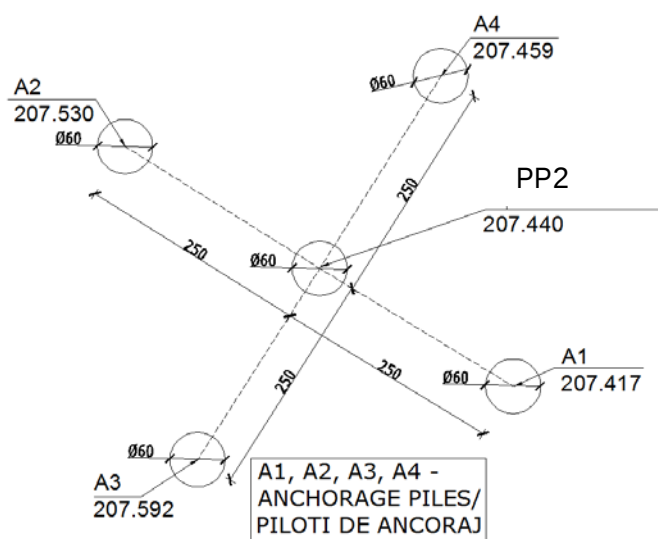


Figure 17. Positioning of the PP2 test pile and anchor piles

For the axial compression load test, the loading scheme in Table 6 was used. A two-cycle loading was applied, respectively loading up to 6,000 kN, unloading at 0 kN and reloading up to the maximum load, with unloading up to 0 kN.

Table 6. Loading steps for axial static compression test PP2

Step	Q (kN)	Cycle
1	1.500	loading
2	3.000	1
3	4.500	
4	6.000	
5	3.000	unloading
6	0	1
7	1.500	reloading
8	3.000	2
9	4.500	
10	6.000	
11	7.500	
12	9.000	
13	10.500	
14	12.000	
15	9.000	unloading
16	6.000	2
17	3.000	
18	0	

The strain gauges were arranged in 6 sections, being placed at the dimensions: -1.80, -7.60, -12.80, -15.10, -16.70, -18.30 relative to ± 0.00 (working platform level for the execution of the PP2 pile).

Considering the level of the working platform at a depth of 70 cm below the level of the natural ground (NGL), the following levels of installation of electronic strain gauges related to NGL result: -2.50, -8.30, -13.50, -15.80, -17.40, -19.00.

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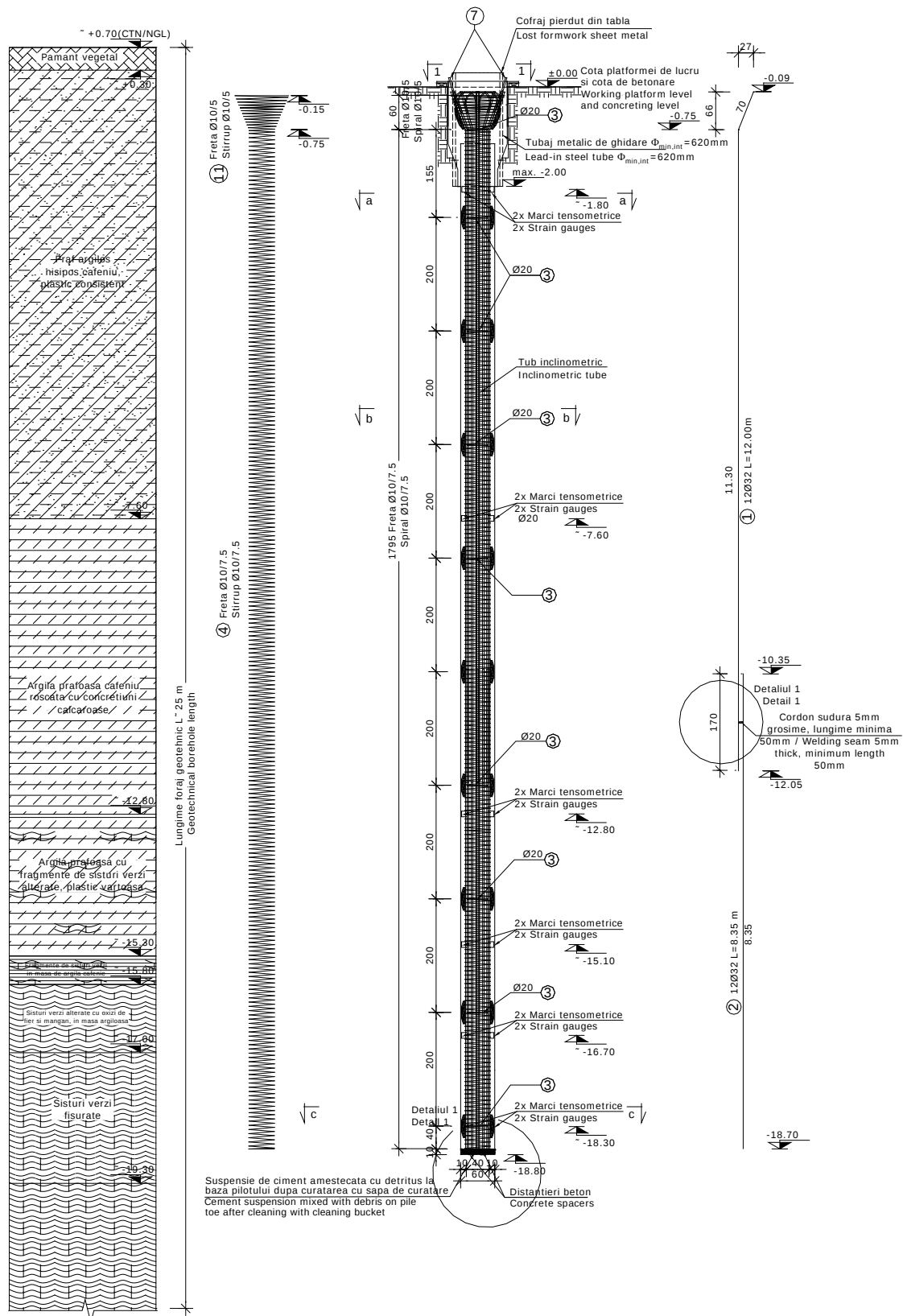


Figure 18. PP2 pile test instrumentation

Based on the linear variation diagram of the deformation modulus E with the specific deformation shown in figure 19, table 7 shows the values obtained of the deformation modulus at different elevations and loading stages.

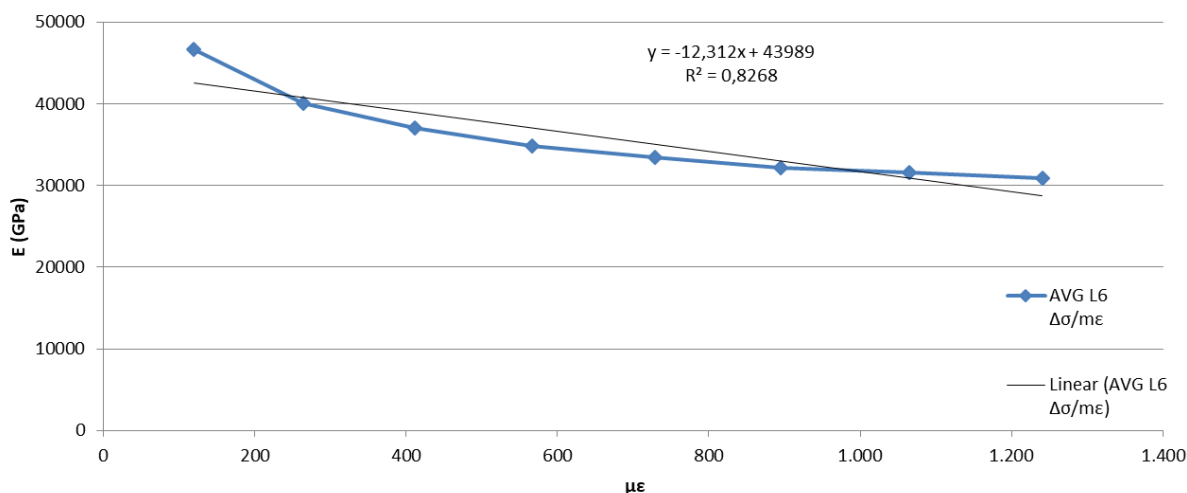


Figure 19. Determination of the deformation modulus for PP2 pile's reinforced concrete section

Table 7. Variation of the deformation modulus calculated on the basis of the measurements on the strain gauges PP2

load (kN)	Es1 (MPa)	Es2 (MPa)	Es3 (MPa)	Es4 (MPa)	Es5 (MPa)	Es6 (MPa)
1500	43921	43852	43746	43601	43382	43251
3000	43732	43497	43159	42837	42568	42365
4500	43569	43071	42456	41997	41716	41452
6000	43432	42574	41646	41049	40792	40501
3000	43575	42986	42440	42163	42148	42106
0	43719	43397	43234	43277	43505	43713
1500	43681	43271	42955	42855	42911	42966
3000	43590	43024	42503	42232	42173	42116
4500	43498	42763	42028	41599	41446	41286
6000	43408	42486	41531	40969	40729	40479
7500	43312	41974	40692	40061	39785	39498
9000	43207	41377	39764	39077	38934	38478
10500	43100	40727	38775	38074	38485	37430
12000	42974	39991	37703	36985	38064	36352
9000	43003	40105	38017	37496	38802	37320
6000	43115	40544	38979	38847	40331	38813
3000	43346	41349	40372	40541	42096	40849
0	43731	42653	42300	42821	44540	43075

The maximum applied load was 12,000 kN, the PP2 pile having a recorded settlement at its head of 21.5 mm. After unloading the pile, a residual settlement of 5.3 mm was recorded at the level of its head (Figure 20).

By applying the linear variation of the deformation mode E of the composite section, the variation curves of the stress along the pile shown in figure 21 were obtained.

