Appendix C

Geotechnical Analysis and Design

C.1 Subsurface Investigation

Geotechnical Boring Program

A boring program was established to collect subsurface data necessary to evaluate the construction of existing embankments, type and condition of dam foundation materials and complete the analysis of several preliminary design features. Borings were also advanced at several properties near the dam site to evaluate materials for potential use as borrow, for earthen embankment construction. The geotechnical investigation was carried out by Braun Intertec.

Borings ST-1 and ST-2 were drilled through the north embankment. Borings ST-4 through ST-7 were drilled within the breach limits of the earthen dam. Borings ST-8 through ST-10 were drilled through the embankment that remains south of the breach. Borings ST-11 and ST-12 were drilled through the existing powerhouse and spillway bridge deck. All borings were advanced to sufficient depths to allow analysis and evaluation of soil and bedrock foundations for embankment/structural stability and seepage.

Soil samples were collected with split spoon and Shelby tube samplers. Blow counts (N-Values) were recorded by the Braun drilling crew. Soil samples were classified and tested. Testing on the soil boring samples included moisture content and dry density, Atterburg Limits, unconfined compression testing, and gradations.

Boring ST-11 and ST-12 were advanced through the existing walls and piers of the powerhouse and spillway. Continuous core samples were collected in the concrete and underlying bedrock foundation. Percent recovery and Rock Quality Designation (RQD) were recorded by the Braun drilling crew for all bedrock core collected. The bedrock core was classified and representative samples tested for unconfined strength.

Borings were also drilled at several properties in the vicinity of the dam to determine the extents and accessibility of loess and till materials for potential use in reconstruction of the earthen portion of the dam. Borings were advanced on the Wilson, Freiburger, and Harbach properties. Soil samples collected from the borings were classified and tested for moisture content, compaction testing and Atterberg Limits.

Borrow and Subsurface Soil Conditions

The north embankment subsurface material consists of up to 28 feet of sand and gravel fill material, underlain by approximately 10 feet of sandy lean clay. The sandy lean clay is underlain by approximately 15 feet of poorly graded sand to approximately elevation 852, where limestone bedrock is encountered.

At the center of the channel, boring ST-5 indicates that the bedrock has dropped off substantially (approximate elevation 842). A thick (20–25 ft) gravely sand (SP) layer lies between the base of the channel and the weathered limestone. At the south end of the channel, Borings ST-6 and ST-7 indicate a thin layer of sandy lean clay underlain by 70 to 80 ft of gravely sand material. No bedrock was encountered. Likewise, borings ST-8 through ST-10, advanced through the south embankment indicate clay fill materials underlain by gravely sand.

Sandy gravels encountered were primarily medium dense to dense with very little fines and high gravel faction. Bedrock encountered was generally moderately hard highly weathered limestone. Rock encountered at the north end of the power house was good in quality with high recoveries and RQD values. Boring ST-11 drilled directly through the power house showed moderately hard to hard vuggy limestone with relatively high recovery and RQD values as well as 3,300 psi to 11,000 psi unconfined compressive strength. From the south end of the powerhouse extending south into the channel, rock samples recovered showed low quality rock with numerous voids. The rock showed very low recovery and RQD values.

The borrow evaluation borings typically encountered two soil types underlying the topsoil. A silty clay loess, overlying a silty clay glacial till soil. The loess soils, while potentially acceptable for embankment construction were typically encountered at very high moisture contents, requiring excavation and spreading (farming) in order to get the material to an acceptable moisture content for placement and compaction. The till soils typically provide a superior material for embankment construction and have in-situ moisture contents closer to those required for placement and compaction in an earthen embankment. The till soils were encountered at depths of 12 feet or more, under the loess soils, so significant excavation would be required to develop these soils for borrow. Additional future investigations by the Contractor may locate the till soils at shallower depths for borrow development. Both materials indicate acceptable strength and seepage properties for use in earthen dams.

Design Parameters

Parameters were developed for use in the seepage and slope stability analysis based on published tables in EM 1110-2-2504 [6]. Laboratory test Atterberg Limits were used to determine effective (drained) parameters for fill materials (empirical correlation between

friction angle and plasticity index from triaxial tests on normally consolidated clays) [6]. Refer to Table C-1 below for design parameters.

Table C-1 Geotechnical Design Parameters

Material Type	Unit Weight (pcf)	Undrained Shear Strength, c (psf)	Friction Angle, φ (deg)	Drained Friction Angle, φ' (deg)
Glacial Till (CL)	110	2000	0	28
Loess (CL)	110	1000	0	28
Foundation (SP)	125	0	30	30

At the time of this report, Braun was in the process of drilling one additional borrow site boring and one additional boring through the powerhouse. The boring logs and corresponding subsurface data for the two additional borings will be provided in subsequent submittals.

The full preliminary geotechnical report developed by Braun Intertec [1] is included within this appendix.

C.2 Seepage Analysis

Methods

Seepage analysis was conducted for proposed embankment and seepage control measures using GeoStudio's SEEP/W finite element seepage modeling program. Soil classification and laboratory gradation results were used to develop input seepage parameters. Permeability coefficients were determined according to Hazen's empirical formula using D_{10} values (particle diameter corresponding to 10% passing). The proposed service and auxiliary embankments (located within the current breach) were modeled with various cutoff depths and configurations. Horizontal blanket drains were also included in the model, for safe collection and conveyance of seepage flows, without saturating the downstream slope of the embankments.

Results

Exit gradients (exit gradient is defined as the rate of change of total head pressure with distance) and seepage flow rates were analyzed to come up with an optimized and adequate cutoff/drainage system. To achieve the target factor of safety of 1.5, the target exit gradient was assumed as 0.67. This assumes a critical gradient of the material of 1.0. To achieve the target gradient, the sheet pile cutoff was designed as 35 feet below base of the new embankment (into sand foundation).

All seepage computations are provided following the narrative portion of this appendix.

C.3 Stability Analysis

Methods

Stability analysis was carried out using GeoStudio's SLOPE/W (2007) modeling program [3]. Spencer's Method was used to find minimum factors of safety for various loading conditions. The United States Army Corps of Engineers' Slope Stability Engineering Manual [4] was consulted for required loading conditions and factors of safety for new earth and rock-fill dams. The Iowa Department of Natural Resources Technical Bulletin on Dam Design Criteria [5] was used as a baseline for the determination of embankment slopes. An end-of-construction case was analyzed on the downstream embankment slope using total stress (undrained) soil parameters. The minimum required factor of safety for the total stress condition is 1.3. Also, long-term steady state seepage conditions were modeled using effective stress soil parameters (drained parameters) with a required minimum factor of safety of 1.5. For the long-term steady state condition, a maximum surcharge pool was assumed with water to the top of the spillway crest (top of labyrinth weir). To account for the decreased water surcharge loading as a result of the labyrinth weir, 50% of the water surcharge load was considered along the width of the weir. A rapid drawdown condition was not modeled because it is unlikely that the pool will ever be rapidly drained.

Results

For proposed new embankment sections, slope stability was analyzed for embankments constructed of locally available borrow materials (identified in Braun Intertec investigation of borrow areas) as well as roller compacted concrete (RCC). It was determined that 3 horizontal on 1 vertical slopes are required for the both the upstream and the downstream faces of embankments constructed of loess or till in order to satisfy all design requirements. Roller compacted concrete faced embankments meet design requirements if constructed with 2.5 horizontal on 1 vertical downstream slopes.

Results of the stability analysis for the various modeled cases are provided in Table C-2 below.

Table C-2 Stability Analysis Results

Spillway	Design Case	Min. FOS (FS_{min})	Required FOS (FS_{req})
Service	Total Stress	1.995	1.3
	Effective Stress	1.539	1.5
Auxiliary	Total Stress	1.916	1.3
	Effective Stress	1.607	1.5
Auxiliary (RCC)[1]	Total Stress	1.817	1.3
	Effective Stress	1.498	1.5

[1] Note that RCC option for aux. spillway was modeled with 2.5:1 slopes.

All stability computations are provided following the narrative portion of this appendix.

C.4 Settlement Analysis

General

Long -term consolidation settlement is not anticipated as embankment construction will take place on subsurface sands. Given the sand foundation material, a majority of settlement will occur as construction proceeds. Settlement within the embankment fill will be limited by proper placement, moisture control, and compaction of embankment fill. As mentioned previously, some of the loess borrow material may require drying prior to placement in order to achieve desired compaction and density values.

C.5 References

1. Braun Intertec Corporation. *Lake Delhi Dam Restoration Geotechnical Services Report*. December 5, 2011.
2. Seepage Modeling with SEEP/W. GeoStudio 2004. GEO-SLOPE International Ltd.
3. Stability Modeling with SLOPE/W. GeoStudio 2007. GEO-SLOPE International Ltd.
4. U.S. Army Corps of Engineers. EM 1110-2-1902. *Slope Stability*. October 2003.
5. Iowa Department of Natural Resources. Technical Bulletin No. 16. *Design Criteria and Guidelines for Iowa Dams*. December 1990.
6. U.S. Army Corps of Engineers. EM 1110-2-2504. *Engineering and Design of Sheet Pile Walls*. March 1994.
7. U.S. Army Corps of Engineers. EM 1110-2-1913. *Design and Construction of Levees*. April 2000.
8. U.S. Army Corps of Engineers. EM 1110-2-1902. *Slope Stability*. October 2003.
9. U.S. Army Corps of Engineers. EM 1110-2-2300. *Engineering and Design – General Design and Construction Considerations for Earth and Rock-Fill Dams*. July 2004.
10. U.S. Army Corps of Engineers. EM 1110-2-1901. *Seepage Analysis and Control for Dams*. April 1993.
11. U.S. Army Corps of Engineers. EM 1110-2-2006. *Roller-Compacted Concrete*. January 2000.

Geotechnical Computations and Reference Material

Braun Intertec Corp. Geotechnical Report

BRAUN
INTERTEC

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Phone: 319.365.0961
Fax: 319.365.1306
Web: braunintertec.com

December 5, 2011 Project CR-11-00665

Mr. Bill Holman, PE
Stanley Consultants Inc.
5775 Wayzata Boulevard, Suite 300
Minneapolis, MN 55416

Re: Geotechnical Services
Soil Boring, Rock Coring, Concrete Coring, and Laboratory Testing
Lake Delhi Dam Restoration
Delhi, Iowa

Dear Mr. Holman:

The purpose of this submittal is to transmit to you the results of our soil borings, rock coring, concrete coring and laboratory testing to assist Stanley Consultants with their analysis and concept development for restoration of the for of the existing levee along the Mississippi River in Clinton, Iowa.

Procedures

Site Access and Utility Clearance

Prior to drilling, our drillers staked the boring locations in the field using a cloth tape and measuring from existing site features based on the plan that you provided to us showing recent survey information. Elevations on the boring logs were interpolated from the topographic lines on these plans. Prior to drilling, we contacted Iowa One Call to request they clear public utilities in the areas to be explored.

Penetration Test Borings

We mobilized an ATV-mounted drill rig to drill ten borings (ST1 to ST10) to depths of about 40 to 80 feet below existing grade or below the existing water level in the Maquoketa River along the centerline of the previously existing dam. Two borings were cored through the existing dam and into the underlying bedrock. These two borings (ST11 and ST12) extended approximately 107 feet below the top of the dam with the upper 57 feet consisting of concrete. Seven borings (B1 through B7) were drilled in farm fields south of the dam site for the purpose of evaluating potential borrow material for new dam construction. The locations of all of these borings are shown on the attached location plans.

The borings were advanced using 2¼-inch hollow stem augers or wash boring methods below the water table. Rock coring was performed with a standard NQ size core barrel. Coring through the concrete dam was performed with a larger HQ core barrel. In general, penetration test samples or thin-walled tube samples of the soils were taken at 2½- to 5-foot intervals. Actual sample intervals and corresponding depths are shown on the boring logs. In the borrow borings, samples were obtained from the augers.

Water level observations are recorded on the boring logs where possible. In some cases, the addition of drilling fluid during wash boring methods obscured water levels. After completion the boreholes that

were drilled into sand below the water table were allowed to collapse. Borrow borings and abutment borings above the water table were backfilled with cuttings. The concrete dam borings were sealed with cement/bentonite grout.

Concrete Coring

Concrete coring was performed at 17 locations on the existing concrete portion of the Lake Delhi Dam at the locations shown on the two core location sketches that were provided to us. Cores were obtained with an electric portable coring machine using a diamond-tipped core barrel 2 to 3 inches in diameter.

Sample Review and Laboratory Testing

The geologic materials encountered were visually and manually classified in accordance with ASTM Standard Practice D 2488 by a geotechnical engineer. A chart explaining the classification system is attached. Samples were placed in jars or bags and returned to our facility for review, storage and laboratory testing.

After initial classification, draft boring logs were provided and a testing schedule was established. The testing program included: mechanical analyses (ASTM D422), unconfined compression tests on rock cores (ASTM D2983), plastic and liquid limits tests (ASTM D4318), laboratory compaction tests (ASTM D698), moisture content measurements (ASTM D2216), and hand penetrometer tests. The results of our tests are provided on the boring logs at the corresponding sample depths. Grain size curves for the mechanical analyses and the moisture density curves for laboratory compaction tests are included on separate sheets.

Results

The results of our field and laboratory work are included with this submittal in the following order:

- Dam Centerline Boring Location Plan and Logs of Borings ST1 through ST12
- Borrow Boring Location Plan and Logs of Borings B1 through B7
- Grain Size Curves
- Moisture-Density Relationship Curves
- Concrete Core Location Plans
- Table of Concrete Core Compressive Strengths and Pictures of Fractured Cores

Use of Report & Standard of Care

This report is for the exclusive use of the parties to which it has been addressed. Without written approval, we assume no responsibility to other parties regarding this report. Our evaluation, analyses and recommendations may not be appropriate for other parties or projects.

This report is based on information obtained from the borings and our experience with these types of soils. Conditions could exist in places other than our borings that could adversely affect levee performance. In performing its services, Braun Intertec used that degree of care and skill ordinarily

exercised under similar circumstances by reputable members of its profession currently practicing in the same locality. No warranty, express or implied, is made.

To have questions answered or schedule a time to meet and discuss these results, please feel free to call us at 319.310.6213.

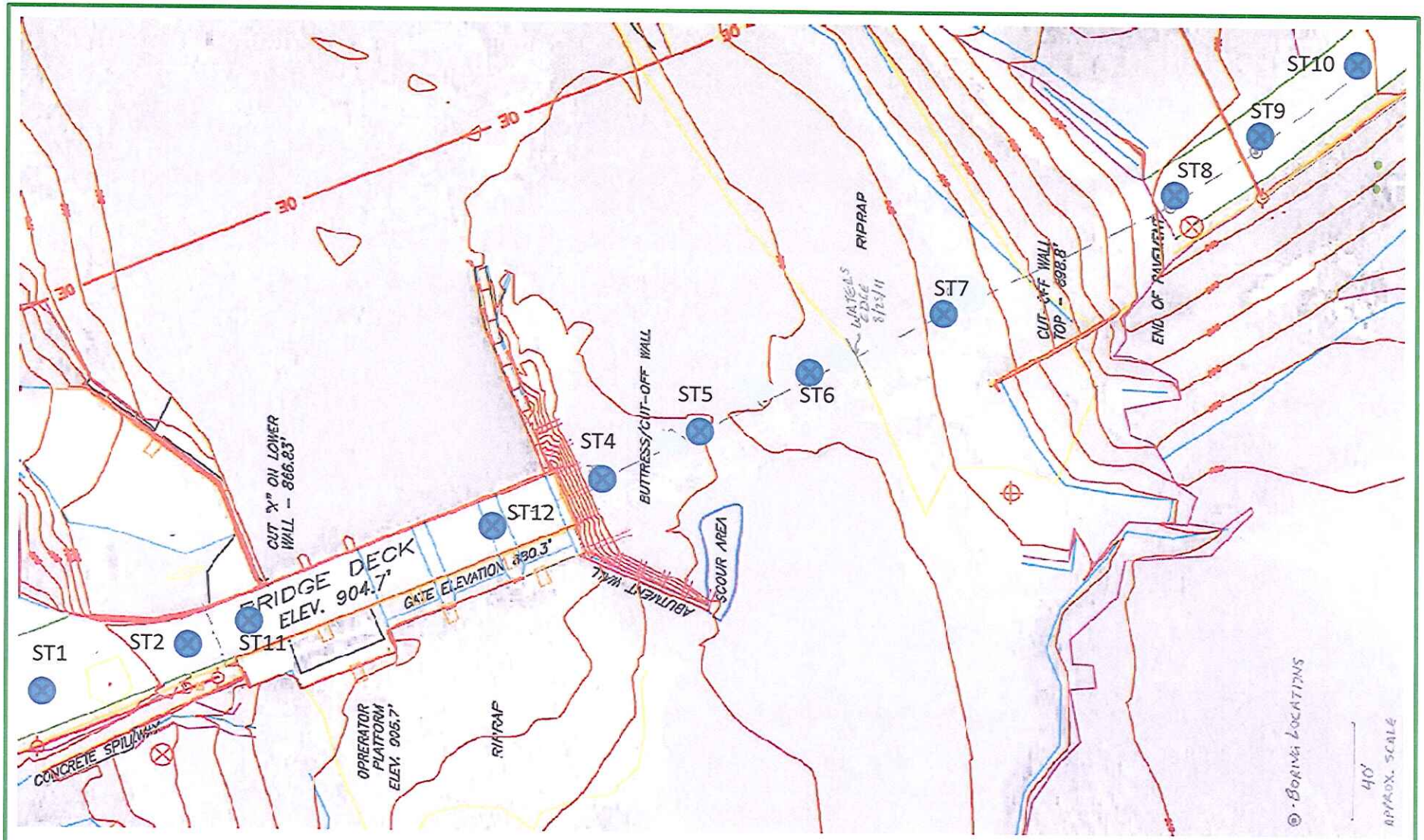
Sincerely,

BRAUN INTERTEC CORPORATION

Timothy T. Wiles
Principal/Senior Engineer

CR-11-00665report

Dam Centerline Boring Location Plan and Logs of Borings ST1 through ST12



Source: Stanley Consultants

Approximate scale as shown

Lake Delhi Dam Restoration Delhi, Iowa	Project: CR-11-00665	Dam Centerline Boring Location Plan	BRAUN INTERTEC

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LOG OF BORING

Braun Project CR-11-00665
Geotechnical Evaluation
Lake Dehli
Delhi, Iowa

BORING: **ST-1**

LOCATION: See attached sketch

DRILLER: R.Hunt/D.Dyer | METHOD: NQ Wireline Core/ Power Auger | DATE: **10/14/11** | SCALE: **1" = 4'**

(See Descriptive Terminology sheet for explanation of abbreviations)

Elev. feet	Depth feet	Symbol	Description of Materials (Soil- ASTM D2488 or D2487, Rock-USACE EM1110-1-2908)	BPF	WL	Tests or Notes
905.0	0.0					
904.2	0.8	PAV	Portland Cement Concrete			
		FILL	FILL: Poorly Graded Gravel with Sand, gray to brown	17		
898.0	7.0					
		FILL	FILL: Lean Clay with Sand and Gravel, brown to dark brown	5		
892.0	13.0					
		LS	Very highly weathered LIMESTONE, gray	50/5		
889.0	16.0					
		LS	Auger Refusal at 16 feet Highly weathered LIMESTONE, gray, moderately hard, highly fractured, numerous small voids, clay seams from 26 to 36 feet			REC = 41% RQD = 12% REC = 10% RQD = 0%

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Geotechnical Evaluation
Lake Dehli
Delhi, Iowa

BORING: **ST-1 (cont.)**

LOCATION: See attached sketch

DRILLER: R.Hunt/D.Dyer | METHOD: NQ Wireline Core/ Power Auger | DATE: **10/14/11** | SCALE: **1" = 4'**

(See Descriptive Terminology sheet for explanation of abbreviations)

Elev. feet	Depth feet	Symbol	Description of Materials (Soil- ASTM D2488 or D2487, Rock-USACE EM1110-1-2908)	BPF	WL	Tests or Notes
873.0	32.0		Highly weathered LIMESTONE, gray, moderately hard, highly fractured, numerous small voids, clay seams from 26 to 36 feet *(continued)*			REC = 25% RQD = 0%
865.0	40.0		END OF BORING. Water not observed while drilling. Boring then backfilled.			

