Report by :
CENGRS GEOTECHNICA PVT. LTD.
SOIL AND FOUNDATION EXPERTS

Final Report on:

Geotechnical Investigation for Exhibition cum Convention Centre Dwarka, New Delhi

Report Volume	Report Contents
Volume-I	**Engineering Analysis & Recommendations**

Submitted to:

M/s. Delhi-Mumbai Industrial Corridor Development Corporation Ltd.
Room 341-B, 3rd Floor, Hotel Ashok, Diplomatic Enclave, 50-B, Chanakyapuri, New Delhi-110021

Project No. 217048 | Date: 12th September, 2017 | Revision: 1

12th September, 2017 | Project No. 217048-I-R1

M/s. Delhi-Mumbai Industrial Corridor Development Corporation Ltd.
Room 341-B 3rd Floor
Hotel Ashok
Diplomatic Enclave
50-B, Chanakyapuri
New Delhi-110021

Subject: **Geotechnical Investigation for Exhibition cum Convention Centre Dwarka, New Delhi**

We have carried out the captioned study in accordance with your work order dated 31st March, 2017. We thank you for your business, and hope that you are satisfied with our services rendered.

This Final Report presents our geotechnical engineering recommendations for the foundation design of the proposed structures, based on the investigations conducted at the project site.

We have prepared this report based on our findings on site, as well as our experience gained in over 5000 projects completed over the past 28 years. We are pleased to have been of service to you on this project and will be glad to consult further with you and your design team.

Yours faithfully,
CENGRS GEOTECHNICA PVT. LTD.

Sanjay Gupta
Managing Director

Ravi Sundaram
Director

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DEFINITION OF ACRONYMS

CENGRS	Cengrs Geotechnica Pvt. Ltd.
UTM	Universal Transverse Mercator coordinates system
NABL	National Accreditation Board for Testing and Calibration Laboratories
ISO	International Standards Organization
BIS	Bureau of Indian Standards
EGL	Existing Ground Level
NGL	Natural Ground Level
RL	Reduced Level
SPT	Standard Penetration Test
DS	Consolidated drained direct shear test

BIS REFERENCES

- Compendium of Indian Standard on Soil Engineering (***Part-2, Field Testing of Soils for Civil Engineering Purposes) SP36 (Part-2:1988) RA 2006***
- Compendium of Indian Standard on Soil Engineering ***(Part-1, Laboratory Testing of Soils for Civil Engineering Purposes) SP36 (Part-1:1987) RA 2006***

1.0 INTRODUCTION

1.1 Project Description

Government of India (*GOI*) is planning to develop an Exhibition cum Convention Center at Sector-25, Dwarka, New Delhi. GOI has envisaged M/s. Delhi-Mumbai Industrial Corridor Development Corporation (*DMICDC*) to establish, promote and facilitate the development of the overall project.

The various agencies involved in the design of the facility are as follows:

(a)	Government of India	: Owner
(b)	Delhi-Mumbai Industrial Corridor Development Corporation	: Client
(c)	AECOM India Pvt. Ltd.	: Programme Management Consultant
(d)	Cengrs Geotechnica Pvt. Ltd.	: Geotechnical Consultant

Delhi-Mumbai Industrial Corridor Development Corporation (*DMICDC*) has awarded the work of detailed geotechnical investigation at the project site to Cengrs Geotechnica Pvt. Ltd (*CENGRS*).

The scope of our investigations includes drilling of about one hundred and sixty two(162) boreholes (including 60 priority boreholes as specified by AECOM), conducting hundred (100) field California bearing ratio (FCBR), ten (10) trial pits, one (1) electrical resistivity test (ERT), ten (10) plate load test and installation of one (1) piezometer at the specified location.

This report volume (Volume-1) presents our geotechnical engineering recommendations for the foundation design of the proposed structures, based on the investigations conducted at the project site.

1.2 Scope of Work

The overall purposes of this study are to investigate the stratigraphy at the site and submission of this factual report. To accomplish these purposes, the study is being conducted in the following phases:

(a) drilling one hundred and sixty two (162) boreholes to 30 m depth or refusal (N>100), in order to determine the site stratigraphy and to collect soil and groundwater samples;

(b) conducting hundred (100) field California bearing ratio (FCBR) tests to provide data for the design of internal roads;

(c) excavating ten (10) trial pits to provide additional information on the stratigraphy at shallow depths;

(d) conducting one (1) electrical resistivity test (ERT) to provide data for the grounding systems;

(e) performing ten (10) plate load test at specified locations to assess the load-settlement behaviour of soils under loading;

(f) installing one (1) piezometer for long-term monitoring of ground water level to aid in foundation construction;

(g) testing selected soil and groundwater samples in the laboratory to determine pertinent index and engineering properties; and

(h) analyzing all field and laboratory data to develop geotechnical recommendations for foundation design and submission of this report.

1.3 Report Format

Our final report shall be presented in seven (7) volumes. The content of each of these report volumes is summarized below:

Report Volume	Report Content	Structures Covered	Number of Boreholes / Tests Covered
Volume I	**Engineering Analysis & Recommendations**	**All structures**	**-**
Volume 2A	Field and Laboratory Test Data of Boreholes	Exhibition Hall 1, Exhibition Hall 5, Convention 7, Retail 10	34
Volume 2B	Field and Laboratory Test Data of Boreholes	Arena 8, Five Star Hotel 11, Office 13, Office 14, Office 15, Retail 16, Office 17, Office 18, Four Star Hotel 21	35
Volume 2C	Field and Laboratory Test Data of Boreholes	Exhibition Hall 2, Exhibition Hall 3, Exhibition Hall 4	33
Volume 2D	Field and Laboratory Test Data of Boreholes	Five Star Hotel 9, Five Star Hotel 12, Four Star Hotel 19, Four Star Hotel 20, Service Apartment 22	31
Volume 2E	Field and Laboratory Test Data of Boreholes	Office 23, Office 24, Three Star Hotel 25, Office 26	29
Volume 2F	Field test results of FCBR, PLT, ERT, Trial pits etc.	-	-

This report volume (Volume-1) presents our geotechnical engineering recommendations for the foundation design of the proposed structures.

1.4 Scope of Work Covered in this Report Volume

Details of the structures and boreholes considered for analysis are as follows:

Structure	Boreholes Covered
Exhibition Hall-1	44,45,46,47,48,49,50,51,52,53,54
Exhibition Hall-2	37,35,36,38,39,40,41,43,42
Exhibition Hall-3	28,34,32,33,26,27,29,30,31
Exhibition Hall-4	18,15,16,17,19,20,21,23,22,25,24
Exhibition Hall-5	2,5,6,1,3,10,7,11,9,12,14
Convention-7	55,56,57,58,59
Arena-8	120,121,122,123,124,125,126,127,128
Five Star Hotel-9	129,130,132
Five Star Hotel-11	133,135,134,136,137
Five Star Hotel-12	70,71,68,69,72
Four Star Hotel-19	145,147,146,149
Four Star Hotel-20	110,113,111,112,114
Four Star Hotel-21	145,147,146,149
Service Apartment	84,87,88,85
Retail-10	61,62,63,64,65,66,67
Office 13,14,15,17,18 & Retail 16	73,74,75,76,77,115,116117,118,119,138,139,140,142,143,144
Office-23,24& Three Star Hotel-25	89,90,91,92,93,98,99104,105,106,107,108,109,150,151,152,153,154,155,156,157,158

2.0 GENERAL SITE CONDITIONS

2.1 Site Description

The site for the proposed Exhibition cum Convention center is located at Sec-25 Dwarka and lies at Latitude 28°33'7.76"N and Longitude 77° 2'35.31"E. The site is situated about 3.0 km west of Terminal-3, IGI Airport and about 1.5 km west of Dwarka Sec-21 Metro Station. The site is bounded by roads on all the sides and covers about 221 acres on plan.

No cable tunnel, duct bank or direct burial was encountered at our test locations. However, localized construction debris along with few dried up wells (*about 15 m deep*) were observed at the site at the time of our field investigations.

2.2 Regional Geology

The deposits in the project area belong to the "Indo Gangetic Alluvium" and are river deposits of the Yamuna, and its tributaries. The alluvial tract[(1)] is in the nature of a synclinal basin formed concomitantly with the elevation of the Himalayas to its north. It was formed during the later stages of the Himalayan Orogeny by the buckling down of the northern border of the peninsular shield beneath the sediments thrust over it from the north.

The Pleistocene and Recent Deposits of the Indo-GangeticBasin are composed of gravels, sands, silts and clays with remains of animal and plants. A generalized description of geological formations encountered in Gurgaon and Delhi is as follows:

Period	Formation	Description
Recent	Newer Alluvium (Younger alluvium)	Unconsolidated, inter-bedded lenses of sand, silt gravel and clay confined to flood plains of Yamuna river.
Quaternary	Older Alluvium	Unconsolidated inter-bedded, inter-fingering deposit sand, clay and kankar, moderately sorted, thickness variable, at places more than 300 m.
~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ Unconformity ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~		
Pre-Cambrian	Pegmatite and Quartz Veins Quartzites and minor Schist Bands	Well stratified, thick-bedded brown to buff colour, hard and compact, intruded locally by pegmatite and quartz veins inter-bedded with mica schists.

The older alluvium is rather dark colored (locally called "Bhanger") and is generally, rich in concretions or nodules of impure calcium carbonate (kankars). The kankars are of all shapes and sizes, varying from small sand sized grains to big grains and big lumps. The age of the "Bhanger" alluvium is Middle to Upper Pleistocene.

The newer alluvium (locally called "Khadar") is light colored and poor in concretions. It contains lenticular beds of sand and gravel as well as peat beds. It is merged by insensible gradations into the Recent or deltaic alluvia and its age is Upper Pleistocene to Recent.

(1) Krishnan, M.S. (1986), ***"Geology of India & Burma"***, CBS Publishers, New Delhi.

2.3 Site Stratigraphy

The deposits encountered within the depths investigated for this study are alluvial in nature. The natural soil at the site typically consists primarily of sandy silt. The liquid limit of the soil generally varies from 21 to 35% with the plasticity index generally ranging 6 to 17. The soil is non-expansive in nature. The general trend of the field SPT values is more or less the same across the site.

Details of the field and laboratory tests carried out at the boreholes are presented in the factual reports (Volume 2A to 2E) submitted. A summary of the borehole profiles is presented on Plates 1 to 34.

2.4 Groundwater

Groundwater was met at 16.1-22.4 m depth below the EGL during the period of our field investigation (April-June, 2017). Fluctuations may occur in the measured water levels due to seasonal variations in rainfall and surface evaporation rates.

One (1) piezometer was installed at BH-159 for long term monitoring of the groundwater level. The water levels at the piezometer location (*as measured by CENGRS & witnessed by AECOM*) during the period of our field investigation is presented graphically on Plate 35 and summarized below:

Piezometer Designation	Date of Measurement	Measured Groundwater Depth Below EGL , m	Measured Ground Water Level (RL), m
PZM-1	12-June-17	23.27	190.88
	19-June-17	23.90	190.25
	01-July-17	23.24	190.91

We suggest that the water level in the piezometer be monitored till the foundation construction is complete for a realistic assessment of the water levels.

3.0 LIQUEFACTION SUSCEPTIBILITY ASSESSMENT

Liquefaction is defined as the transformation of a granular material from a solid to a liquefied state as a consequence of increased pore-water pressure and reduced effective stress (Marcuson, 1978[2]). Increased pore pressure may be induced by the tendency of granular materials to compact when subjected to cyclic shear deformation, such as in the event of an earthquake.

As per IS: 1893 (Part 1) - 2016, liquefaction is likely in loose fine sand (SP) below water table. The following points are highlighted for the soils with regard to liquefaction susceptibility assessment:

1. As mentioned in Section 2.3, the soil at the site consists primarily of sandy silt to the maximum explored depth.

2. As mentioned in Section 2.4, groundwater was met at 16.1-22.4 m depth below the EGL.

Reviewing the soil conditions, we are of the opinion that the soils at this site are not likely to liquefy in the event of a design earthquake owing to the deep water table, high SPT values below groundwater etc.

According to Fig.1 of IS: 1893 (Part1)-2016 showing seismic zones, the proposed site falls under Zone-IV. The design for seismic forces should be done considering the project in Zone-IV.

(2) Marcuson, W.F. (III) (1978), "***Definition of terms related to liquefaction***", J. Geotech Engrg. Div,, ASCE, 104(9), 1197-1200.

4.0 FOUNDATION ANALYSIS AND RECOMMENDATIONS

4.1 General

A suitable foundation for any structure should have an adequate factor of safety against exceeding the bearing capacity of the supporting soils. Also the vertical movements due to compression of the soils should be within tolerable limits for the structure. We consider that foundation designed in accordance with the recommendations given herein will satisfy these criteria.

4.2 Foundation Type and Depth

Isolated / individual foundations or raft foundations or RCC strip footings may be provided to carry the structural loads of the building. Raft foundations may be provided for buildings with heavily loaded columns. For isolated / individual foundations, a beam interconnecting the columns should be provided to restrict the differential settlement.

Please refer to Section 4.5 recommended net allowable bearing pressures for foundations of the proposed structures.

If the planned structural loads exceed the recommended bearing pressures, consideration may be given to the provision of pile foundations or a piled-raft system. Please refer to Section 4.6 recommended safe pile capacities for 600, 750, 900 & 1200mm RCC bored cast-in-situ piles.

4.3 Concepts for Analysis for Open Foundations

Bearing capacity analysis for the open foundations has been done in general accordance with IS: 6403-1981 RA 2002.

The bearing capacity equation used is as follows:

$$q_{net\ safe} = \frac{1}{F}\left[cN_c\zeta_c d_c + q(N_q - 1)\zeta_q d_q + 0.5\,B\,\Upsilon N_\gamma \zeta_\gamma d_\Upsilon R_w\right]$$

where:

$q_{net\ safe}$ = safe net bearing capacity of soil based on the shear failure criterion.
q = overburden pressure
R_w = water table correction factor,
F = Factor of safety, taken as equal to 2.5 in accordance with IS:1904-1986.
$\zeta_c, \zeta_q, \zeta_\gamma$ = Shape factors. For Strip footings, $\zeta_c = \zeta_q = \zeta_\gamma = 1$
For Square footing, $\zeta_c = 1.3$, $\zeta_q = 1.2$, $\zeta_\gamma = 0.6$
d_c, d_q, d_γ = Depth factors
For $\phi \le 10$, $d_c = 1 + 0.2 \tan(45 + \phi / 2)\, D / B$, $d_q = d_\gamma = 1$
For $\phi > 10$, $d_q = d_\gamma = 1 + 0.1 \tan(45 + \phi / 2)\, D / B$

Appropriate values have been substituted into the bearing capacity equation given above to compute the safe net bearing capacity. The values have been checked to determine the settlement of the foundation under the safe bearing pressure. The allowable bearing pressure has been taken as the lower of the two values computed from the bearing capacity shear failure criterion as well as that computed from the tolerable settlement criterion.

Settlement analysis has been performed based on the SPT values in accordance with Clause 9.1.4 of IS 8009 (Part 1)-1976 RA 2003 Fig.9. The values have been cross-checked with settlement computed by the classical theory as sum of the immediate settlement and consolidation settlement. Since groundwater was encountered at deep depths, consolidation settlement is not likely to occur and the same has been ignored for the purpose of analysis.

The elastic settlement has been computed using the following equation [Clause 9.2.3 of IS 8009 Part 1-1976 RA 2003][(3)].

$$S_i = \frac{qB'(1-\mu^2)}{E} I d_f d_r$$

where:

S_i	=	*immediate (elastic) settlement*
B	=	*foundation width, B' = B/2*
μ	=	*Poisson's ratio*
q	=	*applied bearing pressure*
E	=	*modulus of elasticity*
d_f	=	*depth factor*
d_r	=	*rigidity factor*
I	=	*influence factor at corner of rectangular loaded area (B'x L')*

4.4 Concepts for Analysis for Bored Pile Foundations

The axial capacity for bored piles have been computed based on static analysis using c-ϕ values as interpreted from the site stratigraphy, SPT values and laboratory test results.

The ultimate pile compressive capacity has been computed using the following equation as given in IS 2911, Part-I, Sections-1 & 2: 2010.

$$Q_{ult} = \left[\sum_{i=1}^{n} f_s A_s L_i\right] + q_u A_p$$

$$= \left[\sum_{i=1}^{n} (\alpha c_i + p_i k \tan \delta_i) A_s L_i\right] + \left[c_p N_c + q_p N_q + \tfrac{1}{2}\gamma D N_\gamma\right] A_p$$

where:

Q_{ult}	=	*ultimate pile capacity*
fs	=	*unit skin friction*
α	=	*adhesion factor*
ci	=	*cohesion intercept in ith layer*
pi	=	*overburden pressure at centre of ith layer*
k	=	*coefficient of lateral earth pressure*
δi	=	*angle of friction between soil and pile (taken as equal to ϕi) for the ith layer*
As	=	*surface area of pile per m length*
Li	=	*length of pile section in ith layer*
cp	=	*cohesion intercept in bearing strata*
qu	=	*unit end bearing*
qp	=	*overburden pressure in bearing strata*
Nc, Nq	=	*bearing capacity factors, which are a function of ϕ in the bearing strata*
Ap	=	*pile cross sectional area*

The overburden pressure is assumed to become constant below a depth of about 15 times of pile diameter.

The uplift / pullout resistance has been computed from the static formula by ignoring the end bearing component but adding the buoyant weight of the pile to half the computed skin friction component. A factor of safety of 3.0 has been applied to the ultimate pile pullout resistance to obtain the safe pullout capacity.

The lateral load carrying capacity of bored pile has been computed based on IS: 2911 (Part 1/Sect.2)-1979. The pile head is assumed to be fixed.

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(3) Bowles, J.E. (1996), "***Foundation Analysis and Design***", International Edition, pp. 303-317.

The depth of fixity has been computed as per Fig.2 of Appendix C, Clause 5.5.2 of IS: 2911, Part 1, Section 2. The lateral load carrying capacity of pile has been computed for a permissible horizontal deflection of 5 mm using the following equation for fixed head pile.

$$Q = \frac{12\, y E I}{(L_1 + L_f)^3}$$

where:

Q	=	lateral load
E	=	the Young's modulus of pile material
I	=	moment of inertia of pile cross section.
L_f	=	depth of fixity
L_1	=	length of pile section below cut-off-level that may not contribute significantly to lateral resistance (in loose/weak soils)
y	=	horizontal deflection

4.5 Recommended Net Allowable Bearing Pressure

The following table presents our recommended values of net allowable bearing pressures for the foundations bearing at respective depths.

Structure	Basement Case	Planned Basement Level	Foundation Level , m	Recommended Net Allowable Bearing Pressure, T/m^2				Recommended Gross Allowable Bearing Pressure, T/m^2				Modulus of Subgrade Reaction, k, kN/m^3
				Total settlement =25 mm	Total settlement =40 mm	Total settlement =50 mm	Total settlement =75 mm	Total settlement =25 mm	Total settlement =40 mm	Total settlement =50 mm	Total settlement =75 mm	
Exhibition Hall 1	No Basement	-	1.5 m (RL 211 m)	6.3	10.0	12.5	18.8	-	-	-	-	2500
			3 m (RL 209.5 m)	7.8	12.4	15.5	23.3	-	-	-	-	3100
			6 m (RL 206.5 m)	9.3	14.8	18.5	27.8	-	-	-	-	3700
			9 m (RL 203.5 m)	11.3	18.0	22.5	33.8	-	-	-	-	4500
			12 m (RL 200.5 m)	12.5	20.0	25.0	37.5	-	-	-	-	5000
	One Basement	4.9	6 m (RL 206.5 m)	9.3	14.8	18.5	27.8	19.8	25.4	29.1	31.9*	7700
Exhibition hall 2	No Basement	-	1.5 m (RL 210.9 m)	5.8	9.2	11.5	17.3	-	-	-	-	2300
			3 m (RL 209.4 m)	7.5	12.0	15.0	22.5	-	-	-	-	3000
			6 m (RL 206.4 m)	9.3	14.8	18.5	27.8	-	-	-	-	3700
			9 m (RL 203.4 m)	11.3	18.0	22.5	33.8	-	-	-	-	4500
			12 m (RL 200.4 m)	12.5	20.0	25.0	37.5	-	-	-	-	5000
Convention	No Basement	-	1.5 m (RL 211.2 m)	6.3	10.0	12.5	18.8	-	-	-	-	2500
			3 m (RL 209.7 m)	7.8	12.4	15.5	23.3	-	-	-	-	3100
			6 m (RL 206.7 m)	9.5	15.2	19.0	28.5	-	-	-	-	3800
			9 m (RL 203.7 m)	11.3	18.0	22.5	33.8	-	-	-	-	4500
			12 m (RL 200.7 m)	12.5	20.0	25.0	37.5	-	-	-	-	5000
			15 m (RL 197.7 m)	13.3	21.2	26.5	39.8	-	-	-	-	5300
	Double Basement	3.9	5 m (RL 207.7 m)	9.0	14.4	18.0	27.0	17.8	23.2	26.8	31.2*	7200
		8.5	10 m (RL 202.7 m)	13.0	20.8	26.0	39.0	30.8	38.6	43.8	56.8	11400

*restricted by shear criteria

Structure	Basement Case	Planned Basement Level	Foundation Level , m	Recommended Net Allowable Bearing Pressure, T/m^2			Recommended Gross Allowable Bearing Pressure, T/m^2			Modulus of Subgrade Reaction, k, kN/m^3
				Total settlement = 40 mm	Total settlement = 50 mm	Total settlement = 75 mm	Total settlement = 40 mm	Total settlement = 50 mm	Total settlement = 75 mm	
Foyer (Exhibition Hall 1)	Three Basement	10.4	12 m (RL 200.5 m)	20.0	25.0	37.5	41.5	46.5	59.0	11800
	Four Basement	14.4	16 m (RL 196.5 m)	22.4	28.0	42.0	51.3	56.9	70.9	14200
Foyer (Exhibition Hall 2)	Three Basement	10.4	12 m (RL 200.5 m)	20.0	25.0	37.5	41.5	46.5	59.0	11800
	Four Basement	14.4	16 m (RL 196.5 m)	22.4	28.0	42.0	51.3	56.9	70.9	14200
Exhibition hall 3	No Basement	-	1.5 m (RL 210.9 m)	8.8	11.0	16.5	-	-	-	2200
			3 m (RL 209.4 m)	12.4	15.5	23.3	-	-	-	3100
			6 m (RL 206.4 m)	14.8	18.5	27.8	-	-	-	3700
			9 m (RL 203.4 m)	16.8	21.0	31.5	-	-	-	4200
			12 m (RL 200.4 m)	18.8	23.5	35.3	-	-	-	4700
	Three Basement	10.9	13 m (RL 199.4 m)	19.2	24.0	36.0	42.5	47.3	59.3	11900
Foyer (Exhibition Hall 3)	Three Basement	10.4	12 m (RL 200.5 m)	18.8	23.5	35.3	40.3	45.0	56.7	11300
	Four Basement	14.4	16 m (RL 196.5 m)	20.8	26.0	39.0	49.7	54.9	67.9	13600
Exhibition hall 4	No Basement	-	1.5 m (RL 210.5 m)	8.0	10.0	15.0	-	-	-	2000
			3 m (RL 209 m)	10.8	13.5	20.3	-	-	-	2700
			6 m (RL 206 m)	14.4	18.0	27.0	-	-	-	3600
			9 m (RL 203 m)	18.0	22.5	33.8	-	-	-	4500
			12 m (RL 200 m)	20.0	25.0	37.5	-	-	-	5000
Foyer (Exhibition Hall 4)	Three Basement	10.4	12 m (RL 200.5 m)	20.0	25.0	37.5	41.5	46.5	59.0	11800
	Four Basement	14.4	16 m (RL 196.5 m)	22.4	28.0	42.0	51.3	56.9	70.9	14200
Exhibition hall 5	No Basement	-	1.5 m (RL 210.5 m)	8.0	10.0	15.0	-	-	-	2000
			3 m (RL 209 m)	10.8	13.5	20.3	-	-	-	2700
			6 m (RL 206 m)	14.4	18.0	27.0	-	-	-	3600
			9 m (RL 203 m)	18.0	22.5	33.8	-	-	-	4500
			12 m (RL 200 m)	20.0	25.0	37.5	-	-	-	5000

Structure	Basement Case	Planned Basement Level	Foundation Level , m	Recommended Net Allowable Bearing Pressure, T/m^2			Recommended Gross Allowable Bearing Pressure, T/m^2			Modulus of Subgrade Reaction, k, kN/m^3
				Total settlement = 40 mm	Total settlement = 50 mm	Total settlement = 75 mm	Total settlement = 40 mm	Total settlement = 50 mm	Total settlement = 75 mm	
Foyer (Exhibition Hall 5)	Three Basement	10.4	12 m (RL 200.5 m)	20.0	25.0	37.5	41.5	46.5	59.0	11800
	Four Basement	14.4	16 m (RL 196.5 m)	22.4	28.0	42.0	51.3	56.9	70.9	14200
Arena	No Basement	-	1.5 m (RL 211.9 m)	10.4	13.0	19.5	-	-	-	2600
			3 m (RL 210.4 m)	14.4	18.0	27.0	-	-	-	3600
			6 m (RL 207.4 m)	16.4	20.5	30.8	-	-	-	4100
			9 m (RL 204.4 m)	19.2	24.0	36.0	-	-	-	4800
			12 m (RL 201.4 m)	21.2	26.5	39.8	-	-	-	5300
	Double Basement	3.9	5 m (RL 208.4 m)	15.2	19.0	28.5	24.0	27.8	37.3	7500
		7.8	9.5 m (RL 203.9 m)	21.2	26.5	39.8	38.0	43.3	56.6	11300
Five Star Hotel-9	Three Basement	10.4	12 m (RL 201.5 m)	21.2	26.5	39.8	42.7	48.0	61.2	12200
	Four Basement	14.4	16.5 m (RL 197 m)	24.0	30.0	45.0	53.8	59.8	74.8	15000
Retail-10	Three Basement	10.4	12 m (RL 201.2 m)	20.0	25.0	37.5	41.5	46.5	59.0	11800
	Four Basement	14.4	16.5 m (RL 196.7 m)	22.8	28.5	42.8	52.6	58.3	72.5	14500
Five Star Hotel-11	Three Basement	10.4	12 m (RL 201.5 m)	20.0	25.0	37.5	41.5	46.5	59.0	11800
	Four Basement	14.4	16.5 m (RL 197 m)	22.4	28.0	42.0	52.2	57.8	71.8	14400
Five Star Hotel-12	Three Basement	10.4	12 m (RL 200.9 m)	18.8	23.5	35.3	40.3	45.0	56.7	11300
	Four Basement	14.4	16.5 m (RL 196.4 m)	21.6	27.0	40.5	51.4	56.8	70.3	14100
Office-13	Three Basement	10.4	12 m (RL 201.4 m)	18.8	23.5	35.3	40.3	45.0	56.7	11300
	Four Basement	14.4	16.5 m (RL 196.9 m)	21.6	27.0	40.5	51.4	56.8	70.3	14100
Office-14	Three Basement	10.4	12 m (RL 201.4 m)	18.8	23.5	35.3	40.3	45.0	56.7	11300
	Four Basement	14.4	16.5 m (RL 196.9 m)	21.6	27.0	40.5	51.4	56.8	70.3	14100