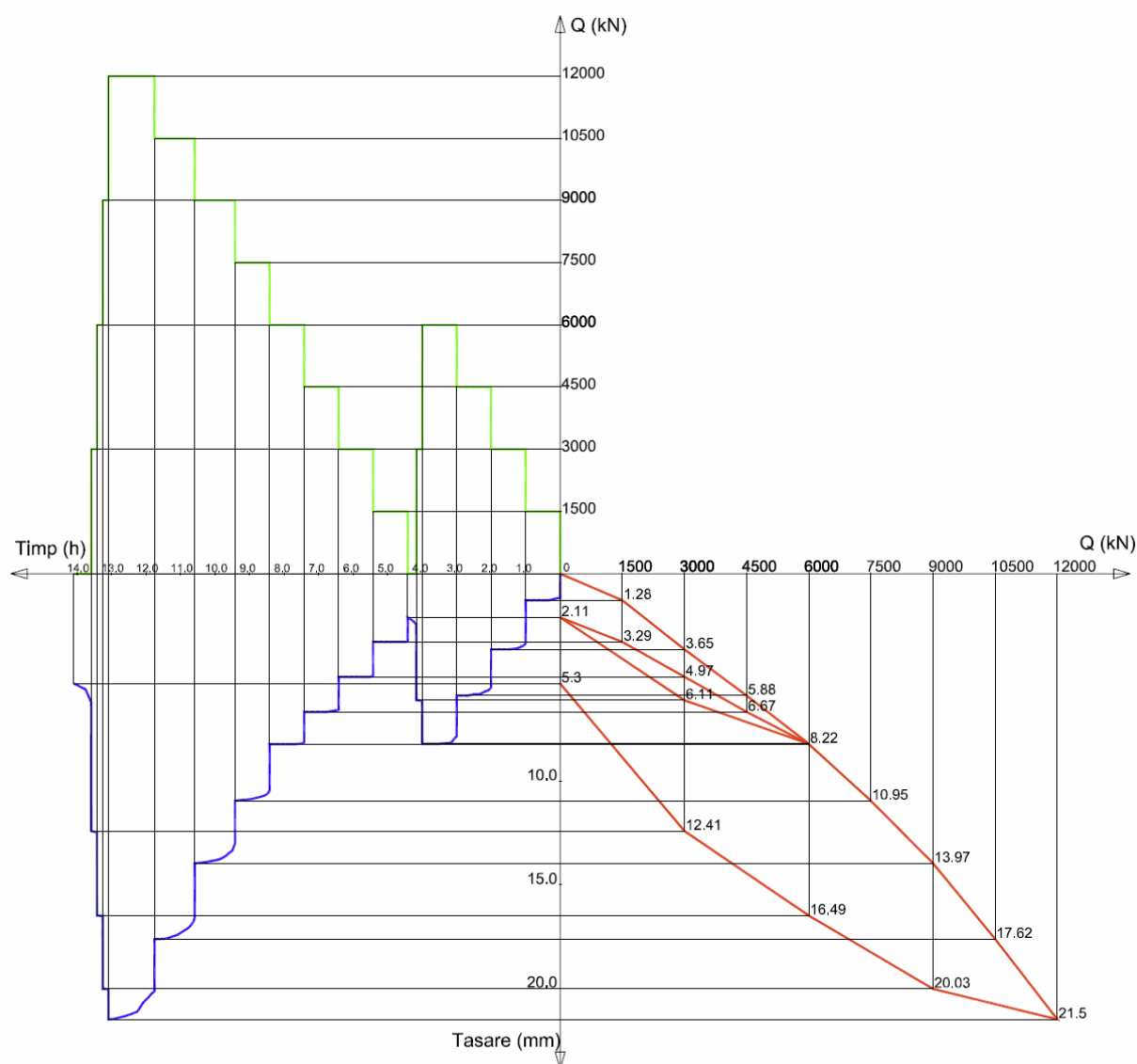


Figure 20. Load-settlement-time diagram PP2

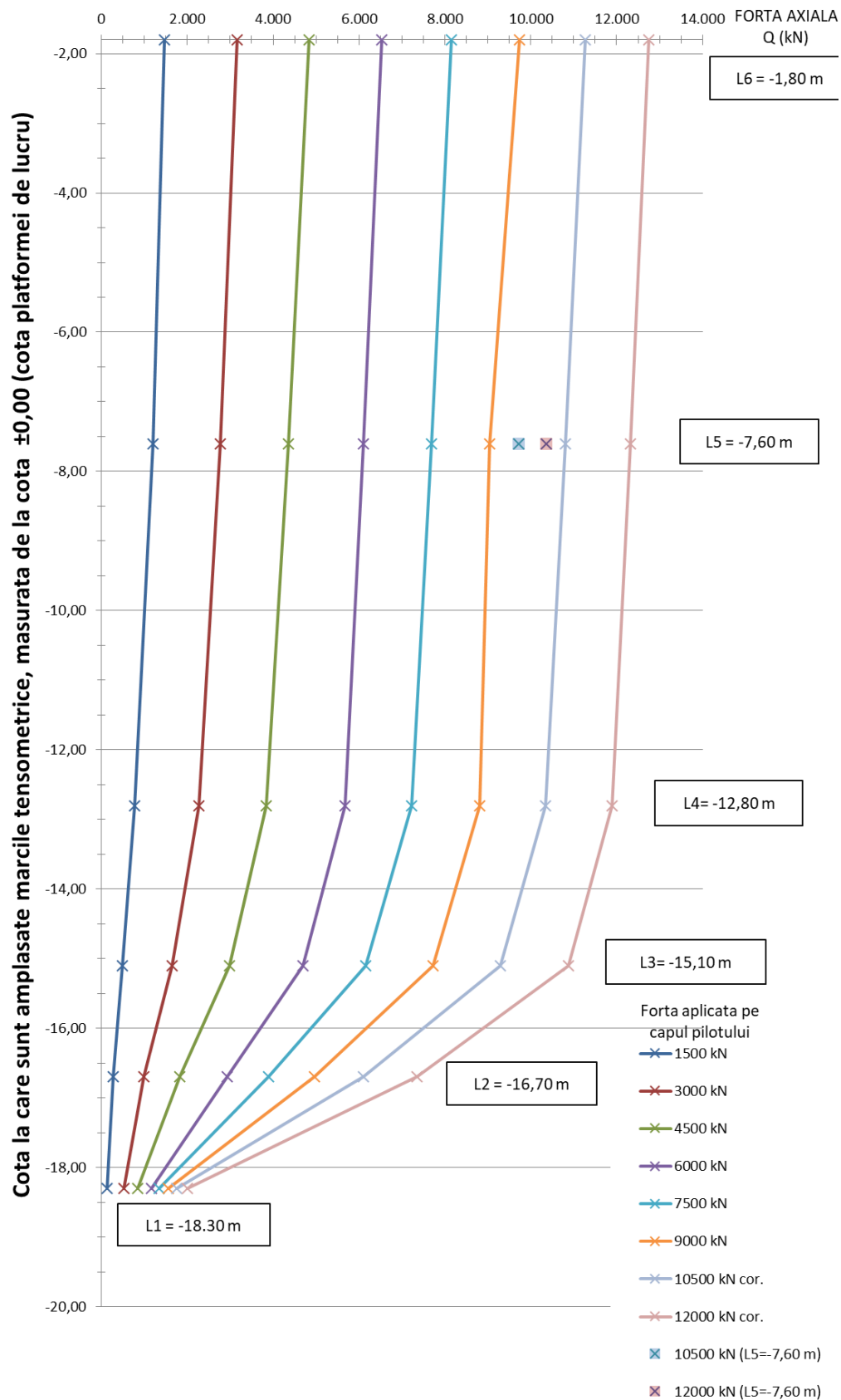


Figure 21. The variation of the stresses on the length of the PP2 pile resulted from the measurements on strain gauges

In the instrumented test pile PP2, the values of the shaft resistance resulting from the processing of the data recorded on the basis of strain gauges are presented in Table 8.

Table 8. Shaft resistance - average values between two instrumented sections

Areas traversed by the test pile	Average displacements of the pile between the two sections	Mobilized shaft resistance, maximum value
D5 (from L6 = -1.80 to L5 = -7.60)	↓ 17.55 mm	64 kPa
D4 (from L5 = -7,60 to L4 = -12,80)	↓ 11,28 mm	52 kPa
D3 (from L4 = -12,80 to L3 = -15,10)	↓ 7,14 mm	254 kPa
D2 (from L3 = -15,10 to L2 = -16,70)	↓ 5,45 mm	1174 kPa
D1 (from L2 = -16,70 to L1 = -18,30)	↓ 4,80 mm	1771 kPa

Figure 22 also shows the shaft resistance mobilization curves.

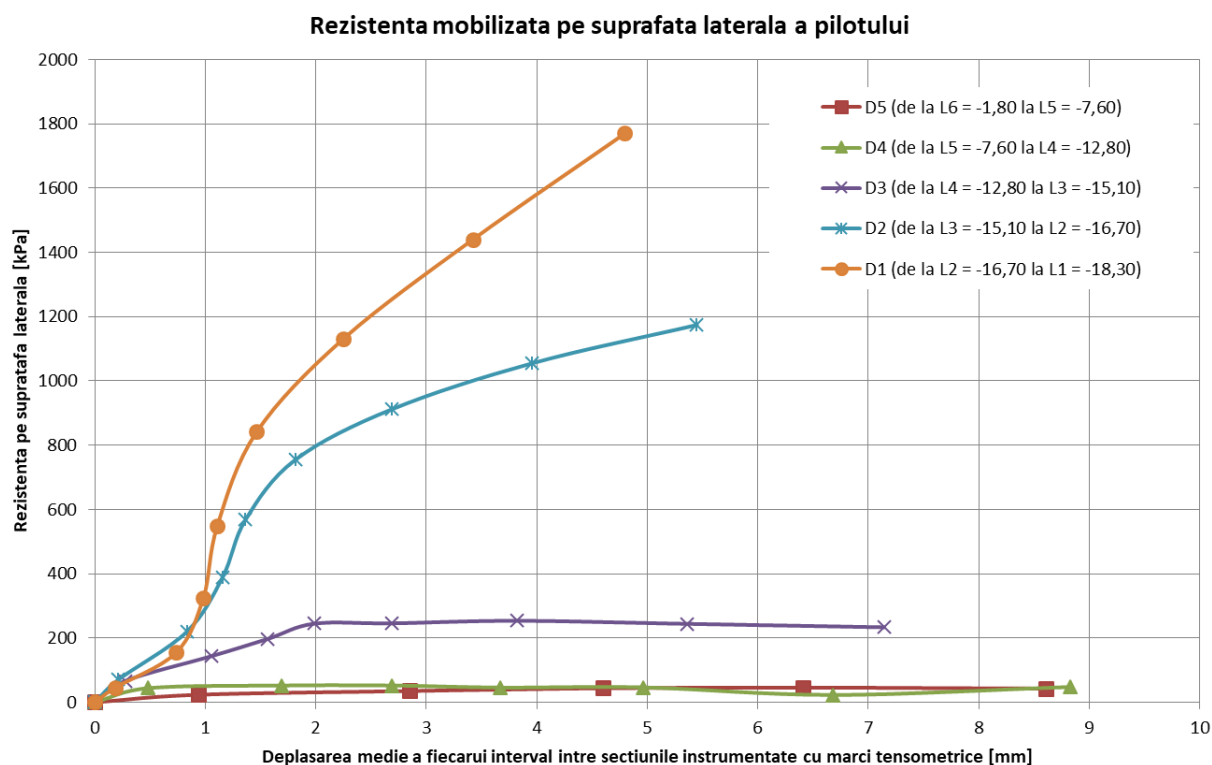


Figure 22. Shaft resistance of the PP2 pile

The maximum value of the unit base pressure of the pile for the last stabilized loading stage $Q = 12$ MN, defined as the ratio between the load transmitted to the ground below the elevation -18.30 and the base area (having a diameter $d_b = 0.62$ m) resulted $q_b \approx 7$ MPa. The graph of base pressure mobilization can be found in figure 23.