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Lake Dehli
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BORING: **ST-2**

LOCATION: See attached sketch

DRILLER: R.Hunt/D.Dyer | METHOD: NQ Wireline Core./HSA | DATE: **10/13/11** | SCALE: **1" = 4'**

Elev. feet	Depth feet	Symbol	Description of Materials (Soil- ASTM D2488 or D2487, Rock-USACE EM1110-1-2908)	BPF	WL	MC %	Tests or Notes
905.0	0.0						
904.5	0.5	PAV	Portland Cement Concrete				
		AIR	Air Void				
903.0	2.0						
		FILL	FILL: Poorly Graded Sand with Gravel and occasional Clay seams	6			
				7			
892.5	12.5						
		FILL	FILL: Poorly Graded Gravel with Sand, gray	7			
				50			
				11			
877.0	28.0						
		CL	SANDY LEAN CLAY, gray, wet, very soft (Alluvium)	WH		19	
873.0	32.0						

(See Descriptive Terminology sheet for explanation of abbreviations)

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BORING: **ST-2 (cont.)**
LOCATION: See attached sketch

DRILLER: R.Hunt/D.Dyer | METHOD: NQ Wireline Core./HSA | DATE: 10/13/11 | SCALE: 1" = 4'

(See Descriptive Terminology sheet for explanation of abbreviations)

Elev. feet	Depth feet	Symbol	Description of Materials (Soil- ASTM D2488 or D2487, Rock-USACE EM1110-1-2908)	BPF	WL	MC %	Tests or Notes
873.0	32.0	CL	SANDY LEAN CLAY, with LIMESTONE fragments, brown, moist, medium (Alluvium)	6		20	
868.0	37.0	SP	POORLY GRADED SAND with GRAVEL, gray, wet, medium dense to dense (Residuum)	31			
				11			
				39	▽		
852.0	53.0	LS	Auger Refusal at 53 feet				REC = 100% RQD = 70%
			Highly weathered LIMESTONE, gray, highly fractured, moderately hard, small voids				REC = 95%

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BORING: **ST-2 (cont.)**

LOCATION: See attached sketch

DRILLER: R.Hunt/D.Dyer | METHOD: NQ Wireline Core./HSA | DATE: **10/13/11** | SCALE: **1" = 4'**

Elev. feet	Depth feet	Symbol	Description of Materials (Soil- ASTM D2488 or D2487, Rock-USACE EM1110-1-2908)	BPF	WL	MC %	Tests or Notes
841.0	64.0						
			Highly weathered LIMESTONE, gray, highly fractured, moderately hard, small voids *(continued)*				RQD = 53%
832.0	73.0						
			END OF BORING.				
			Wate observed at 49 feet while drilling.				
			Boring then backfilled.				

(See Descriptive Terminology sheet for explanation of abbreviations)

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BORING: **ST-4**

LOCATION: See attached sketch

DRILLER: R.Hunt/D.Dyer | METHOD: NQ Wireline Core./HSA | DATE: 9/9/11 | SCALE: 1" = 4'

(See Descriptive Terminology sheet for explanation of abbreviations)

Elev. feet	Depth feet	Symbol	Description of Materials (Soil- ASTM D2488 or D2487, Rock-USACE EM1110-1-2908)	BPF	WL ▽	Tests or Notes
868.0	0.0	WATER	Water			
865.0	3.0	GP	POORLY GRADED GRAVEL, with SAND and SILT, brown, wet			
862.0	6.0	CONC	Portland Cement Concrete			REC = 67% RQD = 6%
861.0	7.0	LS	Highly Weathered LIMESTONE, gray, moderately hard, slightly to moderately fractured, small voids			
857.0	11.0		VOID			
853.5	14.5	LS	Highly Weathered LIMESTONE, gray, moderately hard, highly fractured			
852.0	16.0	LS	Highly Weathered LIMESTONE, gray, moderately hard, very fractured, small voids			REC = 10% RQD = 5%
842.0	26.0	LS	Highly Weathered LIMESTONE, gray, moderately hard, highly fractured			REC = 20% RQD = 8%
839.5	28.5		VOID			
837.0	31.0	LS				

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BORING: **ST-4 (cont.)**
LOCATION: See attached sketch

DRILLER: R.Hunt/D.Dyer | METHOD: NQ Wireline Core./HSA | DATE: **9/9/11** | SCALE: **1" = 4'**

(See Descriptive Terminology sheet for explanation of abbreviations)

Elev. feet	Depth feet	Symbol	Description of Materials (Soil- ASTM D2488 or D2487, Rock-USACE EM1110-1-2908)	BPF	WL	Tests or Notes
836.0	32.0		Highly Weathered LIMESTONE,gray, moderately hard, highly fractured *(continued)*			
832.0	36.0	LS	Highly weathered LIMESTONE, gray, moderately hard, moderately fractured, porous, small voids			REC = 98% RQD = 51%
822.0	46.0	LS	Highly weathered LIMESTONE, moderately hard, moderately factured, vuggy			REC = 90% RQD = 72%
817.0	51.0		END OF BORING.			

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BORING: **ST-5**

LOCATION: See attached sketch

DRILLER: R.Hunt/D.Dyer | METHOD: NQ Wireline Core/Mud Rotary | DATE: 9/13/11 | SCALE: 1" = 4'

Elev. feet	Depth feet	Symbol	Description of Materials (Soil- ASTM D2488 or D2487, Rock-USACE EM1110-1-2908)	BPF	WL	Tests or Notes
868.0	0.0	WATER	Water		▽	
866.5	1.5	SP	POORLY GRADED SAND with GRAVEL, fine- to coarse-grained, loose to medium dense, more gravel at 20 feet (Alluvium)			
				10		
				22		
				27		
842.0	26.0	LS	Auger Refusal at 26 feet			
			Highly weathered LIMESTONE, gray, moderately hard, highly fractured, porous			REC = 40% RQD = 22%
			lost circulation at 31 feet			

(See Descriptive Terminology sheet for explanation of abbreviations)

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BORING: **ST-5 (cont.)**
LOCATION: See attached sketch

DRILLER: R.Hunt/D.Dyer | METHOD: NQ Wireline Core/Mud Rotary | DATE: **9/13/11** | SCALE: **1" = 4'**

(See Descriptive Terminology sheet for explanation of abbreviations)

Elev. feet	Depth feet	Symbol	Description of Materials (Soil- ASTM D2488 or D2487, Rock-USACE EM1110-1-2908)	BPF	WL	Tests or Notes
836.0	32.0		Highly weathered LIMESTONE, gray, moderately hard, highly fractured, porous lost circulation at 31 feet *(continued)*			
832.0	36.0	LS	Highly weathered LIMESTONE, gray, moderately hard, highly fractured, vuggy regained circulation at 44 feet			REC = 20% RQD = 3%
822.0	46.0	LS	Highly weathered LIMESTONE, gray, highly fractured			REC = 0% RQD = 0%
812.0	56.0		END OF BORING.			

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BORING: **ST-6**

LOCATION: See attached sketch

DRILLER: R.Hunt/D.Dyer | METHOD: Mud Rotary | DATE: 9/29/11 | SCALE: 1" = 4'

(See Descriptive Terminology sheet for explanation of abbreviations)

Elev. feet	Depth feet	Symbol	Description of Materials (Soil- ASTM D2488 or D2487, Rock-USACE EM1110-1-2908)	BPF	WL	Tests or Notes
867.0	0.0	SP	POORLY GRADED SAND with GRAVEL, fine- to coarse-grained, moist, dense (Alluvium)	31		
860.0	7.0	CL	LEAN CLAY with SAND and GRAVEL, dark gray, moist, rather soft (Alluvium)	5		
857.5	9.5	SP	POORLY GRADED SAND, with GRAVEL, fine- to coarse-grained, wet, dense (Alluvium)		▽	
853.0	14.0	GP	POORLY GRADED GRAVEL, with SAND, wet, medium dense to dense (Alluvium)	41		No Recovery
				49		
				11		
841.0	26.0	SW	WELL-GRADED SAND, with GRAVEL, fine- to coarse-grained, wet, medium dense to dense (Alluvium)	36		

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Delhi, Iowa

BORING: **ST-6 (cont.)**
LOCATION: See attached sketch

DRILLER: R.Hunt/D.Dyer | METHOD: Mud Rotary | DATE: 9/29/11 | SCALE: 1" = 4'

Elev. feet	Depth feet	Symbol	Description of Materials (Soil- ASTM D2488 or D2487, Rock-USACE EM1110-1-2908)	BPF	WL	Tests or Notes
835.0	32.0		WELL-GRADED SAND, with GRAVEL, fine- to coarse-grained, wet, medium dense to dense (Alluvium) *(continued)*			
				20		
				15		
				22		
				13		
817.0	50.0		END OF BORING.			
			Water observed at 10 feet while drilling.			
			Boring then backfilled.			

(See Descriptive Terminology sheet for explanation of abbreviations)

LOG OF BORING N:\GINT\PROJECTS\CEDARRAPIDS\2011\00665.GPJ BRAUN_V8_CURRENT.GDT 11/23/11 14:06

BRAUN INTERTEC

LOG OF BORING

Braun Project CR-11-00665
Geotechnical Evaluation
Lake Dehli
Delhi, Iowa

BORING: **ST-7**

LOCATION: See attached sketch

DRILLER: R.Hunt/D.Dyer | METHOD: Mud Rotary/HSA | DATE: **9/30/11** | SCALE: **1" = 4'**

(See Descriptive Terminology sheet for explanation of abbreviations)

Elev. feet	Depth feet	Symbol	Description of Materials (Soil- ASTM D2488 or D2487, Rock-USACE EM1110-1-2908)	BPF	WL	Tests or Notes
870.0	0.0	SP	POORLY GRADED SAND with SILTY and GRAVEL, trace Clay, brown, fine- to coarse-grained, moist, loose (Alluvium)			
				9		
				7		
859.0	11.0	SP	POORLY GRADED SAND with GRAVEL, brown, fine- to coarse-grained, wet, loose to medium dense (Alluvium)		▽	
				10		
				6		
				7		
				9		

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BRAUN INTERTEC

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Braun Project CR-11-00665
Geotechnical Evaluation
Lake Dehli
Delhi, Iowa

BORING: **ST-7 (cont.)**
LOCATION: See attached sketch

DRILLER: R.Hunt/D.Dyer | METHOD: Mud Rotary/HSA | DATE: **9/30/11** | SCALE: **1" = 4'**

Elev. feet	Depth feet	Symbol	Description of Materials (Soil- ASTM D2488 or D2487, Rock-USACE EM1110-1-2908)	BPF	WL	Tests or Notes
838.0	32.0		POORLY GRADED SAND with GRAVEL, brown, fine- to coarse-grained, wet, loose to medium dense (Alluvium) *(continued)*	3		
				13		
				12		
				18		
820.0	50.0		END OF BORING.			

(See Descriptive Terminology sheet for explanation of abbreviations)

LOG OF BORING N:\GINT\PROJECTS\CEDARRAPIDS\2011\00665.GPJ BRAUN_V8_CURRENT.GDT 11/23/11 14:07

BRAUN INTERTEC

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Braun Project CR-11-00665
Geotechnical Evaluation
Lake Dehli
Delhi, Iowa

BORING: **ST-8**

LOCATION: See attached sketch

DRILLER: R.Hunt/D.Dyer | METHOD: Mud Rotary/HSA | DATE: 10/3/11 | SCALE: 1" = 4'

Elev. feet	Depth feet	Symbol	Description of Materials (Soil- ASTM D2488 or D2487, Rock-USACE EM1110-1-2908)	BPF	WL	MC %	Tests or Notes
905.0	0.0						
904.5	0.5	AGG	3" Asphaltic Concrete, 3" Portland Cement Concrete				
		FILL	FILL: Very Sandy Lean Clay, brown, moist	13		17	
				4		20	
892.0	13.0						
		FILL	FILL: Lean Clay with Sand and Gravel, brown, moist	10			
887.0	18.0						
		SP	POORLY GRADED SAND with Gravel trace Silt, fine- to coarse-grained, brown, loose	8			
				9			
878.0	27.0						
		SW	WELL-GRADED SAND, trace Gravel, fine- to coarse-grained, brown, medium dense (Alluvium)	16			

(See Descriptive Terminology sheet for explanation of abbreviations)

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Braun Project CR-11-00665
Geotechnical Evaluation
Lake Dehli
Delhi, Iowa

BORING: **ST-8 (cont.)**
LOCATION: See attached sketch

DRILLER: R.Hunt/D.Dyer | METHOD: Mud Rotary/HSA | DATE: **10/3/11** | SCALE: **1" = 4'**

(See Descriptive Terminology sheet for explanation of abbreviations)

Elev. feet 873.0	Depth feet 32.0	Symbol	Description of Materials (Soil- ASTM D2488 or D2487, Rock-USACE EM1110-1-2908)	BPF	WL	MC %	Tests or Notes
			WELL-GRADED SAND, trace Gravel, fine- to coarse-grained, brown, medium dense (Alluvium) *(continued)*	12			
				22			
				22			
				16			
				25			
				18			
				19			

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BRAUN INTERTEC

LOG OF BORING

Braun Project CR-11-00665
Geotechnical Evaluation
Lake Dehli
Delhi, Iowa

BORING: **ST-8**
LOCATION: See attached sketch

DRILLER: R.Hunt/D.Dyer | METHOD: Mud Rotary/HSA | DATE: **10/3/11** | SCALE: **1" = 4'**

(See Descriptive Terminology sheet for explanation of abbreviations)

Elev. feet	Depth feet	Symbol	Description of Materials (Soil- ASTM D2488 or D2487, Rock-USACE EM1110-1-2908)	BPF	WL	MC %	Tests or Notes
905.0	0.0						
904.5	0.5	AGG	3" Asphaltic Concrete, 3" Portland Cement Concrete				
		FILL	FILL: Very Sandy Lean Clay, brown, moist				
				13		17	
				4		20	
892.0	13.0						
		FILL	FILL: Lean Clay with Sand and Gravel, brown, moist	10			
887.0	18.0						
		SP	POORLY GRADED SAND with Gravel trace Silt, fine- to coarse-grained, brown, loose	8			
				9			
878.0	27.0						
		SW	WELL-GRADED SAND, trace Gravel, fine- to coarse-grained, brown, medium dense (Alluvium)	16			

LOG OF BORING N:\GINT\PROJECTS\CEDARRAPIDS\2011\00665.GPJ BRAUN_V8_CURRENT.GDT 11/23/11 14:19

BRAUN INTERTEC

LOG OF BORING

Braun Project CR-11-00665
Geotechnical Evaluation
Lake Dehli
Delhi, Iowa

BORING: **ST-8 (cont.)**
LOCATION: See attached sketch

DRILLER: R.Hunt/D.Dyer | METHOD: Mud Rotary/HSA | DATE: **10/3/11** | SCALE: **1" = 4'**

Elev. feet 873.0	Depth feet 32.0	Symbol	Description of Materials (Soil- ASTM D2488 or D2487, Rock-USACE EM1110-1-2908)	BPF	WL	MC %	Tests or Notes
			WELL-GRADED SAND, trace Gravel, fine- to coarse-grained, brown, medium dense (Alluvium) *(continued)*	12			
				22			
				22			
				16			
				25			
				18			
				19			

(See Descriptive Terminology sheet for explanation of abbreviations)

LOG OF BORING N:\GINT\PROJECTS\CEDARRAPIDS\2011\00665.GPJ BRAUN_V8_CURRENT.GDT 11/23/11 14:19

BRAUN INTERTEC

LOG OF BORING

Braun Project CR-11-00665
Geotechnical Evaluation
Lake Dehli
Delhi, Iowa

BORING: **ST-8 (cont.)**

LOCATION: See attached sketch

DRILLER: R.Hunt/D.Dyer | METHOD: Mud Rotary/HSA | DATE: **10/3/11** | SCALE: **1" = 4'**

Elev. feet	Depth feet	Symbol	Description of Materials (Soil- ASTM D2488 or D2487, Rock-USACE EM1110-1-2908)	BPF	WL	MC %	Tests or Notes
841.0	64.0						
			WELL-GRADED SAND, trace Gravel, fine- to coarse-grained, brown, medium dense (Alluvium) *(continued)*				
837.0	68.0						
		SP	POORLY GRADED SAND, trace Silt and Gravel, fine- to coarse-grained, medium dense	22			
				21			
				27			
825.0	80.0						
			END OF BORING.				
			Water observed at 53 feet while drilling.				
			Boring then backfilled.				