Structure	Basement Case	Planned Basement Level	Foundation Level , m	Recommended Net Allowable Bearing Pressure, T/m^2			Recommended Gross Allowable Bearing Pressure, T/m^2			Modulus of Subgrade Reaction, k, kN/m^3
				Total settlement = 40 mm	Total settlement = 50 mm	Total settlement = 75 mm	Total settlement = 40 mm	Total settlement = 50 mm	Total settlement = 75 mm	
Office-15	Three Basement	10.4	12 m (RL 200.4 m)	18.8	23.5	35.3	40.3	45.0	56.7	11300
	Four Basement	14.4	16.5 m (RL 195.9 m)	21.6	27.0	40.5	51.4	56.8	70.3	14100
Retail-16	Three Basement	10.4	12 m (RL 201.3 m)	18.8	23.5	35.3	40.3	45.0	56.7	11300
	Four Basement	14.4	16.5 m (RL 196.8 m)	21.6	27.0	40.5	51.4	56.8	70.3	14100
Office-17	Three Basement	10.4	12 m (RL 201.5 m)	18.8	23.5	35.3	40.3	45.0	56.7	11300
	Four Basement	14.4	16.5 m (RL 197 m)	21.6	27.0	40.5	51.4	56.8	70.3	14100
Office-18	Three Basement	10.4	12 m(RL 201.6 m)	18.8	23.5	35.3	40.3	45.0	56.7	11300
	Four Basement	14.4	16.5 m (RL 197.1 m)	21.6	27.0	40.5	51.4	56.8	70.3	14100
Four Star Hotel-19	Three Basement	10.4	12 m (RL 200.7 m)	18.8	23.5	35.3	40.3	45.0	56.7	11300
	Four Basement	14.4	16.5 m (RL 196.2 m)	21.6	27.0	40.5	51.4	56.8	70.3	14100
Four Star Hotel-20	Three Basement	10.4	12 m (RL 201.4 m)	18.8	23.5	35.3	40.3	45.0	56.7	11300
	Four Basement	14.4	16.5 m (RL 196.9 m)	21.6	27.0	40.5	51.4	56.8	70.3	14100
Four Star Hotel-21	Three Basement	10.4	12 m (RL 200.8 m)	18.8	23.5	35.3	40.3	45.0	56.7	11300
	Four Basement	14.4	16.5 m (RL 196.3 m)	21.6	27.0	40.5	51.4	56.8	70.3	14100
Service Apartment -22	Three Basement	10.4	12 m (RL 200.5 m)	23.6	29.5	44.3	45.1	51.0	65.7	13100
	Four Basement	14.4	16.5 m (RL 196 m)	26.4	33.0	49.5	56.2	62.8	79.3	15900
Office-23	Three Basement	10.4	12 m (RL 200.8 m)	18.8	23.5	35.3	40.3	45.0	56.7	11300
	Four Basement	14.4	16.5 m (RL 196.3 m)	21.6	27.0	40.5	51.4	56.8	70.3	14100
Office-24	Three Basement	10.4	12 m (RL 200.8 m)	18.8	23.5	35.3	40.3	45.0	56.7	11300
	Four Basement	14.4	16.5 m (RL 196.3 m)	21.6	27.0	40.5	51.4	56.8	70.3	14100

Structure	Basement Case	Planned Basement Level	Foundation Level , m	Recommended Net Allowable Bearing Pressure, T/m²			Recommended Gross Allowable Bearing Pressure, T/m²			Modulus of Subgrade Reaction, k, kN/m³
				Total settlement = 40 mm	Total settlement = 50 mm	Total settlement = 75 mm	Total settlement = 40 mm	Total settlement = 50 mm	Total settlement = 75 mm	
3 Star Hotel-25	Three Basement	10.4	12 m (RL 200.8 m)	18.8	23.5	35.3	40.3	45.0	56.7	11300
	Four Basement	14.4	16.5 m (RL 196.3 m)	21.6	27.0	40.5	51.4	56.8	70.3	14100
Office-26	Three Basement	10.4	12 m (RL 201.3 m)	18.8	23.5	35.3	40.3	45.0	56.7	11300
	Four Basement	14.4	16.5 m (RL 196.8 m)	21.6	27.0	40.5	51.4	56.8	70.3	14100
Office-27	Three Basement	10.4	12 m (RL 200.6 m)	18.8	23.5	35.3	40.3	45.0	56.7	11300
	Four Basement	14.4	16.5 m (RL 196.1 m)	21.6	27.0	40.5	51.4	56.8	70.3	14100
3 Star Hotel-28	Three Basement	10.4	12 m (RL 201 m)	18.8	23.5	35.3	40.3	45.0	56.7	11300
	Four Basement	14.4	16.5 m (RL 196.5 m)	21.6	27.0	40.5	51.4	56.8	70.3	14100
Office-29	Three Basement	10.4	12 m (RL 201.4 m)	18.8	23.5	35.3	40.3	45.0	56.7	11300
	Four Basement	14.4	16.5 m (RL 196.9 m)	21.6	27.0	40.5	51.4	56.8	70.3	14100

The following points are highlighted with regard to the above recommended net bearing pressures:

1. The above bearing pressures include a bearing capacity safety factor of 2.5.

2. The appropriate values of net bearing pressure may be selected as per the permissible settlement criterion.

3. Net bearing pressures for foundations at intermediate depths may be interpolated linearly between the values given above.

4. The soils at foundation level should be compacted thoroughly using a heavy roller. It should be ensured that there are no loose pockets at foundation level.

5. The suggested modulus of sub grade reaction (k) has been estimated as the ratio of the computed gross bearing pressure and corresponding total settlement, and is applicable at the centre of the loaded area[4].

[4] Bowles, J.E. (1996), "***Foundation Analysis and Design Fifth Edition***", The McGraw-Hill Companies Inc., pp. 503

4.6 Recommended Safe Pile Capacities

We recommend the following values of safe pile capacities for 600, 750, 900 & 1200mm RCC bored cast-in-situ piles.

Structure / Facility	Basement Case	Planned Pile Cut-off Level below NGL, m	Pile Diameter, mm	Pile Length below COL, m	Recommended Safe Pile Capacity, Tonnes		
					Compression	Pull-Out	Lateral
Exhibition Hall 1	1 Basement	3.0	600	12 m (RL 200.5 m)	46	16	6.9
				14 m (RL 198.5 m)	55	21	
				16 m (RL 196.5 m)	64	27	
				18 m (RL 194.5 m)	78	32	
			750	12 m (RL 200.5 m)	65	21	10.7
				14 m (RL 198.5 m)	86	29	
				16 m (RL 196.5 m)	101	38	
				18 m (RL 194.5 m)	126	46	
			900	14 m (RL 198.5 m)	114	37	14.8
				16 m (RL 196.5 m)	144	48	
				18 m (RL 194.5 m)	187	61	
			1200	16 m (RL 196.5 m)	227	72	25.1
				18 m (RL 194.5 m)	318	90	
		5.0	600	12 m (RL 200.5 m)	57	20	7.8
				14 m (RL 198.5 m)	65	25	
				16 m (RL 196.5 m)	80	31	
				18 m (RL 194.5 m)	90	37	
			750	12 m (RL 200.5 m)	89	27	11.5
				14 m (RL 198.5 m)	104	35	
				16 m (RL 196.5 m)	129	44	
				18 m (RL 194.5 m)	143	53	
			900	14 m (RL 198.5 m)	148	45	15.8
				16 m (RL 196.5 m)	191	58	
				18 m (RL 194.5 m)	211	71	
			1200	16 m (RL 196.5 m)	324	85	26.6
				18 m (RL 194.5 m)	389	106	

Structure / Facility	Basement Case	Planned Pile Cut-off Level below NGL, m	Pile Diameter, mm	Pile Length below COL, m	Recommended Safe Pile Capacity, Tonnes		
					Compression	Pull-Out	Lateral
Exhibition Hall 2	No Basement	3.0	600	12 m (RL 200.4 m)	46	16	6.9
				14 m (RL 198.4 m)	55	21	
				16 m (RL 196.4 m)	64	27	
				18 m (RL 194.4 m)	78	32	
			750	12 m (RL 200.4 m)	65	21	10.7
				14 m (RL 198.4 m)	86	29	
				16 m (RL 196.4 m)	101	38	
				18 m (RL 194.4 m)	126	46	
			900	14 m (RL 198.4 m)	114	37	14.8
				16 m (RL 196.4 m)	144	48	
				18 m (RL 194.4 m)	187	61	
			1200	16 m (RL 196.4 m)	227	72	25.1
				18 m (RL 194.4 m)	318	90	
Exhibition Hall 3	Three Basement	14.0	600	12 m (RL 200.4 m)	73	24	11.2
				14 m (RL 198.4 m)	83	30	
				16 m (RL 196.4 m)	94	36	
			750	12 m (RL 200.4 m)	119	33	16.3
				14 m (RL 198.4 m)	135	42	
				16 m (RL 196.4 m)	151	52	
			900	12 m (RL 200.4 m)	165	41	22.2
				14 m (RL 198.4 m)	201	55	
				16 m (RL 196.4 m)	223	68	
			1200	14 m (RL 198.4 m)	327	79	35.8
				16 m (RL 196.4 m)	392	100	

Structure / Facility	Basement Case	Planned Pile Cut-off Level below NGL, m	Pile Diameter, mm	Pile Length below COL, m	Recommended Safe Pile Capacity, Tonnes		
					Compression	Pull-Out	Lateral
Exhibition Hall 4	No Basement	3.0	600	12 m (RL 200 m)	46	16	6.9
				14 m (RL 198 m)	55	21	
				16 m (RL 196 m)	64	27	
				18 m (RL 194 m)	78	32	
			750	12 m (RL 200 m)	65	21	10.7
				14 m (RL 198 m)	86	29	
				16 m (RL 196 m)	101	38	
				18 m (RL 194 m)	126	46	
			900	14 m (RL 198 m)	114	37	14.8
				16 m (RL 196 m)	144	48	
				18 m (RL 194 m)	187	61	
			1200	16 m (RL 196 m)	227	72	25.1
				18 m (RL 194 m)	318	90	
		6.0	600	12 m (RL 200 m)	60	22	7.8
				14 m (RL 198 m)	69	27	
				16 m (RL 196 m)	84	33	
				18 m (RL 194 m)	93	39	
			750	12 m (RL 200 m)	96	30	11.5
				14 m (RL 198 m)	109	39	
				16 m (RL 196 m)	135	48	
				18 m (RL 194 m)	150	57	
			900	14 m (RL 198 m)	160	50	15.8
				16 m (RL 196 m)	200	63	
				18 m (RL 194 m)	220	76	
			1200	16 m (RL 196 m)	355	92	26.6
				18 m (RL 194 m)	422	115	

Structure / Facility	Basement Case	Planned Pile Cut-off Level below NGL, m	Pile Diameter, mm	Pile Length below COL, m	Recommended Safe Pile Capacity, Tonnes		
					Compression	Pull-Out	Lateral
Exhibition Hall 5	No Basement	3.0	600	12 m (RL 200.2 m)	46	16	6.9
				14 m (RL 198.2 m)	55	21	
				16 m (RL 196.2 m)	64	27	
				18 m (RL 194.2 m)	78	32	
			750	12 m (RL 200.2 m)	65	21	10.7
				14 m (RL 198.2 m)	86	29	
				16 m (RL 196.2 m)	101	38	
				18 m (RL 194.2 m)	126	46	
			900	14 m (RL 198.2 m)	114	37	14.8
				16 m (RL 196.2 m)	144	48	
				18 m (RL 194.2 m)	187	61	
			1200	16 m (RL 196.2 m)	227	72	25.1
				18 m (RL 194.2 m)	318	90	
Convention	2 Basement	6.0	600	12 m (RL 200.7 m)	60	22	8.5
				14 m (RL 198.7 m)	69	27	
				16 m (RL 196.7 m)	84	33	
				18 m (RL 194.7 m)	93	39	
			750	12 m (RL 200.7 m)	96	30	12.9
				14 m (RL 198.7 m)	109	39	
				16 m (RL 196.7 m)	135	48	
				18 m (RL 194.7 m)	150	57	
			900	12 m (RL 200.7 m)	131	38	18.1
				14 m (RL 198.7 m)	160	50	
				16 m (RL 196.7 m)	200	63	
				18 m (RL 194.7 m)	220	76	
			1200	16 m (RL 196.7 m)	355	92	30.1
				18 m (RL 194.7 m)	422	115	

Structure / Facility	Basement Case	Planned Pile Cut-off Level below NGL, m	Pile Diameter, mm	Pile Length below COL, m	Recommended Safe Pile Capacity, Tonnes		
					Compression	Pull-Out	Lateral
Convention	2 Basement	11.0	600	12 m (RL 200.7 m)	72	23	11.8
				14 m (RL 198.7 m)	82	29	
				16 m (RL 196.7 m)	92	35	
				18 m (RL 194.7 m)	102	41	
			750	12 m (RL 200.7 m)	118	32	17.4
				14 m (RL 198.7 m)	133	41	
				16 m (RL 196.7 m)	149	51	
				18 m (RL 194.7 m)	164	60	
			900	12 m (RL 200.7 m)	163	40	23.7
				14 m (RL 198.7 m)	198	53	
				16 m (RL 196.7 m)	220	67	
				18 m (RL 194.7 m)	242	81	
			1200	16 m (RL 196.7 m)	386	98	38.2
				18 m (RL 194.7 m)	455	121	
Arena	1 Basement	3.0	600	12 m (RL 201.4 m)	46	16	7.8
				14 m (RL 199.4 m)	55	21	
				16 m (RL 197.4 m)	64	27	
				18 m (RL 195.4 m)	78	32	
			750	12 m (RL 201.4 m)	65	21	12.5
				14 m (RL 199.4 m)	86	29	
				16 m (RL 197.4 m)	101	38	
				18 m (RL 195.4 m)	126	46	
			900	14 m (RL 199.4 m)	114	37	17.7
				16 m (RL 197.4 m)	144	48	
				18 m (RL 195.4 m)	187	61	
			1200	16 m (RL 197.4 m)	227	72	29.4
				18 m (RL 195.4 m)	318	90	

Structure / Facility	Basement Case	Planned Pile Cut-off Level below NGL, m	Pile Diameter, mm	Pile Length below COL, m	Recommended Safe Pile Capacity, Tonnes		
					Compression	Pull-Out	Lateral
Arena	2 Basement	6.0	600	12 m (RL 201.4 m)	60	22	9.5
				14 m (RL 199.4 m)	69	27	
				16 m (RL 197.4 m)	84	33	
				18 m (RL 195.4 m)	93	39	
			750	12 m (RL 201.4 m)	96	30	14.2
				14 m (RL 199.4 m)	109	39	
				16 m (RL 197.4 m)	135	48	
				18 m (RL 195.4 m)	150	57	
			900	14 m (RL 199.4 m)	160	50	19.8
				16 m (RL 197.4 m)	200	63	
				18 m (RL 195.4 m)	220	76	
			1200	16 m (RL 197.4 m)	355	92	32.7
				18 m (RL 195.4 m)	422	115	
		10.0	600	12 m (RL 201.4 m)	72	23	9.5
				14 m (RL 199.4 m)	82	29	
				16 m (RL 197.4 m)	92	35	
				18 m (RL 195.4 m)	102	41	
			750	12 m (RL 201.4 m)	116	32	14.5
				14 m (RL 199.4 m)	131	41	
				16 m (RL 197.4 m)	147	50	
				18 m (RL 195.4 m)	162	60	
			900	14 m (RL 199.4 m)	195	53	21.1
				16 m (RL 197.4 m)	217	67	
				18 m (RL 195.4 m)	239	80	
			1200	16 m (RL 197.4 m)	382	97	34.6
				18 m (RL 195.4 m)	451	120	

Structure / Facility	Basement Case	Planned Pile Cut-off Level below NGL, m	Pile Diameter, mm	Pile Length below COL, m	Recommended Safe Pile Capacity, Tonnes		
					Compression	Pull-Out	Lateral
Hotel	3/4 basements	14.0	600	12 m (RL 201 m)	73	24	10.6
				14 m (RL 199 m)	83	30	
				16 m (RL 197 m)	94	36	
				18 m (RL 195 m)	104	42	
			750	12 m (RL 201 m)	119	33	15.7
				14 m (RL 199 m)	135	42	
				16 m (RL 197 m)	151	52	
				18 m (RL 195 m)	167	61	
			900	14 m (RL 199 m)	201	55	21.8
				16 m (RL 197 m)	223	68	
				18 m (RL 195 m)	246	82	
			1200	16 m (RL 197 m)	387	100	35.8
				18 m (RL 195 m)	462	123	
		18.0	600	12 m (RL 201 m)	79	25	11.6
				14 m (RL 199 m)	89	31	
				16 m (RL 197 m)	100	37	
				18 m (RL 195 m)	111	43	
			750	12 m (RL 201 m)	127	34	16.9
				14 m (RL 199 m)	143	44	
				16 m (RL 197 m)	160	53	
				18 m (RL 195 m)	176	63	
			900	14 m (RL 199 m)	211	56	23.4
				16 m (RL 197 m)	234	70	
				18 m (RL 195 m)	258	84	
			1200	16 m (RL 197 m)	408	102	38.2
				18 m (RL 195 m)	479	125	

Structure / Facility	Basement Case	Planned Pile Cut-off Level below NGL, m	Pile Diameter, mm	Pile Length below COL, m	Recommended Safe Pile Capacity, Tonnes		
					Compression	Pull-Out	Lateral
Retail,	3/4 basements	14.0	600	12 m (RL 201 m)	73	24	10.6
				14 m (RL 199 m)	83	30	
				16 m (RL 197 m)	94	36	
				18 m (RL 195 m)	104	42	
			750	12 m (RL 201 m)	119	33	15.7
				14 m (RL 199 m)	135	42	
				16 m (RL 197 m)	151	52	
				18 m (RL 195 m)	167	61	
			900	14 m (RL 199 m)	201	55	21.8
				16 m (RL 197 m)	223	68	
				18 m (RL 195 m)	246	82	
			1200	16 m (RL 197 m)	387	100	35.8
				18 m (RL 195 m)	462	123	
		18.0	600	12 m (RL 201 m)	79	25	11.6
				14 m (RL 199 m)	89	31	
				16 m (RL 197 m)	100	37	
				18 m (RL 195 m)	111	43	
			750	12 m (RL 201 m)	127	34	16.9
				14 m (RL 199 m)	143	44	
				16 m (RL 197 m)	160	53	
				18 m (RL 195 m)	176	63	
			900	14 m (RL 199 m)	211	56	23.4
				16 m (RL 197 m)	234	70	
				18 m (RL 195 m)	258	84	
			1200	16 m (RL 197 m)	408	102	38.2
				18 m (RL 195 m)	479	125	

<table>
<tr><th rowspan="2">Structure / Facility</th><th rowspan="2">Basement Case</th><th rowspan="2">Planned Pile Cut-off Level below NGL, m</th><th rowspan="2">Pile Diameter, mm</th><th rowspan="2">Pile Length below COL, m</th><th colspan="3">Recommended Safe Pile Capacity, Tonnes</th></tr>
<tr><th>Compression</th><th>Pull-Out</th><th>Lateral</th></tr>
<tr><td rowspan="26">Office</td><td rowspan="26">3/4 basements</td><td rowspan="13">14.0</td><td rowspan="4">600</td><td>12 m (RL 201 m)</td><td>73</td><td>24</td><td rowspan="4">10.6</td></tr>
<tr><td>14 m (RL 199 m)</td><td>83</td><td>30</td></tr>
<tr><td>16 m (RL 197 m)</td><td>94</td><td>36</td></tr>
<tr><td>18 m (RL 195 m)</td><td>104</td><td>42</td></tr>
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<tr><td>16 m (RL 197 m)</td><td>151</td><td>52</td></tr>
<tr><td>18 m (RL 195 m)</td><td>167</td><td>61</td></tr>
<tr><td rowspan="3">900</td><td>14 m (RL 199 m)</td><td>201</td><td>55</td><td rowspan="3">21.8</td></tr>
<tr><td>16 m (RL 197 m)</td><td>223</td><td>68</td></tr>
<tr><td>18 m (RL 195 m)</td><td>246</td><td>82</td></tr>
<tr><td rowspan="2">1200</td><td>16 m (RL 197 m)</td><td>387</td><td>100</td><td rowspan="2">35.8</td></tr>
<tr><td>18 m (RL 195 m)</td><td>462</td><td>123</td></tr>
<tr><td rowspan="13">18.0</td><td rowspan="4">600</td><td>12 m (RL 201 m)</td><td>79</td><td>25</td><td rowspan="4">11.6</td></tr>
<tr><td>14 m (RL 199 m)</td><td>89</td><td>31</td></tr>
<tr><td>16 m (RL 197 m)</td><td>100</td><td>37</td></tr>
<tr><td>18 m (RL 195 m)</td><td>111</td><td>43</td></tr>
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<tr><td>16 m (RL 197 m)</td><td>160</td><td>53</td></tr>
<tr><td>18 m (RL 195 m)</td><td>176</td><td>63</td></tr>
<tr><td rowspan="3">900</td><td>14 m (RL 199 m)</td><td>211</td><td>56</td><td rowspan="3">23.4</td></tr>
<tr><td>16 m (RL 197 m)</td><td>234</td><td>70</td></tr>
<tr><td>18 m (RL 195 m)</td><td>258</td><td>84</td></tr>
<tr><td rowspan="2">1200</td><td>16 m (RL 197 m)</td><td>408</td><td>102</td><td rowspan="2">38.2</td></tr>
<tr><td>18 m (RL 195 m)</td><td>479</td><td>125</td></tr>
</table>

Structure / Facility	Basement Case	Planned Pile Cut-off Level below NGL, m	Pile Diameter, mm	Pile Length below COL, m	Recommended Safe Pile Capacity, Tonnes		
					Compression	Pull-Out	Lateral
Service Appt	3/4 basements	14.0	600	12 m (RL 201 m)	73	24	10.6
				14 m (RL 199 m)	83	30	
				16 m (RL 197 m)	94	36	
				18 m (RL 195 m)	104	42	
			750	12 m (RL 201 m)	119	33	15.7
				14 m (RL 199 m)	135	42	
				16 m (RL 197 m)	151	52	
				18 m (RL 195 m)	167	61	
			900	14 m (RL 199 m)	201	55	21.8
				16 m (RL 197 m)	223	68	
				18 m (RL 195 m)	246	82	
			1200	16 m (RL 197 m)	387	100	35.8
				18 m (RL 195 m)	462	123	
		18.0	600	12 m (RL 201 m)	79	25	11.6
				14 m (RL 199 m)	89	31	
				16 m (RL 197 m)	100	37	
				18 m (RL 195 m)	111	43	
			750	12 m (RL 201 m)	127	34	16.9
				14 m (RL 199 m)	143	44	
				16 m (RL 197 m)	160	53	
				18 m (RL 195 m)	176	63	
			900	14 m (RL 199 m)	211	56	23.4
				16 m (RL 197 m)	234	70	
				18 m (RL 195 m)	258	84	
			1200	16 m (RL 197 m)	408	102	38.2
				18 m (RL 195 m)	479	125	

Structure / Facility	Basement Case	Planned Pile Cut-off Level below NGL, m	Pile Diameter, mm	Pile Length below COL, m	Recommended Safe Pile Capacity, Tonnes		
					Compression	Pull-Out	Lateral
Foyer	3/4 basements	14.0	600	12 m (RL 200.3 m)	73	24	10.6
				14 m (RL 198.3 m)	83	30	
				16 m (RL 196.3 m)	94	36	
				18 m (RL 194.3 m)	104	42	
			750	12 m (RL 200.3 m)	119	33	15.7
				14 m (RL 198.3 m)	135	42	
				16 m (RL 196.3 m)	151	52	
				18 m (RL 194.3 m)	167	61	
			900	14 m (RL 198.3 m)	201	55	21.8
				16 m (RL 196.3 m)	223	68	
				18 m (RL 194.3 m)	246	82	
			1200	16 m (RL 196.3 m)	387	100	35.8
				18 m (RL 194.3 m)	462	123	
		18.0	600	12 m (RL 200.3 m)	79	25	11.6
				14 m (RL 198.3 m)	89	31	
				16 m (RL 196.3 m)	100	37	
				18 m (RL 194.3 m)	111	43	
			750	12 m (RL 200.3 m)	127	34	16.9
				14 m (RL 198.3 m)	143	44	
				16 m (RL 196.3 m)	160	53	
				18 m (RL 194.3 m)	176	63	
			900	14 m (RL 198.3 m)	211	56	23.4
				16 m (RL 196.3 m)	234	70	
				18 m (RL 194.3 m)	258	84	
			1200	16 m (RL 196.3 m)	408	102	38.2
				18 m (RL 194.3 m)	479	125	

The following points should be considered while using the above capacities:

1. The above values are based on IS: 2911(Part-1): Section- 2, RA-2010 and include a factor of safety equal to 2.5 in compression and a safety factor 3.0 under uplift.