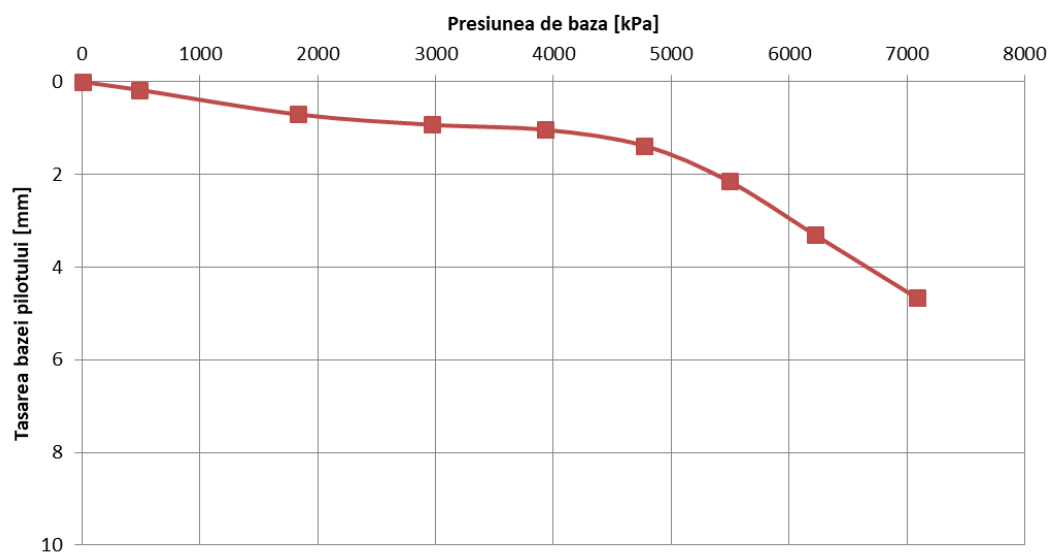


Figure 23. base resistance of PP2 pile

2.3. Full displacement pile (FDP) in a marly clay complex

The PP3 test pile had a diameter $d = 510$ mm and a length of about 13 m. The PP3 test pile was made by FDP technology, therefore it is a ground improvement pile. The working platform level for the test pile was approximately 7.45 m below ± 0.00 level.

The test pile (PP3) was constructed on 25.05.2016. The four anchoring piles, with a diameter of 620 mm, were made on 26.05.2016, by continuous screw drilling (CFA).



Figure 24. Axial compression load test overview PP3

The technical procedure for the execution of piles executed on site by FDP technology, the steps of installation of reinforcement and concreting can be seen in Figure 25.

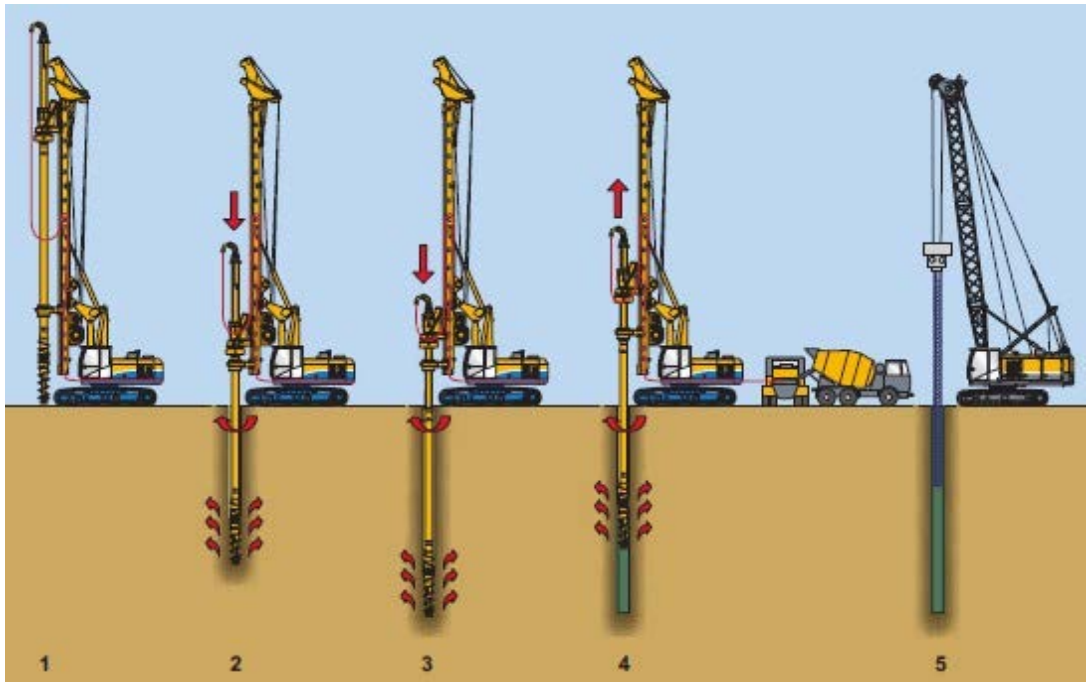


Figure 25. Sketch of the FDP construction technology of PP3 test pile

The materials used in the execution of the PP3 test pile are:

- concrete strength class C25/30, S5 (20 ÷ 24 cm), minimum 400 kg / m³ CEM-II BM 32.5R, W/Cmax = 0.50, Dmaxim 0 16 mm, exposure class XC2, XA1;
- B500C reinforcing class.

In the case of the PP3 test pile, the reinforcing cage has an outer diameter of 350 mm; the total length of the cage is approx. 13.00 m. The upper section of the cage consists of 12 longitudinal bars with a diameter of 18 cm, stiffening rings made of $\Phi 16$ mm bars and spiral $\Phi 8$ mm displaced at a spacing of 15 cm.

The reinforcing cage of the PP3 test pile was previously equipped with electronic vibrating wire strain gauges, on two longitudinally opposite longitudinal reinforcement bars.

The ground stratification consists of two representative layers established on the basis of the geotechnical investigations, related to the natural ground level as follows:

- layer I: Fill down to 12,0-15,5 m;
- layer II: Marly clay Complex below 12,0-15,5 m.

The axial compression load test started on 01.06.2016, 7 days after the pile's execution and was completed on 02.06.2016.

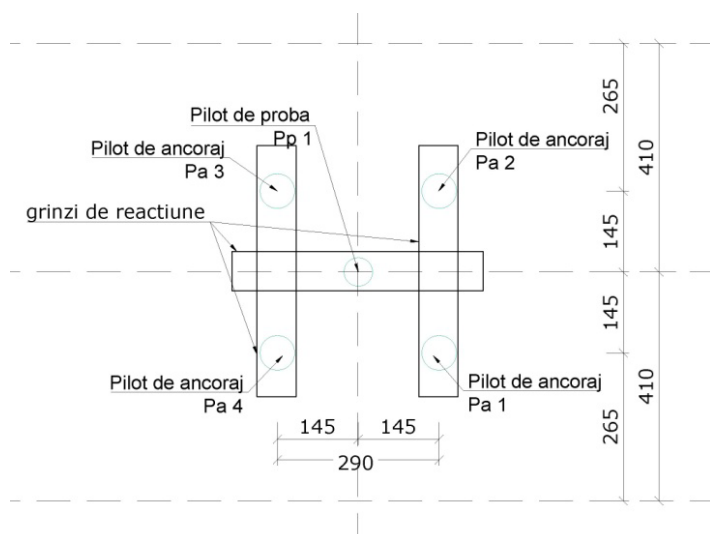


Figure 26. Layout of the PP3 pile and anchoring piles

For the axial compression load test, the maximum load of 2,800 kN was applied in approximately equal steps according to Table 9 and the evolution over time of the PP3 pile settlement was observed, in order to evaluate the pile bearing capacity.

Table 9. Loading steps for axial static compression test PP3

Step	Q (kN)	Cycle
1	350	loading
2	700	
3	1.050	
4	1.400	
5	1.750	
6	2.100	
7	2.450	
8	2.800	
9	2.100	Unloading
10	1.400	
11	700	
12	0	

The strain gauges were installed on 4 levels (-9.30, -11.00, -16.00 and -20.40 relative to the ± 0.00 level), corresponding to the stratification encountered in the geotechnical investigations.

Based on the linear variation diagram of the deformation modulus E with strain shown in figure 27, table 10 shows the values obtained for the deformation modulus at different levels and loading stages.