(See Descriptive Terminology sheet for explanation of abbreviations)

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LOG OF BORING

Braun Project CR-11-00665
Geotechnical Evaluation
Lake Dehli
Delhi, Iowa

BORING: **ST-9**

LOCATION: See attached sketch

DRILLER: R.Hunt/D.Dyer | METHOD: Mud Rotary/HSA | DATE: **10/6/11** | SCALE: **1" = 4'**

(See Descriptive Terminology sheet for explanation of abbreviations)

Elev. feet	Depth feet	Symbol	Description of Materials (Soil- ASTM D2488 or D2487, Rock-USACE EM1110-1-2908)	BPF	WL	MC %	Tests or Notes
907.5	0.0						
907.0	0.5	AGG	3" Asphaltic Concrete, 3" Portland Cement Concrete				
		FILL	FILL: Very Sandy Lean Clay with some Gravel trace Silt, brown, moist				
				21		12	
				5		18	
895.5	12.0						
		FILL	FILL: Lean Clay with Sand and Gravel, brown, moist				
				14		17	
890.5	17.0						
		SP	POORLY GRADED SAND with GRAVEL trace Silt, fine- to coarse-grained, loose to medium dense (Alluvium)				
				3			
				14			
				14			

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Braun Project CR-11-00665
Geotechnical Evaluation
Lake Dehli
Delhi, Iowa

BORING: **ST-9 (cont.)**
LOCATION: See attached sketch

DRILLER: R.Hunt/D.Dyer | METHOD: Mud Rotary/HSA | DATE: **10/6/11** | SCALE: **1" = 4'**

(See Descriptive Terminology sheet for explanation of abbreviations)

Elev. feet	Depth feet	Symbol	Description of Materials (Soil- ASTM D2488 or D2487, Rock-USACE EM1110-1-2908)	BPF	WL	MC %	Tests or Notes
875.5	32.0		POORLY GRADED SAND with GRAVEL trace Silt, fine- to coarse-grained, loose to medium dense (Alluvium) *(continued)*	22	▽		
870.5	37.0	SM	SILTY SAND, fine- to coarse-grained, brown, medium dense	20			
866.5	41.0	SP	POORLY GRADED SAND with GRAVEL trace Silt, fine- to coarse-grained, medium dense to dense	32			
				25			
				24			
				23			
				30			

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Braun Project CR-11-00665
Geotechnical Evaluation
Lake Dehli
Delhi, Iowa

BORING: **ST-9 (cont.)**
LOCATION: See attached sketch

DRILLER: R.Hunt/D.Dyer | METHOD: Mud Rotary/HSA | DATE: **10/6/11** | SCALE: **1" = 4'**

Elev. feet	Depth feet	Symbol	Description of Materials (Soil- ASTM D2488 or D2487, Rock-USACE EM1110-1-2908)	BPF	WL	MC %	Tests or Notes
843.5	64.0		POORLY GRADED SAND with GRAVEL trace Silt, fine- to coarse-grained, medium dense to dense *(continued)*				
				26			
837.5	70.0		END OF BORING.				
			Water observed at 36 feet while drilling.				
			Boring then backfilled.				

(See Descriptive Terminology sheet for explanation of abbreviations)

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Braun Project CR-11-00665
Geotechnical Evaluation
Lake Dehli
Delhi, Iowa

BORING: **ST-10**

LOCATION: See attached sketch

DRILLER: R. Hunt/D.Dyer | METHOD: Mud Rotary/HSA | DATE: **10/10/11** | SCALE: **1" = 4'**

Elev. feet	Depth feet	Symbol	Description of Materials (Soil- ASTM D2488 or D2487, Rock-USACE EM1110-1-2908)	BPF	WL	MC %	Tests or Notes
909.5	0.0						
909.0	0.5	PAV	3" Aggergate, 3" Portland Cement Concrete				
		FILL	FILL: Very Sandy Lean Clay, brown, moist				
				8		18	
				7		15	
897.5	12.0						
		FILL	FILL: Lean Clay with Sand and Gravel, brown, moist				
				13		12	
				12		20	
887.5	22.0						
		SP	POORLY GRADED SAND trace GRAVEL, trace Silt, brown to gray, wet, loose to dense (Alluvium)				
				8			
					▽		
				13			

(See Descriptive Terminology sheet for explanation of abbreviations)

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LOG OF BORING

Braun Project CR-11-00665
Geotechnical Evaluation
Lake Dehli
Delhi, Iowa

BORING: **ST-10 (cont.)**
LOCATION: See attached sketch

DRILLER: R. Hunt/D.Dyer | METHOD: Mud Rotary/HSA | DATE: **10/10/11** | SCALE: **1" = 4'**

Elev. feet	Depth feet	Symbol	Description of Materials (Soil- ASTM D2488 or D2487, Rock-USACE EM1110-1-2908)	BPF	WL	MC %	Tests or Notes
877.5	32.0		POORLY GRADED SAND trace GRAVEL, trace Silt, brown to gray, wet, loose to dense (Alluvium) *(continued)*				
				19			
				37			
				27			
				32			
				27			
				35			
				33			

(See Descriptive Terminology sheet for explanation of abbreviations)

LOG OF BORING N:\GINT\PROJECTS\CEDARRAPIDS\2011\00665.GPJ BRAUN_V8_CURRENT.GDT 11/23/11 14:06

BRAUN INTERTEC

LOG OF BORING

Braun Project CR-11-00665
Geotechnical Evaluation
Lake Dehli
Delhi, Iowa

BORING: **ST-10 (cont.)**
LOCATION: See attached sketch

DRILLER: R. Hunt/D.Dyer | METHOD: Mud Rotary/HSA | DATE: **10/10/11** | SCALE: **1" = 4'**

Elev. feet	Depth feet	Symbol	Description of Materials (Soil- ASTM D2488 or D2487, Rock-USACE EM1110-1-2908)	BPF	WL	MC %	Tests or Notes
845.5	64.0		POORLY GRADED SAND trace GRAVEL, trace Silt, brown to gray, wet, loose to dense (Alluvium) *(continued)*				
				26			
839.5	70.0		END OF BORING.				
			Water observed at 28 feet while drilling.				
			Boring then backfilled.				

(See Descriptive Terminology sheet for explanation of abbreviations)

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BRAUN INTERTEC

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Braun Project CR-11-00665
Geotechnical Evaluation
Lake Dehli
Delhi, Iowa

BORING: **ST-11**

LOCATION: See attached sketch

DRILLER: R.Hunt/D.Dyer | METHOD: NQ Wireline Core/ HQ | DATE: **11/7/11** | SCALE: **1" = 4'**

(See Descriptive Terminology sheet for explanation of abbreviations)

Elev. feet	Depth feet	Symbol	Description of Materials (Soil- ASTM D2488 or D2487, Rock-USACE EM1110-1-2908)	BPF	WL	Tests or Notes
904.5	0.0					
904.0	0.5	PAV	Asphaltic Concrete			
		CONC	Portland Cement Concrete			

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Braun Project CR-11-00665
Geotechnical Evaluation
Lake Dehli
Delhi, Iowa

BORING: **ST-11 (cont.)**

LOCATION: See attached sketch

DRILLER: R.Hunt/D.Dyer | METHOD: NQ Wireline Core/ HQ | DATE: **11/7/11** | SCALE: **1" = 4'**

(See Descriptive Terminology sheet for explanation of abbreviations)

Elev. feet	Depth feet	Symbol	Description of Materials (Soil- ASTM D2488 or D2487, Rock-USACE EM1110-1-2908)	BPF	WL	Tests or Notes
872.5	32.0		Portland Cement Concrete *(continued)*			
847.5	57.0	LS	Highly weathered LIMESTONE, gray, moderately hard, highly fractured, vuggy			REC = 100% RQD = 82% UC = 3300 psi REC = 79% RQD = 23%

LOG OF BORING N:\GINT\PROJECTS\CEDARRAPIDS\2011\00665.GPJ BRAUN_V8_CURRENT.GDT 12/1/11 10:16

BRAUN INTERTEC

LOG OF BORING

Braun Project CR-11-00665
Geotechnical Evaluation
Lake Dehli
Delhi, Iowa

BORING: **ST-11 (cont.)**
LOCATION: See attached sketch

DRILLER: R.Hunt/D.Dyer | METHOD: NQ Wireline Core/ HQ | DATE: 11/7/11 | SCALE: 1" = 4'

Elev. feet 840.5	Depth feet 64.0	Symbol	Description of Materials (Soil- ASTM D2488 or D2487, Rock-USACE EM1110-1-2908)	BPF	WL	Tests or Notes
			Highly weathered LIMESTONE, gray, moderately hard, highly fractured, vuggy *(continued)*			
						REC = 79% RQD = 36%
						REC = 95% RQD = 36% UC = 11,720 psi
						REC = 100% RQD = 51%

(See Descriptive Terminology sheet for explanation of abbreviations)

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LOG OF BORING

Braun Project CR-11-00665
Geotechnical Evaluation
Lake Dehli
Delhi, Iowa

BORING: **ST-11 (cont.)**
LOCATION: See attached sketch

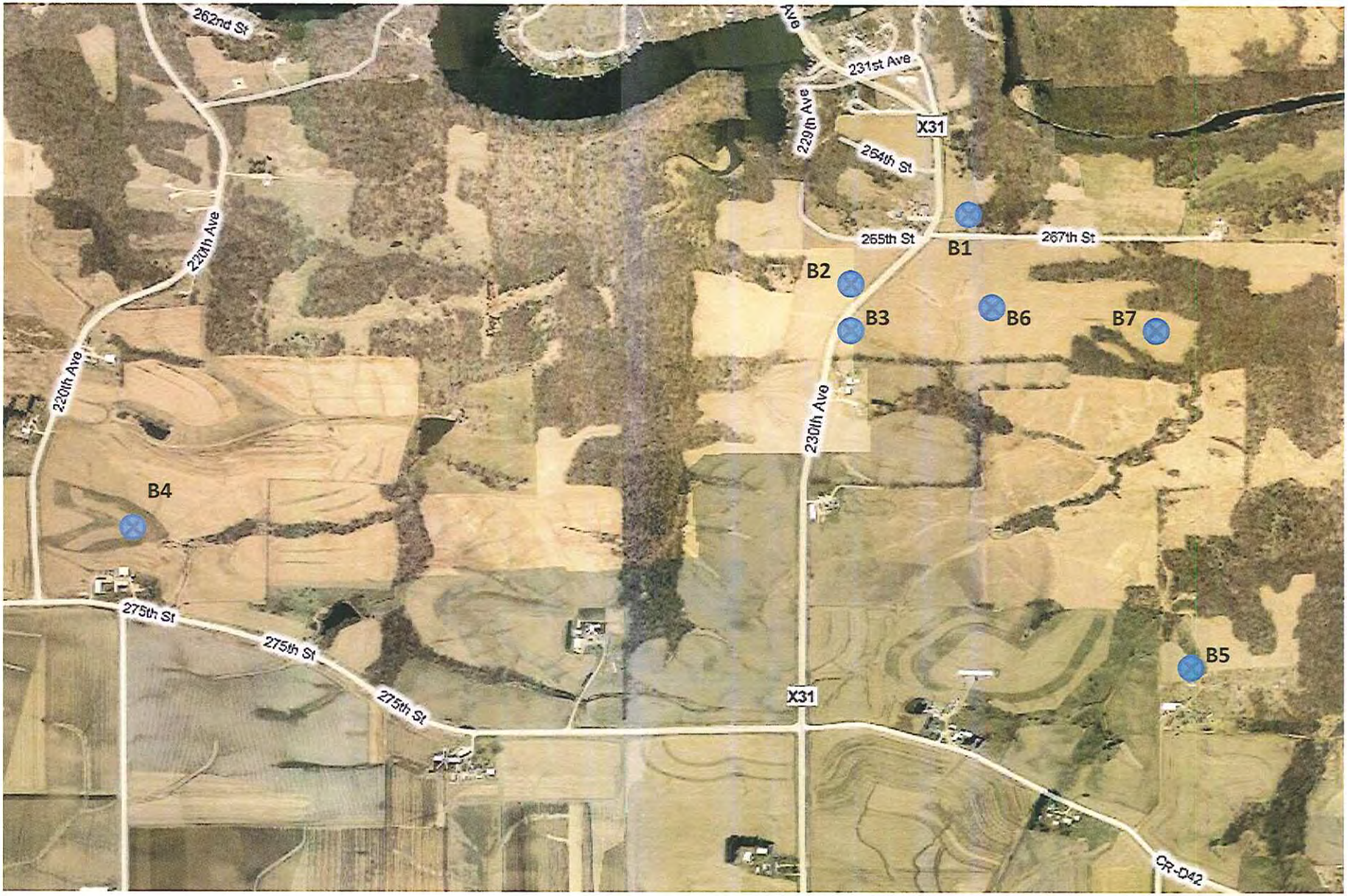
DRILLER: R.Hunt/D.Dyer | METHOD: NQ Wireline Core/ HQ | DATE: 11/7/11 | SCALE: 1" = 4'

Elev. feet	Depth feet	Symbol	Description of Materials (Soil- ASTM D2488 or D2487, Rock-USACE EM1110-1-2908)	BPF	WL	Tests or Notes
808.5	96.0		Highly weathered LIMESTONE, gray, moderately hard, highly fractured, vuggy *(continued)*			REC = 100% RQD = 58% UC = 4,390 psi
797.5	107.0		END OF BORING. Boring then grouted.			

(See Descriptive Terminology sheet for explanation of abbreviations)

LOG OF BORING N:\GINT\PROJECTS\CEDARRAPIDS\2011\00665.GPJ BRAUN_V8_CURRENT.GDT 12/1/11 10:16

Borrow Boring Location Plan and Logs of Borings B1 through B7



Approximate Boring Location -

Lake Delhi Dam Restoration Delhi, Iowa	Project: CR-11-00665	Borrow Boring Location Sketch	BRAUN INTERTEC

BRAUN INTERTEC

LOG OF BORING

Braun Project CR-11-00665
Geotechnical Evaluation
Lake Dehli
Delhi, Iowa

BORING: **B-1**

LOCATION: See attached sketch

DRILLER: R.Hunt/D.Dyer | METHOD: Power Auger | DATE: **10/10/11** | SCALE: **1" = 4'**

Depth feet	Symbol	Description of Materials (Soil- ASTM D2488 or D2487, Rock-USACE EM1110-1-2908)	BPF	WL	Tests or Notes
0.0					
1.0	TS	Topsoil			
	CL	LEAN CLAY, brown, moist, medium (Loess)			LL = 32 PL = 23 PI = 9 Max DD = 108.8 pcf Optimum Moisture = 10.5% Natural Moisture = 26%
25.0		END OF BORING. Water not observed while drilling. Boring then backfilled.			

(See Descriptive Terminology sheet for explanation of abbreviations)

LOG OF BORING N:\GINT\PROJECTS\CEDARRAPIDS\2011\00665.GPJ BRAUN_V8_CURRENT.GDT 11/29/11 11:18

BRAUN INTERTEC

LOG OF BORING

Braun Project CR-11-00665
Geotechnical Evaluation
Lake Dehli
Delhi, Iowa

BORING: **B-2**

LOCATION: See attached sketch

DRILLER: R.Hunt/D.Dyer | METHOD: Power Auger | DATE: **10/10/11** | SCALE: **1" = 4'**

Depth feet 0.0	Symbol	Description of Materials (Soil- ASTM D2488 or D2487, Rock-USACE EM1110-1-2908)	BPF	WL	Tests or Notes
1.0	TS	Topsoil			
	CL	LEAN CLAY, brown, moist, medium (Loess)			LL = 34 PL = 23 PI = 11 Max DD = 107.6 pcf Optimum Moisture = 17.7% Natural Moisture = 25%
25.0		END OF BORING. Water not observed while drilling. Boring then backfilled.			

(See Descriptive Terminology sheet for explanation of abbreviations)

LOG OF BORING N:\GINT\PROJECTS\CEDARRAPIDS\2011\00665.GPJ BRAUN_V8_CURRENT.GDT 11/29/11 11:18

BRAUN INTERTEC

LOG OF BORING

Braun Project CR-11-00665
Geotechnical Evaluation
Lake Dehli
Delhi, Iowa

BORING: **B-3**

LOCATION: See attached sketch

DRILLER: R.Hunt/D.Dyer | METHOD: Power Auger | DATE: 10/10/11 | SCALE: 1" = 4'

Depth feet	Symbol	Description of Materials (Soil- ASTM D2488 or D2487, Rock-USACE EM1110-1-2908)	BPF	WL	Tests or Notes
0.0	TS	Topsoil			
1.0	CL	LEAN CLAY, brown, moist, medium (Loess)			LL = 32 PL = 23 PI = 9 Max DD = 110.8 pcf Optimum Moisture = 14.3% Natural Moisture = 30%
25.0		END OF BORING. Water not observed while drilling. Boring then backfilled.			

(See Descriptive Terminology sheet for explanation of abbreviations)

LOG OF BORING N:\GINT\PROJECTS\CEDARRAPIDS\2011\00665.GPJ BRAUN_V8_CURRENT.GDT 11/29/11 11:18

BRAUN INTERTEC

LOG OF BORING

Braun Project CR-11-00665
Geotechnical Evaluation
Lake Dehli
Delhi, Iowa

BORING: **B-4**

LOCATION: See attached sketch

DRILLER: R.Hunt/D.Dyer | METHOD: Power Auger | DATE: **10/10/11** | SCALE: **1" = 4'**

(See Descriptive Terminology sheet for explanation of abbreviations)

Depth feet	Symbol	Description of Materials (Soil- ASTM D2488 or D2487, Rock-USACE EM1110-1-2908)	BPF	WL	Tests or Notes
0.0					
1.0	TS	Topsoil			
	CL	LEAN CLAY, brown, moist, medium (Loess)			LL = 34 PL = 23 PI = 11 Max DD = 106.2 pcf Optimum Moisture = 13.9% Natural Moisture = 35 %
18.0					
	CL	SANDY LEAN CLAY, trace Gravel, brown, moist, rather stiff (Glacial Till)			LL = 30 PL = 19 PI = 16 Max DD = 119.0 pcf Optimum Moisture = 10.7% Natural Moisture = 16%
25.0					
		END OF BORING. Water not observed while drilling. Boring then backfilled.			