2. Compression and pull-out capacities for piles of intermediate lengths may be linearly interpolated between the values given above.

3. It should be ensured that the bottom of the pile bore is cleaned properly before casting the pile. This is important because the sand particles tend to settle down at the bottom of the pile bore, which can cause reduction in the actual pile capacities achieved on site.

4. Lateral capacities given in the above table is for fixed head pile considering permissible deflection of 5 mm at the pile head.

5. The capacities given above may be taken as a guideline for initial design. Final pile capacities should be confirmed by conducting initial pile load tests as per IS: 2911-Part-IV (2010). Also, routine load tests should be conducted on sufficient working piles so as to ensure that the working load on the piles is equal to or less than the design pile capacity.

6. Low strain pile integrity tests (PIT) should be done on all working piles as a quality check. Also, we suggest that high-strain dynamic load tests (PDA)[3] may be conducted on selected working piles. A quality assurance plan should be developed and sufficient number of piles should be tested so as to ensure that the piles are safe for the design loads.

4.7 Definition of Net and Gross Bearing Pressure

For the purposes of this report, the net allowable bearing pressure should be calculated as the difference between total load on the foundation and the weight of the soil overlying the foundation divided by the effective area of the foundation. The gross bearing pressure is the total pressure at the foundation level including overburden pressure and surcharge load. The following equations may be used:-

$$q_{net} = [(P_s + W_f + W_s) / A_f] - S_v$$
$$q_{gross} = q_{net} + S_v = (P_s + W_f + W_s) / A_f$$

where:

q_{net}	=	net allowable bearing pressure
q_{gross}	=	gross bearing pressure
P_s	=	superimposed static load on foundation
W_f	=	weight of foundation
W_s	=	weight of soil overlying foundation
A_f	=	effective area of foundation
S_v	=	overburden pressure at foundation level prior to excavation for foundation.

It may please be noted that safe bearing pressures recommended in this report refer to “net values”. Fill placed over the EGL should be considered as surcharge load.

4.8 Basement Design

Groundwater met at 19.2-22.4 m depth below the EGL during the period of our field investigation (April-June, 2017). Therefore, hydrostatic uplift is unlikely for proposed foundations at site.

However there is a possibility that the soils at shallow depth may get saturated temporarily due to seepage from surface sources, leaking water pipes, etc. We suggest that a hydrostatic uplift equivalent to 1 m head of water be considered in the design to account for the worst condition.

We suggest the following values of coefficients of lateral earth pressure for the design of basement retaining walls:

Depth, m		Soil Description	k_a	k_p	k_0
From	To				
0	3.0	Sandy Silt	0.33	3.00	0.50
3.0	10.0	Sandy Silt	0.32	3.12	0.48
10.0	15.0	Sandy Silt	0.30	3.25	0.47

A suitable safety factor should be applied on the passive earth pressures in the design of the wall.

5.0 FOUNDATION CONSTRUCTION CONSIDERATIONS

5.1 Excavation and Dewatering

We suggest the following slopes for temporary excavations for foundation construction:

0 to 3 m depth : Nearly vertically (side slopes of 1 vertical on 0.1-0.2 horizontal).
3 to 10 m depth : 1-vertical on 0.3 to 0.5-horizontal with 1.5 m wide horizontal berms at 3 & 6 m depth
10 to 18 m depth : 1-vertical on 0.6 to 1.0-horizontal with 1.5 m wide horizontal berms at 10 & 14 m depth

In the sand zones, the slopes should be flatter. If excessive sloughing or caving occurs, the slopes may be flattened further to ensure stability.

If sufficient space is not available to cut excavation slopes at the above recommended slopes, consideration may be given to provision of sheet piles or contiguous piles.

5.2 Foundation Level Preparation

The area shall be excavated up to the foundation level. All loose soils should be removed and the exposed foundation bearing surface should be watered and compacted properly using rammers / rollers.

In case mechanical means like excavators are deployed for excavations, the excavations should be carried out up to 0.5 m above the proposed level. The last 0.5 m depth of excavation should be carried out manually, so that the founding soils are not disturbed / loosened.

The surface should be protected from disturbances due to construction activities so that the foundations may bear on the natural undisturbed ground. We recommend the placement of a 75 to 100 mm thick “blinding layer” of lean concrete to facilitate placement of reinforcing steel and to protect the soils from disturbance.

5.3 Pile Construction

For construction of piles, properly mixed drilling mud should be used to control the caving of the borehole during drilling and concreting. The concrete used for the pile construction use of tremie concreting is recommended so as to ensure that the groundwater does not mix with the fresh concrete. It should be coherent, with a minimum cement content of 400 kg/m^3. It should have a slump of about 150 to 180 mm.

The piling activity should ensure minimum disturbance to the soil around the pile shaft. The piling works should be executed by a specialist agency with sufficient experience in such works.

5.4 Pile Testing Program

A program of initial and routine static pile load tests under compression, pullout and lateral loading condition should be drawn up and sufficient number of piles should be load tested in accordance with IS: 2911 (Part-IV)-1985 in order to ensure that the safe load on the pile is either equal to or greater than the working load on the piles.

We suggest that low-strain pile integrity testing (PIT) be conducted on all the working piles as a quality control measure. The integrity test results should be used as a basis for selecting the working / routine piles to be load-tested.

In addition to static pile load tests, we recommend that high strain dynamic pile load tests (HSDLT)[5] (preferably using 8-channel PDA equipment) be carried out on some of the test piles to quickly assess the safe pile capacity and pile integrity. HSDLT can effectively supplement static load test and may result in substantial savings in the time and cost of foundation testing.

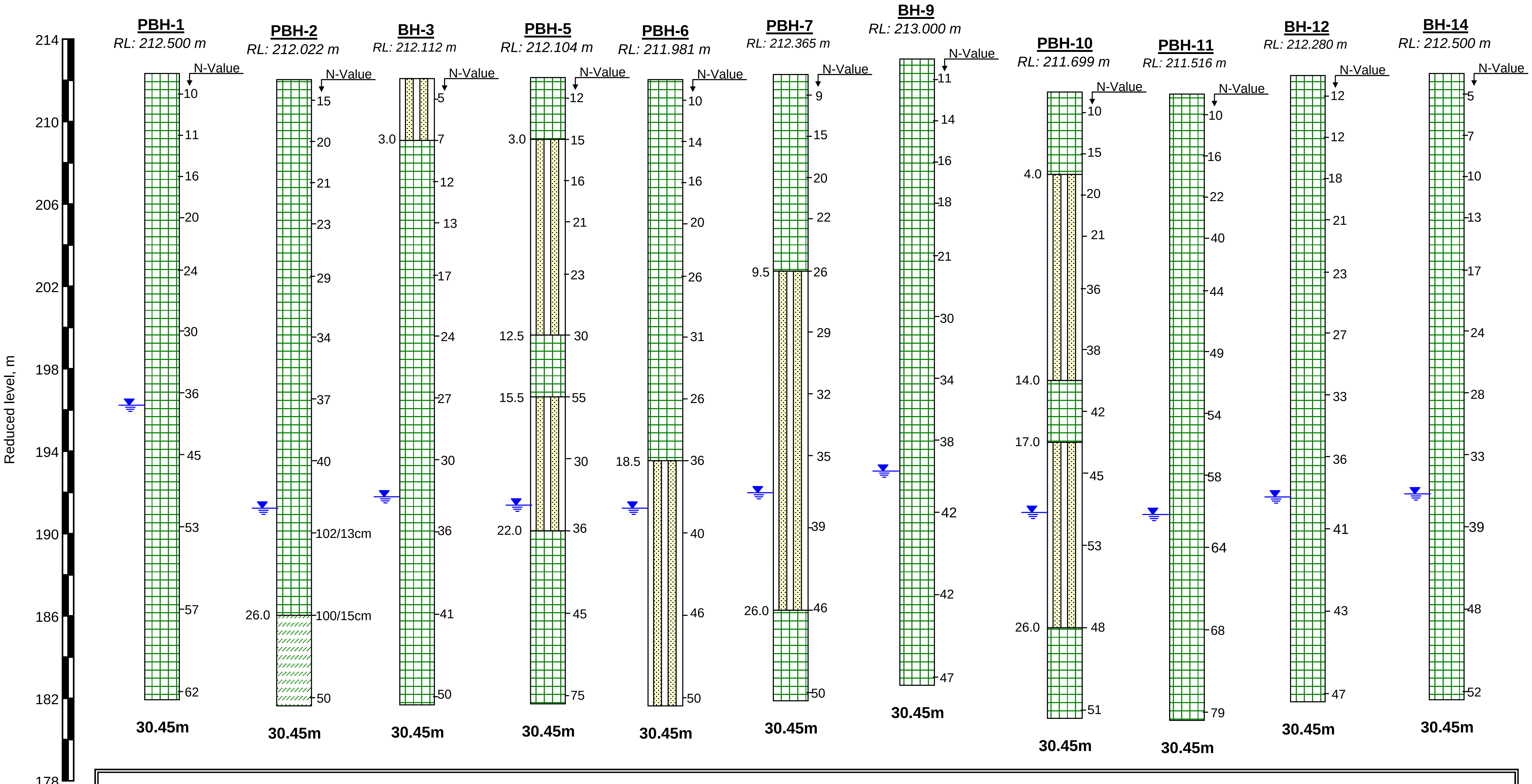
5.5 Backfilling and Compaction

The natural soils at site are suitable material for filling behind the wall. Fill should be placed in layers not exceeding 20 to 30 cm thickness and should be compacted to at least 95 percent of the maximum dry density determined in accordance with IS: 2720 (Part VII)-1980 RA 2011. In confined area, the layer thickness should be restricted to 10-15 cm.

6.0 VARIABILITY IN SUBSURFACE CONDITIONS

Subsurface conditions encountered during construction may vary somewhat from the conditions encountered during the site investigation. In case significant variations are encountered during construction, we request to be notified so that our engineers may review the recommendations in this report in light of these variations.

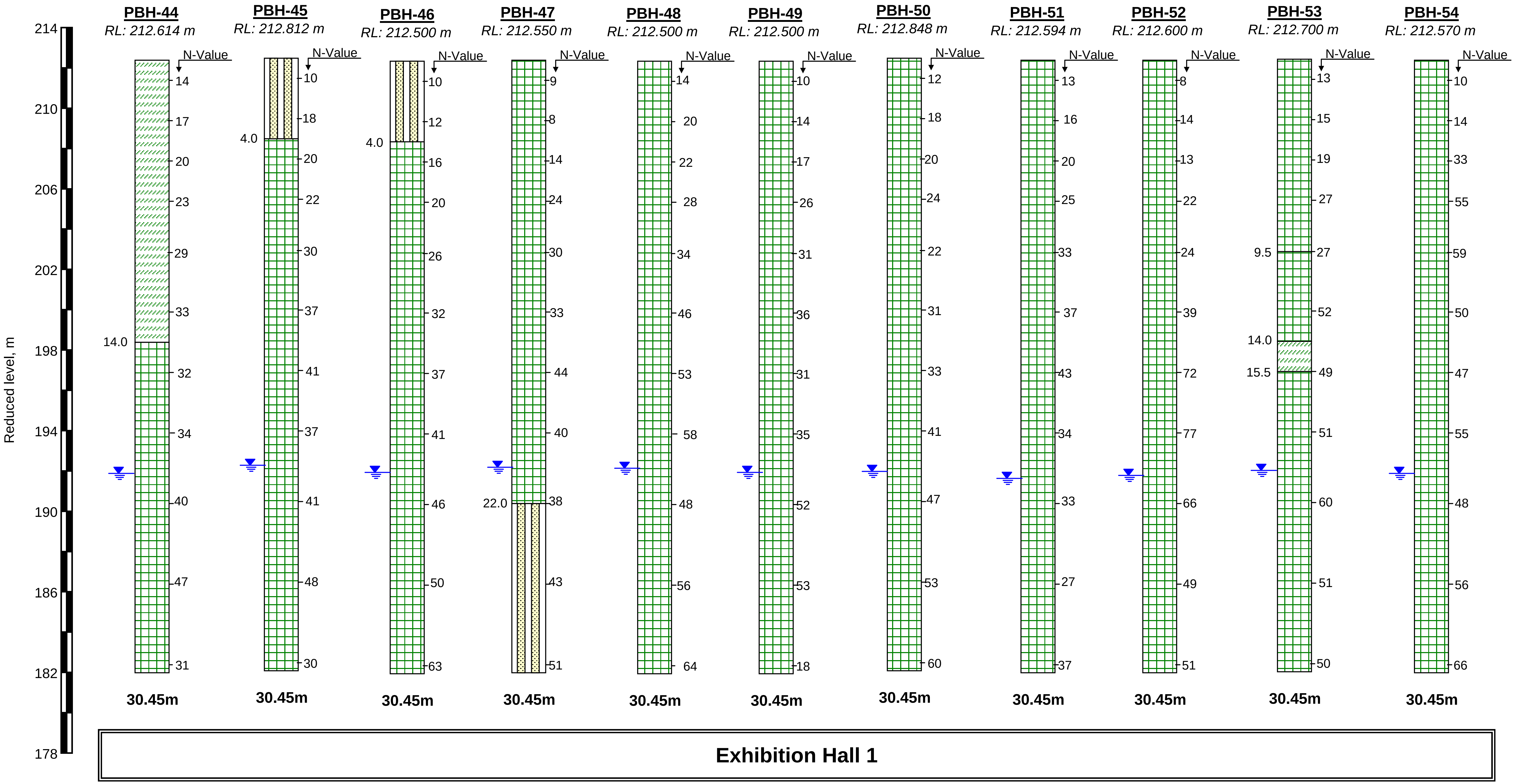
5) ASTM D4945 - 08 Standard Test Method for High-Strain Dynamic Testing of Piles



Exhibition Hall 5

LEGEND	
SYMBOL	DESCRIPTION
	Sandy silt (CL)
	Clayey silt (CI)
	Silty fine sand (SM)
	Water table

Summary of Borehole Profiles



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	Clayey silt (CI)
	Silty fine sand (SM)
	Water table

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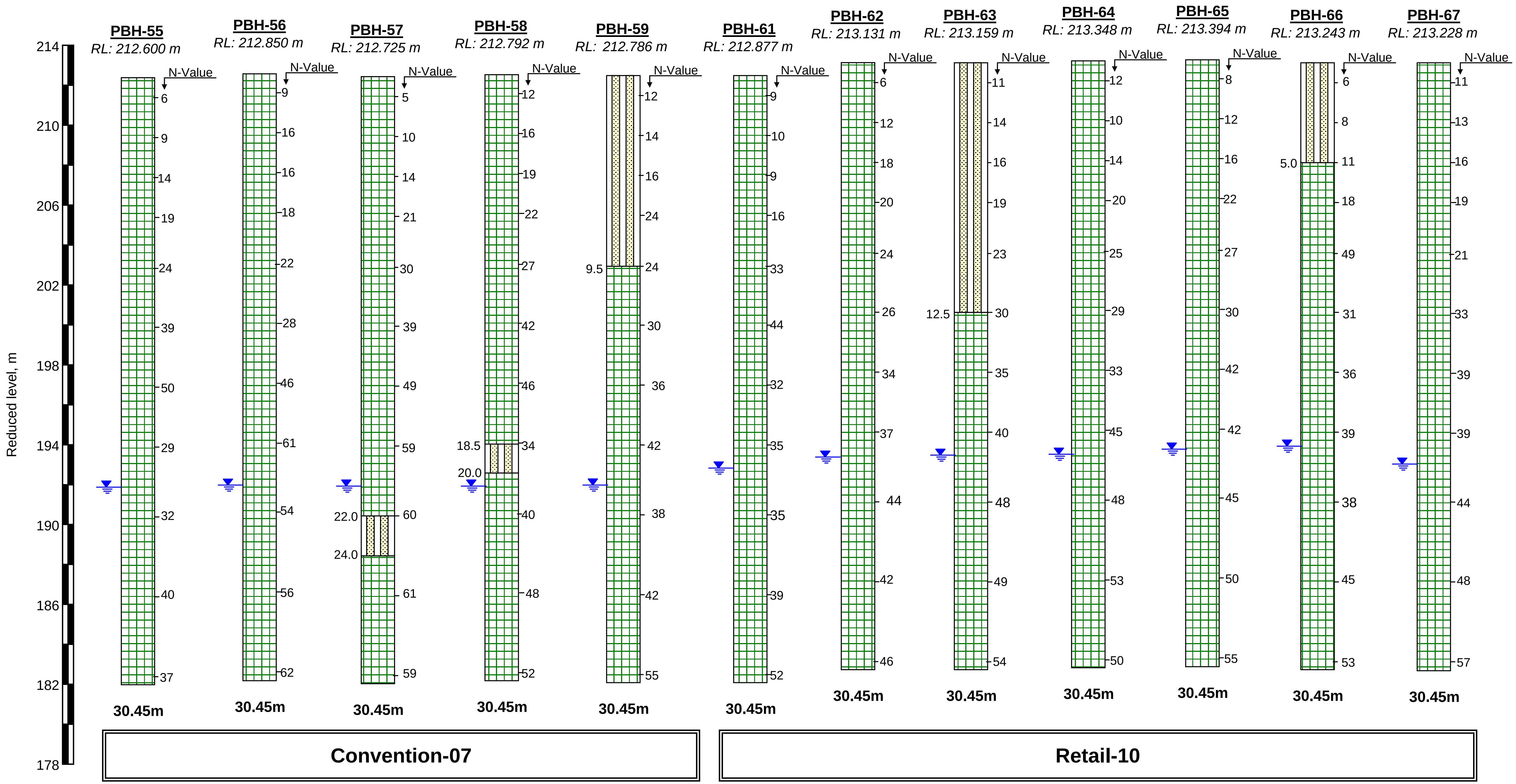

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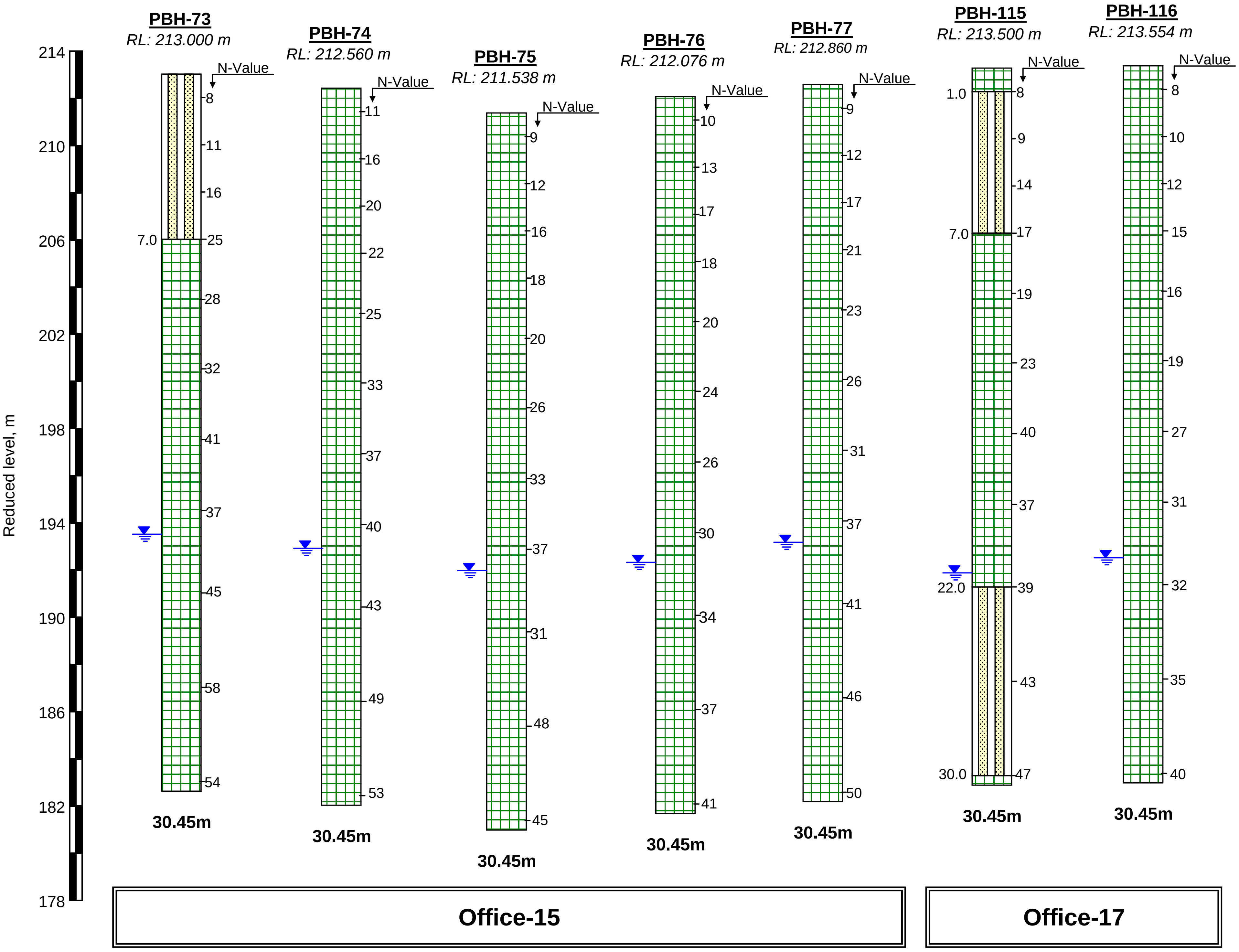
	Silty fine sand (SM)
	Water table

Summary of Borehole Profiles



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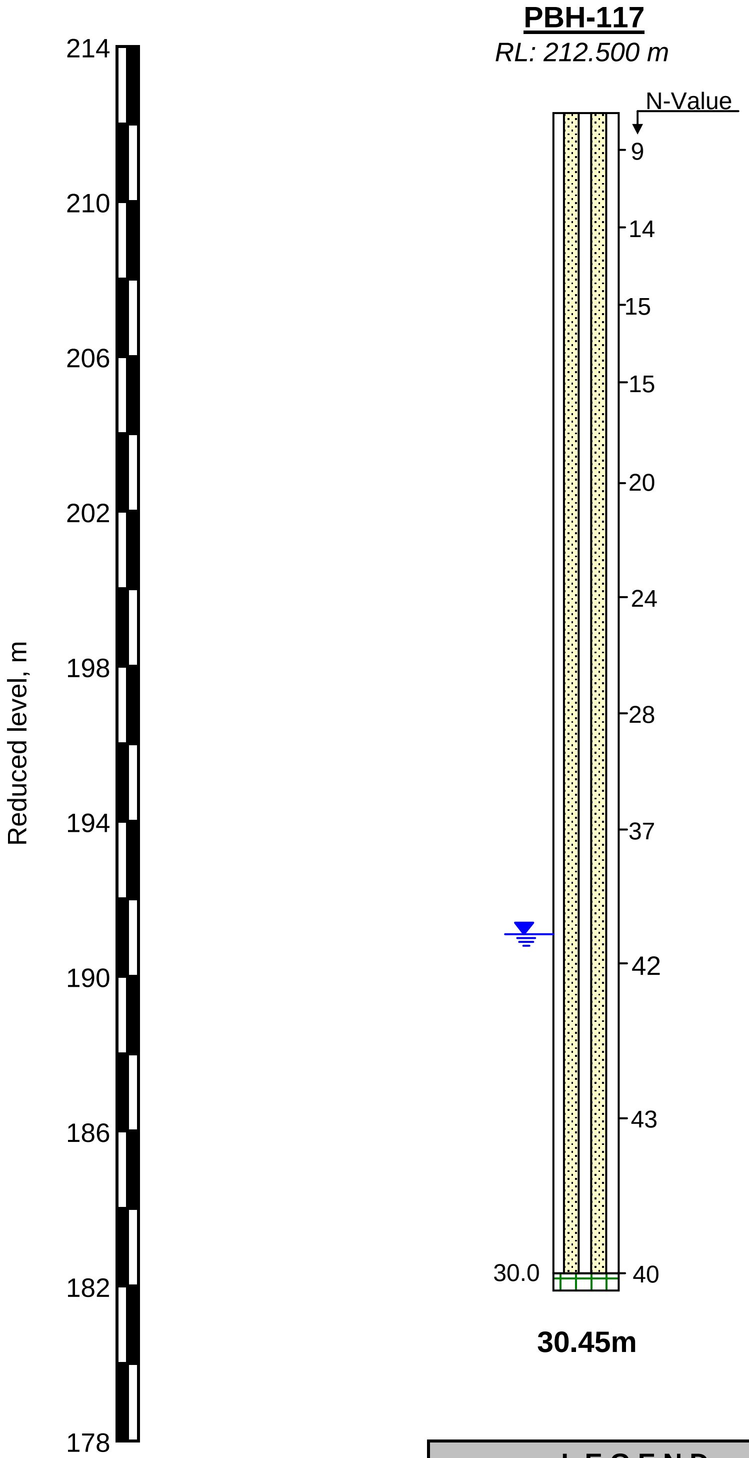
	Silty fine sand (SM)
	Water table