Table 10. Variation of the deformation modulus E calculated on the basis of measurements on PP3 strain gauges

Load (kN)	Es (MPa)			
	-9,30m	-11,00m	-16,00m	-20,40m
350	32885	32157	32443	32707
700	31028	31094	31615	32333
1050	29965	30006	30756	31896
1400	28887	28791	29846	31395
1750	27783	27473	28884	30861
2100	26365	25766	27654	30184
2450	24981	24074	26414	29505
2800	23468	22165	24969	28725
2100	25087	23671	25934	29168
1400	26759	25305	27137	29759
700	28969	27656	28857	30646
0	31635	31054	30893	31662

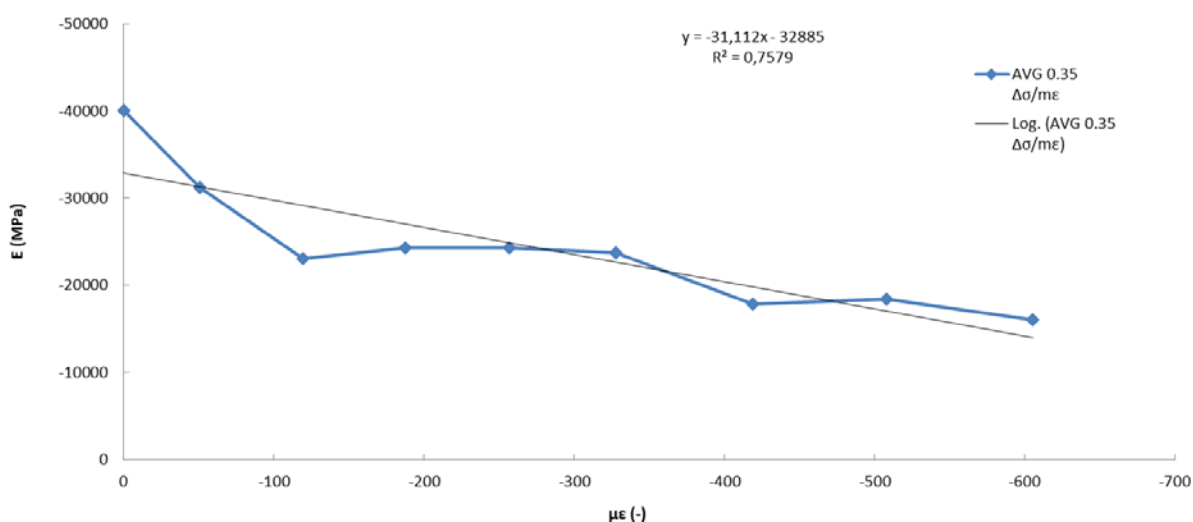


Figure 27. Determination of the deformation modulus for PP3 pile reinforced concrete section