LOG OF BORING N:\GINT\PROJECTS\CEDARRAPIDS\2011\00665.GPJ BRAUN_V8_CURRENT.GDT 11/29/11 11:18

BRAUN INTERTEC

LOG OF BORING

Braun Project CR-11-00665
Geotechnical Evaluation
Lake Dehli
Delhi, Iowa

BORING: **B-5**

LOCATION: See attached sketch

DRILLER: R.Hunt/D.Dyer | METHOD: Power Auger | DATE: **10/10/11** | SCALE: **1" = 4'**

Depth feet	Symbol	Description of Materials (Soil- ASTM D2488 or D2487, Rock-USACE EM1110-1-2908)	BPF	WL	Tests or Notes
0.0					
1.0	TS	Topsoil			
	CL	LEAN CLAY, brown, moist, medium (Loess)			LL = 29 PL = 20 PI = 9 Max DD = 112.7 pcf Optimum Moisture = 14.8 % Natural Moisture = 24%
12.0					
	CL	SANDY LEAN CLAY, trace Gravel, brown, moist, rather stiff (Glacial Till)			LL = 33 PL = 16 PI = 17 Max DD = 116.3 pcf Optimum Moisture = 12.6% Natural Moisture = 15%
25.0					
		END OF BORING. Water not observed while drilling. Boring then backfilled.			

(See Descriptive Terminology sheet for explanation of abbreviations)

LOG OF BORING N:\GINT\PROJECTS\CEDARRAPIDS\2011\00665.GPJ BRAUN_V8_CURRENT.GDT 11/29/11 11:18

BRAUN INTERTEC

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Lake Dehli
Delhi, Iowa

BORING: **B-6**

LOCATION: See attached sketch

DRILLER: R.Hunt/D.Dyer | METHOD: Power Auger | DATE: 10/10/11 | SCALE: 1" = 4'

Depth feet	Symbol	Description of Materials (Soil- ASTM D2488 or D2487, Rock-USACE EM1110-1-2908)	BPF	WL	Tests or Notes
0.0					
1.0	TS	Topsoil			
	CL	LEAN CLAY, brown, moist, medium (Loess)			LL = 38 PL = 23 PI = 15 Natural Moisture = 27%
25.0		END OF BORING. Water not observed while drilling. Boring then backfilled.			

(See Descriptive Terminology sheet for explanation of abbreviations)

LOG OF BORING N:\GINT\PROJECTS\CEDARRAPIDS\2011\00665.GPJ BRAUN_V8_CURRENT.GDT 11/30/11 11:06

BRAUN INTERTEC

LOG OF BORING

Braun Project CR-11-00665
Geotechnical Evaluation
Lake Dehli
Delhi, Iowa

BORING: **B-7**

LOCATION: See attached sketch

DRILLER: R.Hunt/D.Dyer | METHOD: Power Auger | DATE: **10/25/11** | SCALE: **1" = 4'**

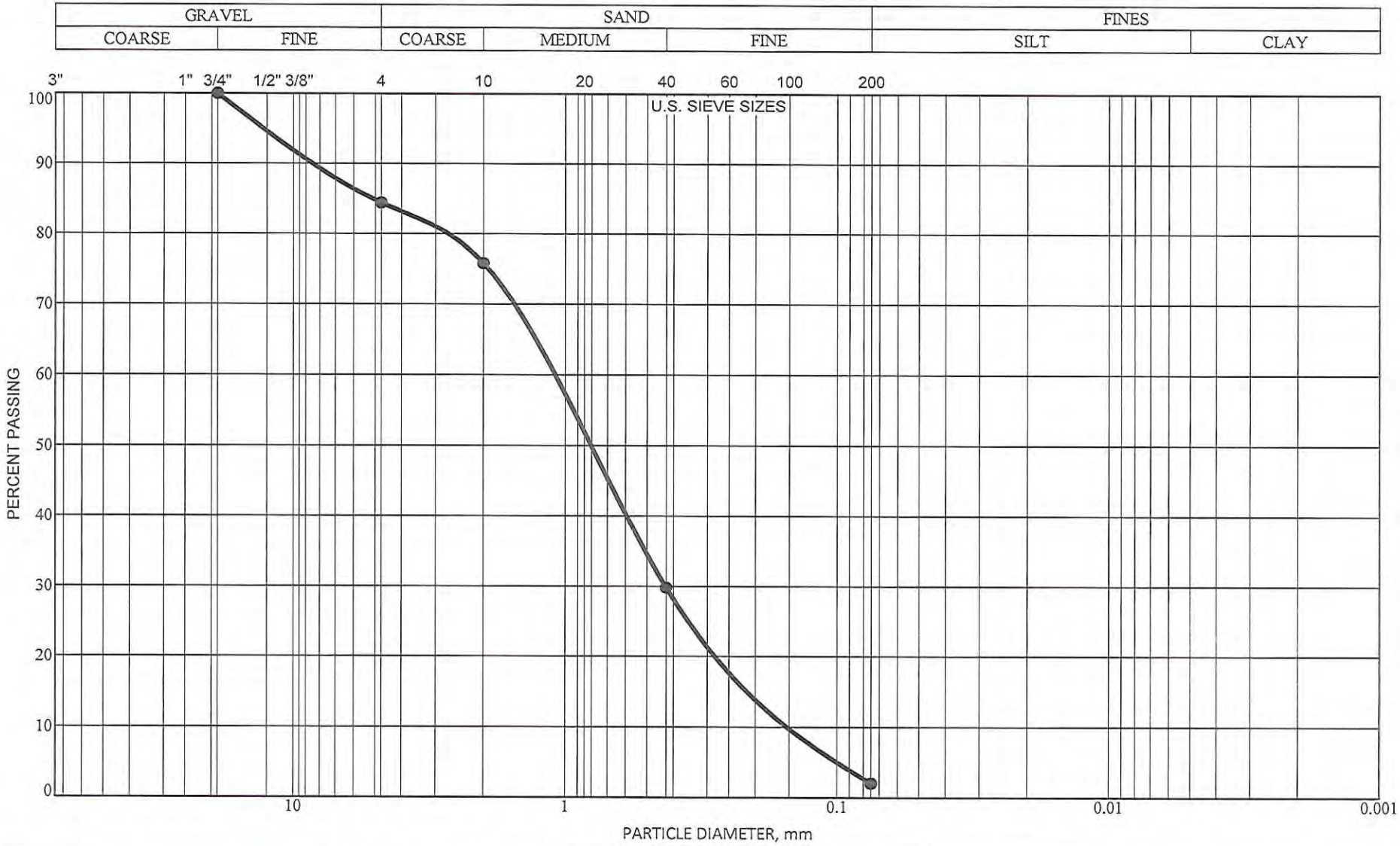
Depth feet	Symbol	Description of Materials (Soil- ASTM D2488 or D2487, Rock-USACE EM1110-1-2908)	BPF	WL	Tests or Notes
0.0	TS	Topsoil			
1.0	CL	LEAN CLAY, brown, moist, medium (Loess)			LL = 39 PL = 23 PI = 16 Natural Moisture = 26%
25.0		END OF BORING. Water not observed while drilling. Boring then backfilled.			

(See Descriptive Terminology sheet for explanation of abbreviations)

LOG OF BORING N:\GINT\PROJECTS\CEDARRAPIDS\2011\00665.GPJ BRAUN_V8_CURRENT.GDT 11/30/11 11:02

Grain Size Curves

GRAIN SIZE ACCUMULATION CURVE (ASTM)



BRAUN INTERTEC

Braun Project CR-11-00665
Geotechnical Evaluation
Lake Dehli
Delhi, Iowa

BORING: ST-6 DEPTH: 28.5'

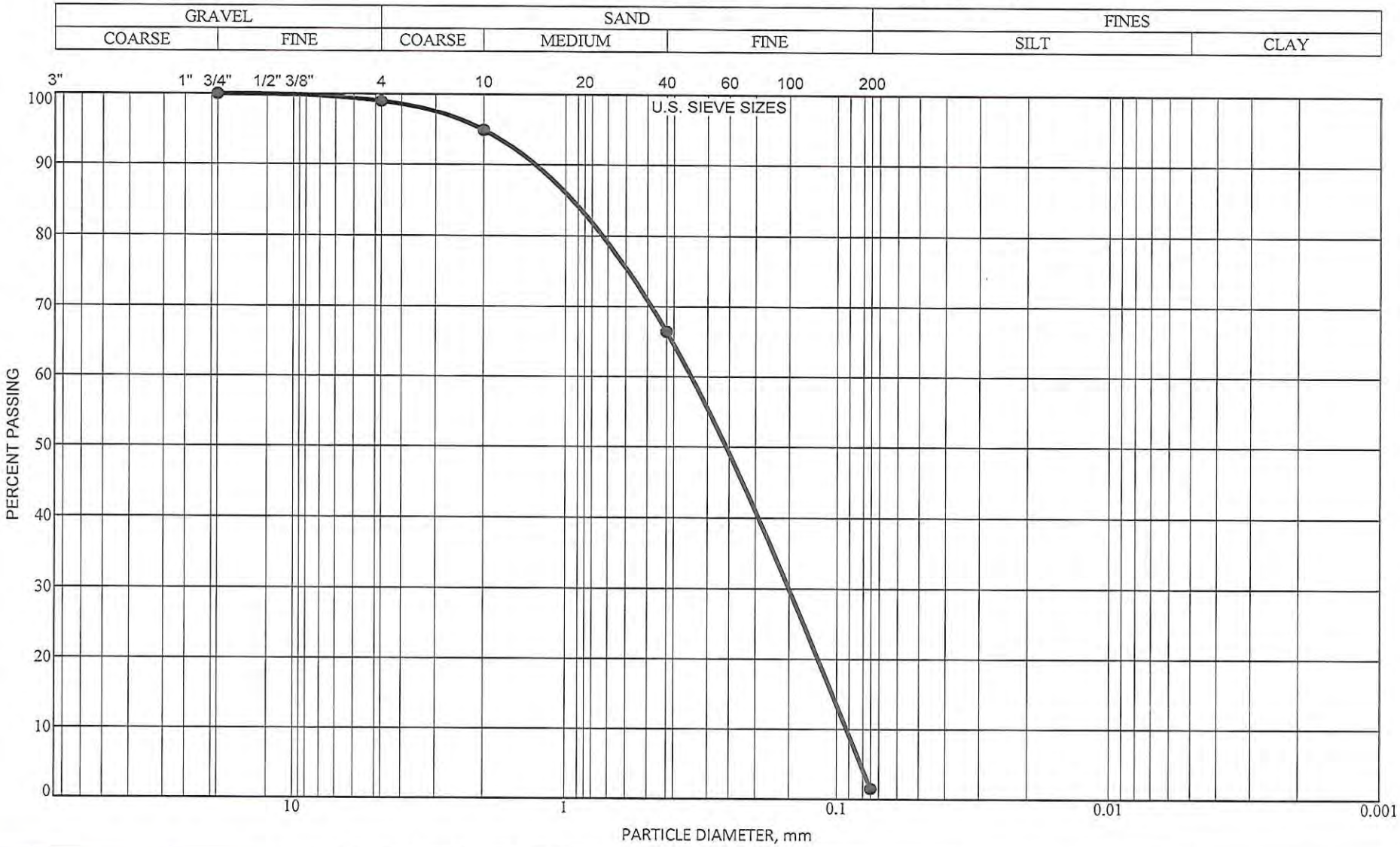
GRAVEL	15.6%
SAND	82.4%
FINES	2.0%

D60=1.175
D30=0.428
D10=0.124

Cu=9.5
Cc=1.3

CLASSIFICATION:
WELL-GRADED SAND with GRAVEL(SW)

GRAIN SIZE ACCUMULATION CURVE (ASTM)



BRAUN INTERTEC

Braun Project CR-11-00665
Geotechnical Evaluation
Lake Dehli
Delhi, Iowa

BORING: ST-7 DEPTH: 33.5'

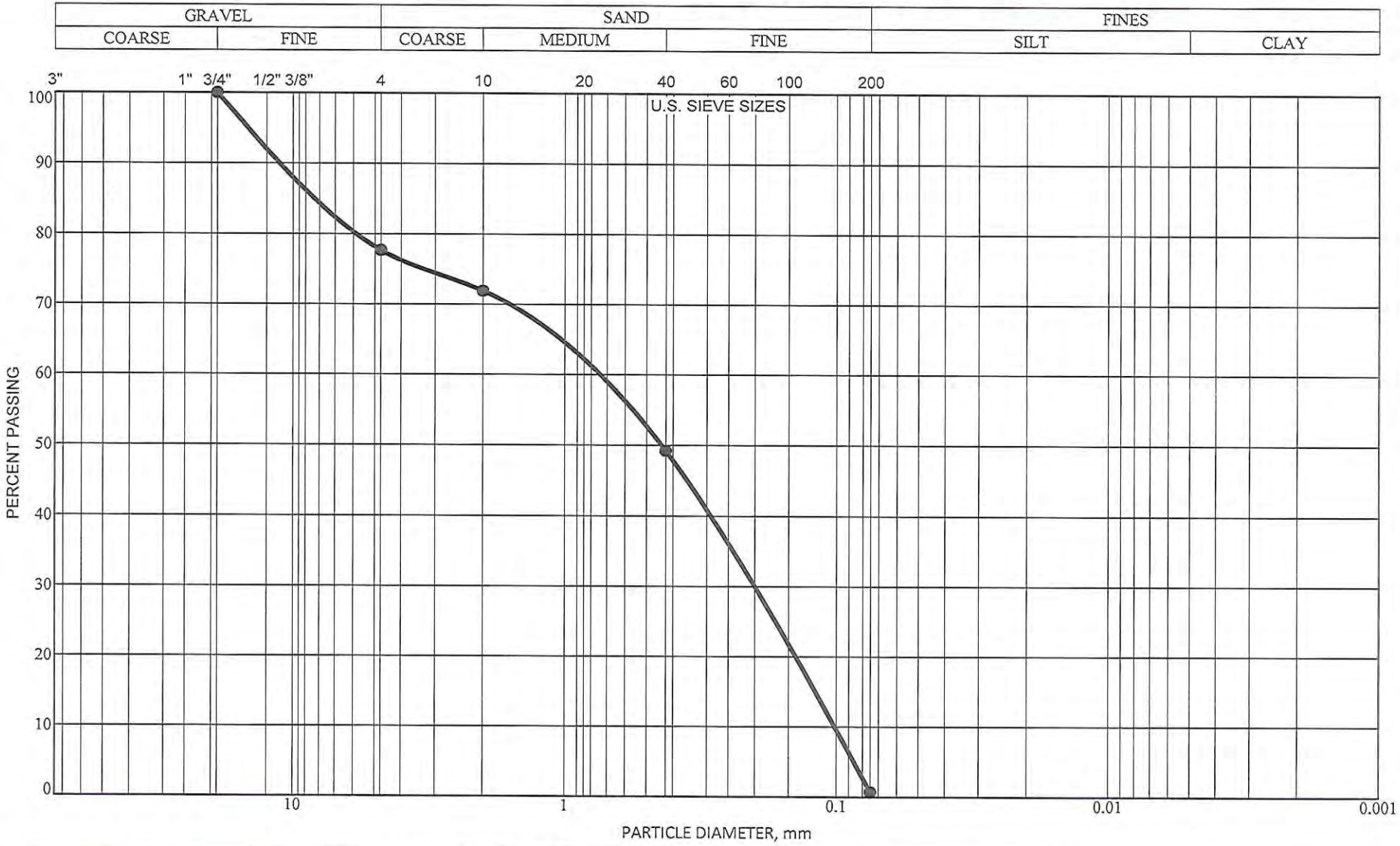
GRAVEL	1.0%
SAND	97.5%
FINES	1.5%

D60=0.358
D30=0.161
D10=0.094

Cu=3.8
Cc=0.8

CLASSIFICATION:
POORLY GRADED SAND(SP)

GRAIN SIZE ACCUMULATION CURVE (ASTM)



BRAUN INTERTEC

Braun Project CR-11-00665
Geotechnical Evaluation
Lake Dehli
Delhi, Iowa

BORING: ST-8 DEPTH: 18.5'

