U.S. Department
of Transportation
**Federal Highway
Administration**

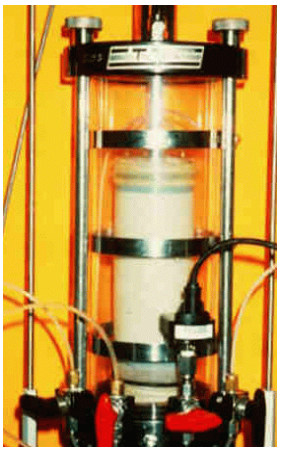
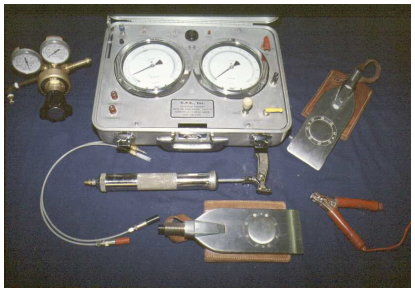
**Publication No. FHWA NHI-01-031
May 2002**

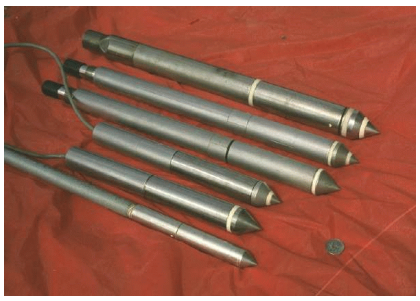
NHI Course No. 132031

Subsurface Investigations
— Geotechnical Site Characterization

Reference Manual





National Highway Institute

NOTICE

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect policy of the U.S. Department of Transportation. This report does not constitute a standard, specification, or regulation. The United States Government does not endorse products or manufacturers. Trade or manufacturer's names appear herein only because they are considered essential to the object of this document.

Technical Report Documentation Page

1. REPORT NO.	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
FHWA-NHI-01-031		

4. TITLE AND SUBTITLE	5. REPORT DATE
Subsurface Investigations (Geotechnical Site Characterization)	May 2002
	6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
Paul W. Mayne, Ph.D., P.E., Barry R. Christopher, Ph.D., P.E. and Jason DeJong, Ph.D.	

9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. WORK UNIT NO.
Ryan R. Berg & Associates, Inc. 2190 Leyland Alcove Woodbury, MN 55125	11. CONTRACT OR GRANT NO. DTFH61-00-T-25043

12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT & PERIOD COVERED
National Highway Institute Federal Highway Administration U.S. Department of Transportation Washington, D.C.	14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

FHWA Technical Consultants: J.A. DiMaggio, P.E. and P. Osborn, P.E.

COTR - L. Jones

This manual is an update and revision of FHWA-HI-97-021 prepared by Parsons Brinckerhoff Quade & Douglas, Inc, in association with Woodward-Clyde Consultants; Principal Investigator: George Munfakh; Authors: Ara Arman, Naresh Samtani, Raymond Castelli and George Munfakh; FHWA Technical Consultants: J.A. DiMaggio, A. Muñoz, A. Kilian, and P. Osborn

16. ABSTRACT

This manual is the reference text used for the FHWA NHI course No. 13231 on **Subsurface Investigations** and reflects current practice for such. The planning, execution, and interpretation of geotechnical site explorations in natural soil and rock are presented with regard to the design and construction of transportation facilities. The role of the geotechnical engineer in subsurface investigation, exploration methods, equipment types and their suitability are discussed. Various in-situ tests are presented, including cone penetration, dilatometer, pressuremeter, vane, and standard penetration. Rotary drilling and rock coring are reviewed in terms of the proper handling, transportation, and storage of soil and rock samples for laboratory testing. Geophysical wave and electromagnetic methods are covered. Laboratory index, strength, and stiffness testing are reviewed in complement to the field testing program. Geomaterial characterization requires the interpretation and correlation of engineering properties from the acquired field and lab measurements. The results are summarized in a geotechnical report with available geological, topographical, hydrological, and geotechnical data collected towards the analysis and design of earthwork structures and foundation design.