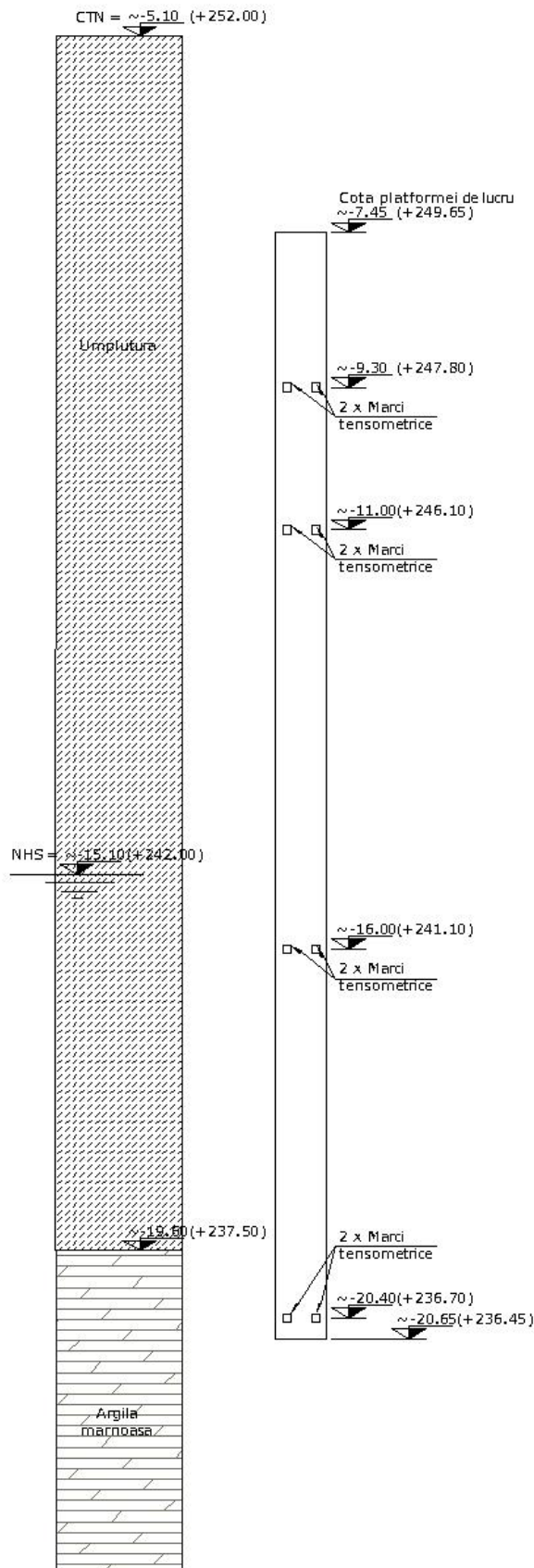


Figure 28. Schematic section of the Ø510 mm PP3 pile

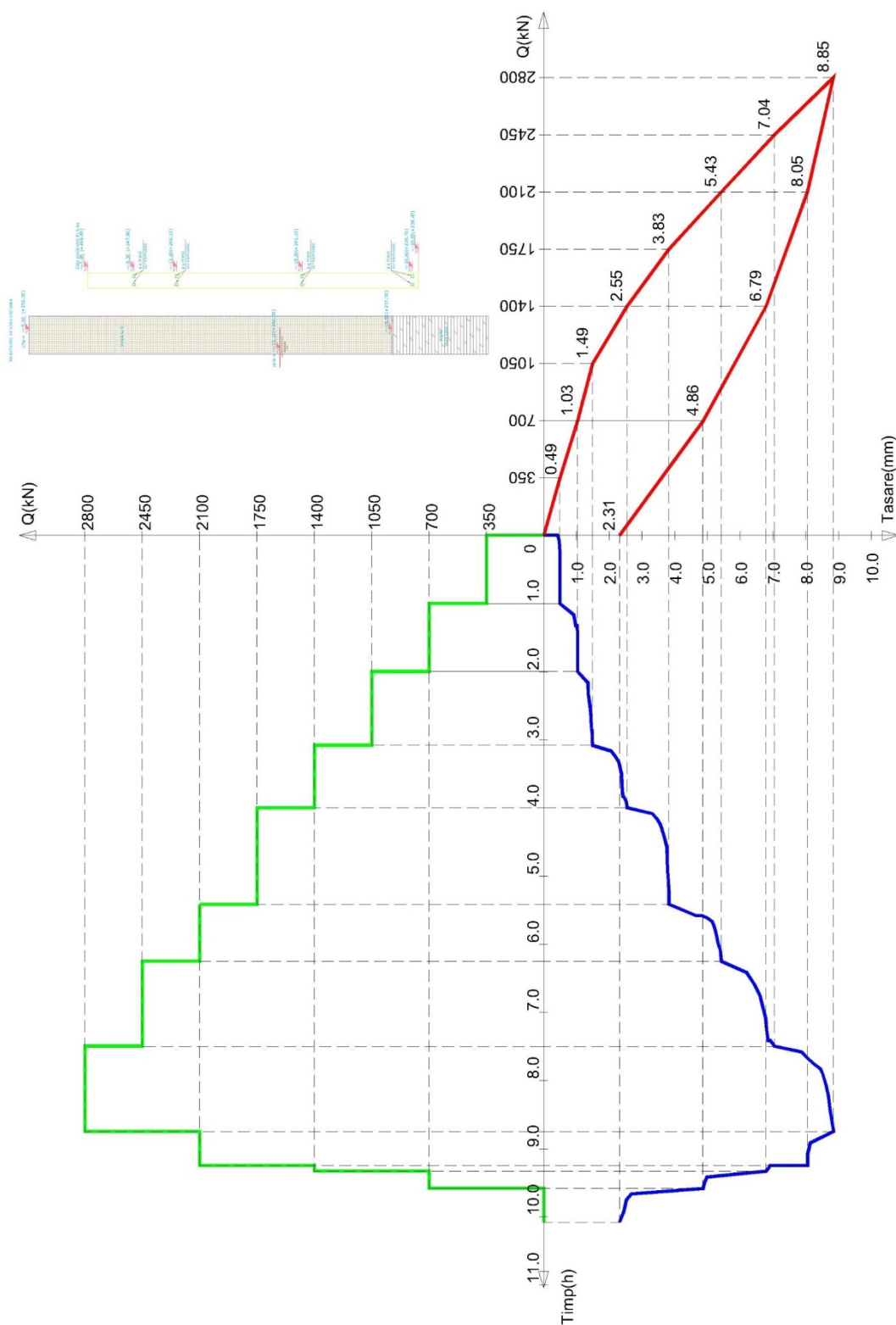


Figure 29. Load-settlement-time diagram PP3

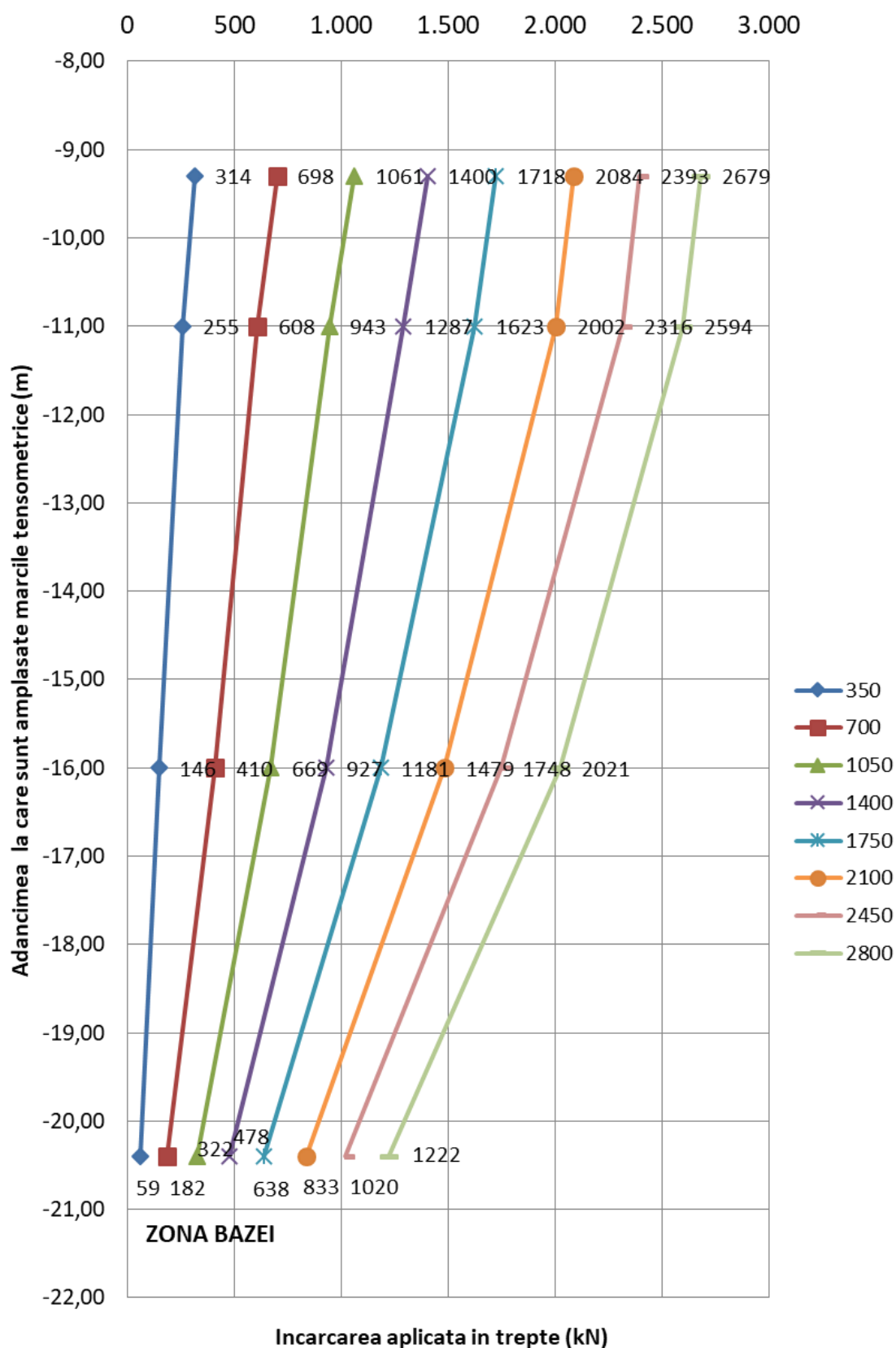


Figure 30. The variation of the stresses on the length of the PP3 pile resulted from the measurements on strain gauges

The test pile (PP3) was loaded in steps applied according to table 9, with the conventional stabilization of settlements indicated in NP 045-2000, up to the maximum load of 2800 kN. The graphical representation of the displacements is presented in figure 29.

At the maximum stabilized load of 2800 kN the test pile recorded a settlement at its head of 8.85 mm. After unloading the pile, a residual settlement of 2.31 mm was recorded at the level of its head.

In the test performed, the values of the shaft resistance resulting from the processing of data recorded on the basis of strain gauges are presented in Table 11. Figure 31 also shows the mobilization curves of the shaft resistance..

Table 11. The shaft resistance values between two sections instrumented by strain gauges PP3

Depths of areas traversed by the test pile [m]	Mobilized shaft resistance, maximum value $q_{s,m}$ [kPa]
from -9,30 to -11,00	47
from -11,00 to -16,00	81
from -16,00 to -20,40	128

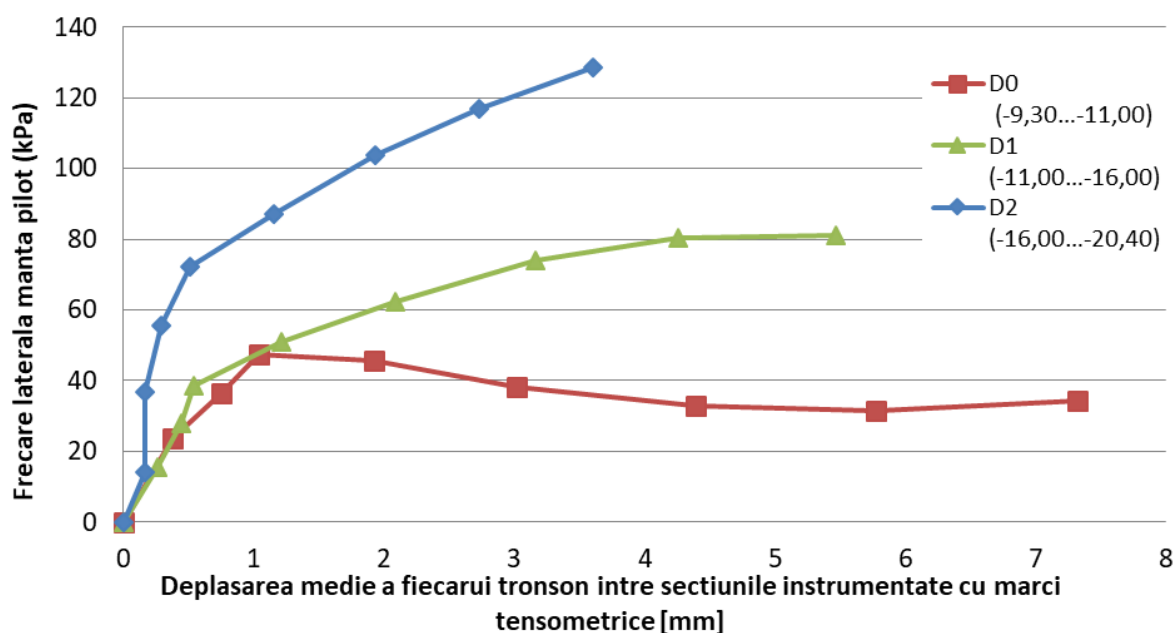


Figure 31. Mobilized unit shaft resistances of the PP3 pile determined by strain gauges

The maximum value of the unit base resistance on the pile for the last stabilized loading stage $Q = 2,800$ kN, defined as the ratio between the load transmitted to the ground below the elevation -20,40 and the base area (having a diameter $d_b=0.51$ m) resulted $q_b \approx 7.7$ MPa. The mobilization graph of the base resistance can be found in figure 32

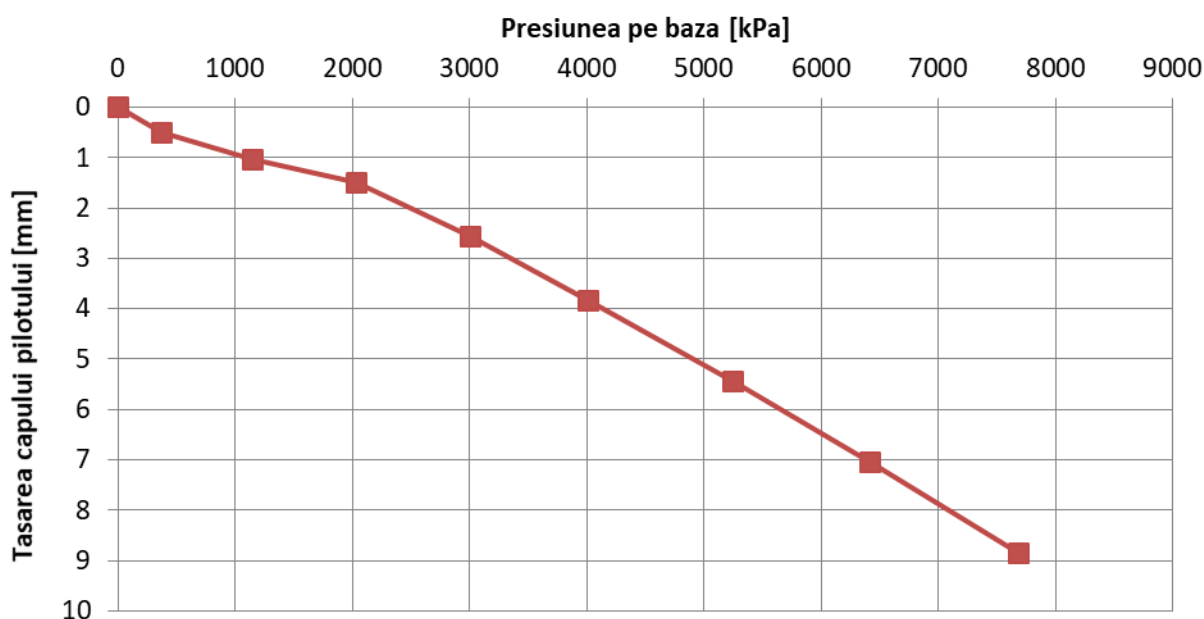


Figure 32. Base resistance pile PP3

2.4. CFA pile in a sandy layer (PP4)

The PP4 test pile had a diameter $d = 620$ mm and a length of approximately 20.5 m and was made using CFA technology. Figure 33 shows schematically the execution technology of the PP4 pile.

The working platform level for the test pile was approximately 25 cm below the natural ground level (NGL).

The PP4 pile was constructed on 07.04.2016.

The four anchoring piles, having the same characteristics as the one above, were executed between 06.04.2016 and 14.04.2016.

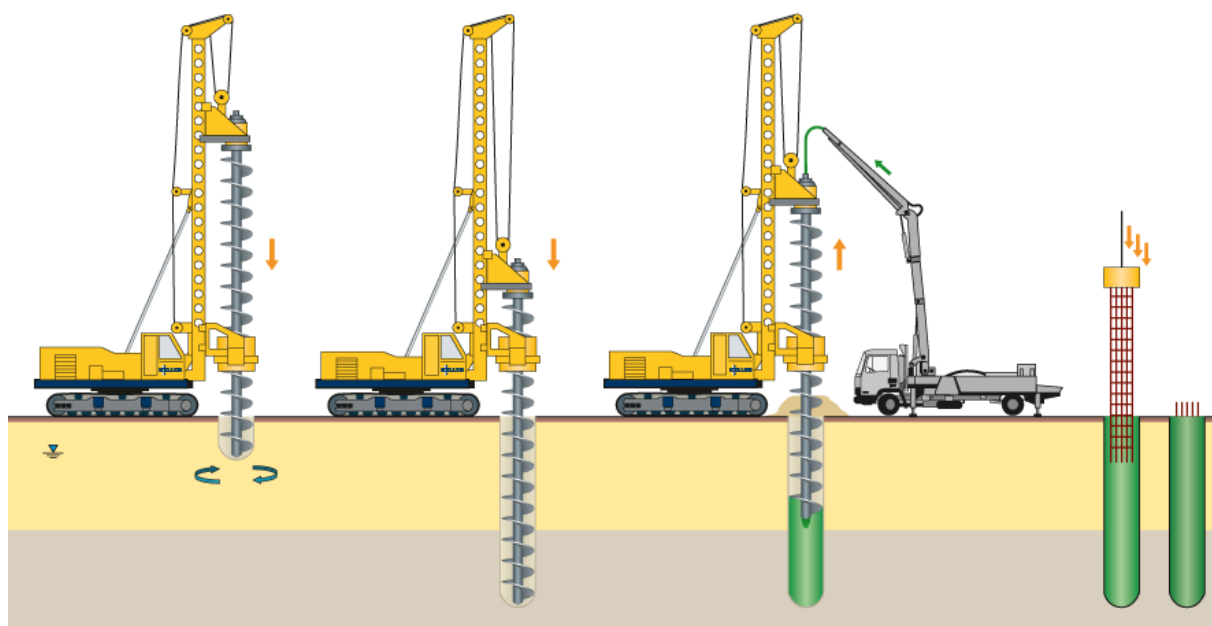


Figure 33. Sketch of technology for the construction of CFA test pile (PP4)

The materials used in the execution of the PP4 pile are:

- concrete strength class C25/30, S5 (22 ÷ 24 cm), minimum 375 kg / m³ CEM-II BM 32.5R, W/Cmax = 0.48, Dmaxim 0 16 mm, exposure class XC2, XA1.