Summary of Borehole Profiles



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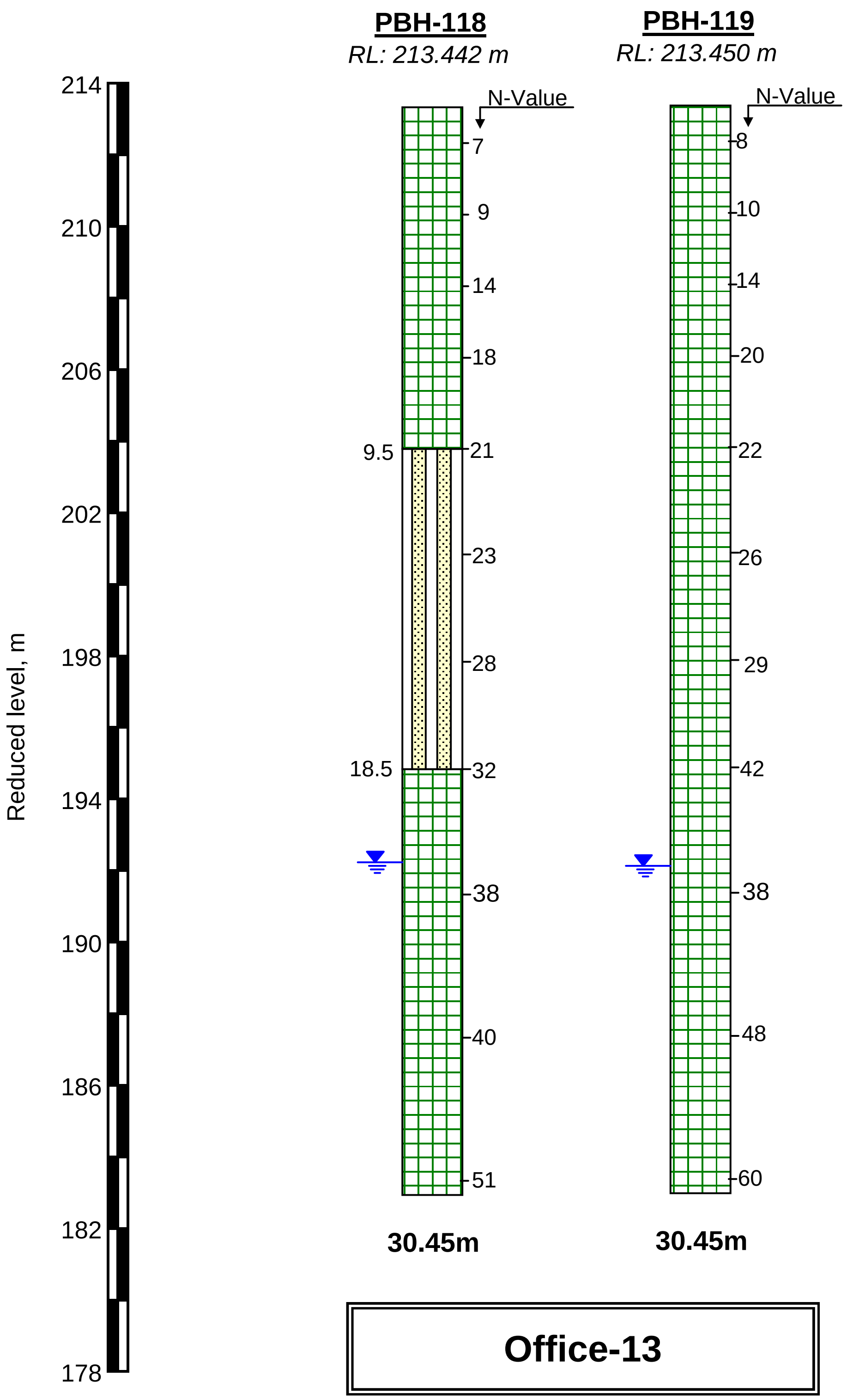
	Silty fine sand (SM)
	Water table

Summary of Borehole Profiles



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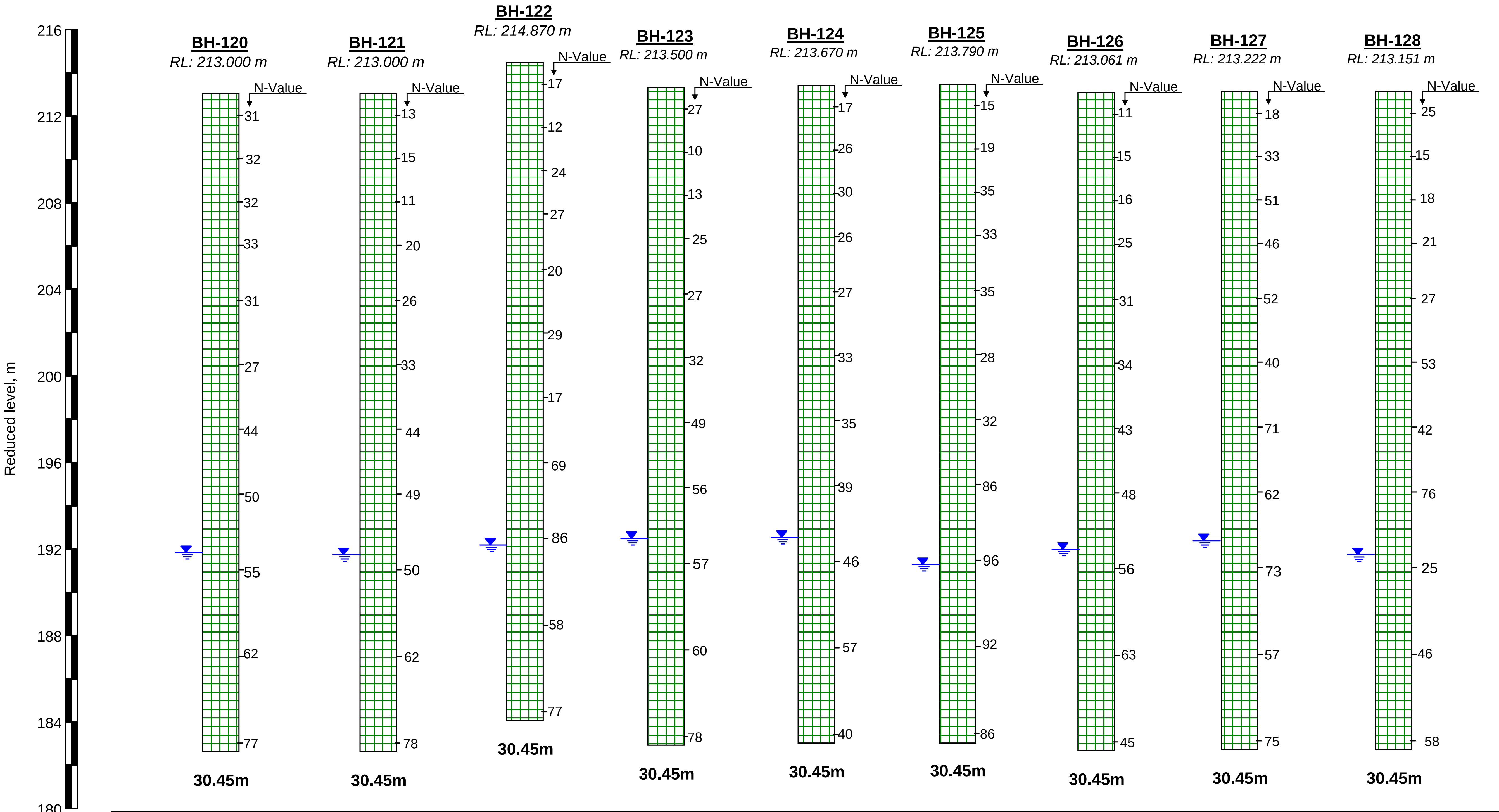
	Silty fine sand (SM)
	Water table

Summary of Borehole Profiles



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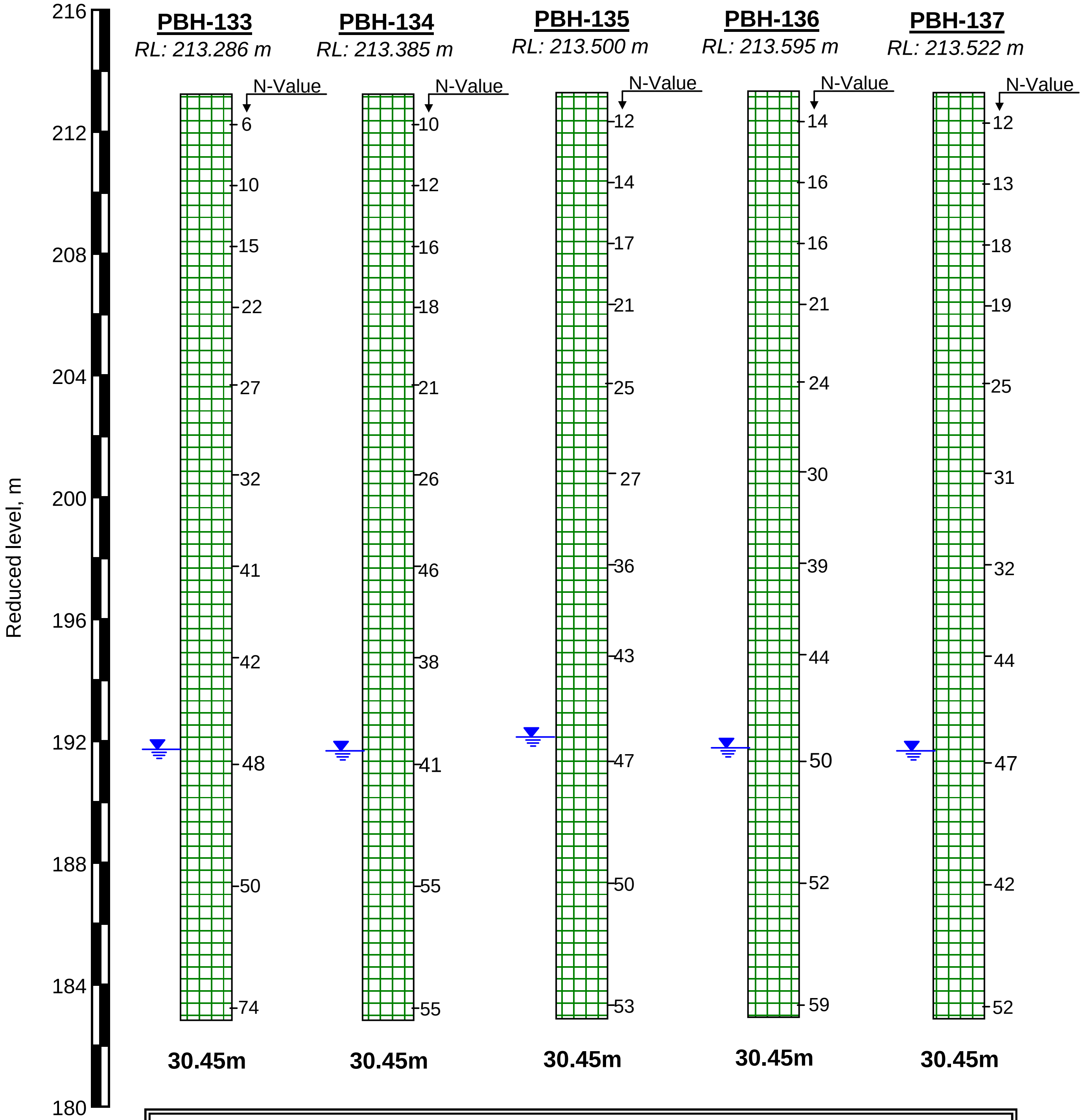

5*Hotel-11

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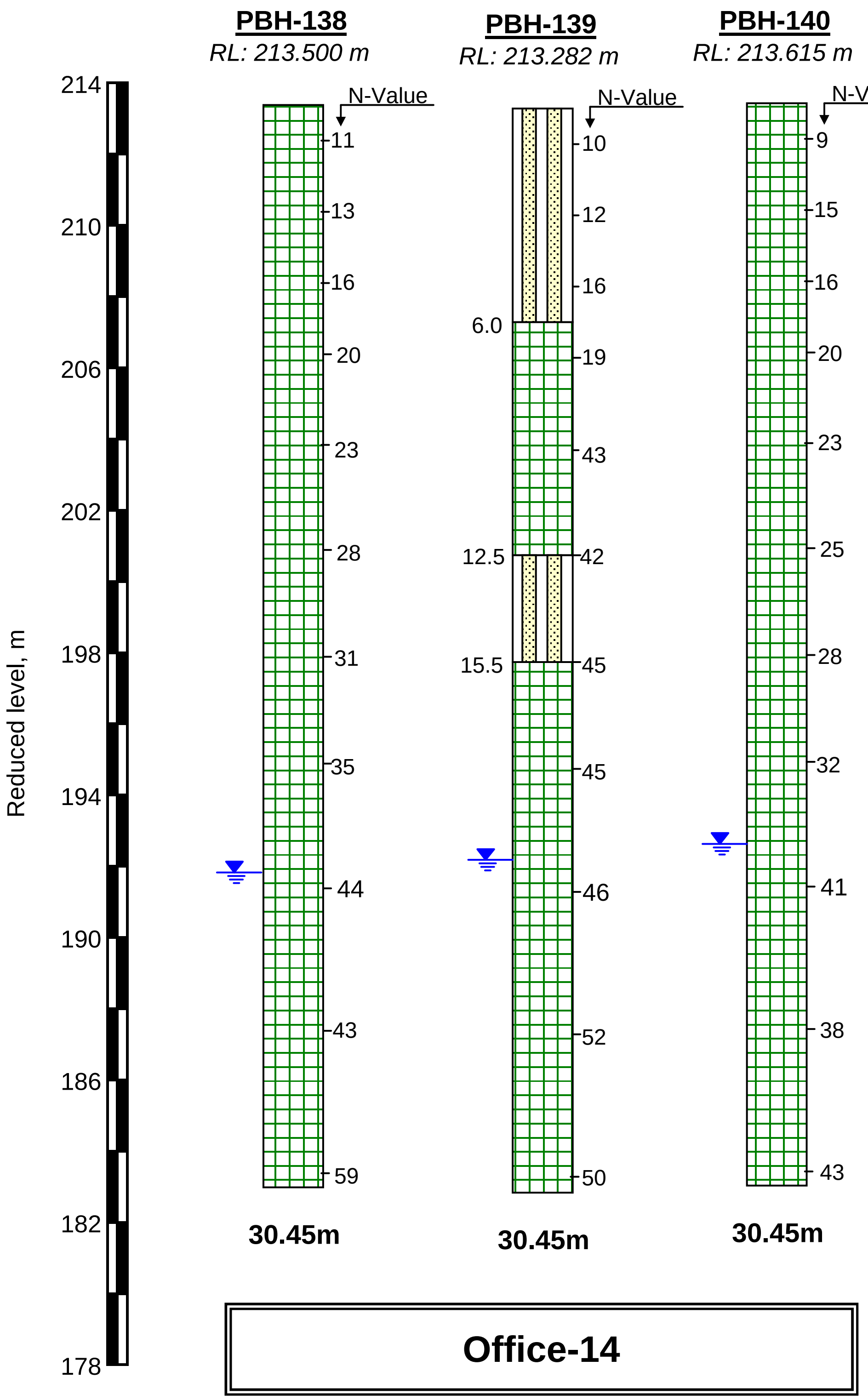

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	Silty fine sand (SM)
	Water table

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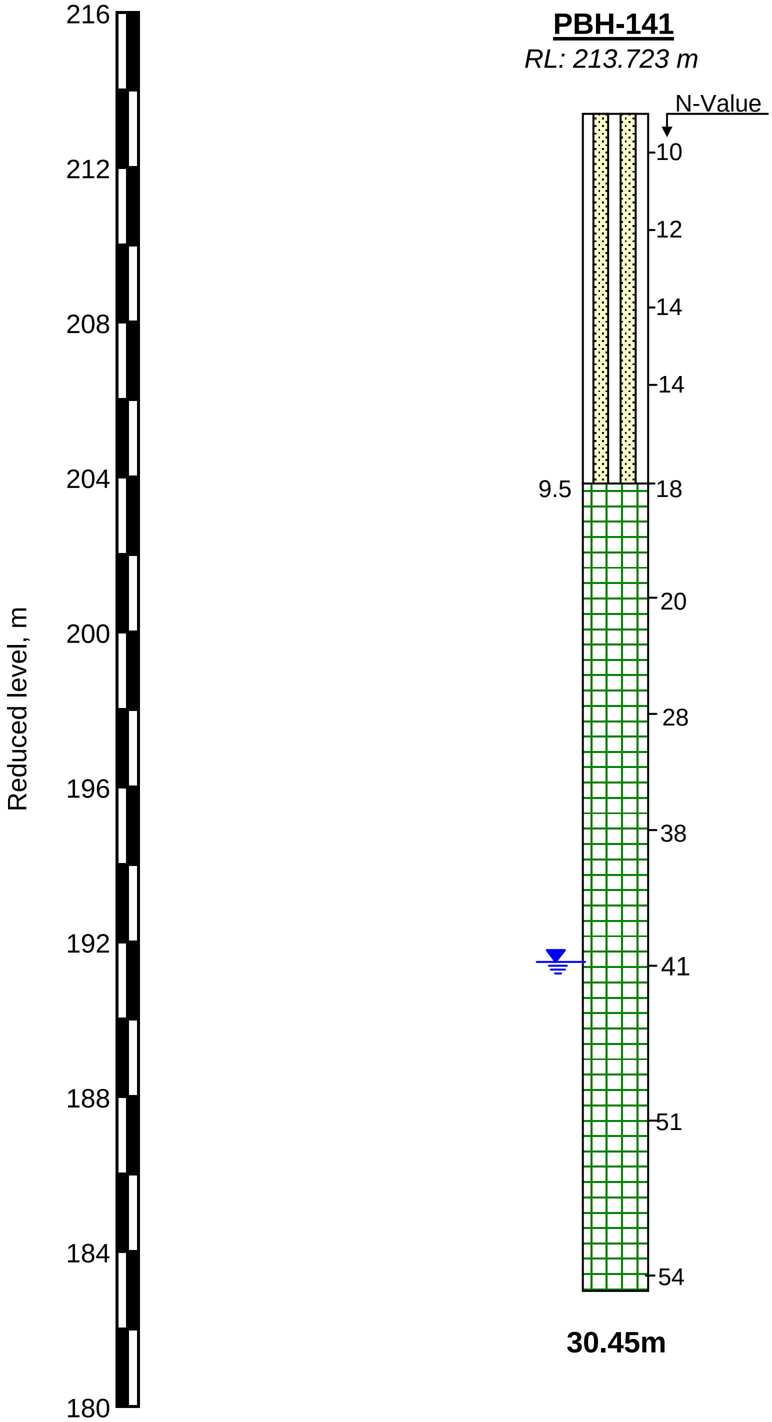

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	Silty fine sand (SM)
	Water table

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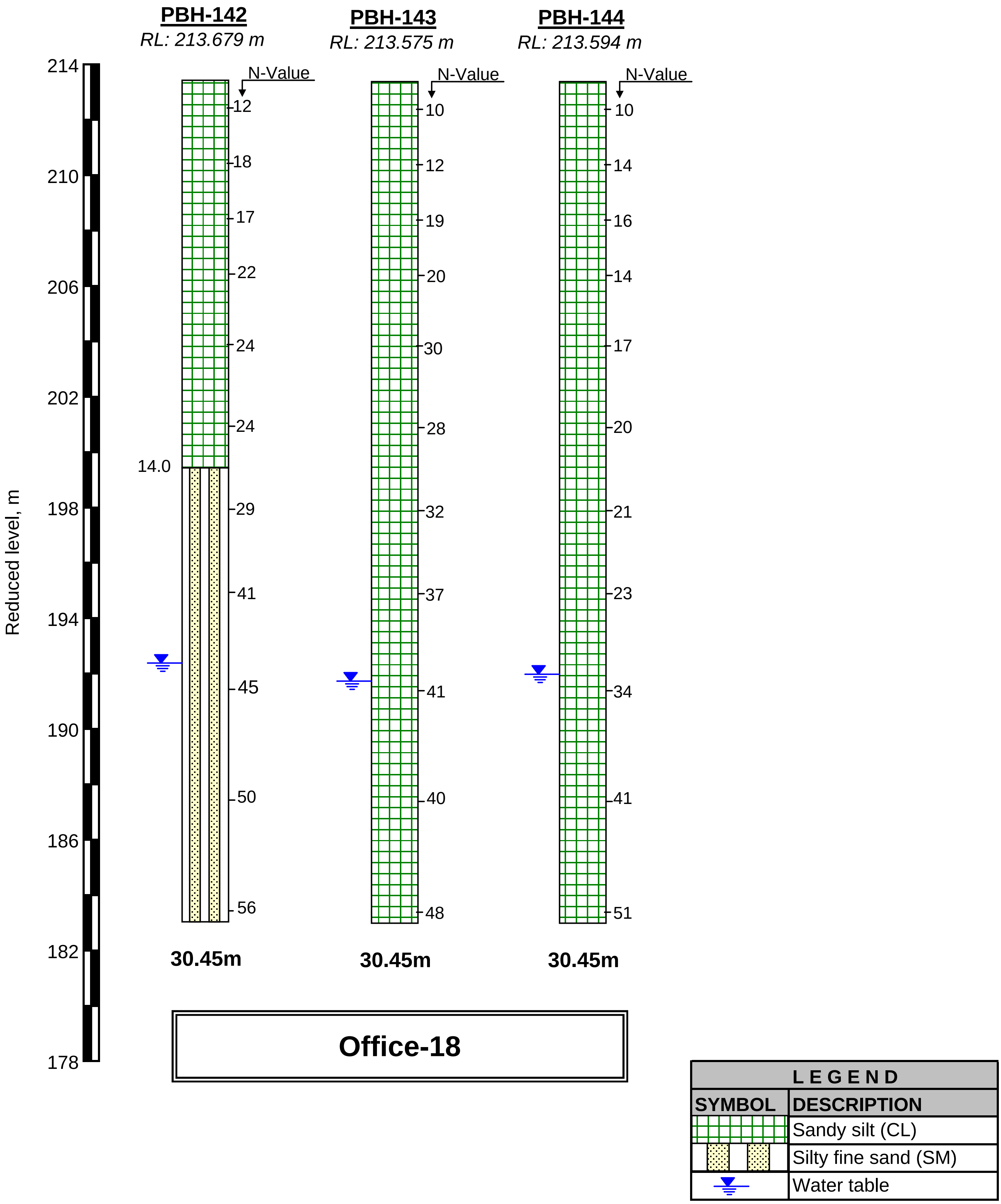

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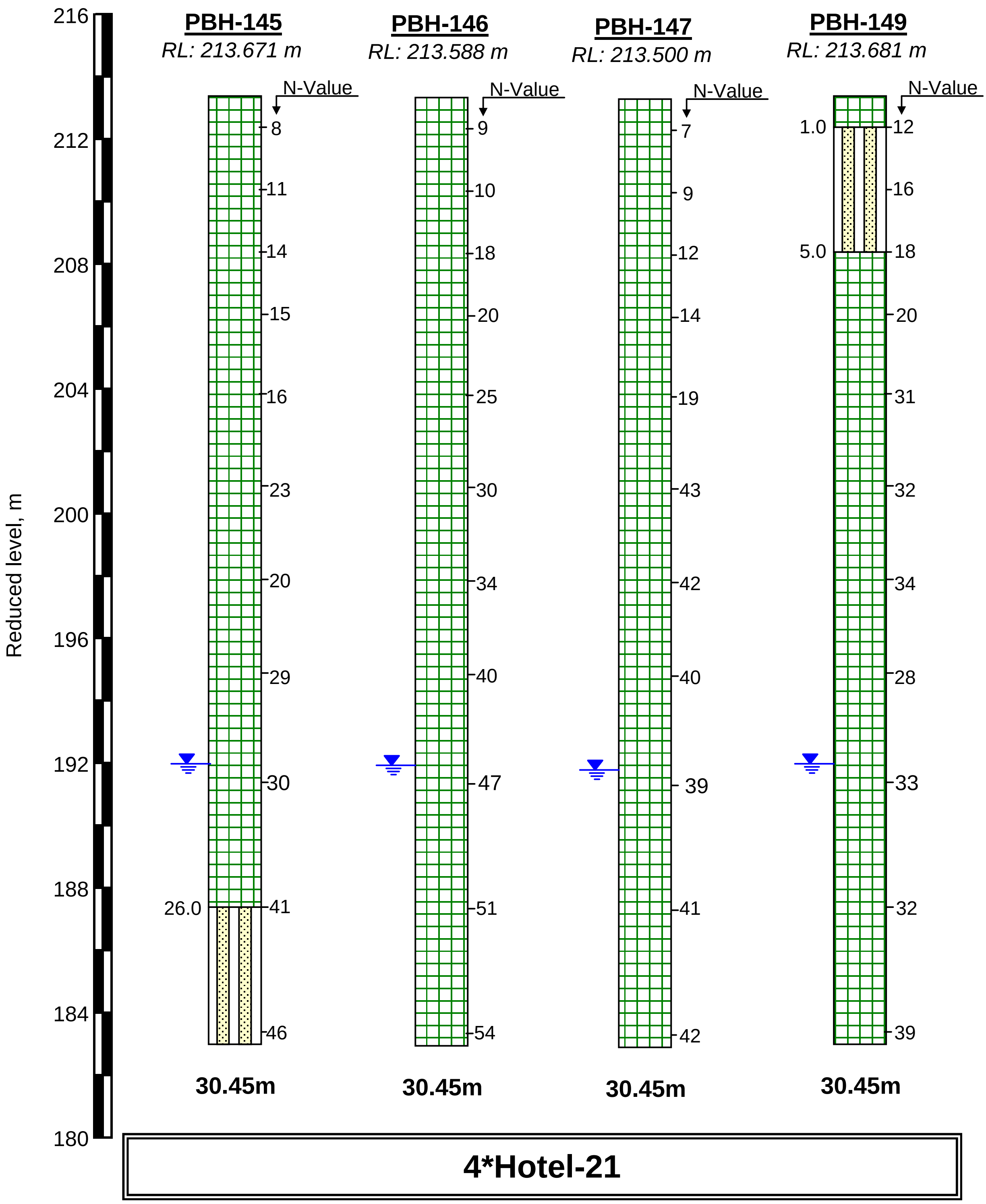

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	Silty fine sand (SM)
	Water table