17. KEY WORDS	18. DISTRIBUTION STATEMENT
Subsurface, investigation, geomaterials, subgrade, exploration, drilling, coring, sampling, soil, rock, field testing, in-situ, laboratory testing, geophysics, cone penetrometer, vane, groundwater, geotechnical report, transportation, tunnels, slopes, highways, bridges.	No restrictions.

19. SECURITY CLASSIF.	20. SECURITY CLASSIF.	21. NO. OF PAGES	22. PRICE
Unclassified	Unclassified	300	

[Blank]

PREFACE

This module is the first in a series of twelve modules that constitute a comprehensive training course in geotechnical and foundation engineering. Sponsored by the National Highway Institute (NHI) of the Federal Highway Administration (FHWA), the training course is given at different locations in the U.S. The intended audience includes civil engineers and engineering geologists involved in the design and construction of transportation facilities. This manual is designed to present the latest methodologies in the planning, execution and interpretation of the various subsurface investigation methods, and the development of appropriate soil and rock parameters for engineering applications.

The authors have made every effort to present the general state of the practice of subsurface exploration and geotechnical site characterization. It is understood that the procedures discussed in the manual are subject to local variations. It is important, therefore, for the reader to become thoroughly familiar with the local practices as well. This guide focuses on the scope and specific elements of typical geotechnical investigation programs for design and construction of highways and related transportation facilities. Considering the broad scope and fundamental importance of this subject, this manual on subsurface investigations is organized as follows:

- Chapters 1 through 6 discuss various aspects of field investigations, including soil borings, augering, rock coring, sampling, in-situ testing, and geophysical exploration methods.
- Chapters 7 and 8 discuss laboratory testing of soil and rock materials.
- Chapters 9 and 10 present interpretation procedures for soil and rock properties.
- Chapters 11 and 12 address issues related to data management and interpretation, including evaluation and synthesis of the field and laboratory test data, development of soil and rock design parameters, and the presentation of investigation findings in geotechnical reports.
- Chapter 13 contains a list of cited references for further details & information.
- Appendix A contains information on health and safety issues.
- Appendix B lists names and websites of soil & rock drilling and in-situ testing equipment manufacturers, distributors, and service companies.

This manual is not intended to be an exclusive reference on subsurface investigations and it is highly recommended that the references given in Chapter 13 be made part of the reader's library and reviewed in detail. Two important references are the *Manual on Subsurface Investigations* by AASHTO (1988) and the FHWA Manual *Evaluation of Soil and Rock Properties* (Geotechnical Engineering Circular No. 5, 2001). Finally, this manual is developed to be used as a living document. After attending the training session, it is intended that the participant will use it as a manual of practice in everyday work. Throughout the manual, attention is given to ensure the compatibility of its content with those of the participants manuals prepared for the other training modules. Special efforts are made to ensure that the included material is practical in nature and represents the latest developments in the field.

SI CONVERSION FACTORS

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
ml	millimeters	0.034	fluid ounces	fl oz
l	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
		TEMPERATURE		
°C	Celsius	1.8 C + 32	Fahrenheit	°F
		WEIGHT DENSITY		
g/cc	grams per cubic centimeter	62.4	poundforce /cubic foot	pcf
kN/m^3	kilonewton /cubic meter	6.36	poundforce /cubic foot	pcf
		FORCE and LOAD		
N	newtons	0.225	poundforce	lbf
kN	kilonewtons	225	poundforce	lbf
kg	kilogram (force)	2.205	poundforce	lbf
MN	meganewtons	112.4	tons (force)	t
		PRESSURE and STRESS*		
kPa*	kilopascals	0.145	poundforce /square inch	psi
kPa	kilopascals	20.9	poundforce /square foot	psf
MPa	megapascal	10.44	tons per square foot	tsf
kg/cm^2	kilograms per square cm	1.024	tons per square foot	tsf

*Notes: 1 kPa = kN/m^2 = one kilopascal = one kilonewton per square meter.