- reinforcement class B500C - cage consisting of two sections; the total length of the cage is 19.80 m, the two sections being overlapped on a length of 1.40 m. The upper section consists of 8 longitudinal bars with a diameter of 20 mm, outer stiffening ring of bars of $\Phi 20$ mm and spiral $\Phi 10$ mm displaced at a step of 15 cm on the first 5.10 m.

To apply the compressive load on the piles' heads, a steel load distribution plate was placed so as to avoid cracking of the concrete at high loads. A hydraulic cylinder with a capacity of 5,000 kN, with a diameter of 400 mm, was installed on it.

The anchor piles have the same characteristics as the corresponding test pile, with the difference that the reinforcements at the top are extended with ~ 0.35 m, in order to allow the welding to the anchor beams.

For the execution of the axial static compression load test on the PP4 pile, a crushed stone working platform was arranged at ~ -0.25 related to ± 0.00 (Figure 34).

The ground stratification is indicated in table 12.

Table 12. Ground stratification relative to natural ground level $\sim \pm 0.00$

Depth (m)	Stratification
0,00 – 1,00	Fill
1,00 – 3,00	Loess
3,00 – 10,00	Moistened loess
10,00 – 18,00	Silty clay with sandy layers
18,00 – 30,00	Fine yellow-gray silty sand

Pile base level:
 $\approx -21,00$ relative to the level ± 0.00 of the construction



Figure 34. Axial compression load test overview PP4

The axial compression load test started on 23.04.2016, 16 days after the execution of the pile and was completed on 25.04.2016.

The layout of the piles, the reaction beams and the position of the group of piles executed by CFA, on which the test was performed, is shown in Figure 35.

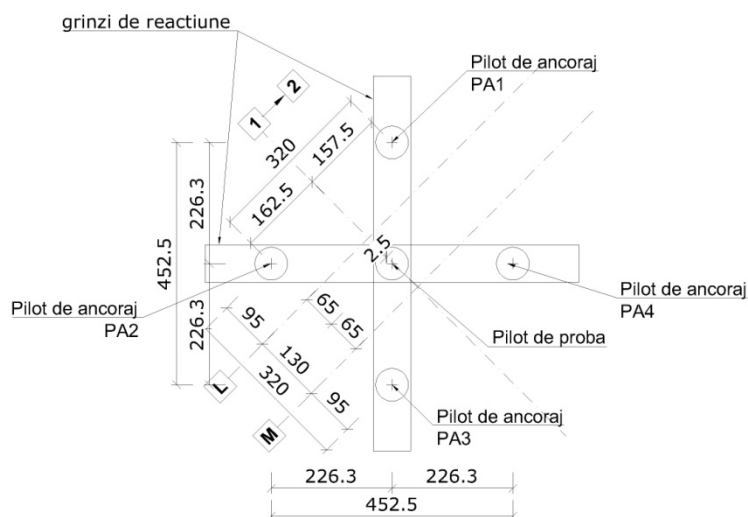


Figure 35. Positioning of the PP4 test pile and anchor piles

The loading and unloading steps shown in the following table were used for the axial compression load test.

Table 13. Loading steps for axial static compression test PP4

Step	Q (kN)	Cycle
1	250	loading
2	500	
3	750	
4	1000	
5	1250	
6	1500	
7	1750	
8	2000	
9	1500	unloading
10	1000	
11	500	
12	0	

The strain gauges were installed on 5 levels (-0.55, -3.20, -8.70, -16.20 and -19.85), corresponding to the stratification encountered in the geotechnical investigations (figure 36).

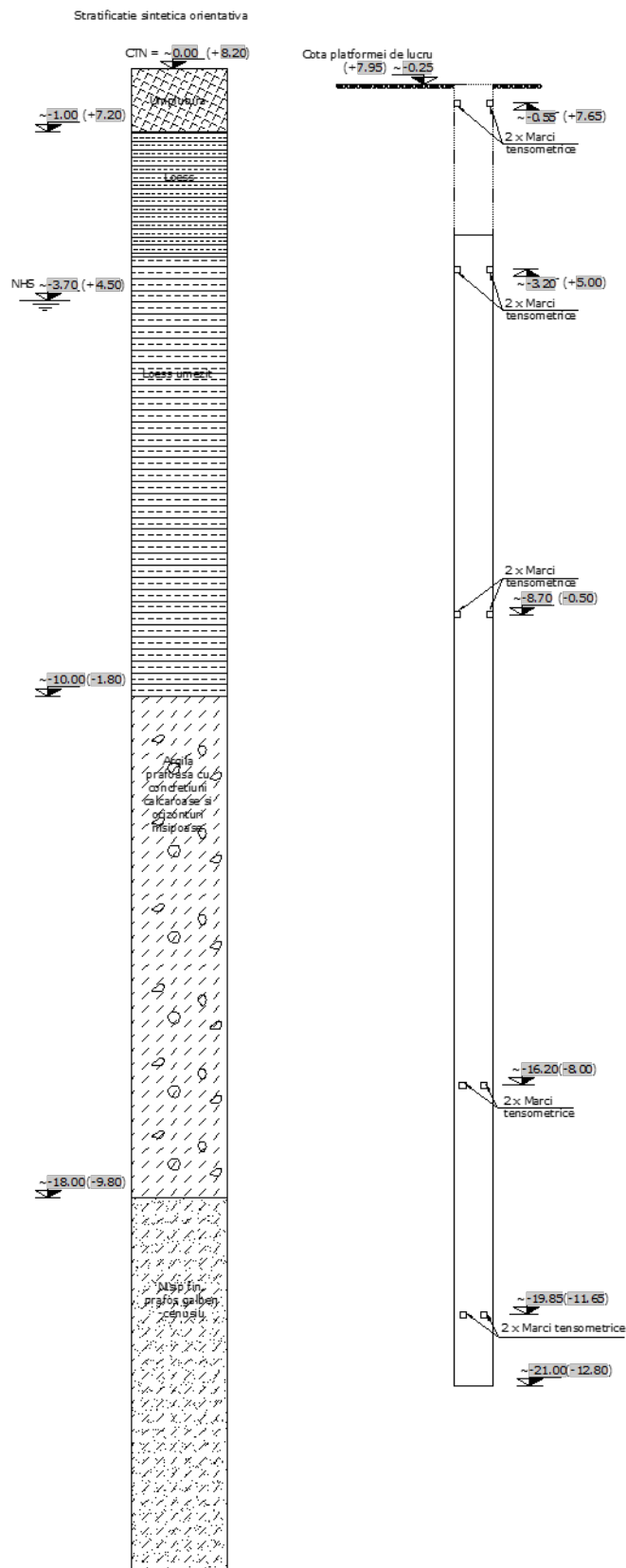


Figure 36. Schematic section of the PP4 $\Phi 620$ mm test pile

After performing the axial compression load test on the $\varnothing 620\text{mm}$ instrumented pile, during the excavation of the material around the pile to the final level of excavation for the foundations, increases of the pile section were observed on the free length of the pile, as follows: pile diameter up to an elevation -1.25 it is $\sim 0.72\text{ m}$, respectively the diameter $\sim 1.0\text{ m}$ up to elevation 2.25 (figure 37). This finding highlight that there are uncontrollable variations in pile diameter that need to be identified and subsequently correlated in the interpretation of the tests, in order to correctly identify the values of strength on the base and shaft.



Figure 37. Extended pile section PP4

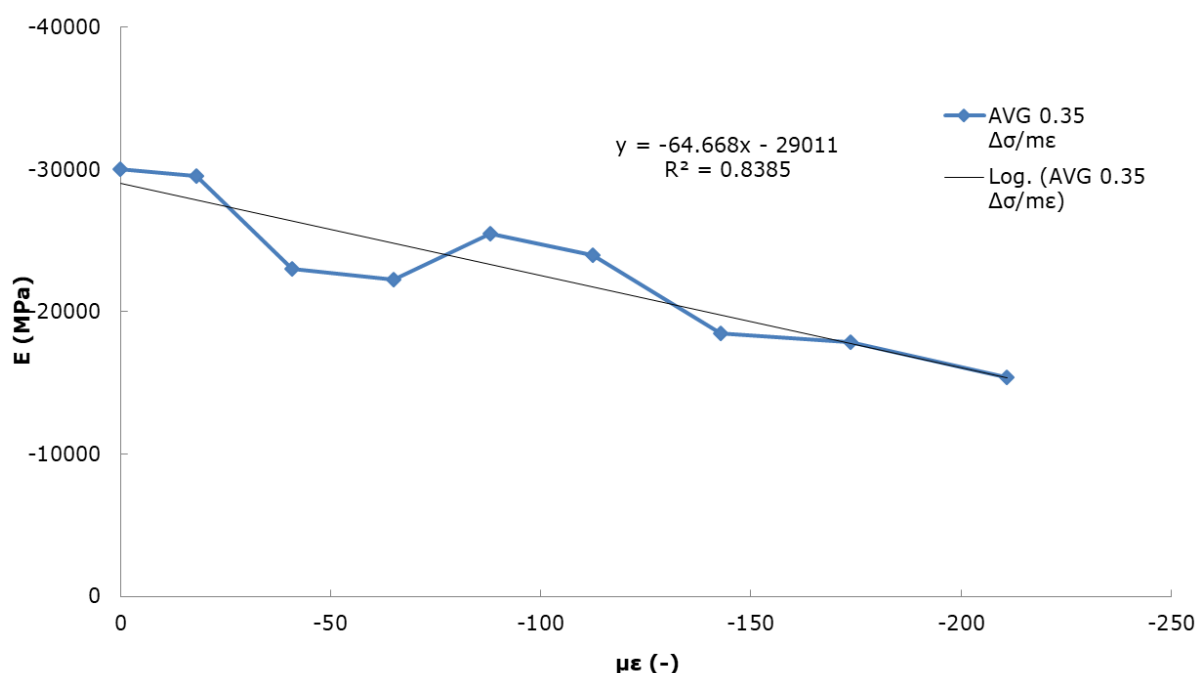


Figure 38. Determination of the deformation modulus of the reinforced concrete section for strain gauges - PP4

Based on the graph in figure 38, table 14 shows the values obtained of the deformation modulus at different levels and loading steps.