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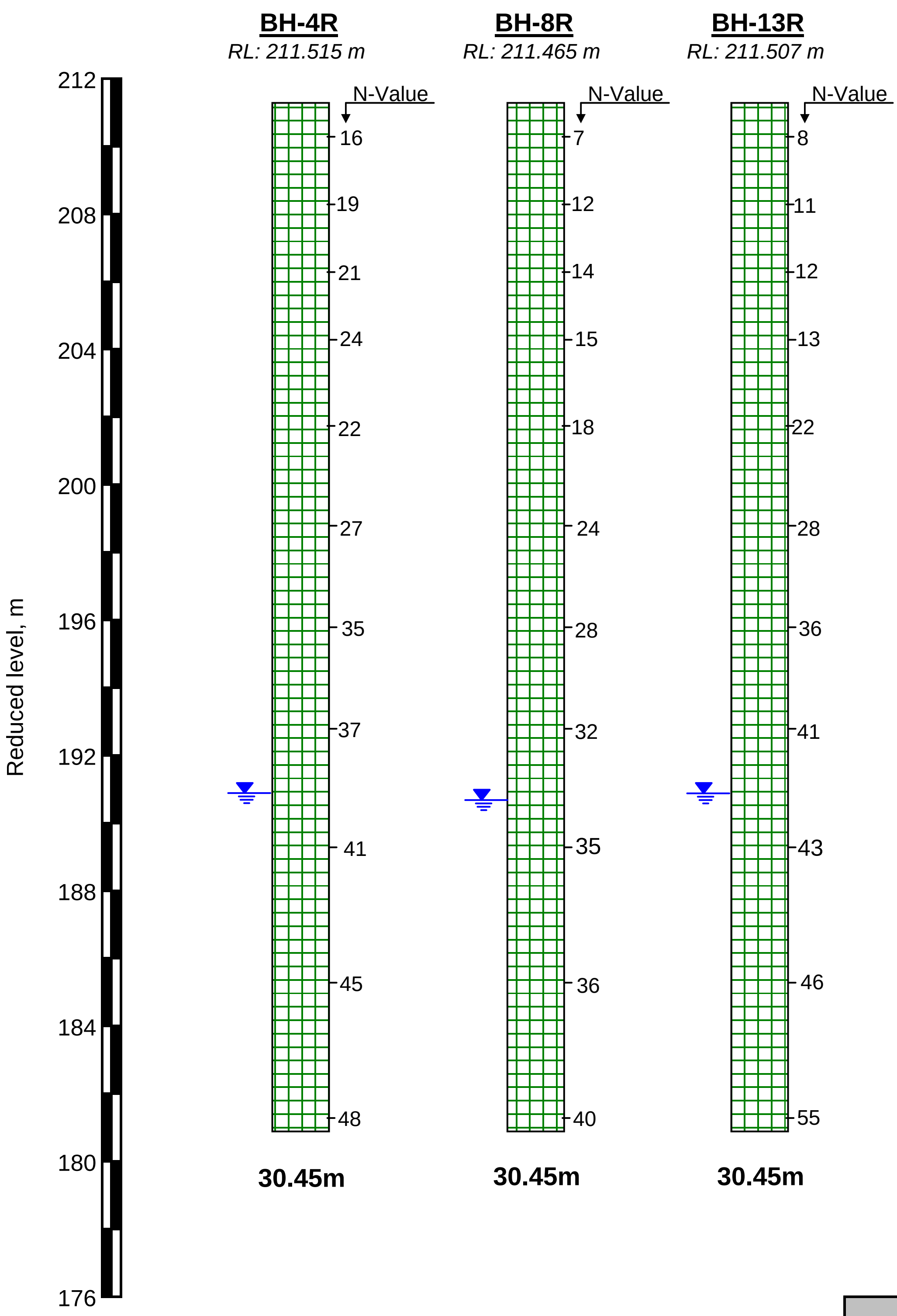

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	Water table

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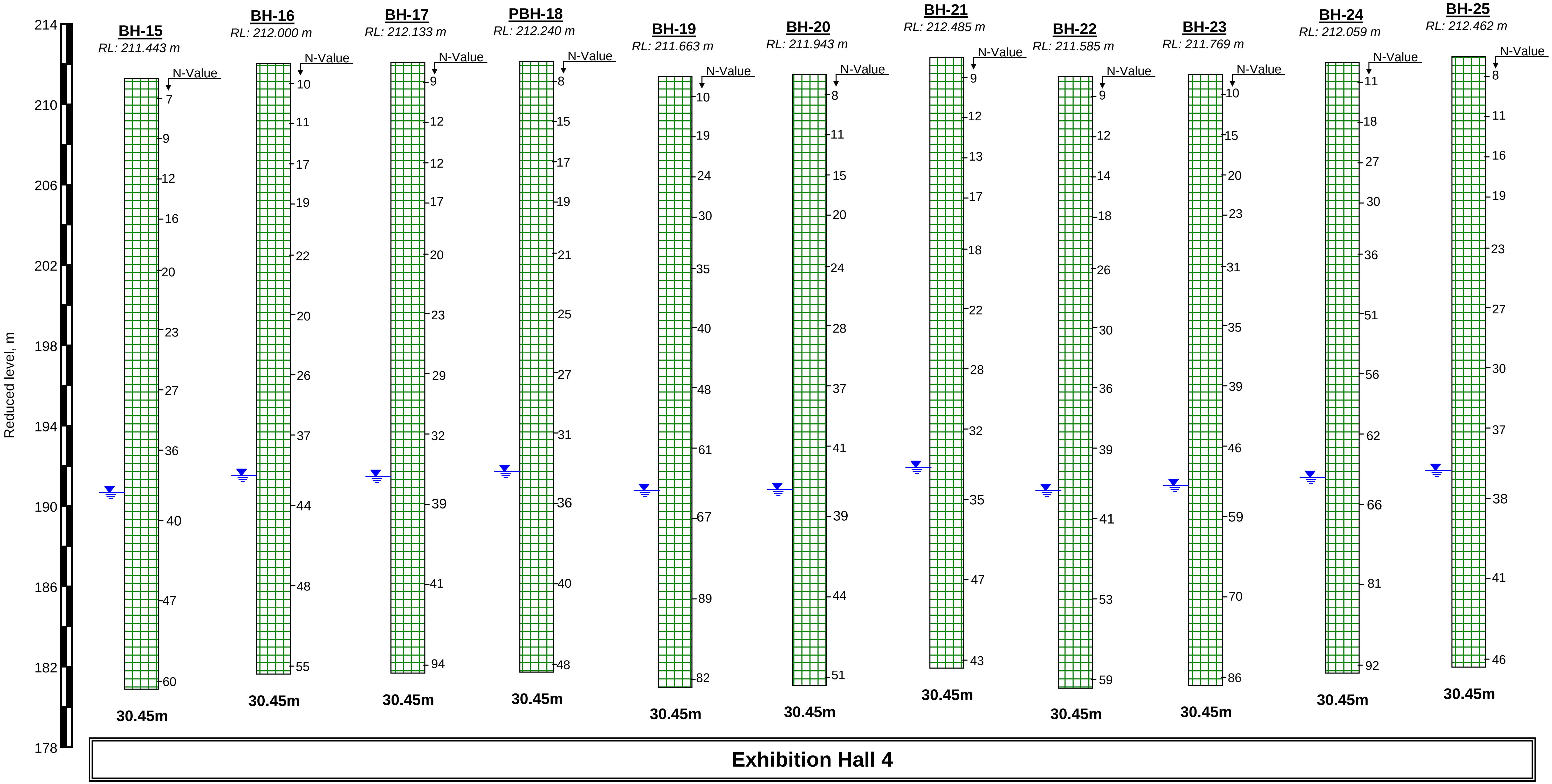

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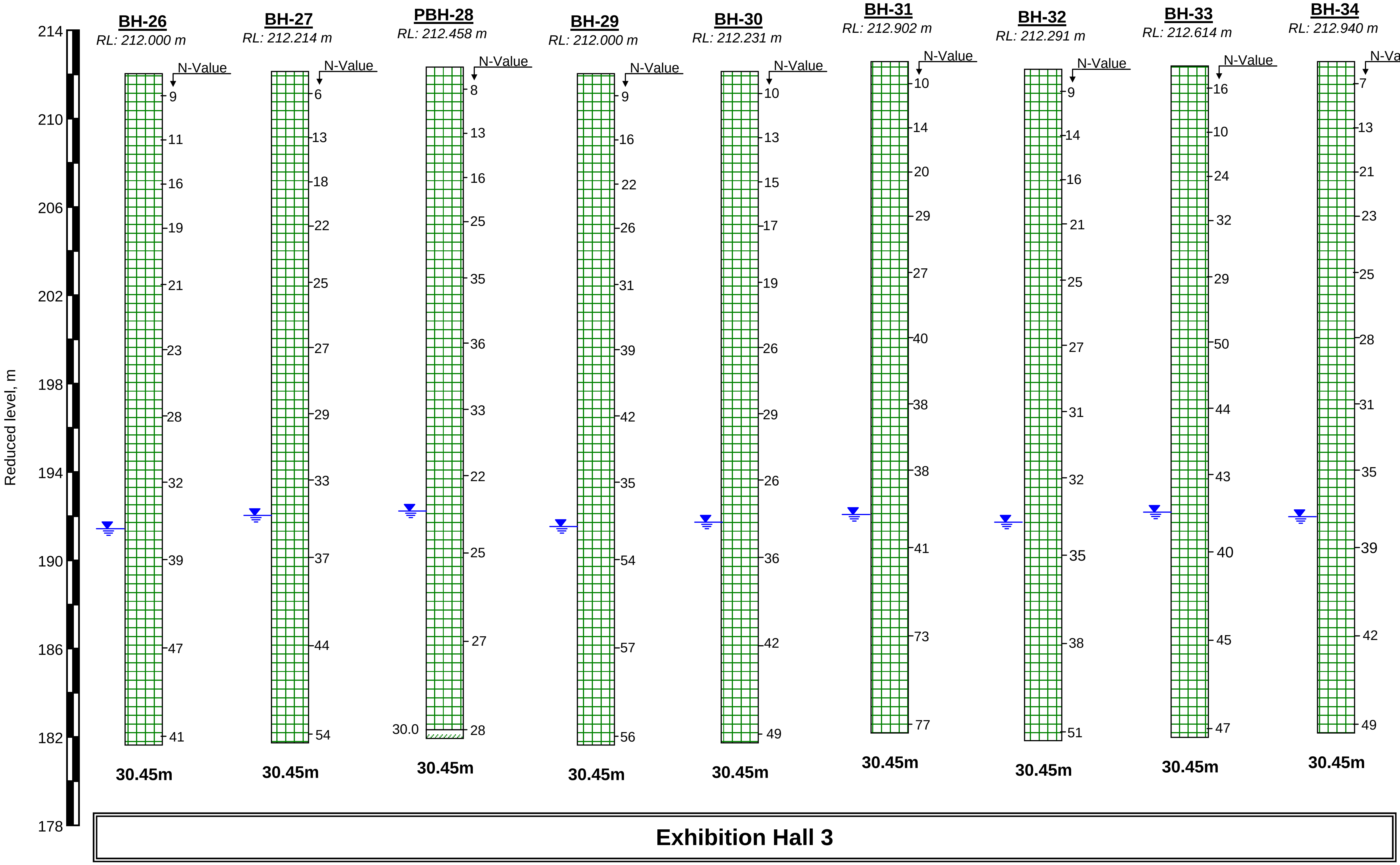
	Water table

Summary of Borehole Profiles



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	Clayey silt (CI)
	Water table

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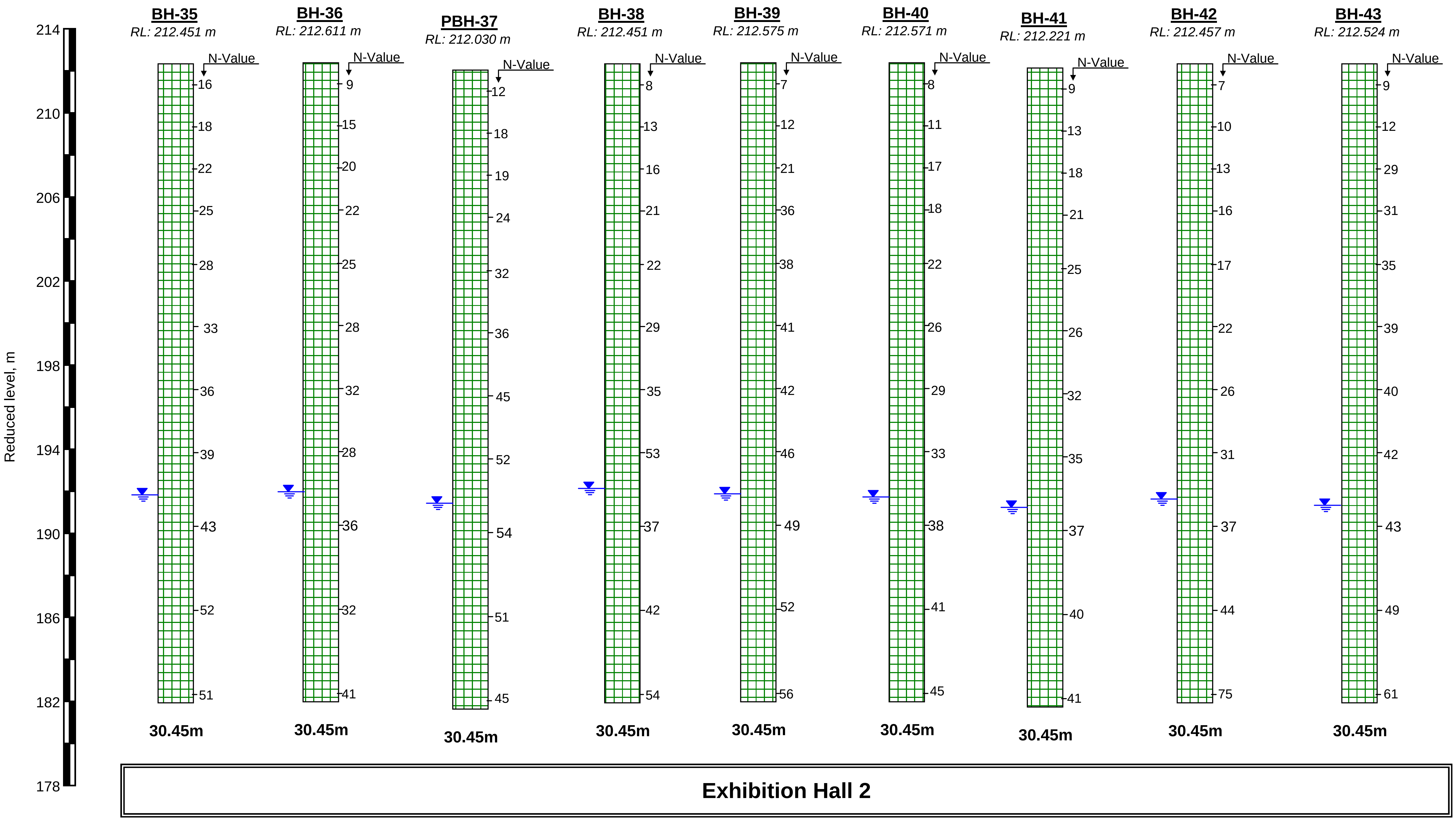

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	Water table

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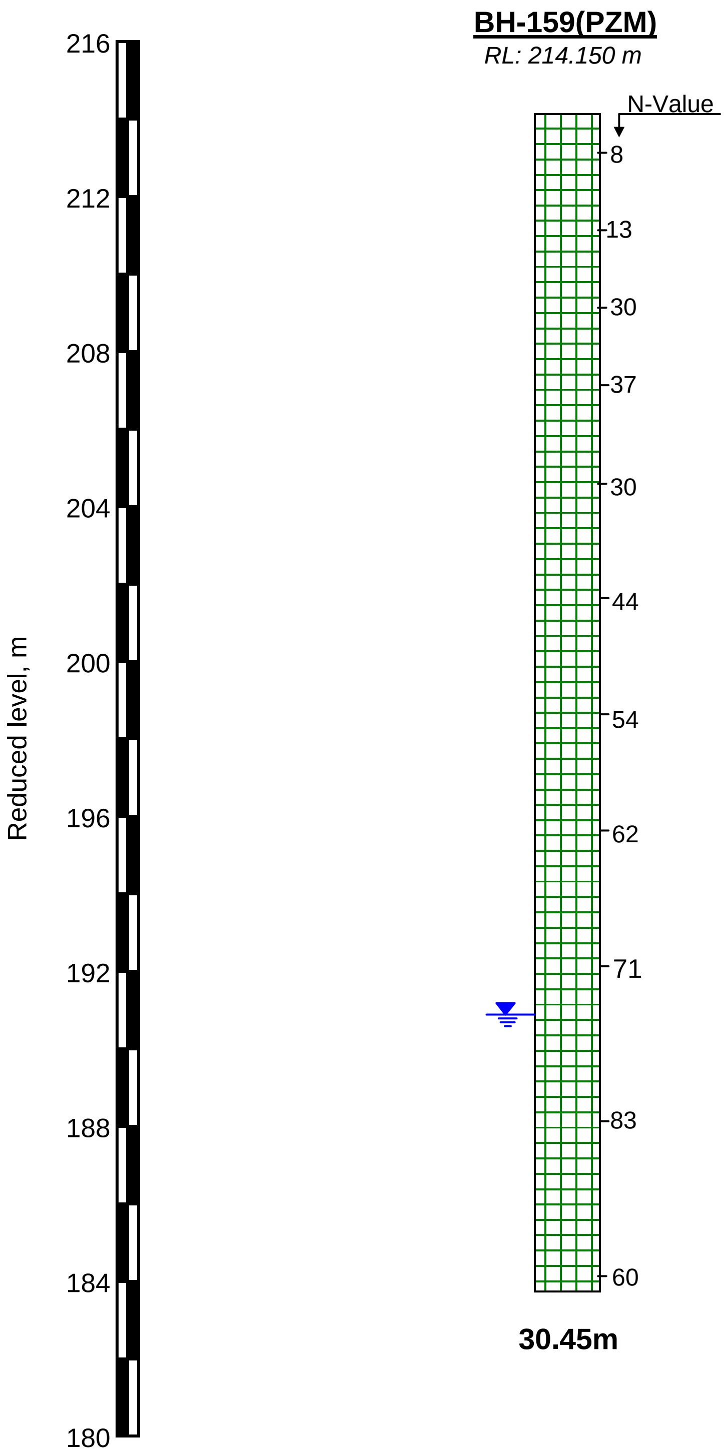

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	Water table

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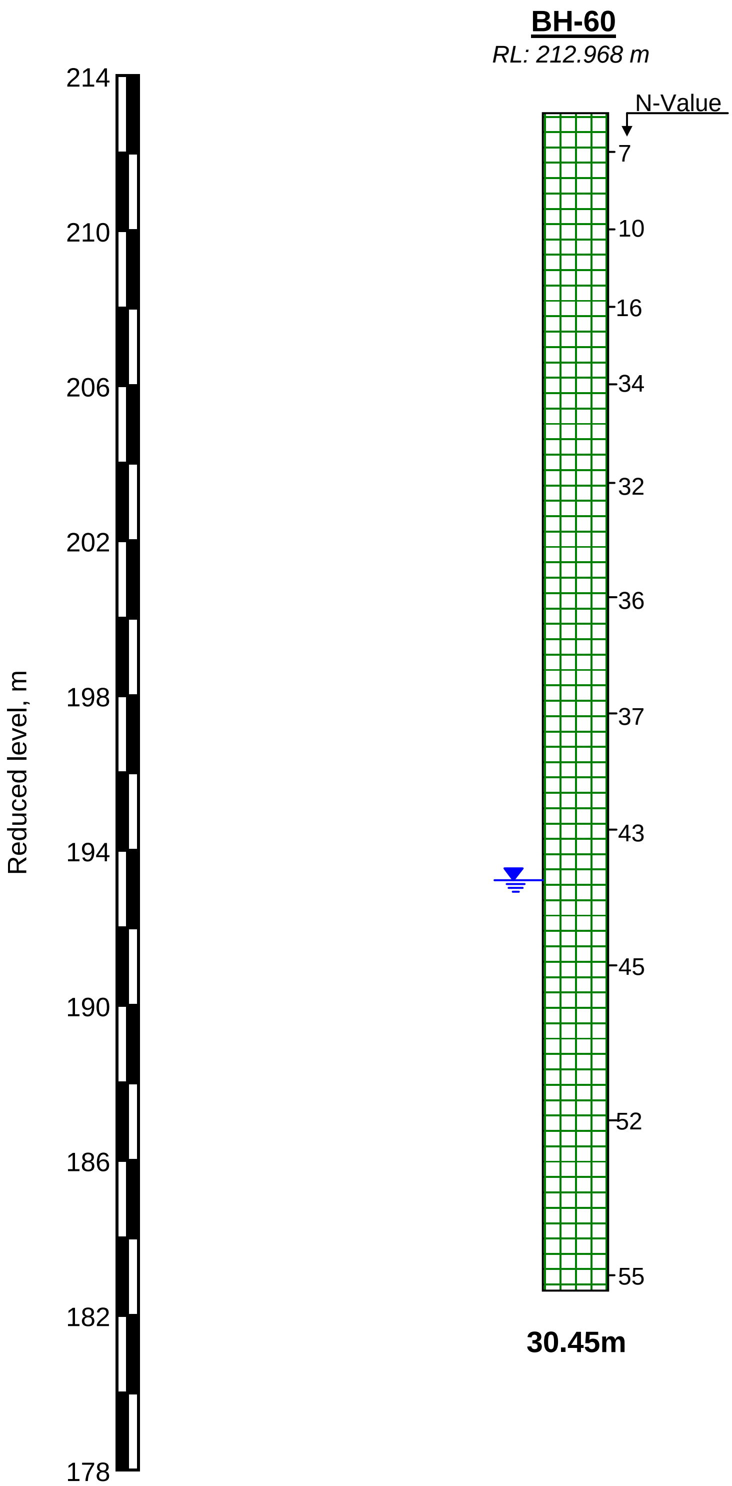

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	Water table

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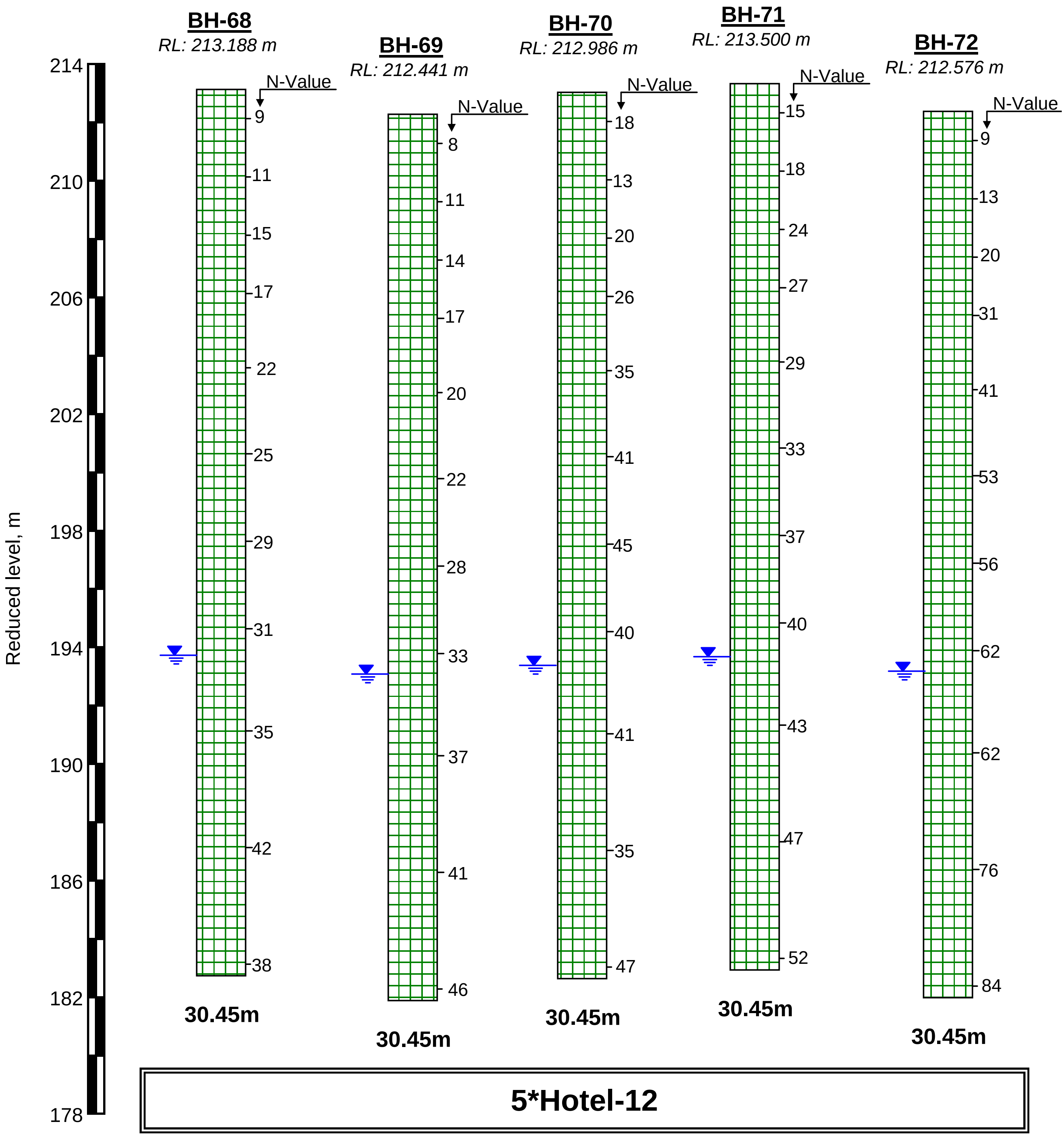

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	Sandy silt (CL)
	Water table