For dimensionless graphs and equations, a reference stress of one atmosphere can be used, such that $\sigma_a = p_{atm} = 1$ bar = 100 kPa . 1 tsf . 1 kg/cm^2.

SUBSURFACE INVESTIGATIONS

TABLE OF CONTENTS

[Blank]

LIST OF TABLES

LIST OF FIGURES

[Blank]

Nomenclature & Symbols

α_j	Joint dip direction
α_s	Slope dip direction
β	Average dip angle of rock bedding
β_j	Joint dip
β_s	Slope dip
γ'	Buoyant (or effective or submerged) unit weight of geomaterial
γ	Unit weight of soil
γ_d, γ_{dry}	Dry unit weight of soil
γ_{dmax}	Dry unit weight of soil in its densest state
γ_{dmin}	Dry unit weight of soil in its loosest state
γ_{sat}	Saturated unit weight of soil
γ_t	Total unit weight of soil
γ_w	Unit weight of water (9.81 kN/m^3)
δ	Horizontal movement of soil mass in a Direct Shear Test
$\Delta\varepsilon_a$	Change in axial strain
$\Delta\sigma$	Change in applied axial stress
ΔD	Change in diameter of rock sample
Δe	Change in void ratio over Δp
ΔH	Vertical movement of soil mass in a Direct Shear Test
ΔH	Change in height of rock sample
Δp	Additional loading due to foundation or embankment construction
Δt	Time for standpipe head to fall
ε_a, ε_{axial}	Axial strain in soil or rock sample ($\Delta H/H$)
ε_{radial}	Radial strain in rock sample ($\Delta D/D$)
η	Viscosity of the permeant
η_{FV}	Correction factor for vane shear strength to mobilized strength
ν	Poisson's ratio
ρ	Resistivity; = $2\pi dV/I$
σ'	Effective stress
σ	Normal stress
σ_1, σ_2, σ_3	Major, intermediate and minor total principal stresses, respectively.
σ_1', σ_2', σ_3'	Major, intermediate and minor effective principal stresses
$\sigma_{a(ult)}$	Uniaxial compressive strength of rock
σ_{CIR}	Uniaxial compressive strength of Intact Rock
σ_n	Normal stress on joint
σ_u	Applied axial stress
σ_v	Total overburden pressure
σ_{vo}	Total (vertical) overburden stress
σ_{vo}'	Effective (vertical) overburden stress
τ	Shear stress
$(\tau_u)_{corr}$	Corrected vane shear strength
$(\tau_u)_{field}$	Vane shear strength measured in the field (uncorrected)
ϕ'	Drained or effective friction angle of soil or rock