Table 14. Variation of the deformation modulus calculated based on measurements on strain gauges

Load (kN)	Es (MPa)				
	-0.55	-3.20	-8.70	-16.20	-19.85
250	28428	28626	28606	28801	28971
500	27691	28221	28123	28537	28919
750	26911	27816	27685	28276	28854
1000	26162	27404	27208	27982	28788
1250	25375	26992	26731	27701	28723
1500	24390	26524	26138	27311	28632
1750	23395	26086	25720	27109	28566
2000	22191	25605	25227	26697	28435
1500	23678	26307	26066	27641	28752
1000	26923	27996	27919	28428	29003
500	28494	28921	28987	29110	29247
0	28654	29048	29114	29250	29342

At the maximum stabilized load of 2000 kN the PP4 pile recorded a settlement at its head of 6.7 mm. After unloading the pile, a residual compression of 3.54 mm was recorded at the level of its head (fig. 39).

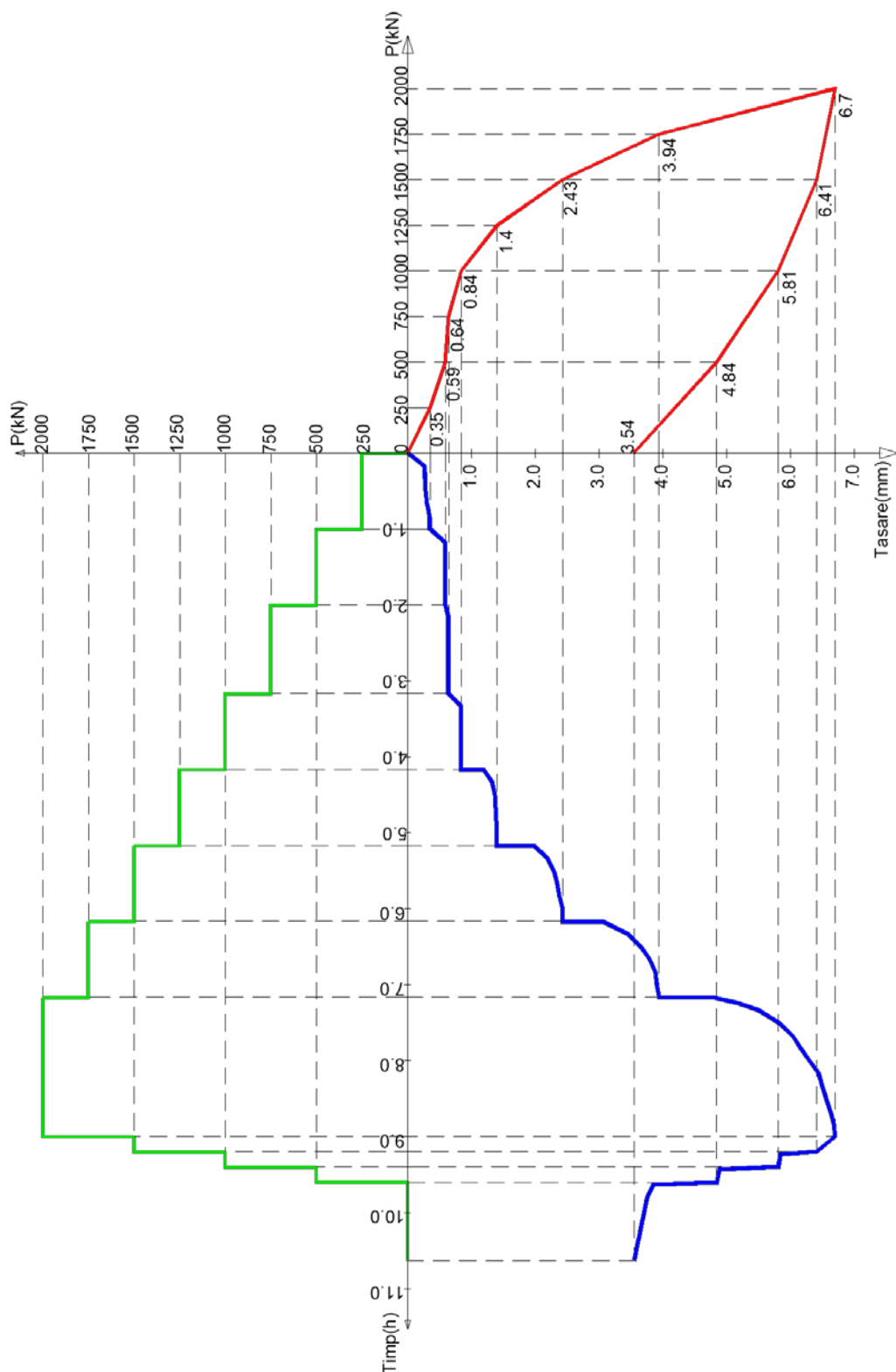


Figure 39. load-settlement-time diagram - PP4

Applying the linear variation of the deformation mode E of the composite section, the stress variation curves along the PP4 pile shown in Figure 40 were obtained.

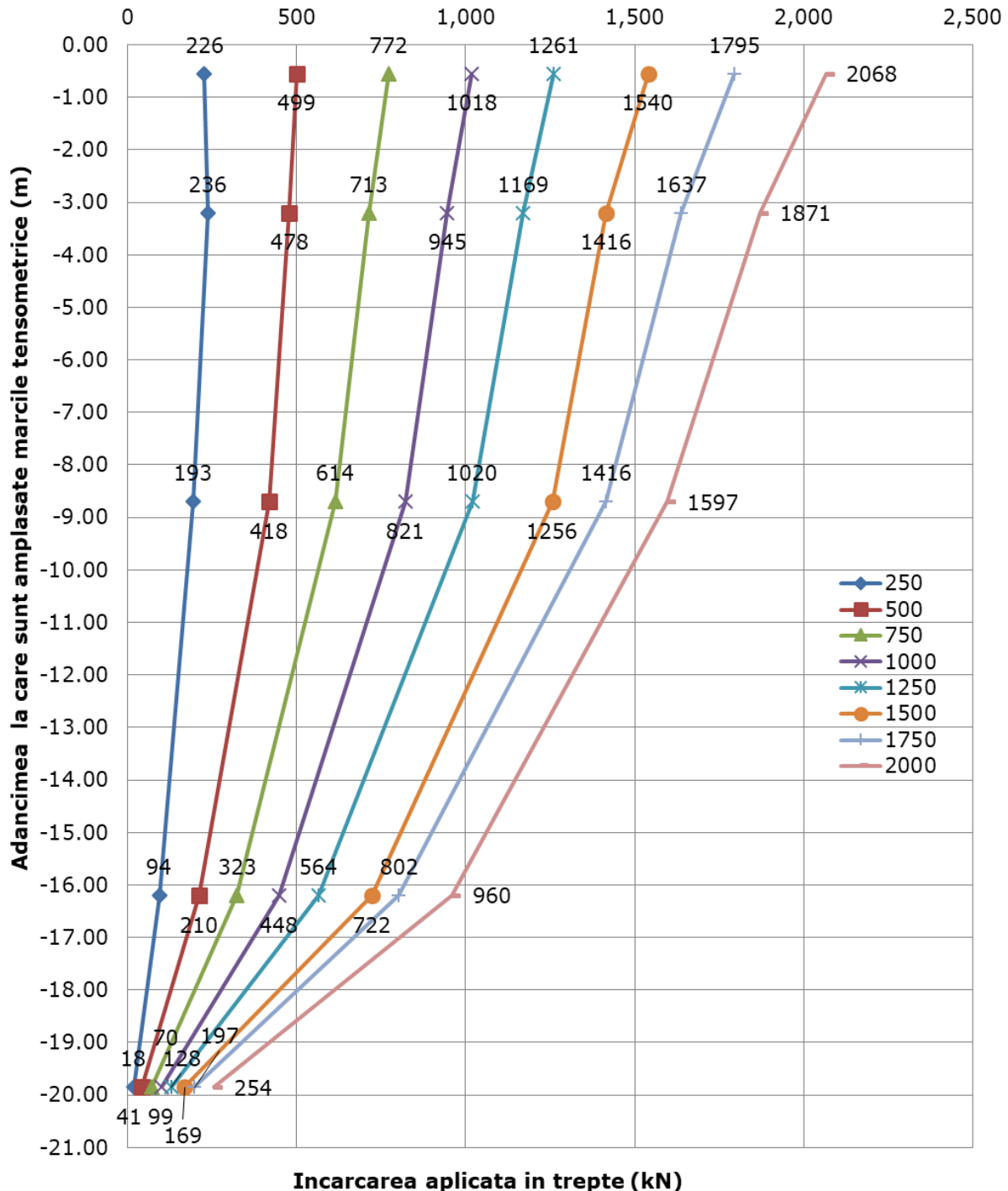


Figure 40. Variation of the stress on the length of the test pile, measured on the PP4 strain gauges

In the test performed on the PP4 pile, the values of the resistance on the lateral surface resulting from the processing of the data recorded on the basis of strain gauges are presented in Table 15. Figure 41 also shows the mobilization curves of the resistance on the lateral surface.