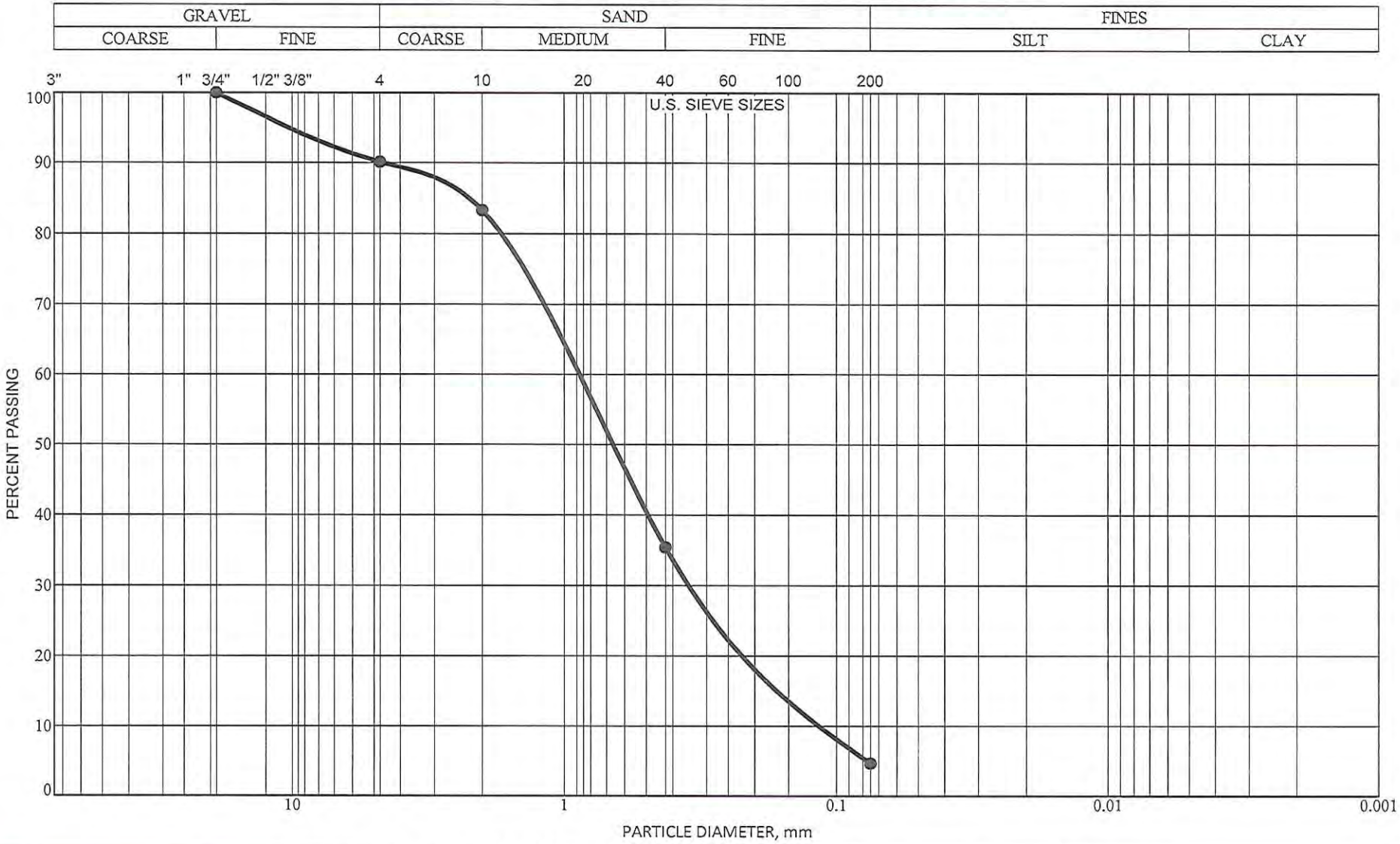
GRAVEL	22.3%
SAND	77.0%
FINES	0.7%

D60=0.888
D30=0.214
D10=0.105

Cu=8.5
Cc=0.5

CLASSIFICATION:
POORLY GRADED SAND with GRAVEL(SP)

GRAIN SIZE ACCUMULATION CURVE (ASTM)



BRAUN INTERTEC

Braun Project CR-11-00665
Geotechnical Evaluation
Lake Dehli
Delhi, Iowa

BORING: ST-8 DEPTH: 33.5'

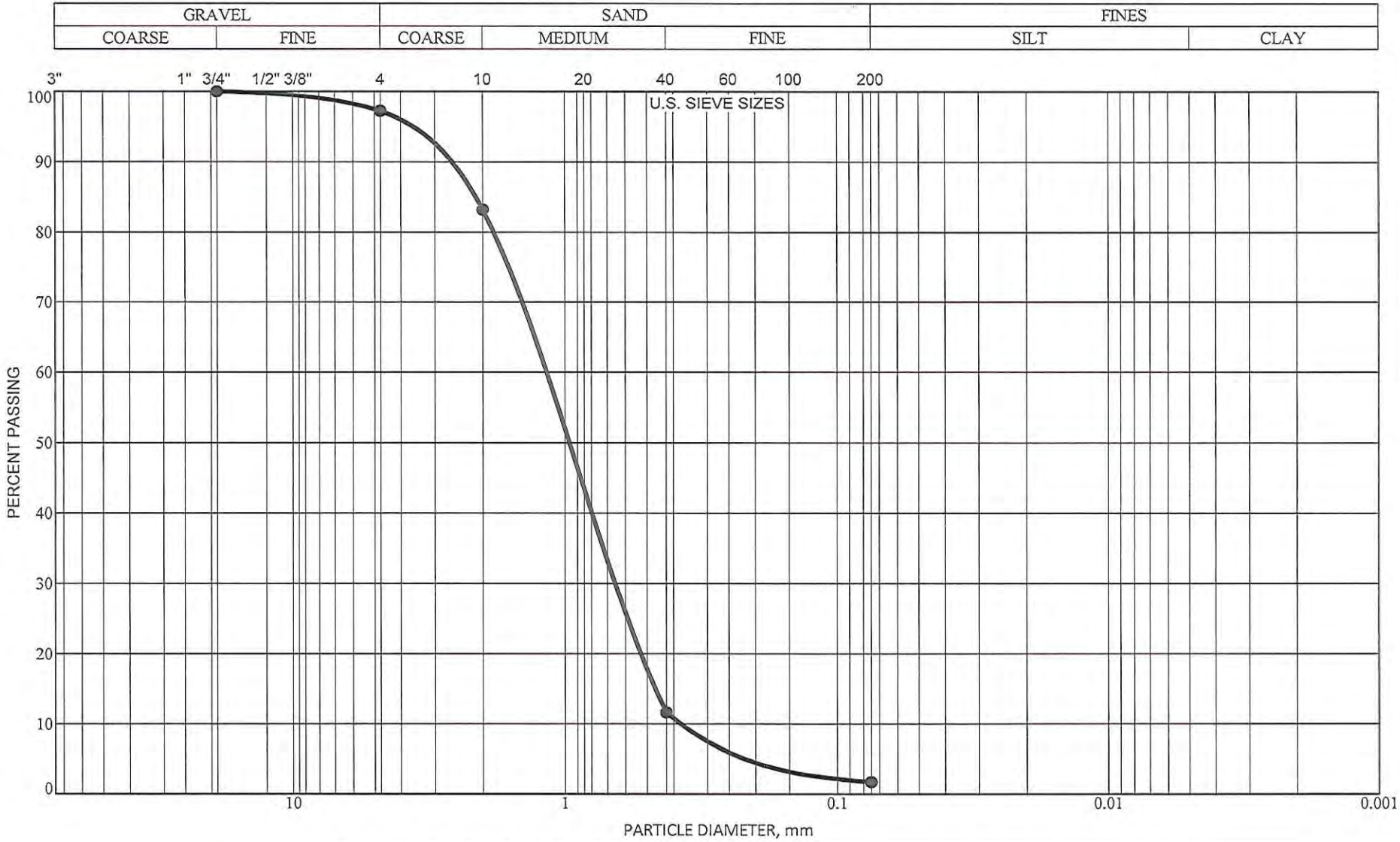
GRAVEL	9.9%
SAND	85.4%
FINES	4.7%

D60=0.942
D30=0.313
D10=0.101

Cu=9.3
Cc=1.0

CLASSIFICATION:
WELL-GRADED SAND(SW)

GRAIN SIZE ACCUMULATION CURVE (ASTM)



BRAUN INTERTEC

Braun Project CR-11-00665
Geotechnical Evaluation
Lake Dehli
Delhi, Iowa

BORING: ST-8 DEPTH: 68.5'

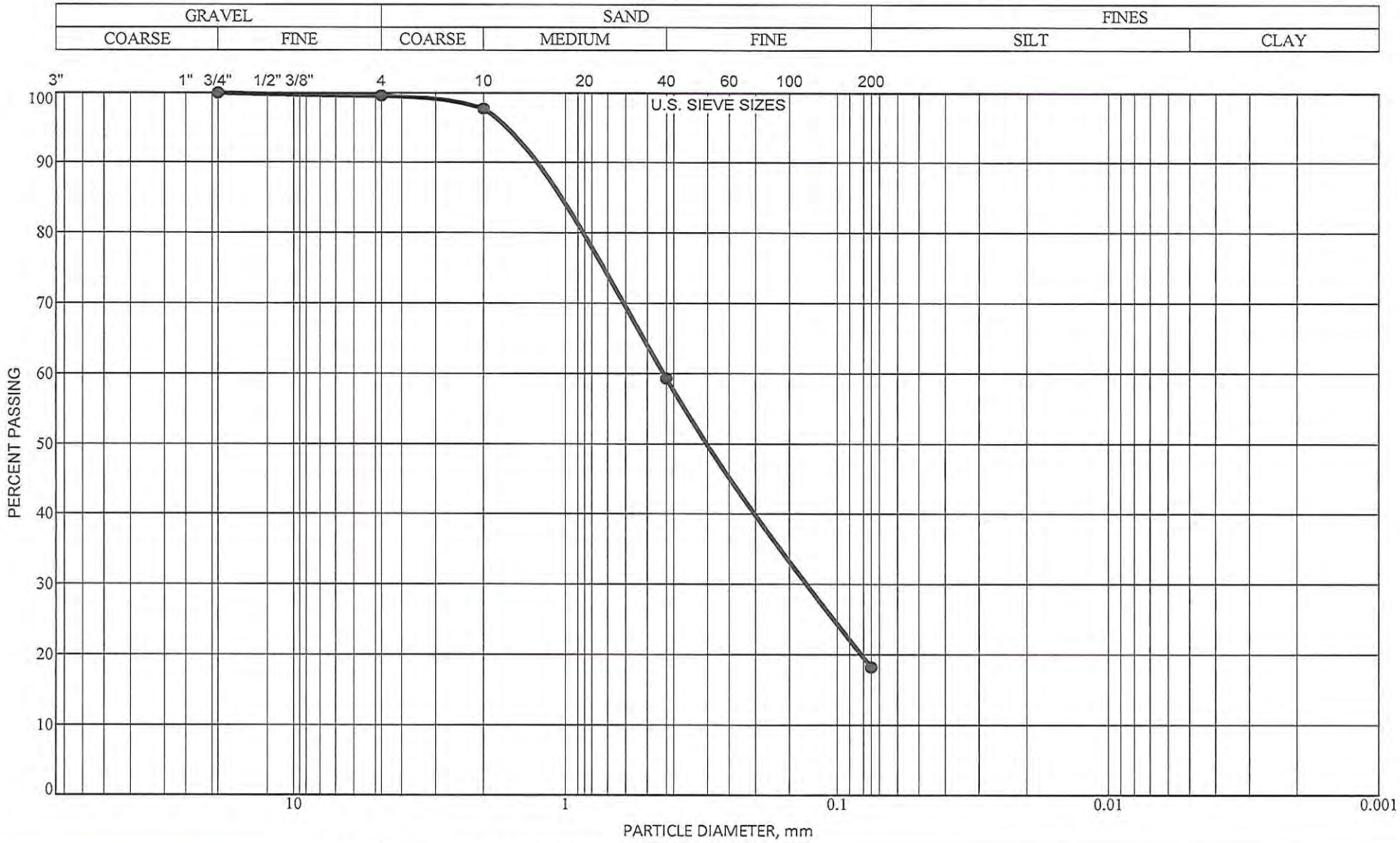
GRAVEL	2.8%
SAND	95.5%
FINES	1.7%

D60=1.211
D30=0.633
D10=0.321

Cu=3.8
Cc=1.0

CLASSIFICATION:
POORLY GRADED SAND(SP)

GRAIN SIZE ACCUMULATION CURVE (ASTM)



BRAUN INTERTEC

Braun Project CR-11-00665
Geotechnical Evaluation
Lake Dehli
Delhi, Iowa

BORING: ST-9 DEPTH: 38.5'

GRAVEL	0.4%
SAND	81.4%
FINES	18.2%

D60=0.437
D30=0.123
D10=

Cu=
Cc=

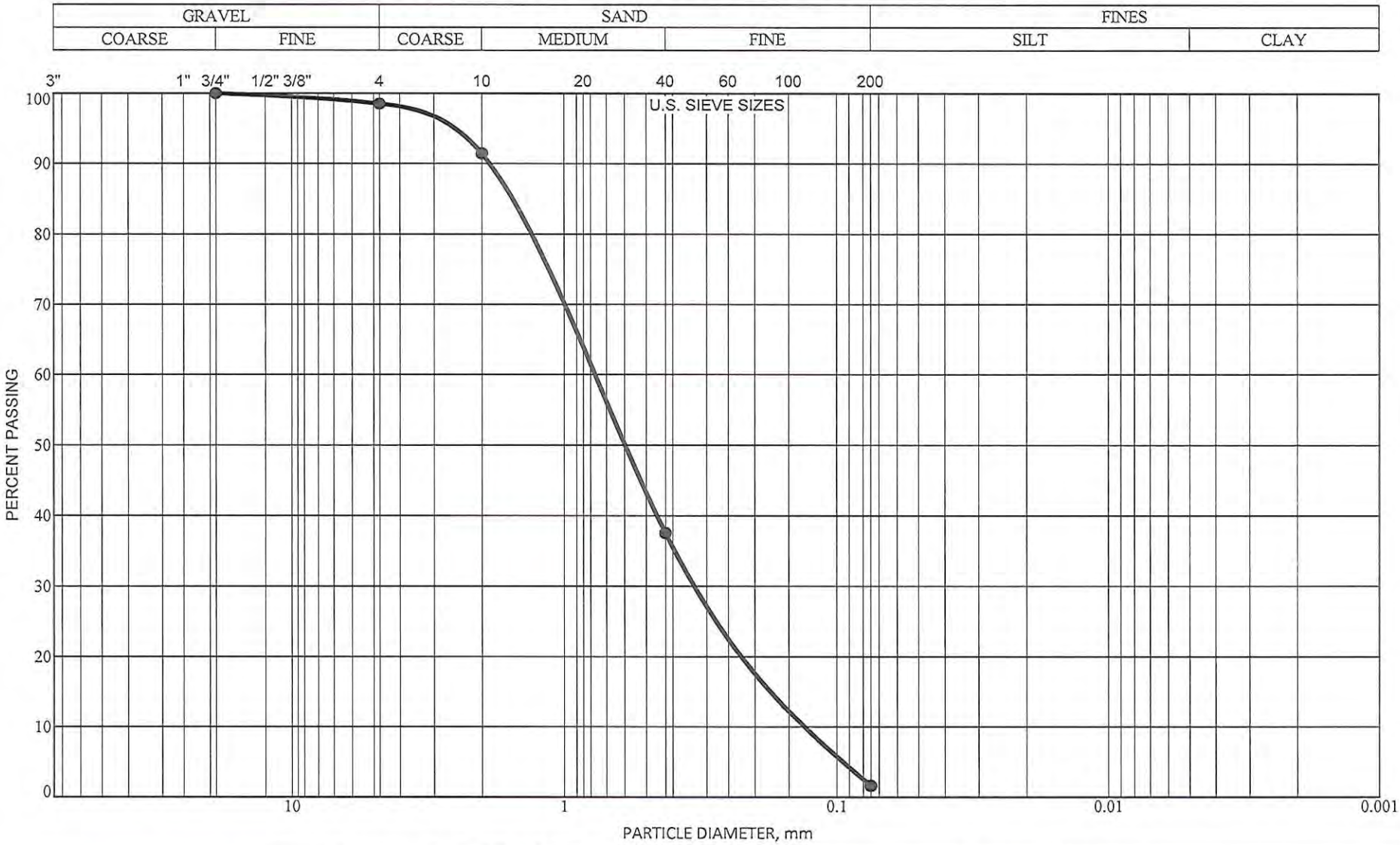
CLASSIFICATION:

CR-11-00665

Braun Intertec Corporation

GS ASTM N:\GINT\PROJECTS\CEDARRAPIDS\2011\00665.GPJ BRAUN_V8_CURRENT.GDT 11/22/11 14:41

GRAIN SIZE ACCUMULATION CURVE (ASTM)



BRAUN INTERTEC

Braun Project CR-11-00665
Geotechnical Evaluation
Lake Dehli
Delhi, Iowa

BORING: ST-10 DEPTH: 23.5'

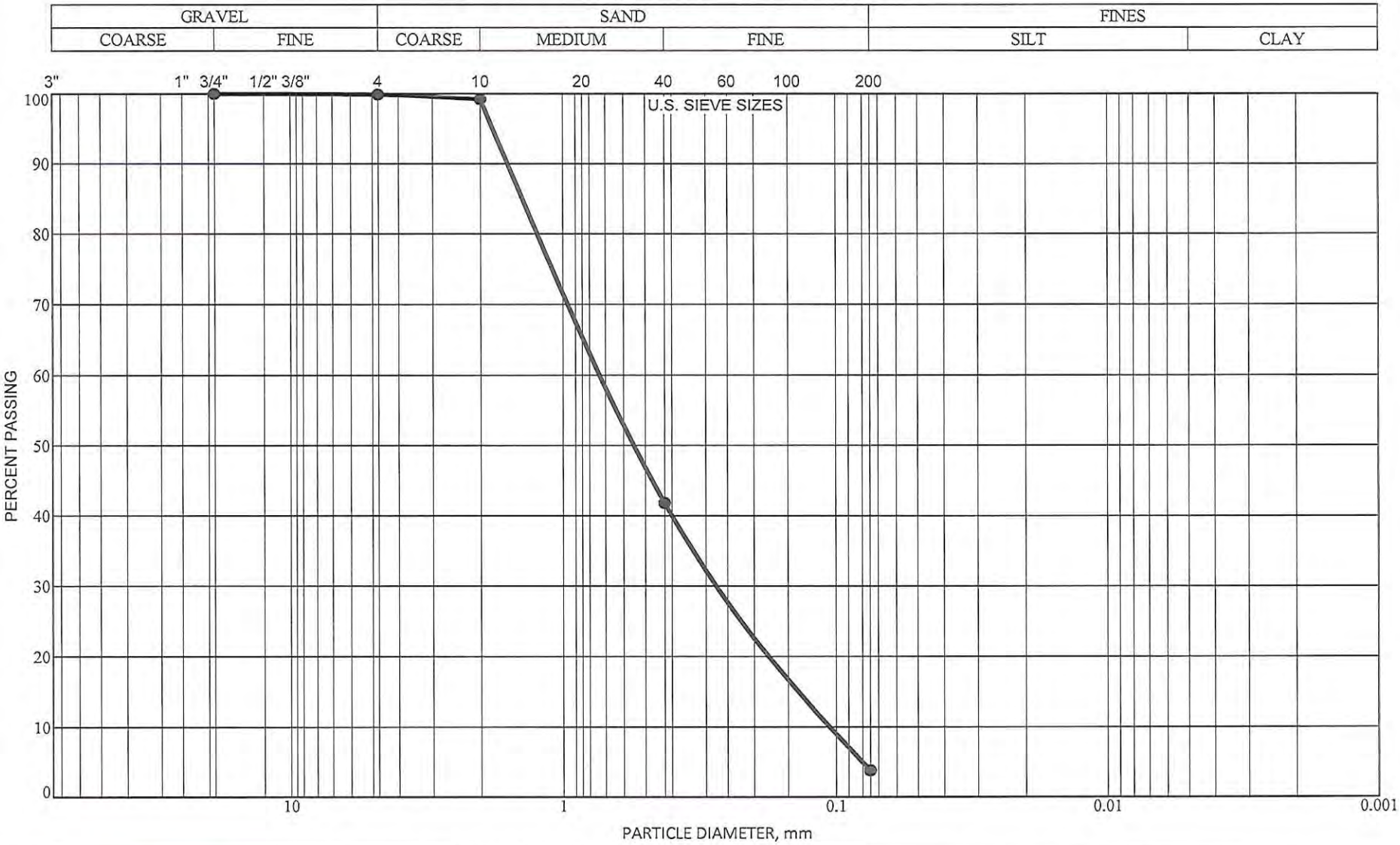
GRAVEL	1.5%
SAND	96.9%
FINES	1.6%

D60=0.811
D30=0.296
D10=0.113

Cu=7.2
Cc=1.0

CLASSIFICATION:
POORLY GRADED SAND(SP)