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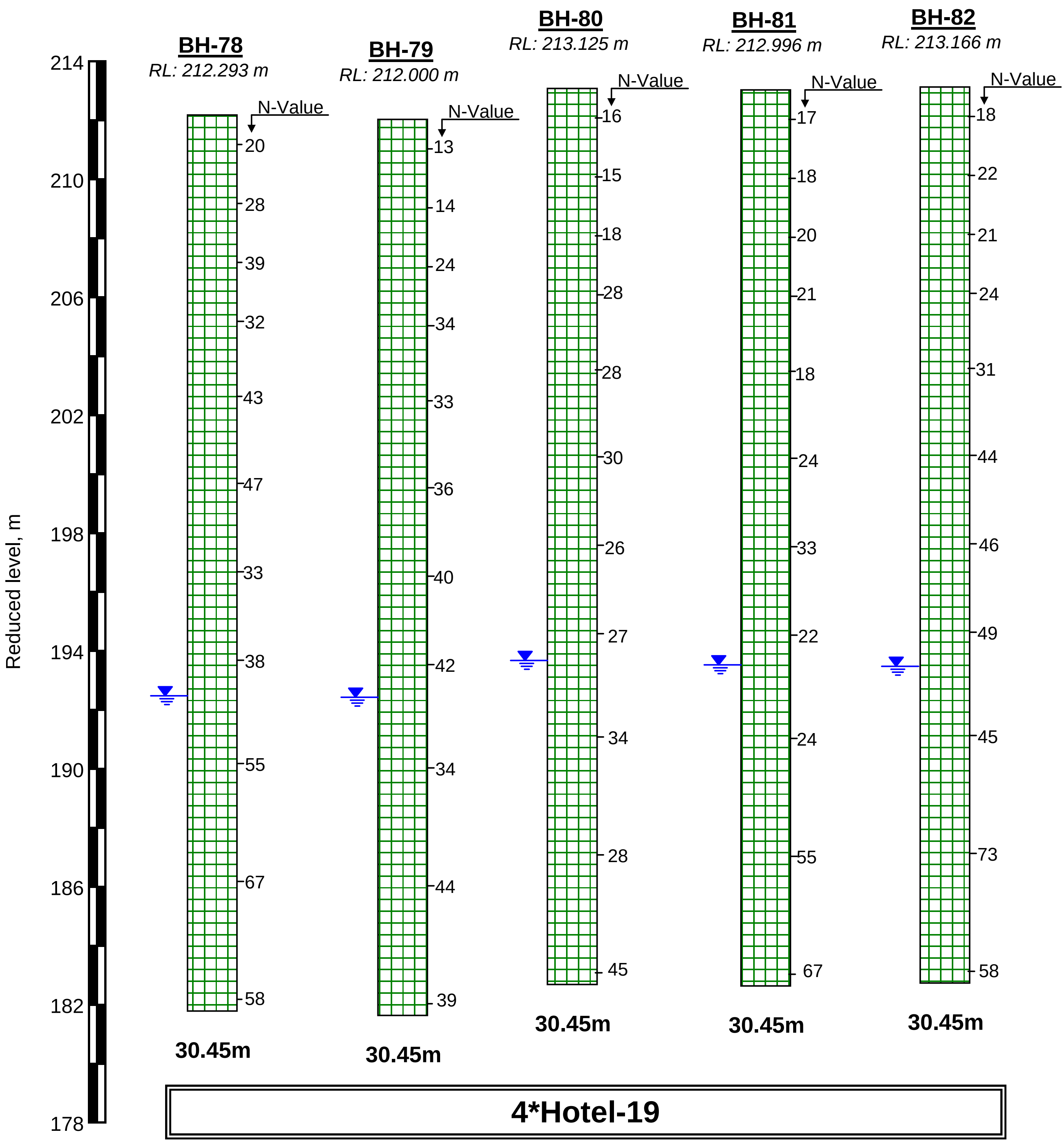

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	Sandy silt (CL)
	Water table

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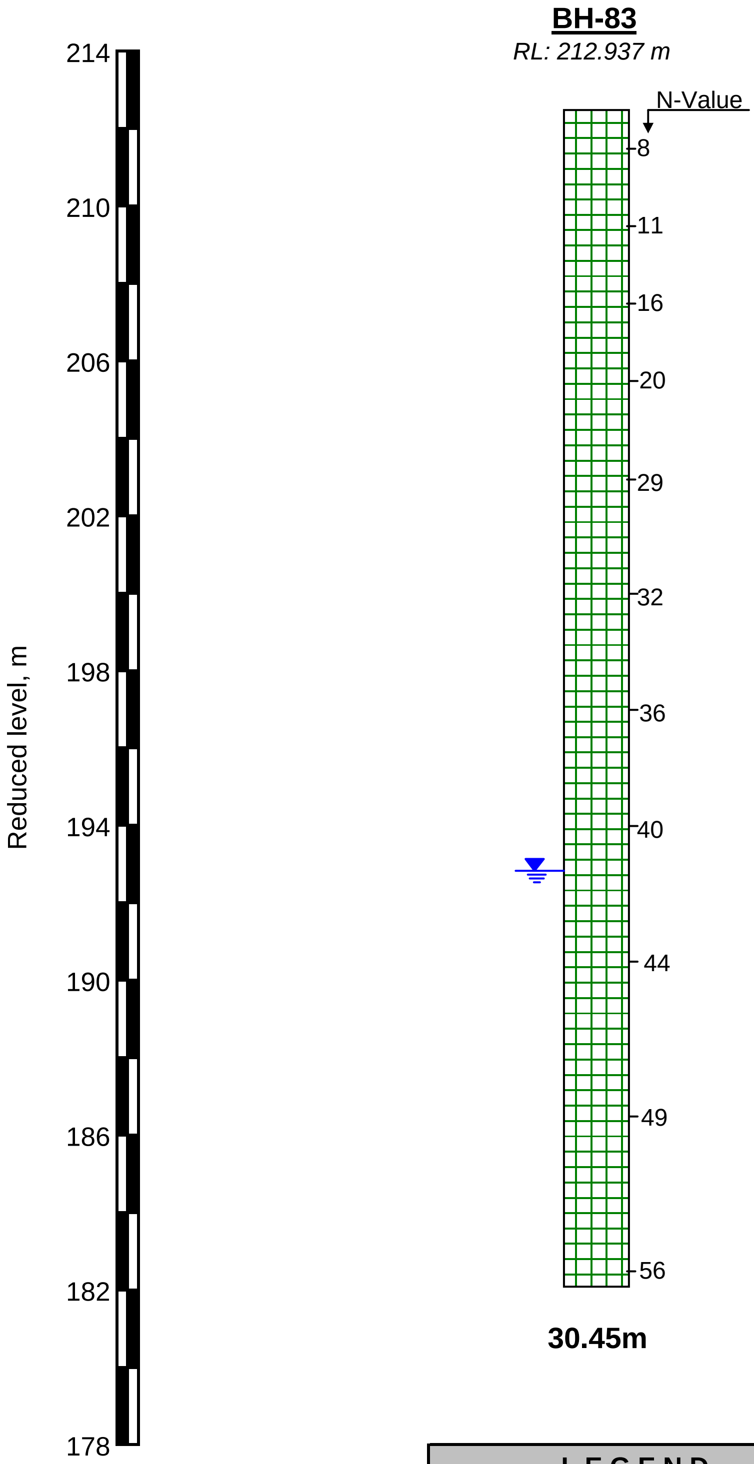

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	Sandy silt (CL)
	Water table

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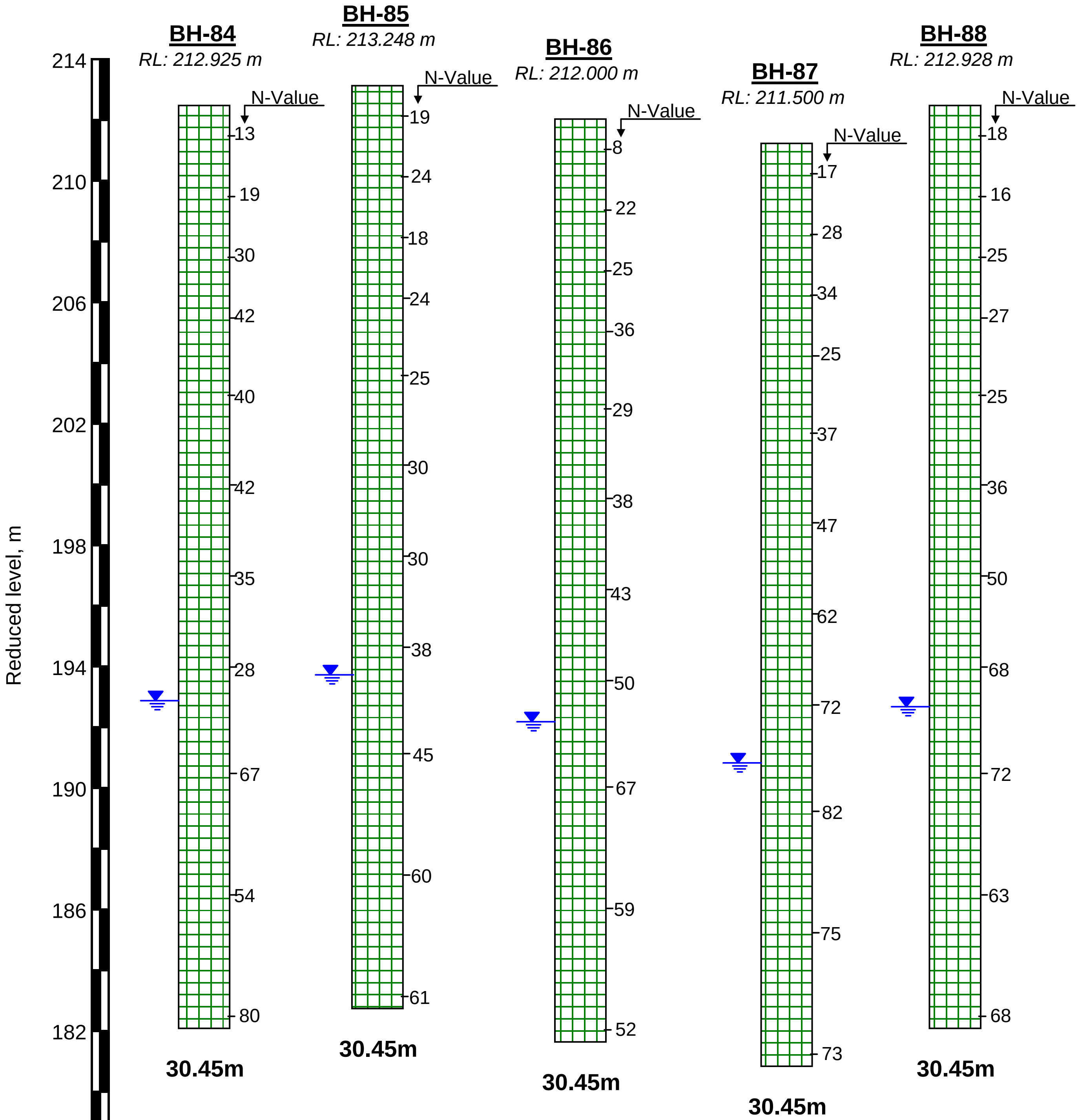

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LEGEND	
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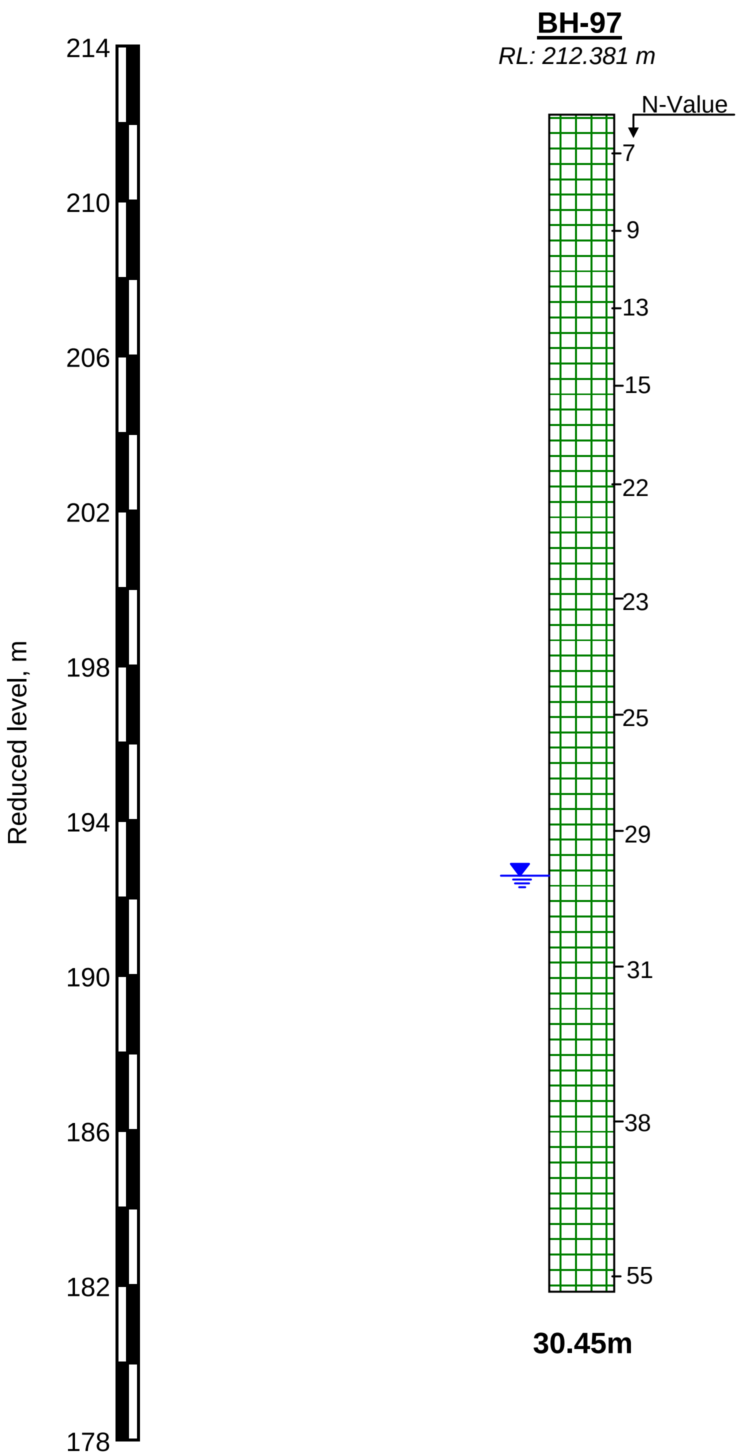
(water table symbol)	Water table

Summary of Borehole Profiles



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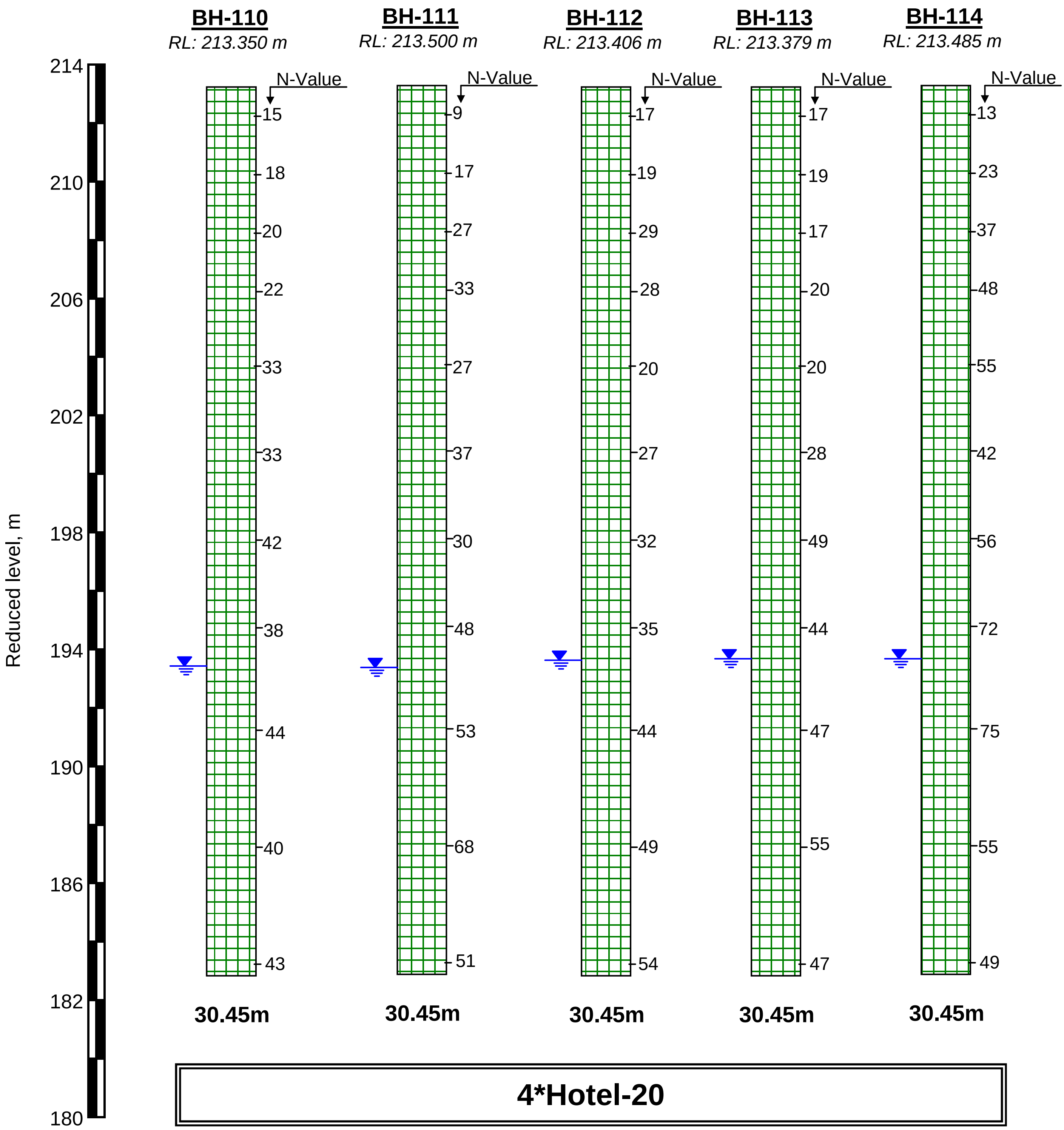
	Sandy silt (CL)
	Water table

Summary of Borehole Profiles



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	Water table

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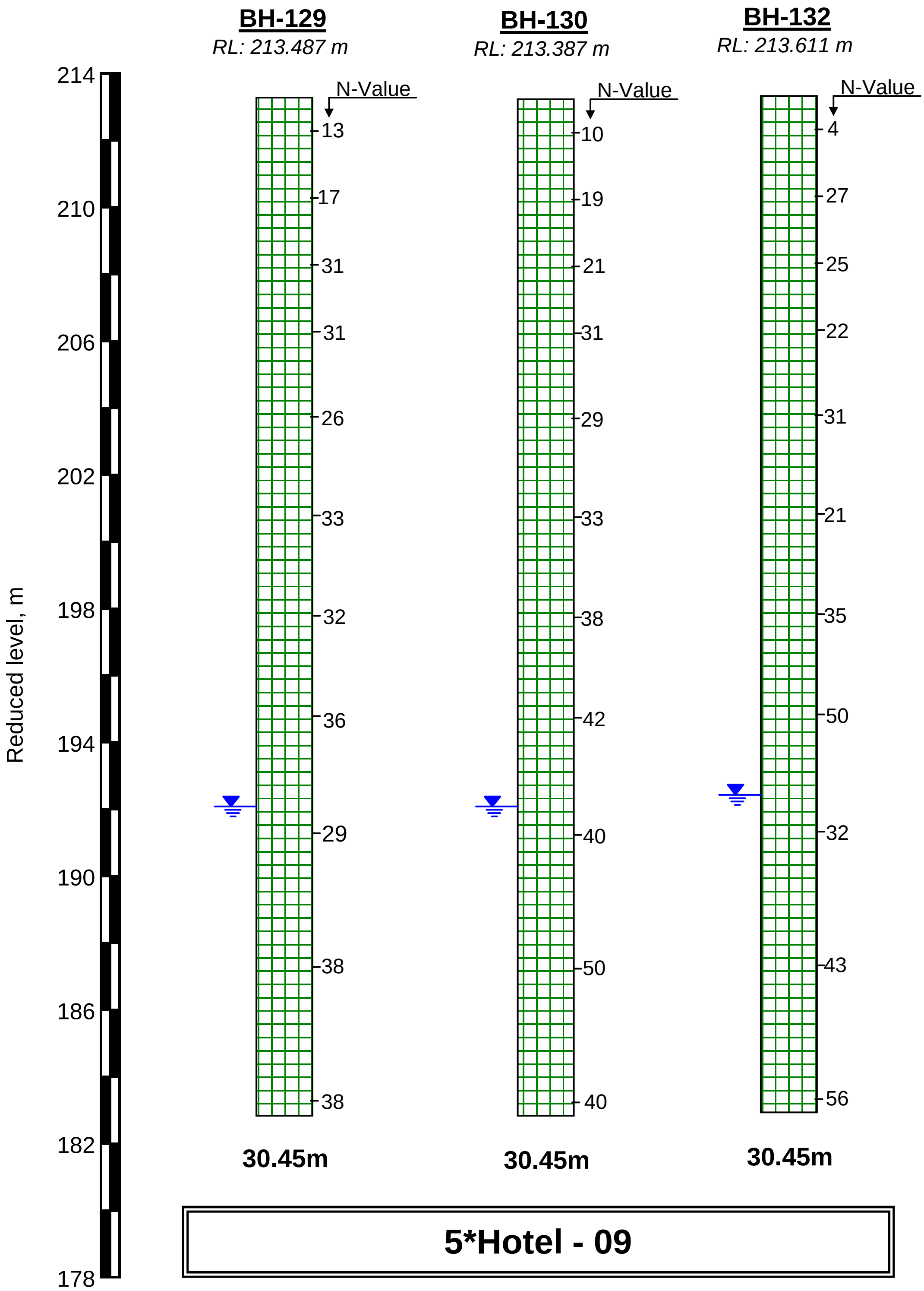

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	Water table

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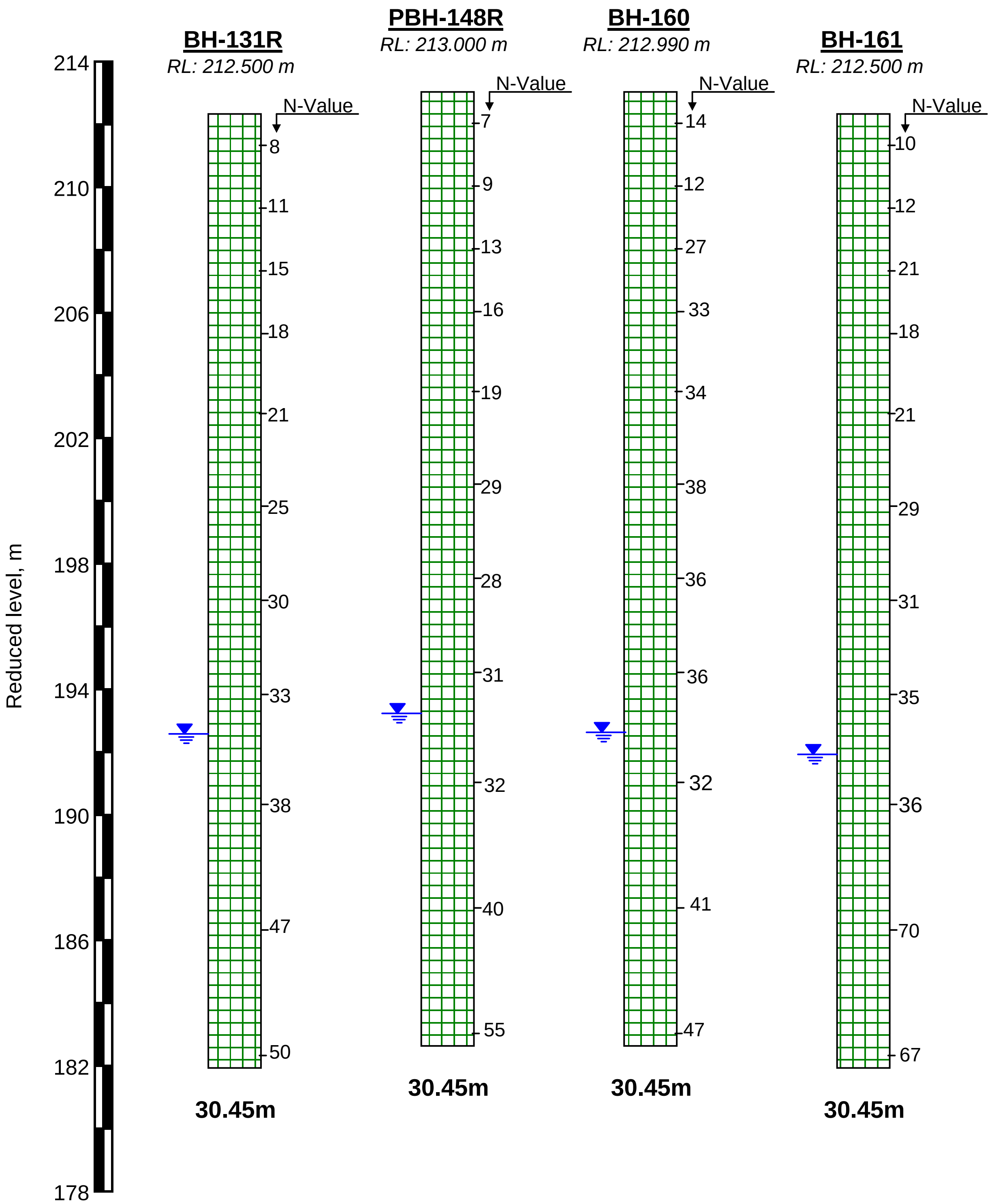