Table 15. Shaft resistance; values between two sections instrumented with strain gauges

Depths traversed by the test pile [m]	Mobilized shaft resistance, maximum value $q_{s,m}$ [kPa]
from -0.55 to -3.20	25
from -3.20 to -8.70	19
from -8.70 to -16.20	34
from -16.20 to -19.85	77

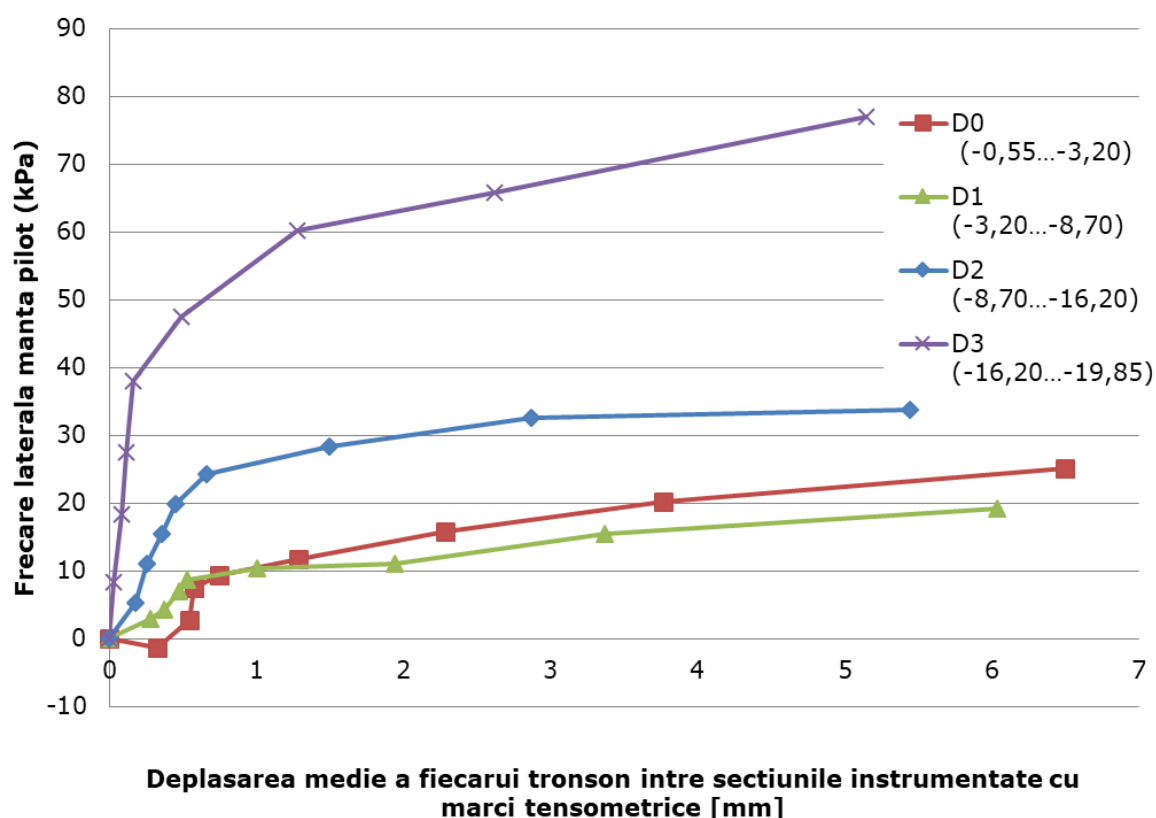


Figure 41. Shaft resistance of the PP4 pile

The maximum value of the unit base resistance for the last stabilized loading step $Q = 2000$ kN, defined as the ratio between the force transmitted to the ground below the level -20.50 and the base area (having a diameter

$d_b=0.62$ m) resulted $q_b \approx 500$ kPa. The graph of mobilization of the base resistance can be found in figure 42.

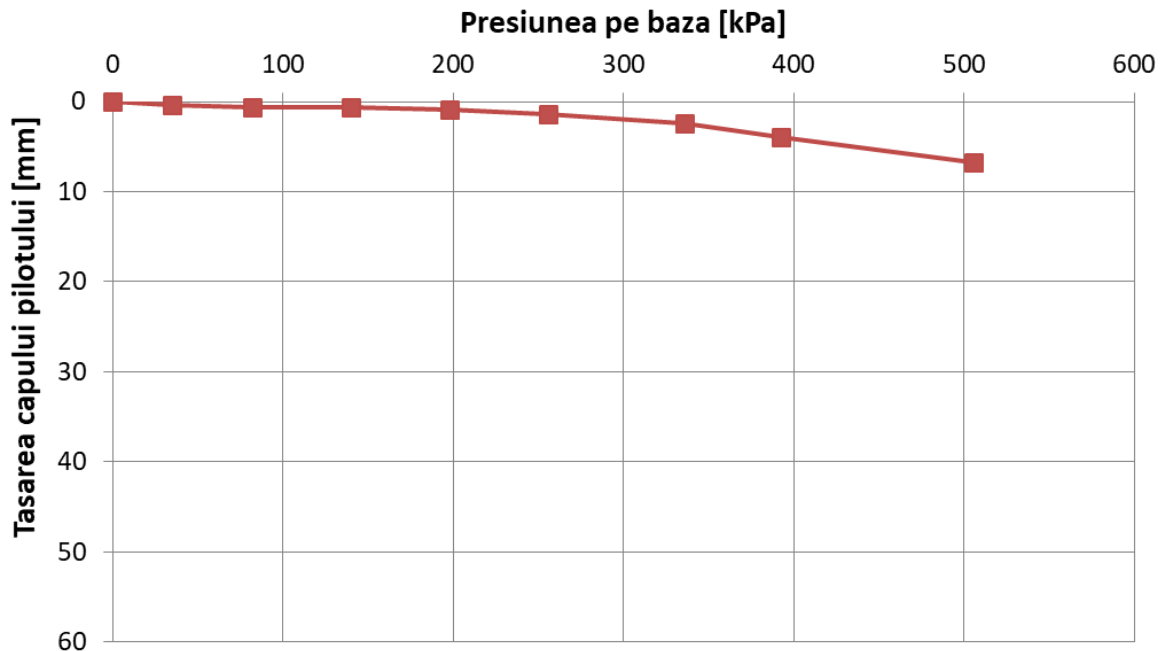


Figure 42. Base resistance for pile PP4

3. Conclusions

The interpretation of the instrumentation with strain gauges measurements for the four piles was performed using the method proposed by B.H. Fellenius. Following the results of the interpretations, essential information is obtained for the design of foundations on piles and piled foundations, having at hand essential tools in evaluating the calculation of foundation systems (mobilization curves for shaft and base resistance). Also, the obtained results and the mobilization curves can be extrapolated according to the principles of SR EN 1997-1:2004 to all piles within the foundation system, depending on the number of tests available.

The applied method is a modern one and brings a detail of the components of the pile bearing capacity. For example, in the publication *Pile Design and Construction Practice* Sixth edition, Michael Tomlinson and John Woodward, published in 2014, a book that enjoys a wide spread and international recognition, there are no references to the instrumentation of piles or the interpretation of the results obtained. However, in this book there are two

loading procedures presented Maintained Load test (ML) and Constant Rate of Penetration test (CRP).

Looking at the American ASTM standards, we can find the ASTM D1143M 07 (2013) Standard Test Methods for Deep Foundations Under Static Axial Compressive Load, which also does not refer to the instrumentation of the pilots. However, with the 2007 revision, it introduced seven pilot test methods, as follows: A.Quick Test, B.Maintained Test (optional), C.Loading in Excess of Maintained Test (optional), D.Constant Time Interval Test (optional), E.Constant Rate of Penetration Test (optional) F.Constant Movement Increment Test (optional), G.Cyclic Loading Test (optional).

In the present research, the indications given by the national norm NP 045-2000 were observed, which by similarity is considered Maintained Load test. However, there are some differences in the national standard compared to the method indicated in ASTM D1143M 07 (2013).

Referring to this American norm, it can be seen first of all that the limiting settlement for stopping the test is 15% of the diameter of the pile compared to 10% of the diameter in the case of the national norm..

Also, the stabilization condition of the loading steps is different 0,25 mm / hour with the limitation of maintaining the step to 2 hours, followed by the continuation of the test until the maximum loading. In the norm NP 045-2000 the stabilization condition is of 0.1 mm / 20 minutes and the maintenance of the load at most 24 hours otherwise is considered the failure of the pile.

Specifically, during the test on the enlarged base pile PP1 following the provisions of the norm NP 045-2000, a much longer time was observed for reaching the condition of stabilization of the loading stages once the base started working. This is due to the enlarged base which is considerably larger than the base of a usual large diameter pile and mobilizes a larger active area.

In this regard, in the case of piles with an enlarged base or piles with a base diameter of more than 1,5 m, I propose to revise the stabilization condition in the national standard NP 045: 2000, by including a limitation to 4 hours on the loading steps, except for the maximum stage, in order to continue the test and to obtain the actual bearing capacity of the tested pile.

ISSMGE also identified the need to improve the standardization of ML and CRP test procedures. Thus, during the 2003 ECSMGE conference, the document Axial static pile test in compression or in tension was published - Recommendations from ERTC - Piles, De Cock, F., Legrand, C. and Huybrechts, N., Vol. 3, 2003, 717–741.

It can be seen that the concrete age of the four tested piles was between 7 and 18 days after pouring. The following research report will analyze the influence of the age of the concrete on the results, due to the creep of the concrete under the effect of axial loads.

During the axial compression test loads no displacements of the reference beams between the tested pile and the anchor piles were detected. It can therefore be concluded that not all the tensile load capacity of the anchor piles has been mobilized.

In interpreting the tests it must be borne in mind that we do not know the exact diameter of the pile at full depth and that the deformation modulus of reinforced concrete in the pile has the same properties as the concrete at the top of the pile where the linear variation of the module is identified.

As shown in Figure 37, the actual diameter of the piles is not well known. In this respect, in the interpretation, the test results must be judiciously calibrated, based on geotechnical investigations performed directly on the test site (geotechnical drilling and laboratory tests, but also CPT and SDMT in situ tests would be recommended).

Regarding the change of the properties of the concrete on the depth of the piles, it is recommended to perform sonic logging tests to identify possible significant variations of them.

It should also be noted that the linear variation of the deformation modulus depending on the unit stress in the section is much more significant for piles that have a rigid layer in the area of the piles base that produces a shortening of the reinforced concrete section ($\mu\epsilon > 250$).

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