ϕ	Angle of internal friction
ϕ_d	Drained friction angle
ϕ_r	Residual friction angle
A	Uncorrected pressure required to cause flat dilatometer diaphragm to just lift-off
A	Loaded area; Cross-sectional area of soil sample
A	Code for Auger sample to be entered in the "Samples Type" column of boring log
AASHTO	American Association of State Highway and Transportation Officials
ADSC	Association of Drilled Shaft Contractors
AQ Wireline	Designation of rock core barrel
ASTM	American Society for Testing and Materials
B	Bedding (used to describe type of discontinuity in rock core log)
B	Uncorrected pressure for 1.1 mm deflection of flat dilatometer membrane.
B_f	Width of footing
BHS	Code for Borehole shear test to be entered in the column of boring log
BQ	Dimension of rock core size
BX	Rock cored with BX core barrel, which obtains a 41 mm-diameter core
C	Code for Denison or pitcher-type core barrel sample
C	Code for consolidation test for "Samples Type" column of boring log
C	Close (used to describe discontinuity spacing in rock core log)
C	Uncorrected pressure during deflation of flat plate dilatometer membrane.
c	Shape factor
c'	Drained or effective cohesion intercept of soil or rock from drained lab shear test.
C_α	Coefficient of secondary consolidation
$C_{\alpha\varepsilon}$	Coefficient of secondary compression in terms of strain
$C_{\alpha e}$	Coefficient of secondary compression in terms of void ratio
C_1	Hazen's coefficient
Ca	Calcite (used to describe type of infilling in rock core log)
CBR	California Bearing Ratio
C_c	Coefficient of curvature
C_c	(Virgin) Compression index
CD	Consolidated Drained
CDS	Completely Decomposed State
CH	Inorganic clays of high plasticity
Ch	Chlorite (used to describe type of infilling in rock core log)
c_h	Coefficient of horizontal consolidation
CL	Inorganic clays of low to medium plasticity
Cl	Clay (used to describe type of infilling in rock core log)
c_o	Cohesion of as-compacted soil
CP	Designation of rock core barrel
CPT	Cone Penetration Test
CR	Compression Ratio = $C_c/(1+e)$
C_r	Recompression Index
C_U	Uniformity coefficient; = D_{60} /D_{10}
CU	Consolidated Undrained (Triaxial shear test)
c_u	Undrained shear strength
c_v	Coefficient of vertical consolidation

D	Original diameter of rock sample
D	Apparent diameter of the soil particles
d	Primary consolidation at a specific load level
d	Depth
d	Distance between electrodes in resistivity survey.
D_{10}	Grain size than which 10% of the sample is smaller
D_{30}	Grain size than which 30% of the sample is smaller
D_{50}	Mean Grain Size; size than which 50% of the sample is finer
D_{60}	Grain size than which 60% of the sample is smaller
D_{max}	Largest grain size in soil sample
D_{min}	Smallest grain size in soil sample
DMT	Flat plate dilatometer test
D_r	Relative density of soil
DS	Code for direct shear test to be entered in the "Other Tests" column of boring log
D_s	Effective particle diameter
DSS	Direct Simple Shear
E	Elastic or Young's Modulus
e	Void ratio of soil
E_{av}	Average Young's Modulus
E_D	Equivalent elastic modulus obtained from flat dilatometer.
e_f	Final void ratio
E_M	Menard modulus from standard (prebored) pressuremeter test.
E_m	In-situ modulus of deformation
e_{max}	Void ratio of soil in its loosest state
e_{min}	Void ratio of soil in its densest state
e_o	Initial void ratio of sample
e_r	Void ratio at beginning of rebound
EROS	Earth Resources Observations Systems
E_s	Secant Young's Modulus
E_t	Tangent Young's Modulus
EW	Designation of flush-joint casing
EX	Designation of rock core barrel
F	Friable (term to describe rock hardness)
F	Fault (used to describe type of discontinuity in rock core log)
F	Fines; Corresponding to percent soil passing No. 200 sieve
f	Shear wave frequency
Fe	Iron oxide (used to describe type of infilling in rock core log)
Fi	Filled (used to describe amount of infilling in rock core log)
Fo	Foliation (used to describe type of discontinuity in rock core log)
f_s	Measured sleeve friction during CPT
FV	Field Vane or Vane Shear Test
GC	Clayey gravels, poorly graded gravel-sand-clay
GI	Group index in the AASHTO soil classification system
GM	Silty gravels, poorly graded gravel-sand-silt
GP	Poorly graded clean gravels, gravel-sand mixture
GPR	Ground Penetrating Radar