GRAIN SIZE ACCUMULATION CURVE (ASTM)



BRAUN INTERTEC

Braun Project CR-11-00665
Geotechnical Evaluation
Lake Dehli
Delhi, Iowa

BORING: ST-10 DEPTH: 48.5'

GRAVEL	0.1%
SAND	96.1%
FINES	3.8%

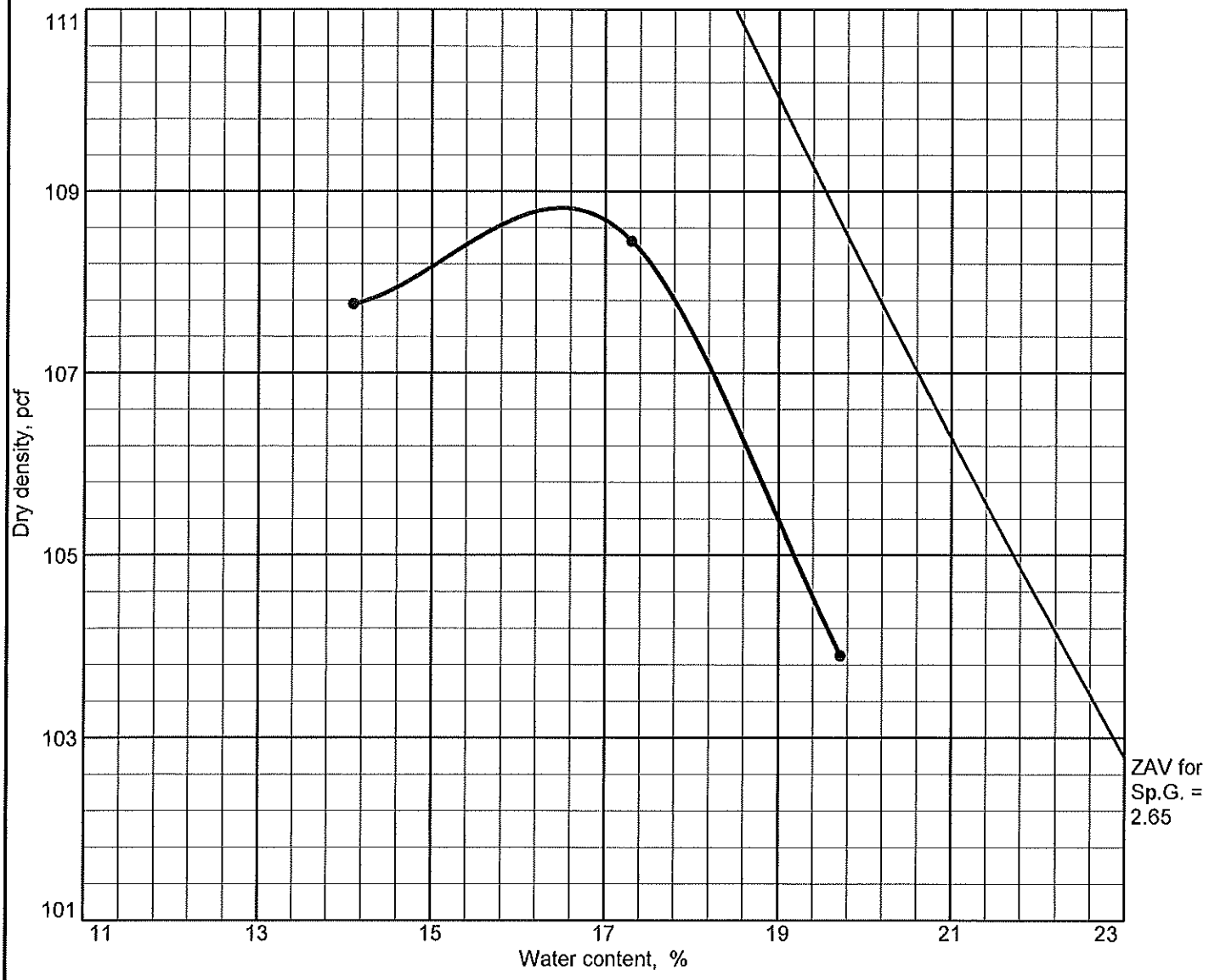
D60=0.694
D30=0.248
D10=0.100

Cu=7.0
Cc=0.9

CLASSIFICATION:
POORLY GRADED SAND(SP)

Moisture-Density Relationship Curves

Moisture-Density Relationship



Test specification: ASTM D 698-07e1 Method A Standard

Elev/ Depth	Classification		Nat. Moist.	Sp.G.	LL	PI	% > No.4	% < No.200
	USCS	AASHTO						
0-25'	CL		26		32	9		

TEST RESULTS	MATERIAL DESCRIPTION
Maximum dry density = 108.8 pcf Optimum moisture = 16.5 %	Lean Clay

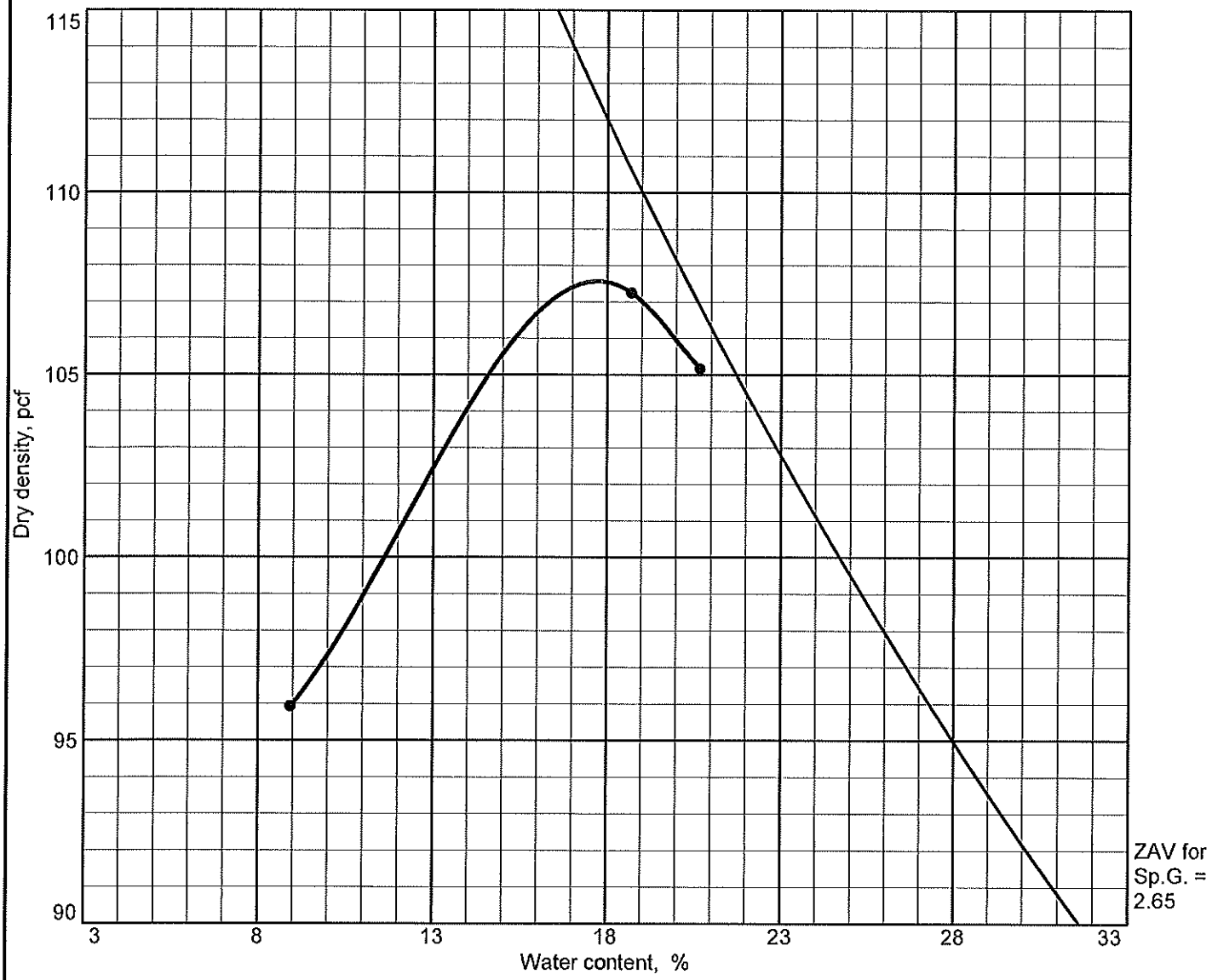
Project No.: CR-11-00665 **Client:**
Project: Lake Delhi Dam Repairs

● **Location:** Boring B-1

Remarks:

BRAUN™ INTERTEC

Moisture-Density Relationship



Test specification: ASTM D 698-07e1 Method A Standard

Elev/ Depth	Classification		Nat. Moist.	Sp.G.	LL	PI	% > No.4	% < No.200
	USCS	AASHTO						
0-25'	CL		25		34	11		

TEST RESULTS	MATERIAL DESCRIPTION
Maximum dry density = 107.6 pcf Optimum moisture = 17.7 %	Lean Clay

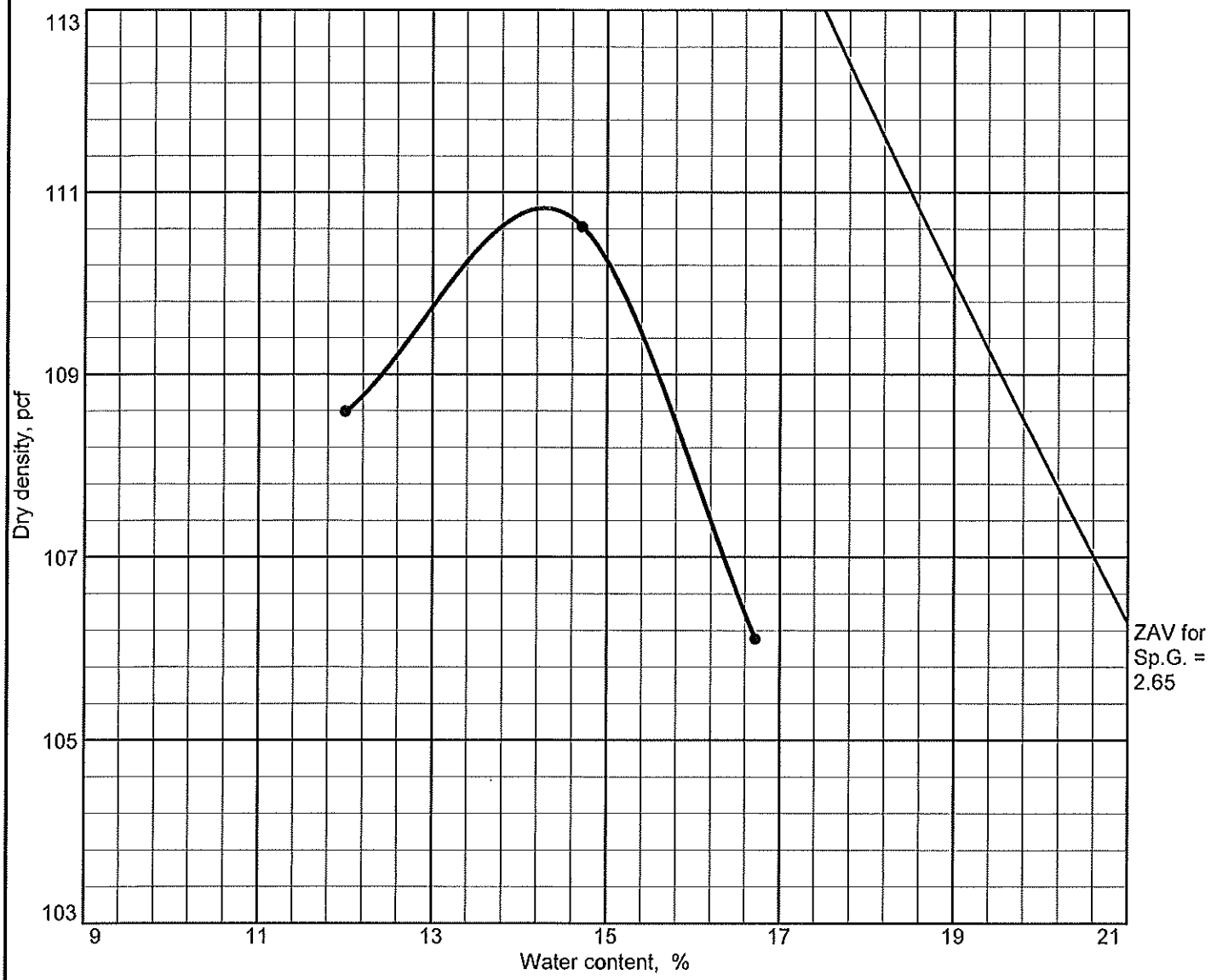
Project No.: CR-11-00665 **Client:**
Project: Lake Delhi Dam Repairs

● **Location:** Boring B-2

Remarks:

BRAUN INTERTEC

Moisture-Density Relationship



Test specification: ASTM D 698-07e1 Method A Standard

Elev/ Depth	Classification		Nat. Moist.	Sp.G.	LL	PI	% > No.4	% < No.200
	USCS	AASHTO						
0-25'	CL		30		32	9		

TEST RESULTS	MATERIAL DESCRIPTION
Maximum dry density = 110.8 pcf Optimum moisture = 14.3 %	Lean Clay

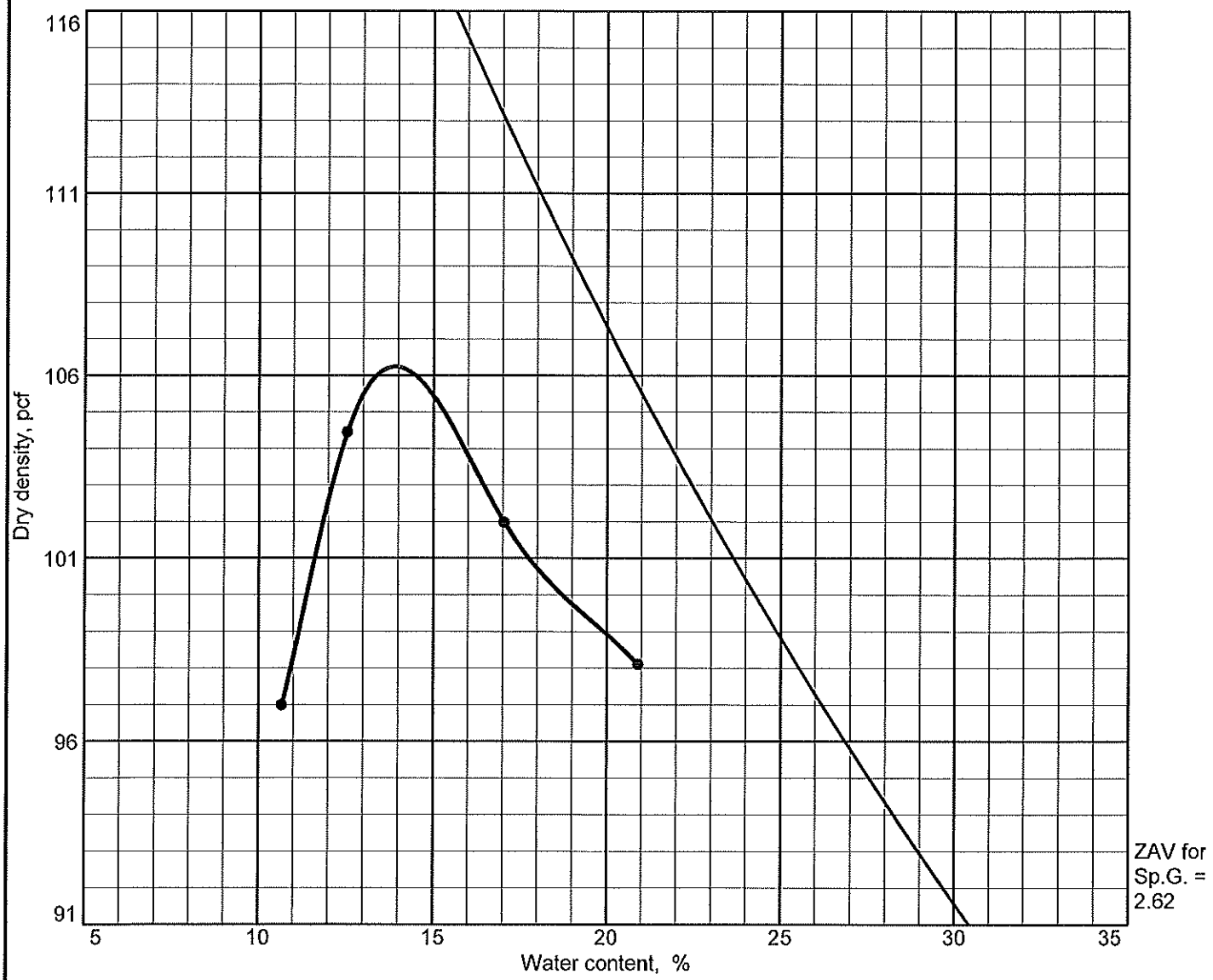
Project No.: CR-11-00665 **Client:**
Project: Lake Delhi Dam Repairs