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	Water table

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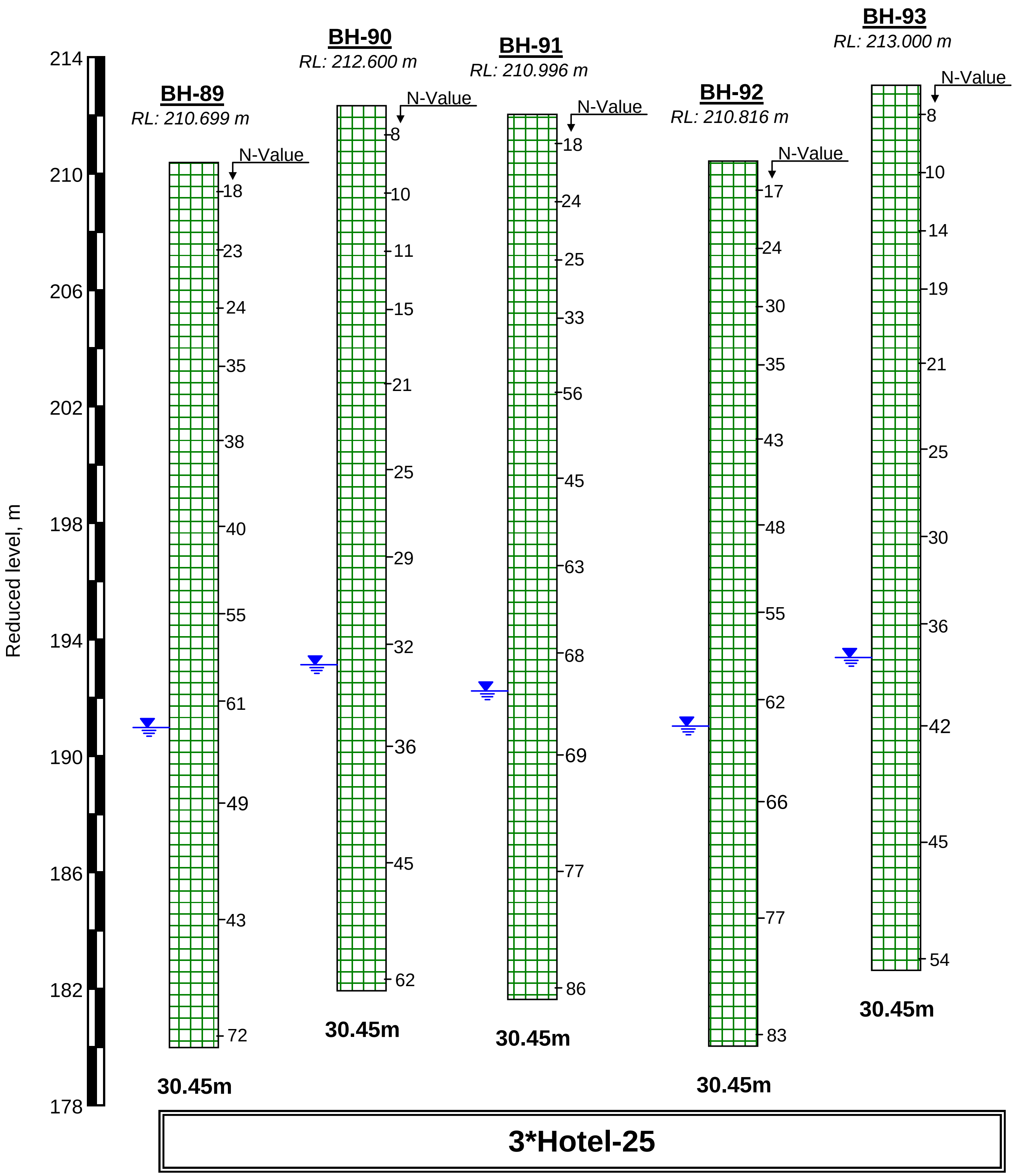

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	Water table

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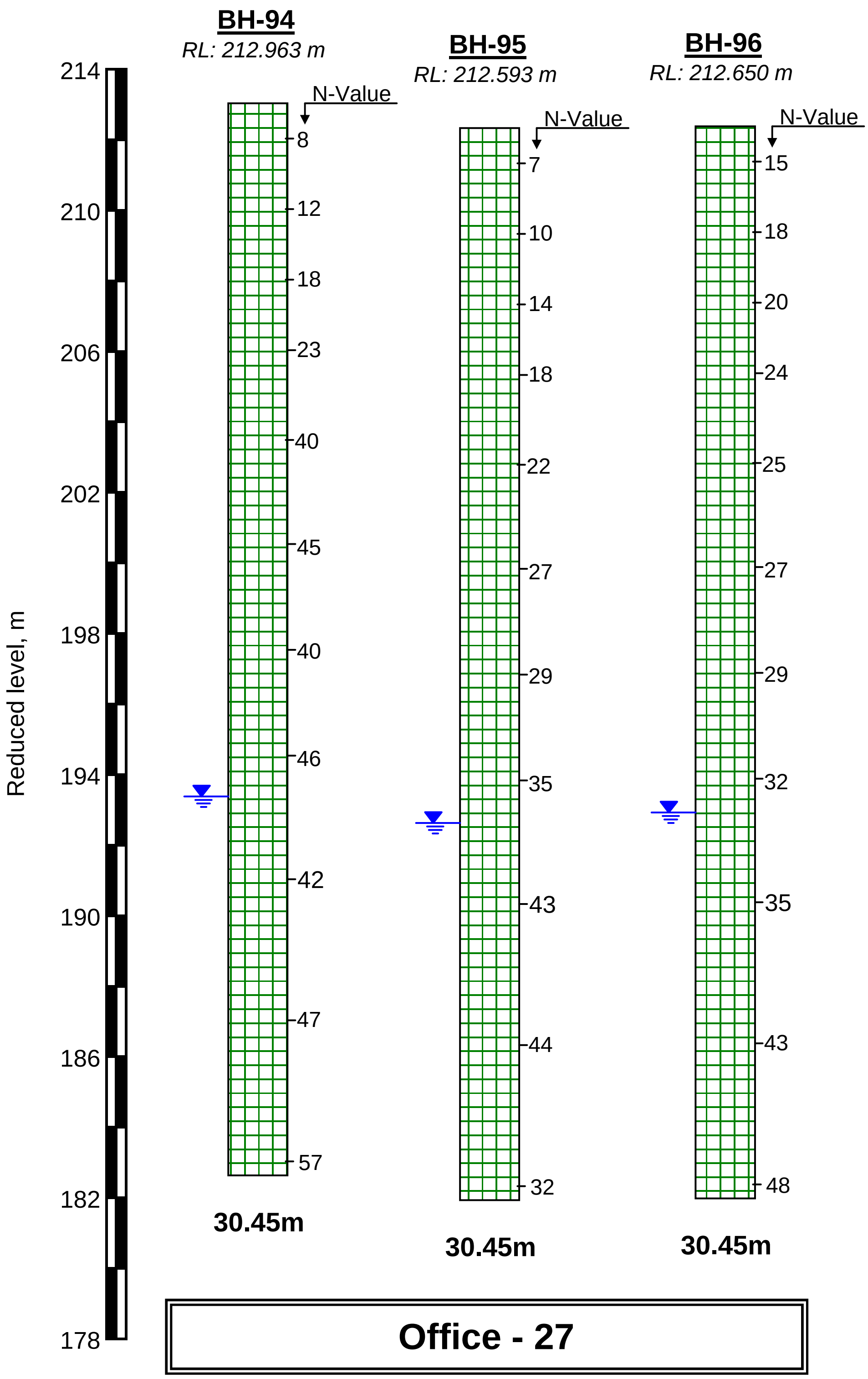

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	Water table

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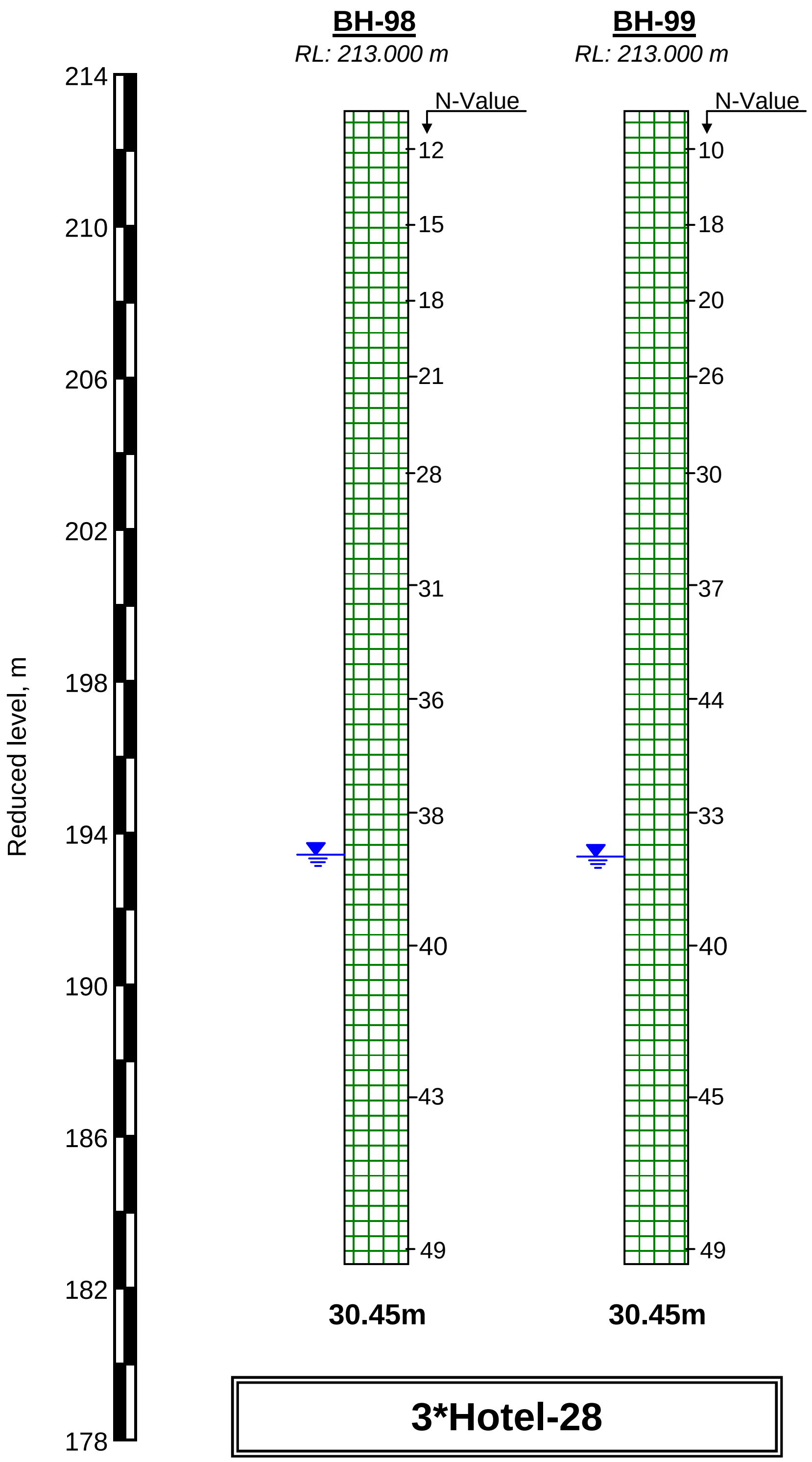

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	Water table

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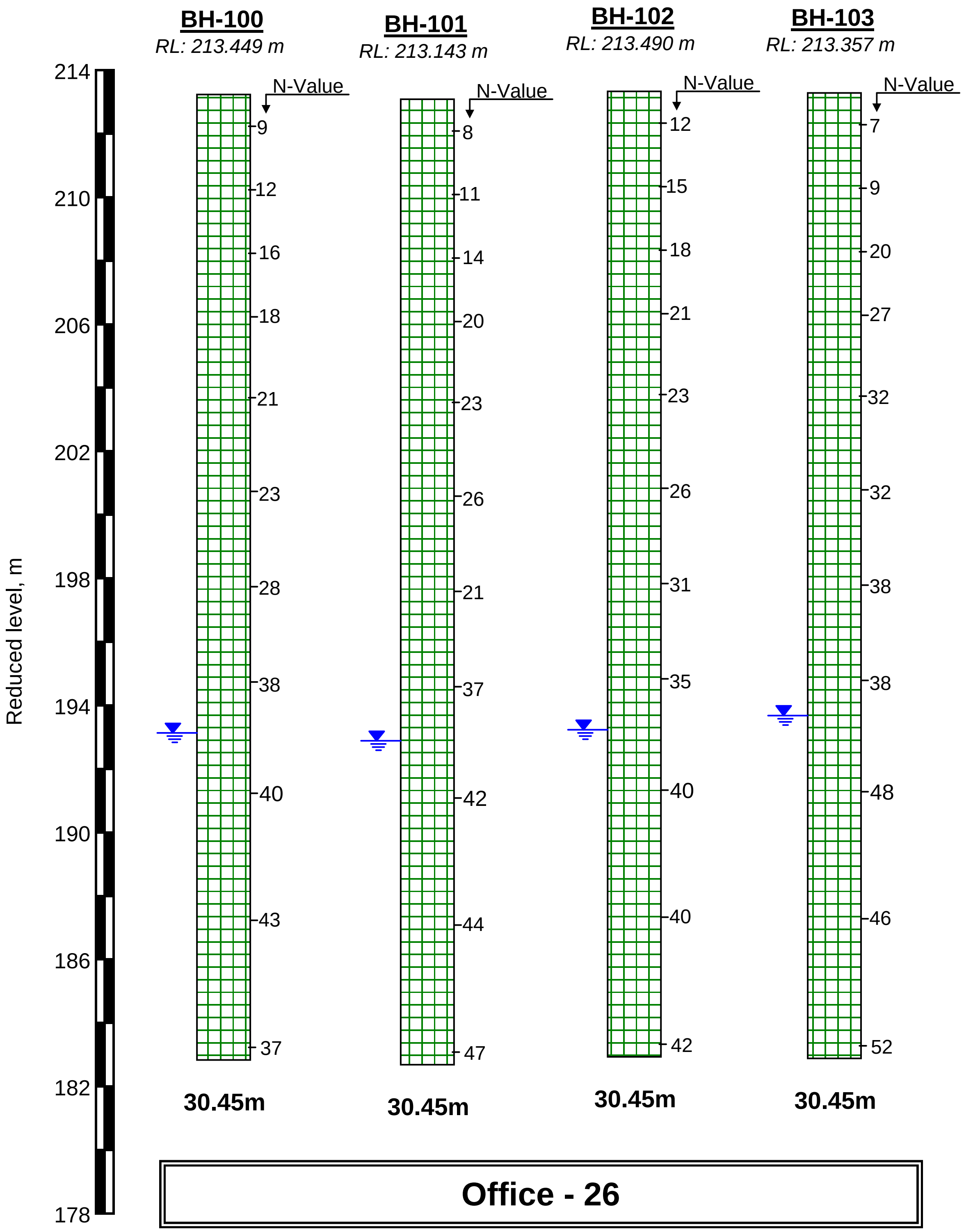

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	Water table

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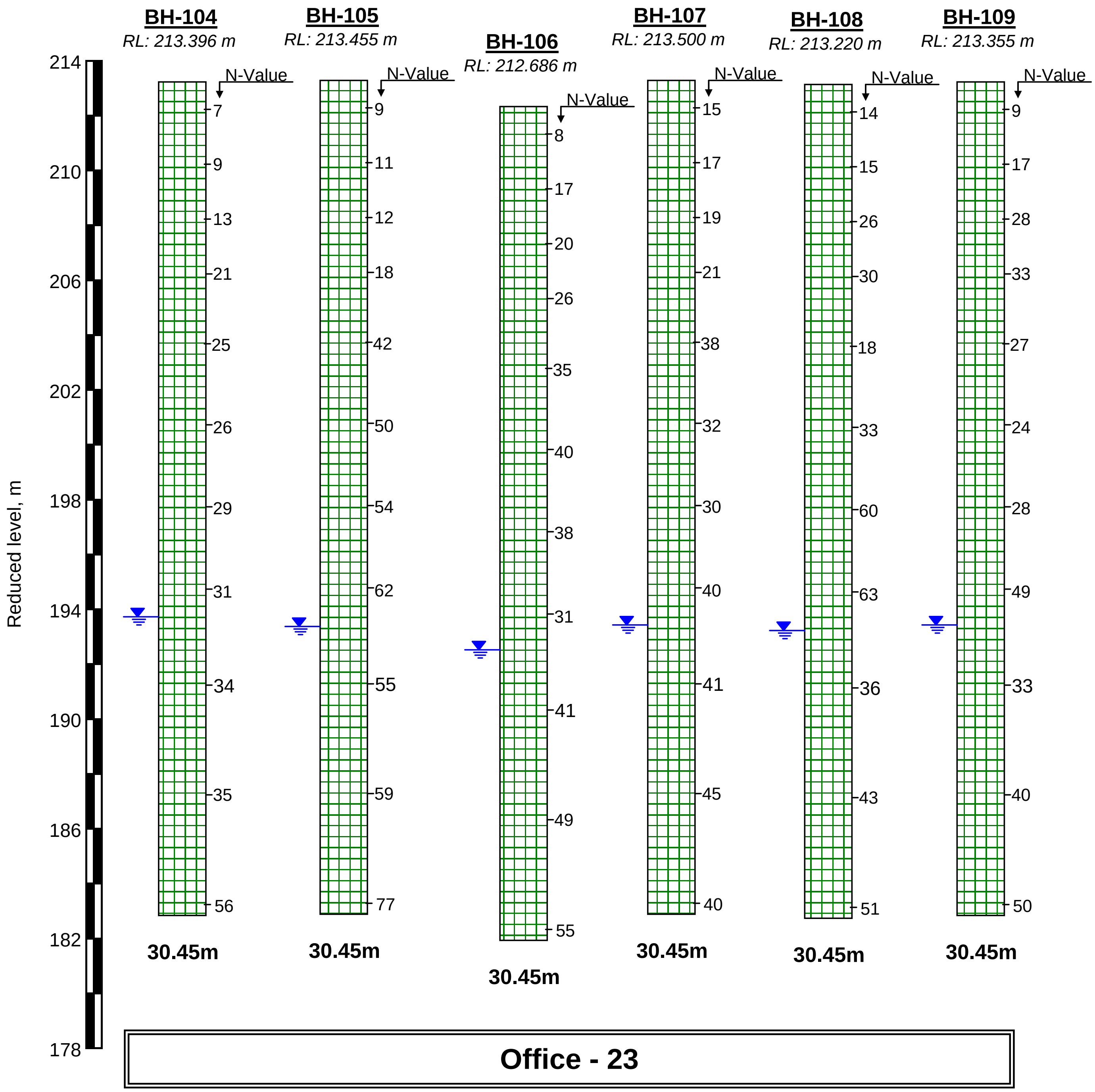

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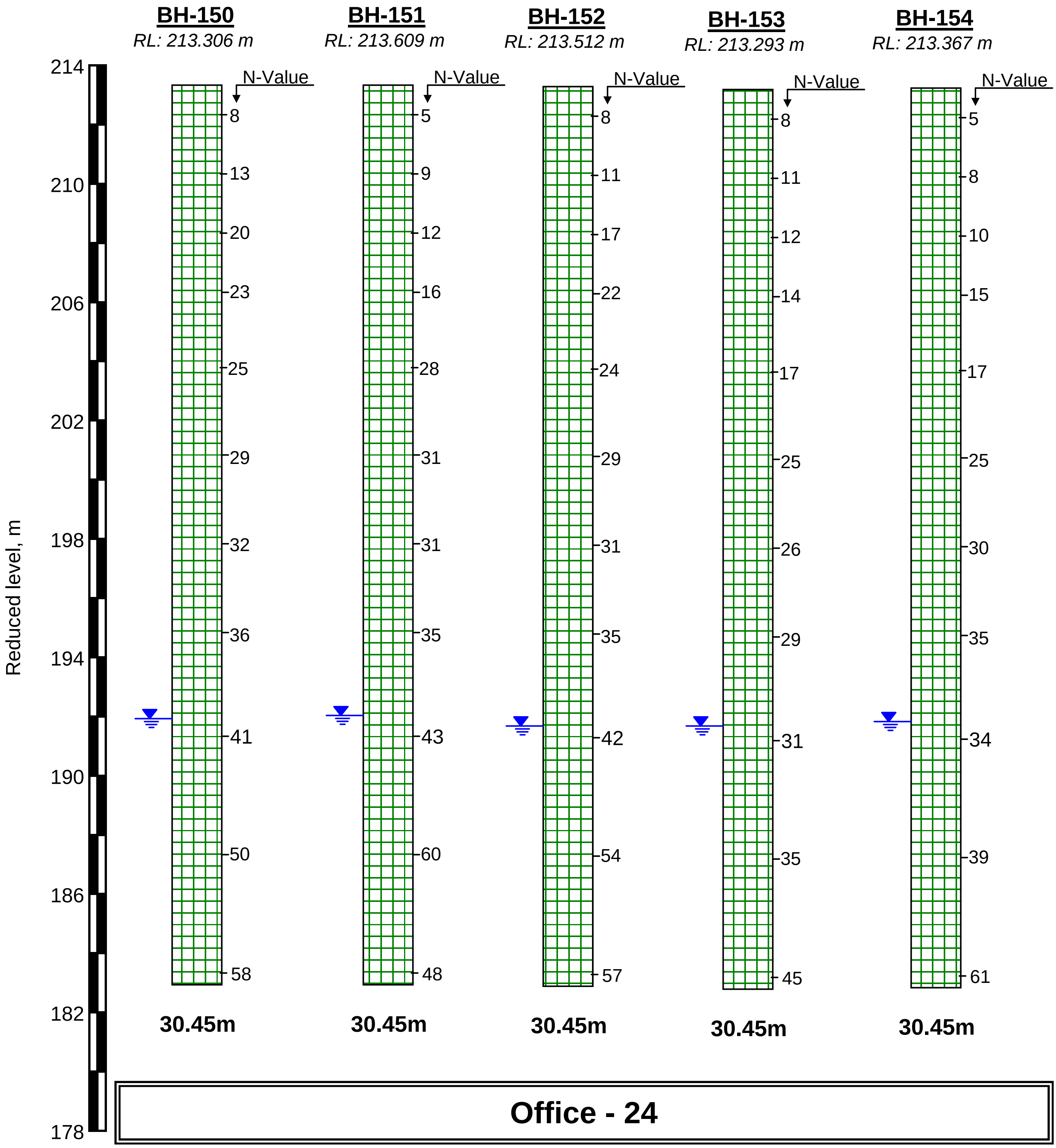
	Water table

Summary of Borehole Profiles



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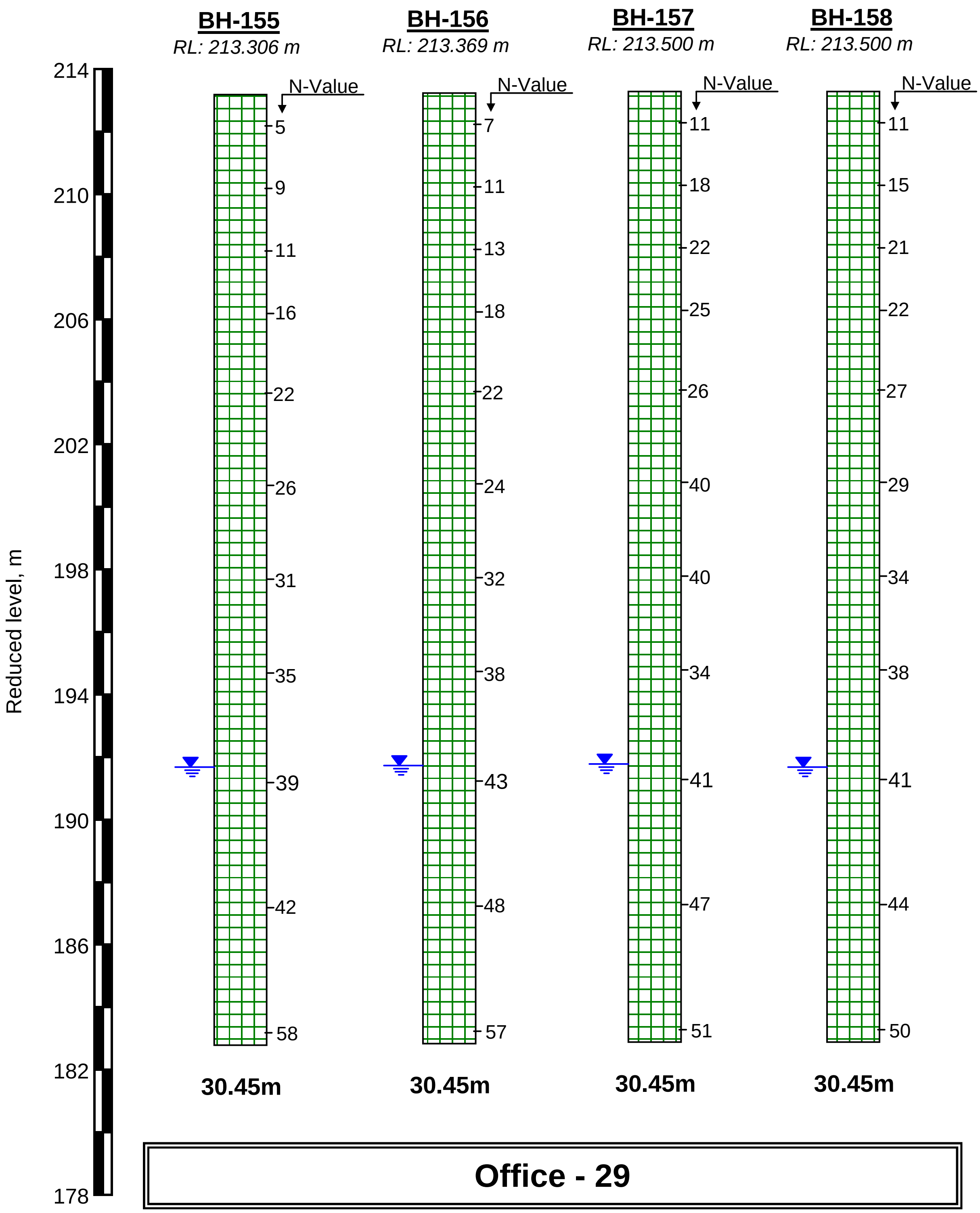
	Water table