G_s	Specific gravity of soil solids
GW	Well graded clean gravels, gravel-sand mixture
Gy	Gypsum/Talc (used to describe a special type of infilling in rock core log)
H	High modulus ratio
H	Healed (used to describe type of infilling in rock core log)
H	Differential head of pressure on the test section
H	Hard (term to describe rock hardness)
H	Half height of consolidation sample (Length of longest drainage path)
H	Original height of rock sample
h_1, h_2	Heads at times t_1 and t_2, respectively
HQ	Dimension of rock core size
HW	Designation of drill rod
i	Angle of irregularities with average dip line
$I_{a(50)}$	Anisotropic point load strength index of rock specimen
I_D	Material index for obtaining soil type from flat plate dilatometer test.
I_{d2}	Slake-Durability Index
I_p, PI	Plasticity Index
Ir	Irregular (used to describe surface shape of joint in rock core log)
I_s	Point-load index
$I_{s(50)}$	Point load strength index of rock specimen with diameter = 50 mm
ISRM	International Society for Rock Mechanics
J	Joint (used to describe type of discontinuity in rock core log)
J_a	Joint alteration number in the Q System
JCS	Joint wall Compressive Strength
J_r	Joint roughness coefficient in the Q System
JRS	Joint Roughness Coefficient
J_v	Number of joints in unit volume of rock
k	Coefficient of permeability (hydraulic conductivity)
K_D	Lateral stress index from flat dilatometer.
K_o	Lateral stress coefficient for geostatic case.
L	Length of soil sample
L	Low modulus ratio
L_f	Length of footing
LFC	Length of fully cylindrical rock core piece
LH	Low hardness (term to describe rock hardness)
LI	Liquidity Index
LL	Liquid Limit
LPS	Latent Planes of Separation
LT	Length of rock core piece measured from tip to tip
M	Moderate (used to describe discontinuity spacing in rock core log)
M	Average modulus ratio
M	Mechanical (sieve or hydrometer) analysis
MFS	Micro Fresh State
MH	Inorganic clayey silts, elastic silts
MH	Moderately Hard (term to describe rock hardness)

ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts (Group symbol in Unified Soil Classifications System)
ML-CL	Mixtures of inorganic silts and clays
MW	Moderately wide (used to describe discontinuity width in rock core log)
N	Uncorrected Standard Penetration Test N-value (or blow counts).
n	Porosity
N_1	N-value normalized to an effective overburden stress of 1 atmosphere
N_{60}	SPT N-value corrected for energy to average 60% standard of practice.
$(N_1)_{60}$	SPT N-value corrected to 60% energy efficient and stress-normalized.
NC	Normally Consolidated
N_{corr}	N-value of saturated fine or silty sands corrected for pore pressure
N_{field}	N-value measured in the field
NGI	Norwegian Geotechnical Institute
No	None (used to describe amount or type of infilling in rock core log)
NQ	Dimension of rock core size
NR	No recovery of sample
NV	Designation of rock core barrel
NW	Designation of drill rod
NX	Rock cored with NX core barrel, which obtains a 53 mm-diameter core
OC	Overconsolidated
OCR	Overconsolidation Ratio
OH	Organic clays of medium to high plasticity, organic salts (Group symbol in Unified Soil Classifications System)
OL	Organic silts and organic silty clays of low plasticity (Group symbol in Unified Soil Classifications System)
OMC	Optimum Moisture Content
P	Piezometer
P	Code for thin-wall tube sample in the “Samples Type” column of boring log
p_1	Pressure B corrected for diaphragm stiffness in flat dilatometer test.
Pa	Partially filled (used to describe amount of infilling in rock core log)
p_c	Preconsolidation stress
PDS	Partly Decomposed State
p_f	Creep pressure during Menard-type pressuremeter test
PI	= LL - PL ; Plasticity index
PL	Plastic Limit
p_l	Limit pressure during Menard-type pressuremeter test
PLT	Point Load Test
PMT	Pressuremeter Test
P_o	Pressure corresponding to volume V_o during Menard-type pressuremeter test
p_o	Pressure A corrected for diaphragm stiffness in flat dilatometer tes.
PQ	Dimension of rock core size
Ps	Code for piston sample to be entered in the “Samples Type” column of boring log
Pt	Peat and other highly organic soils
PVC	Poly-vinyl chloride
PW	Designation of flush-joint casing
Py	Pyrite (used to describe type of infilling in rock core log)