● **Location:** Boring B-3

Remarks:

BRAUN INTERTEC

Moisture-Density Relationship



Test specification: ASTM D 698-07e1 Method A Standard

Elev/ Depth	Classification		Nat. Moist.	Sp.G.	LL	PI	% > No.4	% < No.200
	USCS	AASHTO						
0' - 18'	CL		35		34	11		

TEST RESULTS	MATERIAL DESCRIPTION
Maximum dry density = 106.2 pcf Optimum moisture = 13.9 %	Lean Clay

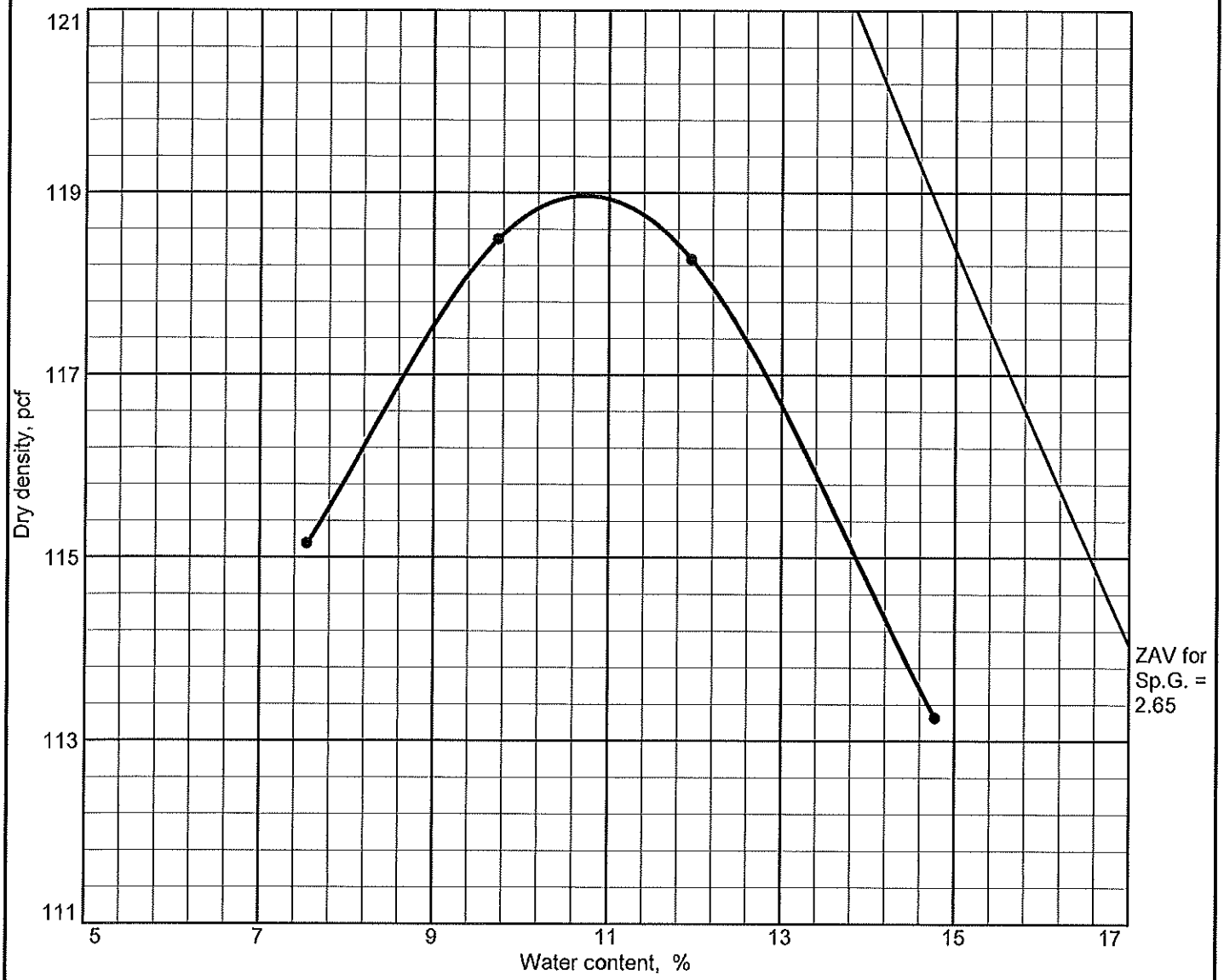
Project No.: CR-11-00665 **Client:**
Project: Lake Delhi Dam Repairs

● **Location:** Boring B-4

Remarks:

BRAUN™ INTERTEC

Moisture-Density Relationship



Test specification: ASTM D 698-07e1 Method A Standard

Elev/ Depth	Classification		Nat. Moist.	Sp.G.	LL	PI	% > No.4	% < No.200
	USCS	AASHTO						
19 - 25'	CL		16		30	16		

TEST RESULTS	MATERIAL DESCRIPTION
Maximum dry density = 119.0 pcf Optimum moisture = 10.7 %	Sandy Lean Clay

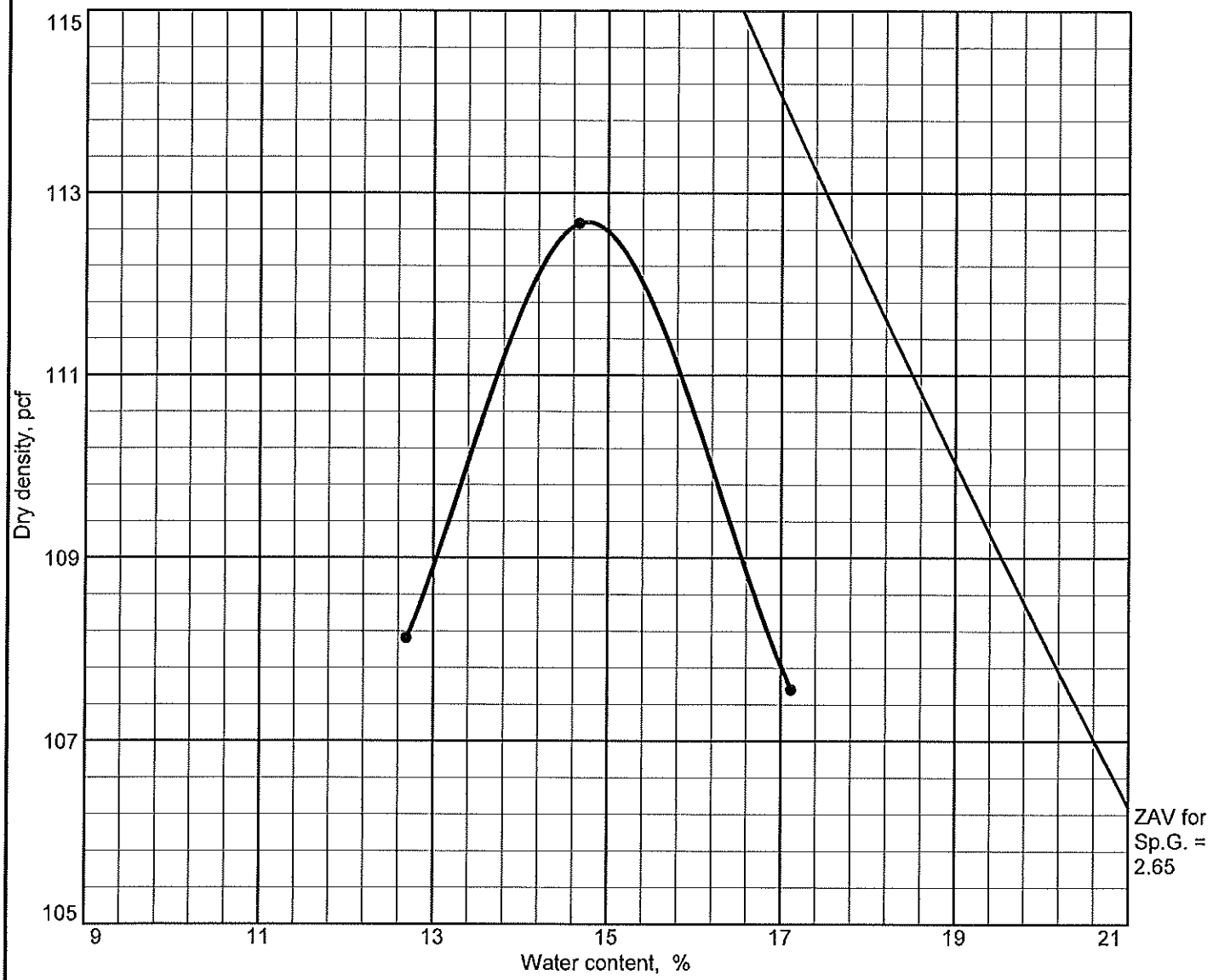
Project No.: CR-11-00665 **Client:**
Project: Lake Delhi Dam Repairs

● **Location:** Boring B-4

Remarks:

BRAUN INTERTEC

Moisture-Density Relationship



Test specification: ASTM D 698-07e1 Method A Standard

Elev/ Depth	Classification		Nat. Moist.	Sp.G.	LL	PI	% > No.4	% < No.200
	USCS	AASHTO						
0' - 12'	CL		24		29	9		

TEST RESULTS	MATERIAL DESCRIPTION
Maximum dry density = 112.7 pcf Optimum moisture = 14.8 %	Lean Clay

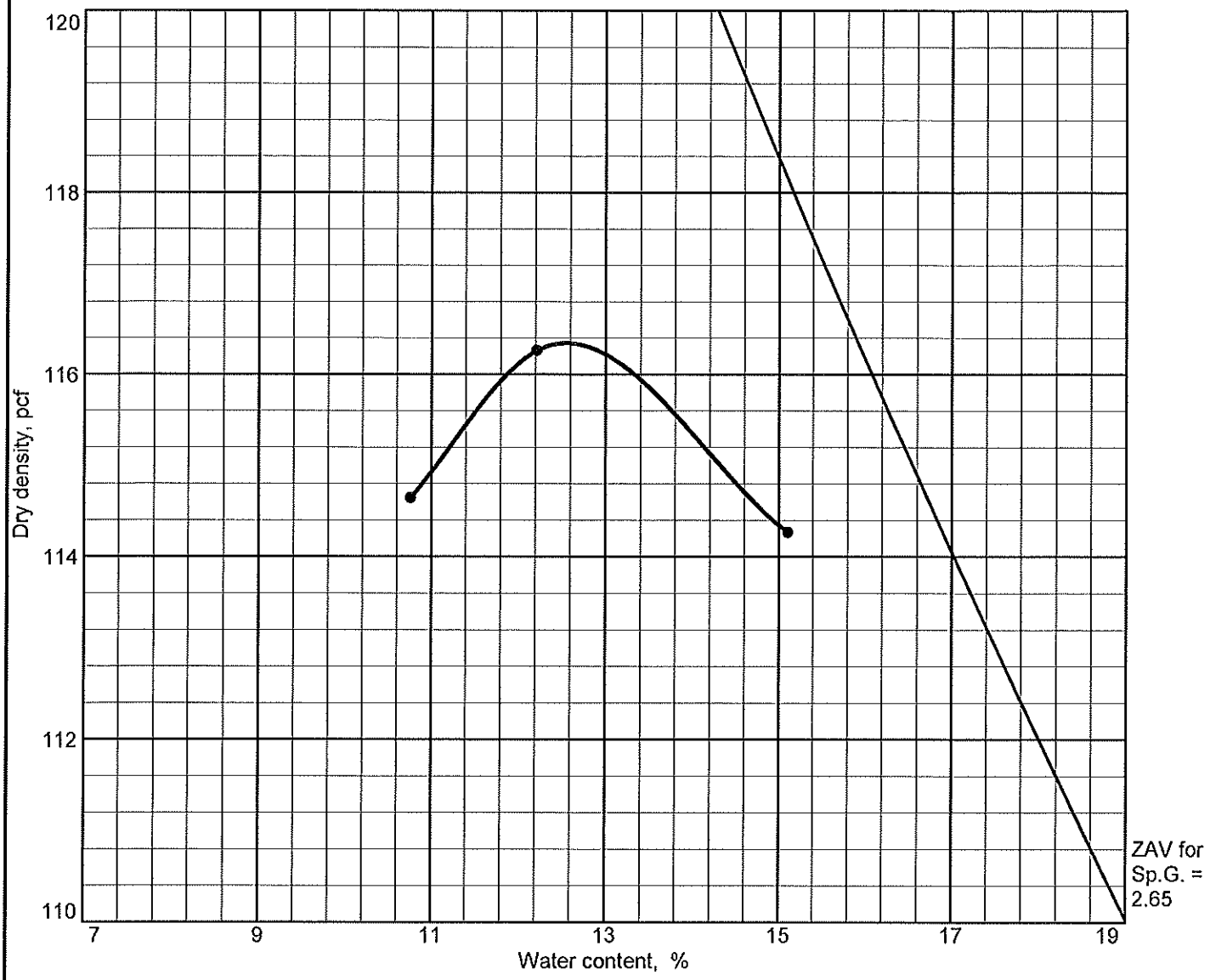
Project No.: CR-11-00665 **Client:**
Project: Lake Delhi Dam Repairs

● **Location:** Boring B-5

Remarks:

BRAUN INTERTEC

Moisture-Density Relationship



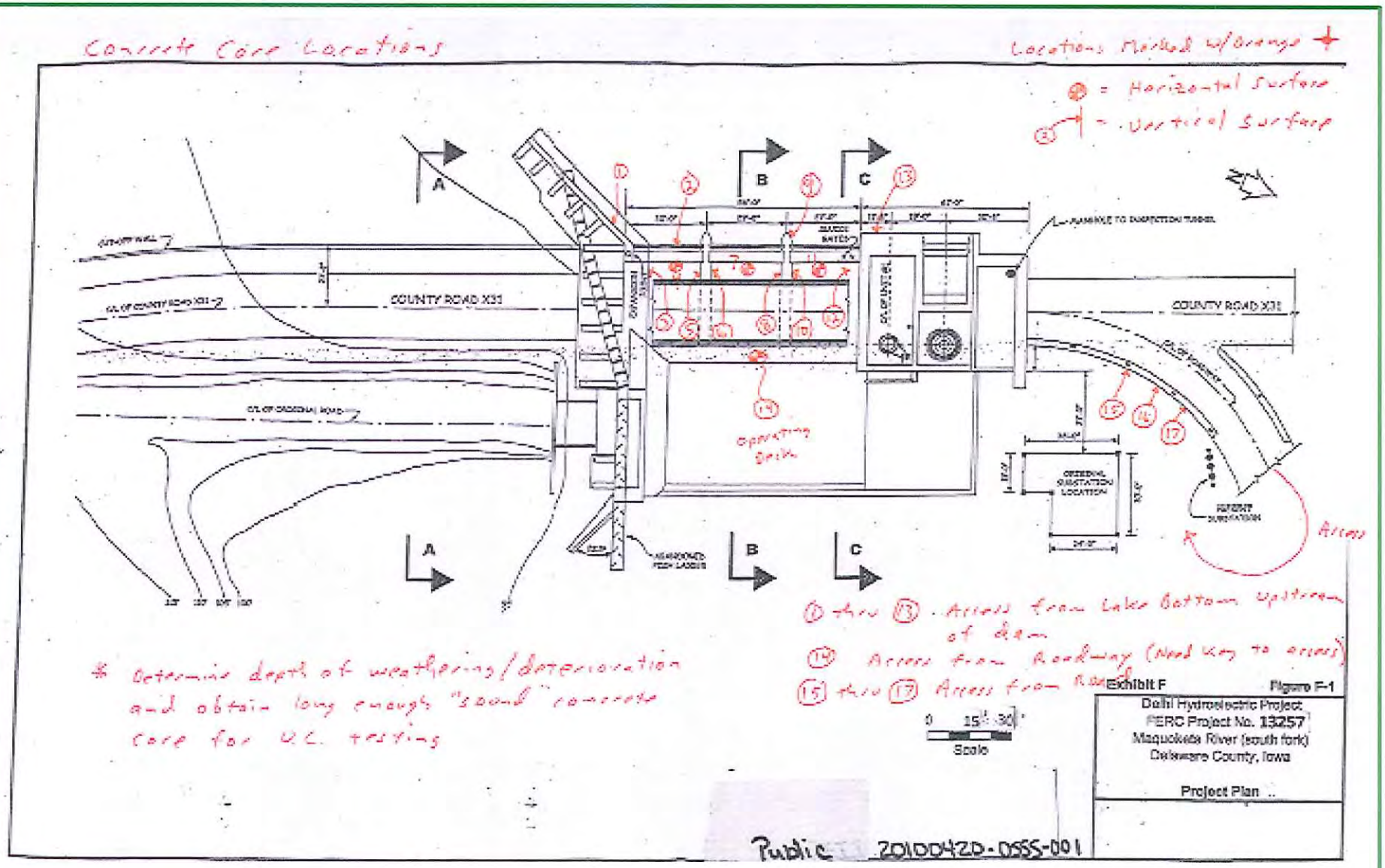
Test specification: ASTM D 698-07e1 Method A Standard

Elev/ Depth	Classification		Nat. Moist.	Sp.G.	LL	PI	% > No.4	% < No.200
	USCS	AASHTO						
13 - 25'	CL		15		33	17		