Summary of Borehole Profiles



Office - 29

LEGEND	
SYMBOL	DESCRIPTION
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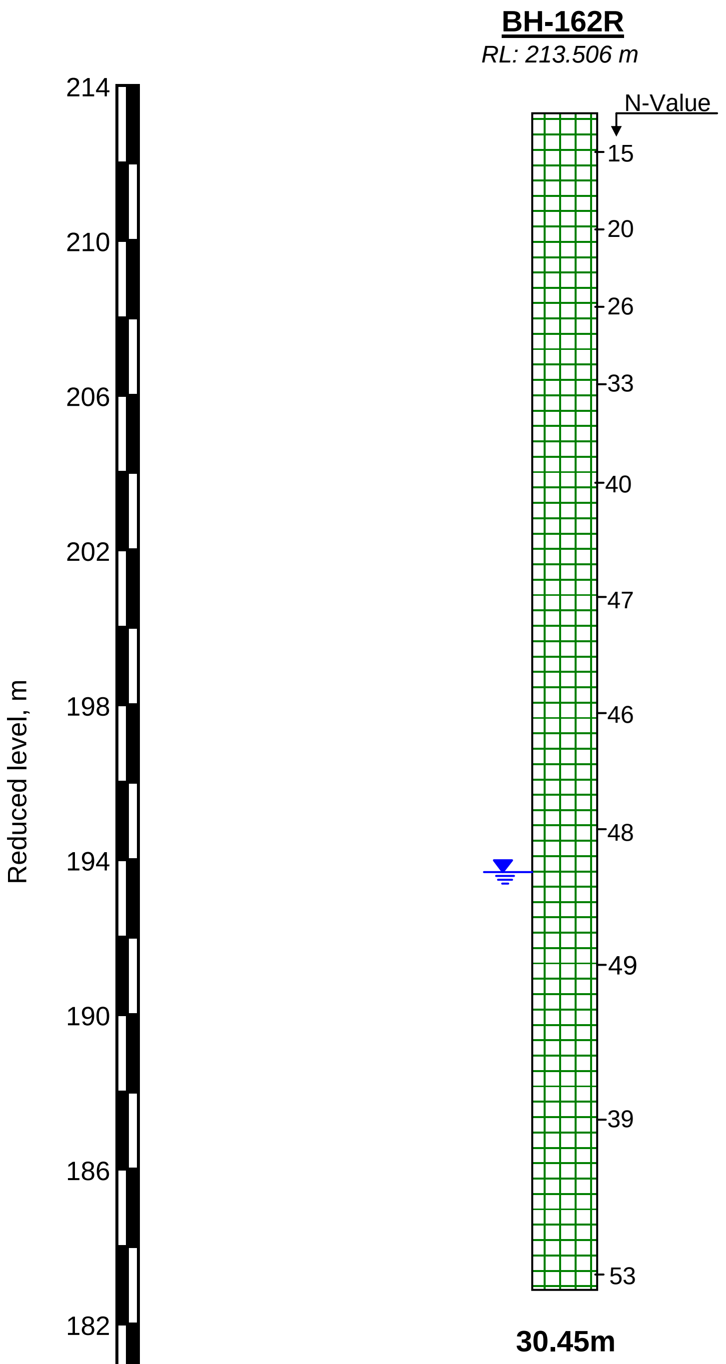
	Water table

Summary of Borehole Profiles



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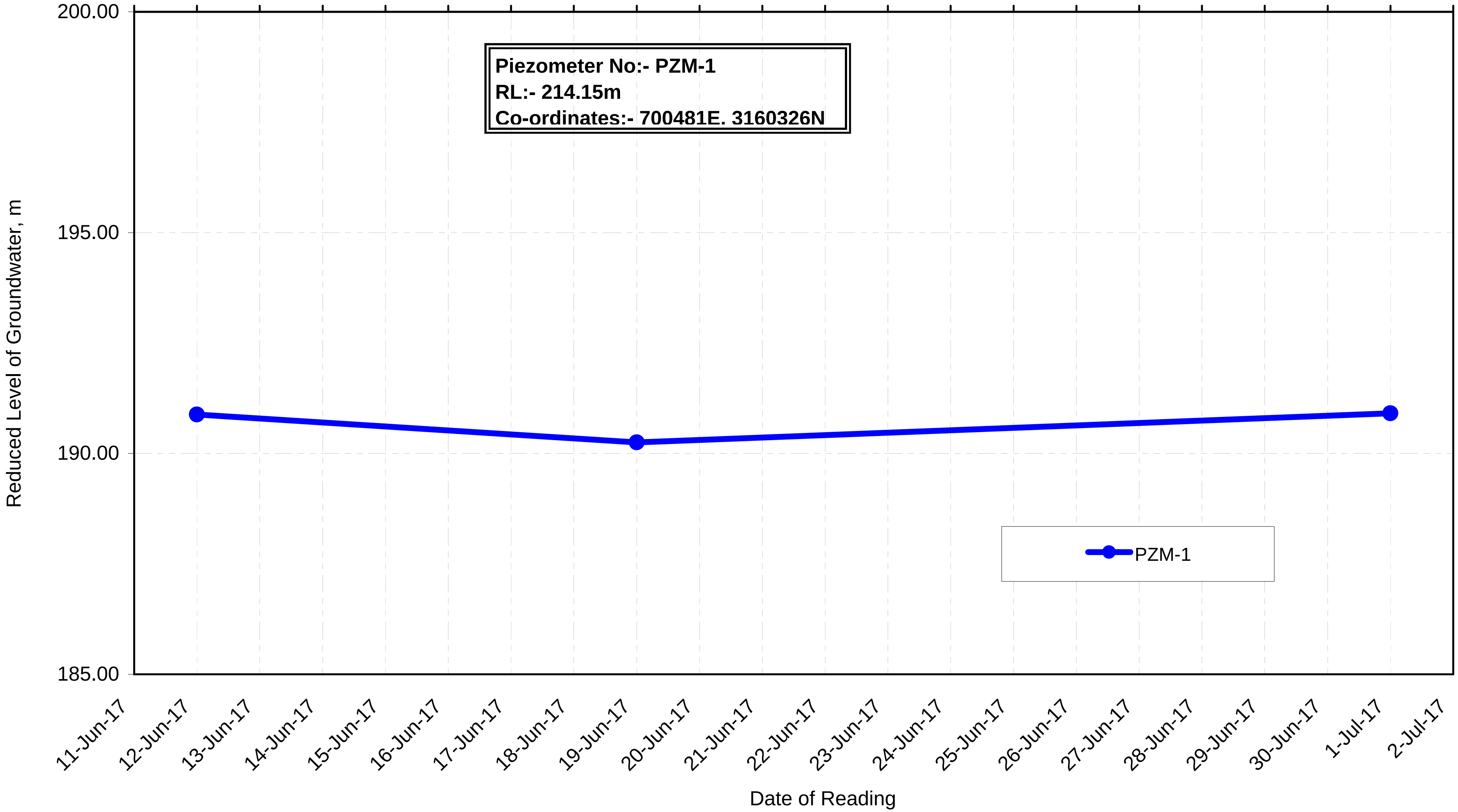
	Water table

Summary of Borehole Profiles



Plot of measured groundwater levels at Piezometer Locations

APPENDIX-A

TYPICAL CALCULATIONS

OPEN FOUNDATIONS

Bearing Capacity Analysis for Shallow Foundations

Analysis as per IS 6403-1981

5 STAR HOTEL PLOT NO.-9
Isolated & raft foundation at depth m

The bearing capacity equation is as follows :

$$q_{net\ safe} = (1/FS)\{cN_cz_cd_c + q(N_q-1)z_qd_q + 0.5B\gamma N_\gamma z_\gamma d_\gamma R_w\}$$

where:

- $q_{net\ safe}$ = safe net bearing capacity; c = cohesion intercept
- q = overburden pressure; B = Foundation width
- γ = Bulk density of soil below founding level
- R_w = Water table correction factor; FS = Factor of safety
- N_c, N_q, N_γ = bearing capacity factors, which are a function of f
- d_c, d_q, d_γ = Depth factors
- z_c, z_q, z_γ = Shape factors

Soil parameters :

c = 0.00 T/m² ; ϕ = 31.0 degrees ; GENERAL SHEAR FAILURE
c' = 0.00 T/m² ; ϕ = 21.8 degrees ; LOCAL SHEAR FAILURE

General Shear Failure : N_c = 32.67 ; N_q = 20.63 ; N_γ = 25.99
Local Shear Failure : N_c' = 16.69 ; N_q' = 7.69 ; N_γ' = 6.96

Factor of safety = 2.5

Design Water Table depth = 18.0 m

R_w factor: Constant value(**V**) for worst condition or calculate(**C**) based on WT Depth ? : V ; Rw = 0.60

Depth factor to be considered ? Y

For computation of Depth Factor, depth below GL to be ignored to account for loose soils,poorly compacted backfill above foundation, scour etc. = 10.4 m

FAILURE CRITERIA : **GENERAL** **SHEAR FAILURE**

Bulk Density Profile

Depth, m From	Depth, m To	γ T/m³
0.0	10.4	
10.4	14.0	1.85
14.0	30.0	1.90

Foundation Dimensions B, m	Foundation Dimensions L, m	FOUNDATION SHAPE	Depth,m	R_w	Shape Factors z_c	z_q	z_γ	Depth factors (GSF) d_c	d_q	d_γ	Depth factors (LSF) d_c'	$d_{q'}$	d_γ'	$q_{net\ safe}$, T/m² GSF	LSF	Safe Net Bearing Capacity T/m²	Gross Bearing Capacity (Safe) T/m²
6.0	**6.0**	*Square*	**12.0**	0.60	1.30	1.20	0.80	1.09	1.05	1.05				58.7		**58.7**	61.7

Settlement Analysis for Shallow Foundation Based on N- Values

Analysis as per IS:8009 (Part 1)-1976, Clause 9.1.4

5 STAR HOTEL PLOT NO.-9
Isolated and raft foundation at depth m

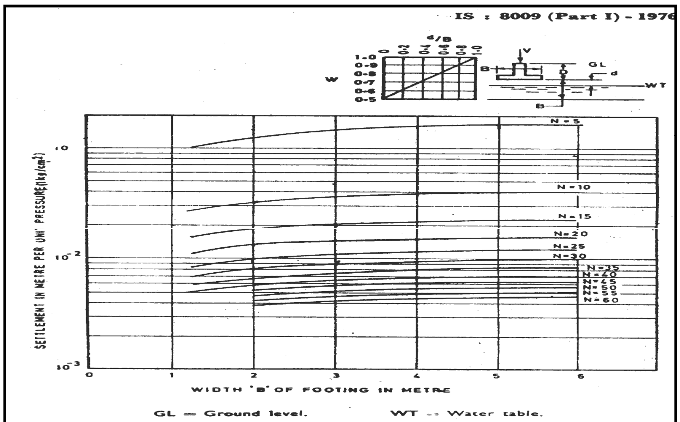


FIG. 9 SETTLEMENT PER UNIT PRESSURE FROM STANDARD PENETRATION RESISTANCE

Design Water Table Depth : 18.0 m

R_w *factor* : Calculate (**C**) based on water table depth or Fixed Value(**V**) for worst condition : V Rw factor for design : 0.6

Fox's Depth Factor to be considered ? Y

Depth to be ignored in Depth Factor Computation for loose soils, poorly compacted backfill, scour, etc. 10.4 m

Foundation Width,m	Foundation Length,m	Foundation Depth,m	Shape	Design N-Value	Design Net Bearing Pressure, T/m^2	Settlement @ 1kg/cm^2 (as read off from graph).	R_w	Fox's Depth Factor, d_f	Rigidity Factor, d_r	Computed Settlement, mm
6.0	6.0	12.0	Square	20.0	**26.5**	15.4	0.60	0.93	0.8	50.0

Settlement Analysis for Shallow Foundations
Elastic Settlement Computed From Theory of Elasticity

Analysis as per IS : 8009 Part 1 - 1976, Clause 9.2

5 STAR HOTEL PLOT NO.-9

Isolated and raft foundation at depth m

Total settlement computed as equal to elastic/immediate settlement.
No consolidation settlement - analysis valid for granular soils,weathered rocks, hard clays & cohesive soils above water table

ELASTIC / IMMEDIATE SETTLEMENT

$$S_i = \frac{q \; B' (1 - \mu^2) \; I}{E} \; d_f \, d_r$$

Reference : *Foundation Analysis & Design by J.E.Bowles* fifth edition (1996)

where B = Foundation width B' = B/2 L' = L/2 μ = Poisson's Ratio

q = Applied Bearing Pressure E = Modulus of Elasticity

d_f = Fox's Depth factor d_r = Rigidity factor

I = Influence factor at corner of rectangular loaded area(B' x L'), computed from theory of elasticity using Steinbrenner's factors

Settlement at centre of footing of size B x L = 4 x Settlement at corner of area B' x L'

Poisson's Ratio : 0.33

Is Rigid Layer met ? N

Layer No.	Depth,m		Soil Classification	Modulus of Elasticity,T/m^2
	From	To		
1	0.0	3.0	Sandy silt	800
2	3.0	14.0	Sandy silt	1400
3	14.0	30.0	Sandy silt	2200

Fox's Depth Factor to be considered ? Y

Depth to be ignored in Depth Factor Computation for loose soils, poorly compacted backfill, scour etc. = 10.4 m

Founda-tion Width (B), m	Founda-tion Length (L), m	Embed-ment Depth (D), m	Applied Bearing Press. T/m^2	Rigidity Factor, d_r	Fox's Depth Factor	M = L'/B'	N = H/B'	Influence Factor	E(weigh-ted ave.) T/m^2	Elastic Settle-ment mm
6.0	6.0	12.0	**26.5**	0.79	0.93	1.00	10.00	0.506	2111	**49.9**

PILE FOUNDATIONS

Computation of Safe Axial Compressive Pile Capacity

By Static Analysis

Analysis in accordance with IS 2911 (Part 1 / Section 2) : 2010

Ex. Hall-1
600 mm

Pile Type : **Bored Cast in Situ** RCC Pile   Loading : Axial Compression

The safe pile capacity is computed as :

$$Q_{safe}=(1/FS)\{\Sigma_{1\ to\ n}[(\alpha c+pk\tan\delta)A_sL]+[(cN_c+pN_q+0.5D\ \gamma'\ N_\gamma)A_p]\}$$

where :

Q_{safe}	=	Safe axial pile capacity, kN	FS	=	Factor of safety
α	=	Adhesion factor (*function of C_u*)	p	=	Overburden pressure, kN/m²
δ	=	Angle of wall friction between soil and pile, degrees	L	=	Pile segment length in selected layer
c	=	Cohesion intercept, kN/m²	k	=	Coefficient of earth pressure
γ'	=	Effective density of soil, kN/m³	D	=	Pile diameter
N_c, N_q, N_γ	=	Bearing capacity factors, which are a function of ϕ	A_s	=	Pile surface area per m length
n	=	Number of layers	A_p	=	Pile end bearing area

Pile Cross section : Circle   Pile cut-off Level (COL) : 3.0 m

Pile Diameter ,D : 600 **mm**

Pile Surface Area, A_s = 1.885 m²/m length   Pile cross-section Area, A_p = 0.283 m²

Overburden Pressure to be considered below : 6.0 m

Consider overburden pressure to 15 pile diameters, i.e. 9.0 m below 6.0 m

become constant below : i.e. 15.0 m below 0.0 m

Design Water Table Depth: 6.0 m

Factor of Safety : 2.5 as per IS 2911 (Part 1 / Section 2) : 2010

Layer No.	Depth,m		Soil Classification	c, kN/m²	δ(=φ), degrees	γ, kN/m³	k	α	N_c	N_q	N_γ
	From	To									
1	0.0	3.0	Sandy silt	10	28	17.5	1.0	1.00			
2	3.0	10.0	Sandy silt	10	29	18.0	1.0	1.00	9.0	18.08	19.34
3	10.0	20.0	Sandy silt	10	32	19.0	1.1	1.00	9.0	28.88	30.21
4	20.0	30.0	Sandy silt	10	33	20.0	1.2	1.00	9.0	34.86	35.19

Pile Capacity Calculation at following Pile Length(s) below cut-off Level (m)	12.0	14.0	16.0	18.0	

Computation of Safe Axial Compressive Pile Capacity

By Static Analysis

Analysis in accordance with IS 2911 (Part 1 / Section 2) : 2010

Ex. Hall-1
600 mm

Pile Type : **Bored Cast in Situ** RCC Pile   Loading : Axial Compression

Pile Dia = 600 mm

Depth Below GL , m	Pile Length below COL, m	Layer No.	Soil Parameters: c, kN/m²	Soil Parameters: φ (=δ), degrees	Soil Parameters: γ_{eff}, kN/m³	Overburden Pressure kN/m²	Unit Skin Friction kN/m²	Skin Friction in Layer kN	Cumulative Skin Friction kN	Unit End Bearing kN/m²	Total End Bearing kN	Ult. Pile Capacity kN	Weight of Pile kN	Safe Pile Capacity kN	Safe Pile Capacity MT
0.0															
		1	10.0	28			0	0	0						
3.0	**0.0**														
		2	10.0	29											
4.2	**1.2**														
		2	10.0	29											
6.0	**3.0**					0.0									
		2	10.0	29	8.0	16.0	19	142	142						
10.0	**7.0**					32.0									
		3	10.0	32	9.0	37.4	36	81	223						
11.2	**8.2**					42.8									
		3	10.0	32	9.0	59.9	51	367	590	2395	677	1267	56	**451**	**46**
15.0	**12.0**					77.0									
		3	10.0	32	9.0	77.0	63	237	827	2395	677	1504	64	**538**	**55**
17.0	**14.0**					77.0									
		3	10.0	32	9.0	77.0	63	214	1040	2395	677	1718	71	**616**	**63**
18.8	**15.8**					77.0									
		3	10.0	32	9.0	77.0	63	24	1064	2395	677	1741	72	**625**	**64**
19.0	**16.0**					77.0									
		3	10.0	32	9.0	77.0	63	119	1183	2395	677	1860	76	**668**	**68**
20.0	**17.0**					77.0									
		4	10.0	33	10.0	77.0	68	127	1310	2880	814	2124	80	**770**	**78**
21.0	**18.0**					77.0									

Computation of Safe Axial Compressive Pile Capacity

By Static Analysis
Analysis in accordance with IS 2911 (Part 1 / Section 2) : 2010

Ex. Hall-1
600 mm

Pile Type : **Bored Cast in Situ** RCC Pile   Loading : Axial Compression
Pile Dia = 600 mm

Depth Below GL , m	Pile Length below COL, m	Layer No.	Soil Parameters			Overburden Pressure	Unit Skin Friction	Skin Friction in Layer	Cumulative Skin Friction	Unit End Bearing	Total End Bearing	Ult. Pile Capacity	Weight of Pile	Safe Pile Capacity	Safe Pile Capacity
			c, kN/m^2	ϕ (=δ), degrees	γ_{eff}, kN/m^3	kN/m^2	kN/m^2	kN	kN	kN/m^2	kN	kN	kN	kN	MT
21.0	**18.0**					77.0		*127*	1310	2880	814	2124	80	**770**	**78**

Computation of Safe Axial Pullout Capacity of Pile

By Static Analysis

Analysis in accordance with IS 2911 (Part 1 / Section 2) : 2010

Ex. Hall-1
600 mm

Pile Type : **Bored Cast in Situ** **RCC Pile**
Loading : Axial Pullout (Uplift)
The safe uplift capacity of pile is calculated as :

$$Q_{safe}=(1/FS)\{\Sigma_{1\ to\ n}[(\alpha c+pk\tan\delta)A_sL]\} + W$$

where

Q_{safe}	=	Safe axial pile capacity, kN	FS	=	Factor of safety
α	=	Adhesion factor (*function of C_u*)	p	=	Overburden pressure, kN/m^2
δ	=	Friction angle between soil and pile, degrees (= ϕ)	L	=	Pile segment length in selected layer
c	=	Cohesion intercept, kN/m^2	k	=	Coefficient of earth pressure
γ'	=	Effective density of soil, kN/m^3	D	=	Pile diameter
n	=	Number of layers	A_s	=	Pile surface area per m length
W	=	Weight of the pile			

Pile cross section shape : circle
Pile cut-off Level (COL) : 3.0 m
Pile Diameter ,D : **600** **mm**
Pile Surface Area, A_s = 1.885 m^2/m length

Overburden Pressure to be considered below : 6.0 m
Consider overburden press. to become constant below : 15 pile diameters, i.e. 9.0 m below 6.0 m
i.e. 15.0 m below 0.0 m
Design Water Table Depth : 6.0 m
Factor of Safety : 3.0 *as per IS 2911 (Part1 / Section 2) : 2010 Clause 6.3.2*
Percentage of Ultimate Shaft Resistance to be used for Ultimate Pullout Capacity: 0.7

Layer No.	Depth,m From	Depth,m To	Soil Classification	c, kN/m^2	$\delta(=\phi)$, degrees	γ, kN/m^3	k	α
1	0.0	3.0	Sandy silt	0	30	17.5	1.0	
2	3.0	10.0	Sandy silt	0	31	18.0	1.1	
3	10.0	20.0	Sandy silt	0	32	18.5	1.1	
4	20.0	30.0	Sandy silt	0	33	19.0	1.2	

Pile Capacity Calculation at following Pile Length(s) below cut-off Level (m)	**12.0**	**14.0**	**16.0**	**18.0**	

Computation of Safe Axial Pullout Capacity of Pile

By Static Analysis

Analysis in accordance with IS 2911 (Part 1 / Section 2) : 2010

Ex. Hall-1
600 mm

Pile Type : **Bored Cast in Situ** **RCC Pile**
Pile Dia = 600 mm Bored Cast in Situ RCC Pile

Depth Below GL , m	Pile Length below COL,m	Layer No.	Soil Parameters: c, kN/m²	Soil Parameters: φ (=δ), degrees	Soil Parameters: γ_{eff}, kN/m³	Overburden Pressure kN/m²	Unit Skin Friction kN/m²	Skin Friction in Layer kN	Cumulative Skin Friction kN	Weight of Pile kN	UltimatePullout Capacity kN	Safe Pullout Capacity kN	Safe Pullout Capacity MT
0.0	-												
		1	0.0	30									
3.0	**0.0**												
		2	0.0	31			0.0	0	0				
6.0	**3.0**					0.0							
		2	0.0	31	8.00	16.0	10.1	76	76				
10.0	**7.0**					32.0							
		3	0.0	32	8.50	53.3	36.6	345	421	56	351	**154**	**16**
15.0	**12.0**					74.5							
		3	0.0	32	8.50	74.5	51.2	193	614	64	494	**207**	**21**
17.0	**14.0**					74.5							
		3	0.0	32	8.50	74.5	51.2	193	807	72	637	**260**	**27**
19.0	**16.0**					74.5							
		3	0.0	32	8.50	74.5	51.2	97	904	76	708	**287**	**29**
20.0	**17.0**					74.5							
		4	0.0	33	9.00	74.5	55.6	105	1009	80	786	**315**	**32**
21.0	**18.0**					74.5							

Lateral Load Carrying Capacity for Pile Foundations

Analysis in accordance with: IS: 2911 Part 1 Section 2 - 2010

Ex. Hall-1

600 mm

Pile Type : Bored Cast in Situ RCC Pile
Pile cross-section : Circle
Pile Dia : 600 mm
Pile Cut-off-Level below GL 3.0 m Pile Length : m
Pile Head : Fixed Head Condition
Grade of Concrete : M 25 Modulus of Elasticity : 25000 MPa
Moment of Inertia, I : 6.362E-03 m^4
Soil Classification: Granular
Design SPT N Value of Sand/Silty Sand = 15.0
Saturation : Submerged

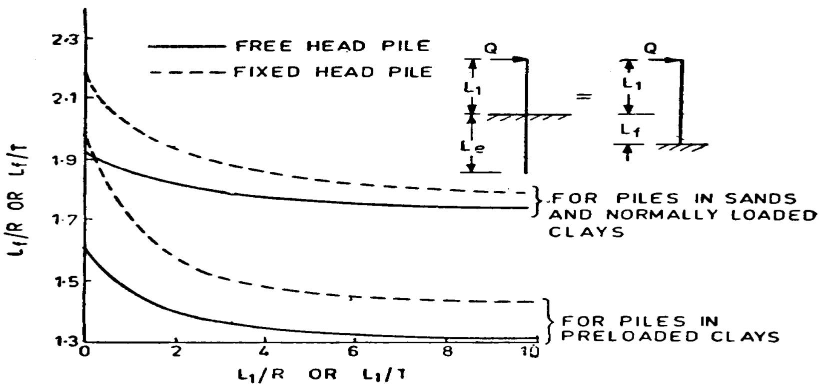


FIG. 2 DETERMINATION OF DEPTH FIXITY

T =	$(EI/\eta_h)^{1/5}$	for Granular Soils and NC Clays	R =	$(EI/KB)^{1/4}$	for Preconsolidated Clays

Modulus of Subgrade Reaction, ηh = 2.1 MN/m^3 T = 2.37 m
Free Standing Length of Pile or Length of pile below cut-off-level not contributing substantially to lateral capacity (**e**) : 0.0 m
e/T = 0.0 Reading off from graph, zf/T = 2.19
Depth of Fixity, z_f = 5.19 m e + z_f = 5.19 m

$$\text{Deflection, } y = \frac{H\,(e + z_f)^3}{3\,EI} x10^3$$ .... *for free-head pile*

$$\text{Deflection, } y = \frac{H\,(e + z_f)^3}{12\,EI} x10^3$$ .... *for fixed-head pile*

where : y = Lateral deflection at pile top e = Free-standing length of pile
H = Lateral load applied z_f = Depth of fixity

Permissible Horizontal Deflection at top of pile, Y = 5.0 mm

Computed Lateral Capacity of Pile, H =	**68**	**kN**	**=**	**6.9 Tonnes**