Q	Constant rate of flow of water into the hole; Total discharge volume
q_c	Uncorrected cone tip resistance measured during CPT
q_t	Corrected cone tip stress or resistance during CPT
q_u	Unconfined compressive strength; Uniaxial compressive strength of rock
Qz	Quartz (used to describe type of infilling in rock core log)
R	Rough (used to describe roughness of surface in rock core log)
R	Shale rating
r	Radius of the test borehole
R-value	Value of resistance of the soil to lateral deformation when a vertical load acts on it
RMR	Rock Mass Rating
RQD	Rock Quality Designation
RR	Recompression Ratio = $C_r/(1+e)$
RW	Designation of drill rod
RW	Designation of flush-joint casing
S	Degree of saturation of soil
S	Smooth (used to describe roughness of surface in rock core log)
SC	Clayey sands, poorly graded sand-clay mixture
Sd	Sand (used to describe type of infilling in rock core log)
SDI	Slake Durability Index
Sh	Shear (used to describe type of discontinuity in rock core log)
SL	Shrinkage limit
Slk	Slickensided (used to describe roughness of surface in rock core log)
SM	Silty sands, poorly graded sand-silt mixture
SM-SC	Sand-silt-clay with slightly plastic fines
SMR	Slope rock Mass Rating
SP	Poorly graded clean sands, sand-gravel mixture
Sp	Spotty (used to describe amount of infilling in rock core log)
SPB	Preferred Breakage
SPT	Standard Penetration Test
SR	Slightly rough (used to describe roughness of surface in rock core log)
SRB	Random Breakage
SRS	Shale Rating System
SS	Code for standard spoon sample in the “Samples Type” column of boring log
St	Stepped (used to describe surface shape of joint in rock core log)
STS	Stained State
Su	Surface stain (used to describe amount of infilling in rock core log)
s_u	Undrained shear strength
s_{uv}	Vane shear strength (uncorrected)
$s_u/F_{vo}r$	Normalized undrained shear strength to effective overburden stress ratio.
SW	Well-graded sands, gravelly sands, little or no fines (Group symbol in USCS).
SW	Designation of flush-joint casing
T	Code for triaxial compression test in the “Other Tests” column of boring log
T	Topping failure; Tight (used to describe discontinuity width in rock core log)
T	Shear force on soil in a Direct Shear Test
t	Time
t_{100}	Time required for 100% consolidation at a specific load level

t_{50}	Time required for 50% consolidation at a specific load level
TV	Code for torvane index in the "Other Tests" column of boring log
U	Code for unconfined compression test in the "Other Tests" column of boring log
u	Porewater pressure
u_1	Porewater pressure during type 1 piezocone (midface element)
u_2	Porewater pressure during type 2 piezocone (shoulder element)
u_o	In-situ hydrostatic porewater pressure
USCS	Unified Soil Classification System
UU	Unconsolidated Undrained
UW	Designation of flush-joint casing
V	Potential drop in resistivity surveys
V	Vein (used to describe type of discontinuity in rock core log)
VC	Very close (used to describe discontinuity spacing in rock core log)
V_c	Initial volume of probe during Menard's pressuremeter test
V_f	volume corresponding to creep pressure p_f during Menard's pressuremeter test
VH	Very hard (term to describe rock hardness)
V_m	$(V_o + V_f)$ during Menard pressuremeter test
VN	Very narrow (used to describe discontinuity width in rock core log)
v_o	Difference between the volume of the hole and v_c
VR	Very rough (used to describe roughness of surface in rock core log)
V_s	Shear wave velocity
W	Wide (used to describe discontinuity width in rock core log)
W	Code for unit weight and water content in the "Other Tests" column of boring log
w	Natural moisture content
Wa	Wavy (used to describe surface shape of joint in rock core log)
W_n	Natural water content
X	Distance
X	Code for special tests performed in the "Other Tests" column of boring log
ZW	Designation of flush-joint casing
z	Depth (below ground)

[Blank]