TEST RESULTS	MATERIAL DESCRIPTION
Maximum dry density = 116.3 pcf Optimum moisture = 12.6 %	Sandy Lean Clay
Project No.: CR-11-00665 **Client:** **Project:** Lake Delhi Dam Repairs ● **Location:** Boring B-5	**Remarks:**

BRAUN INTERTEC

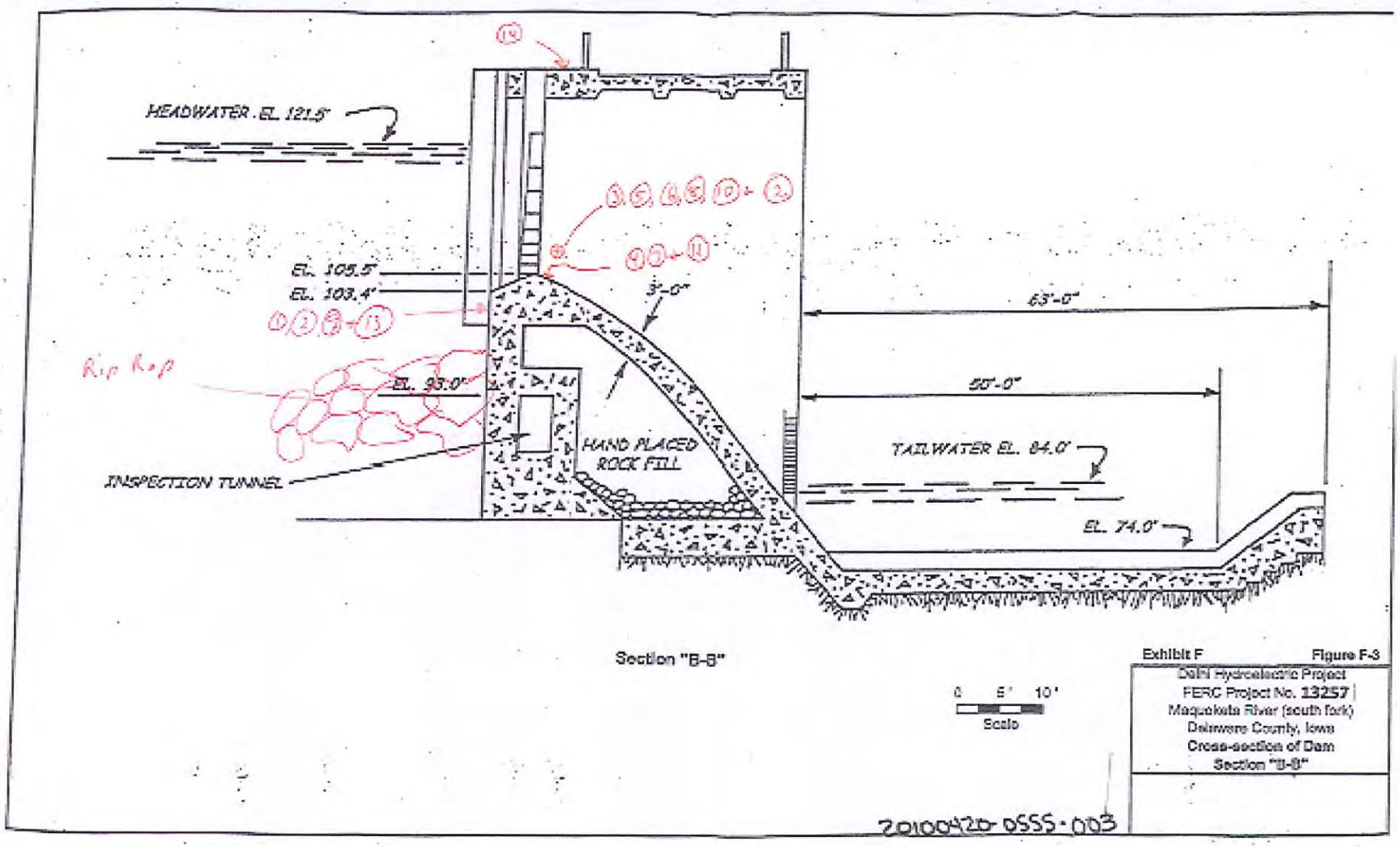
Concrete Core Location Plans



Source: Stanley Consultants

Approximate scale as shown

Lake Delhi Dam Restoration Delhi, Iowa	Project: CR-11-00665	Concrete Coring Location Sketch Page 1	BRAUN INTERTEC



Source: Stanley Consultants

Approximate scale as shown

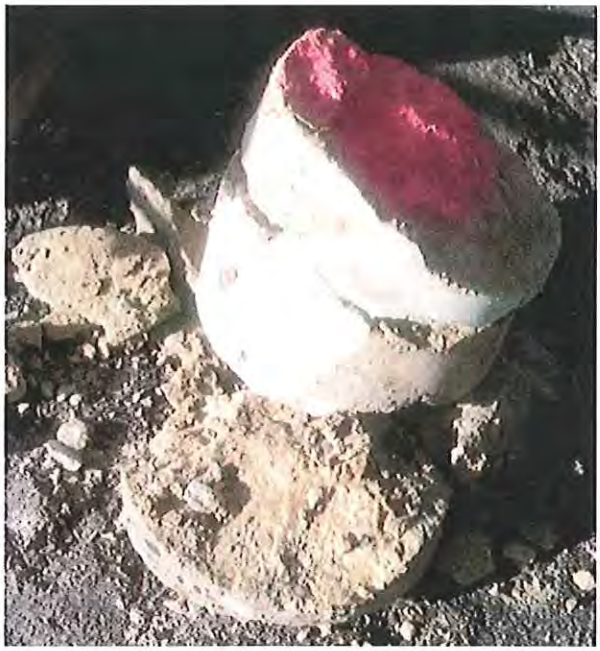
Lake Delhi Dam Restoration Delhi, Iowa	Project: CR-11-00665	Concrete Coring Location Sketch Page 2	BRAUN INTERTEC

Table of Concrete Core Compressive Strengths and Pictures of Fractured Cores

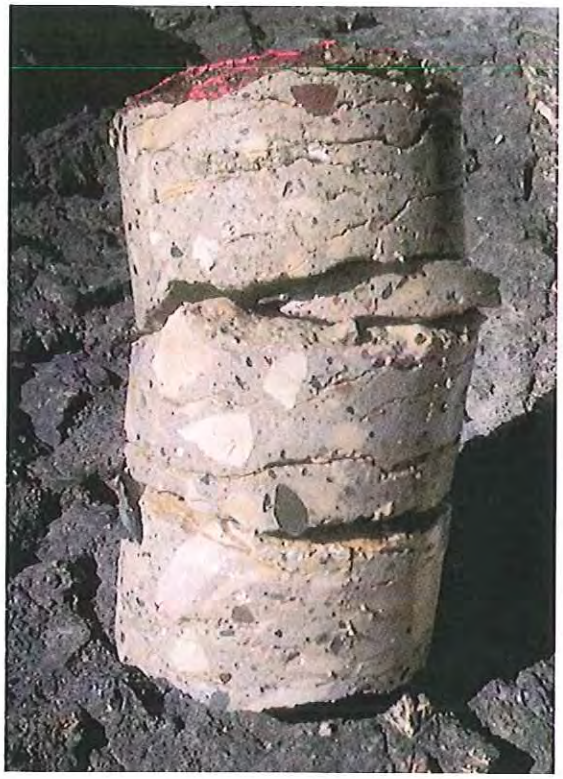
The following table shows the results of compressive strength testing where possible.

Core Number	Compressive Strength (psi)
1	6590
2	1480
3	2680
4	4180
7	4310
11	5120
15	3860
16	6470
17	1940

In general, the concrete did not respond well to coring and many of the cores broke or turned to rubble during the coring operation. The cores taken from vertical surfaces were typically in poorer condition than those taken from horizontal surfaces. Three examples of cores that were too short to test are in the following pictures. More than one attempt was made at several locations to obtain intact cores. The results of the petrographic analysis will be forwarded under separate cover.



Core Number 5



Core Number 6

Core Number 8

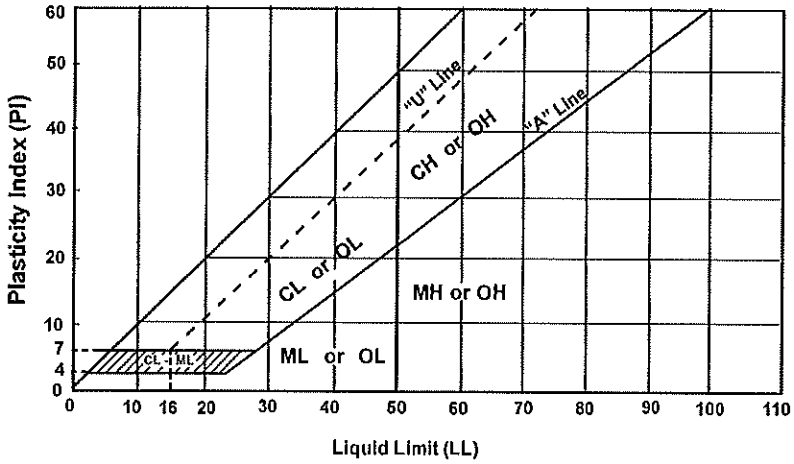
BRAUN
INTERTEC

Descriptive Terminology of Soil

Standard D 2487 - 00
Classification of Soils for Engineering Purposes
(Unified Soil Classification System)

Criteria for Assigning Group Symbols and Group Names Using Laboratory Tests [a]				Soils Classification	
				Group Symbol	Group Name [b]
Coarse-grained Soils more than 50% retained on No. 200 sieve	Gravels More than 50% of coarse fraction retained on No. 4 sieve	Clean Gravels 5% or less fines [e]	$C_u \geq 4$ and $1 \leq C_c \leq 3$ [c]	GW	Well-graded gravel [d]
			$C_u < 4$ and/or $1 > C_c > 3$ [c]	GP	Poorly graded gravel [d]
		Gravels with Fines More than 12% fines [e]	Fines classify as ML or MH	GM	Silty gravel [d f g]
			Fines classify as CL or CH	GC	Clayey gravel [d f g]
	Sands 50% or more of coarse fraction passes No. 4 sieve	Clean Sands 5% or less fines [i]	$C_u \geq 6$ and $1 \leq C_c \leq 3$ [c]	SW	Well-graded sand [h]
			$C_u < 6$ and/or $1 > C_c > 3$ [c]	SP	Poorly graded sand [h]
		Sands with Fines More than 12% [i]	Fines classify as ML or MH	SM	Silty sand [f g h]
			Fines classify as CL or CH	SC	Clayey sand [f g h]
Fine-grained Soils 50% or more passed the No. 200 sieve	Silts and Clays Liquid limit less than 50	Inorganic	PI > 7 and plots on or above "A" line [j]	CL	Lean clay [k l m]
			PI < 4 or plots below "A" line [j]	ML	Silt [k l m]
		Organic	Liquid limit - oven dried / Liquid limit - not dried < 0.75	OL	Organic clay [k l m n]
				OL	Organic silt [k l m o]
	Silts and clays Liquid limit 50 or more	Inorganic	PI plots on or above "A" line	CH	Fat clay [k l m]
			PI plots below "A" line	MH	Elastic silt [k l m]
		Organic	Liquid limit - oven dried / Liquid limit - not dried < 0.75	OH	Organic clay [k l m p]
				OH	Organic silt [k l m q]
Highly Organic Soils		Primarily organic matter, dark in color and organic odor		PT	Peat

a. Based on the material passing the 3-in (75mm) sieve.
b. If field sample contained cobbles or boulders, or both, add "with cobbles or boulders or both" to group name.
c. $C_u = D_{60}/D_{10}$ $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$
d. If soil contains ≥15% sand, add "with sand" to group name.
e. Gravels with 5 to 12% fines require dual symbols:
GW-GM well-graded gravel with silt
GW-GC well-graded gravel with clay
GP-GM poorly graded gravel with silt
GP-GC poorly graded gravel with clay
f. If fines classify as CL-ML, use dual symbol GC-GM or SC-SM.
g. If fines are organic, add "with organic fines" to group name.
h. If soil contains ≥ 15% gravel, add "with gravel" to group name.
i. Sands with 5 to 12% fines require dual symbols:
SW-SM well-graded sand with silt
SW-SC well-graded sand with clay
SP-SM poorly graded sand with silt
SP-SC poorly graded sand with clay
j. If Atterberg limits plot in hatched area, soil is a CL-ML, silty clay.
k. If soil contains 10 to 29% plus No. 200, add "with sand" or "with gravel" whichever is predominant.
l. If soil contains ≥ 30% plus No. 200, predominantly sand, add "sandy" to group name.
m. If soil contains ≥ 30% plus No. 200 predominantly gravel, add "gravelly" to group name.
n. PI ≥ 4 and plots on or above "A" line.
o. PI < 4 or plots below "A" line.
p. PI plots on or above "A" line.
q. PI plots below "A" line.



Laboratory Tests

DD	Dry density, pcf	OC	Organic content, %
WD	Wet density, pcf	S	Percent of saturation, %
MC	Natural moisture content, %	SG	Specific gravity
LL	Liquid limit, %	C	Cohesion, psf
PL	Plastic limit, %	∅	Angle of internal friction
PI	Plasticity index, %	qu	Unconfined compressive strength, psf
P200	% passing 200 sieve	qp	Pocket penetrometer strength, tsf

Particle Size Identification

Boulders ..... over 12"
Cobbles ..... 3" to 12"
Gravel
Coarse ..... 3/4" to 3"
Fine ..... No. 4 to 3/4"
Sand
Coarse ..... No. 4 to No. 10
Medium ..... No. 10 to No. 40
Fine ..... No. 40 to No. 200
Silt ..... < No. 200, PI < 4 or below "A" line
Clay ..... < No. 200, PI ≥ 4 and on or above "A" line

Relative Density of Cohesionless Soils

Very loose ..... 0 to 4 BPF
Loose ..... 5 to 10 BPF
Medium dense ..... 11 to 30 BPF
Dense ..... 31 to 50 BPF
Very dense ..... over 50 BPF

Consistency of Cohesive Soils

Very soft ..... 0 to 1 BPF
Soft ..... 2 to 3 BPF
Rather soft ..... 4 to 5 BPF
Medium ..... 6 to 8 BPF
Rather stiff ..... 9 to 12 BPF
Stiff ..... 13 to 16 BPF
Very stiff ..... 17 to 30 BPF
Hard ..... over 30 BPF

Drilling Notes

Standard penetration test borings were advanced by 3 1/4" or 6 1/4" ID hollow-stem augers unless noted otherwise, Jetting water was used to clean out auger prior to sampling only where indicated on logs. Standard penetration test borings are designated by the prefix "ST" (Split Tube). All samples were taken with the standard 2" OD split-tube sampler, except where noted.

Power auger borings were advanced by 4" or 6" diameter continuous-flight, solid-stem augers. Soil classifications and strata depths were inferred from disturbed samples augered to the surface and are, therefore, somewhat approximate. Power auger borings are designated by the prefix "B."

Hand auger borings were advanced manually with a 1 1/2" or 3 1/4" diameter auger and were limited to the depth from which the auger could be manually withdrawn. Hand auger borings are indicated by the prefix "H."

BPF: Numbers indicate blows per foot recorded in standard penetration test, also known as "N" value. The sampler was set 6" into undisturbed soil below the hollow-stem auger. Driving resistances were then counted for second and third 6" increments and added to get BPF. Where they differed significantly, they are reported in the following form: 2/12 for the second and third 6" increments, respectively.

WH: WH indicates the sampler penetrated soil under weight of hammer and rods alone; driving not required.

WR: WR indicates the sampler penetrated soil under weight of rods alone; hammer weight and driving not required.

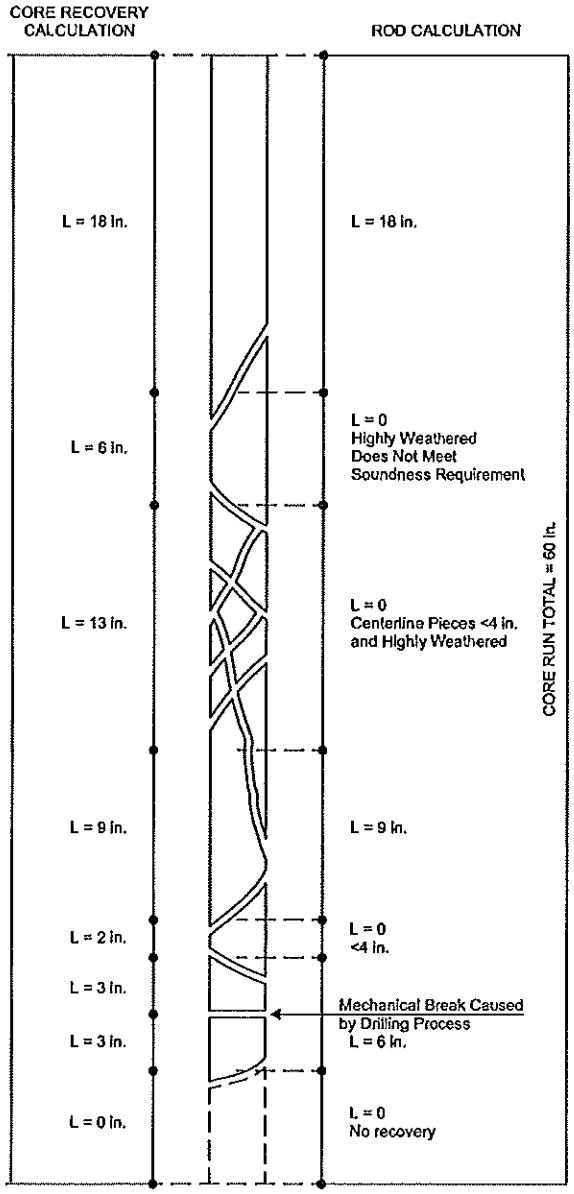
TW indicates thin-walled (undisturbed) tube sample.

Note: All tests were run in general accordance with applicable ASTM standards.

Rev. 7/07

Descriptive Terminology of Rock

Based on U.S. Army Corps of Engineers EM 1110-1-2908



Example Calculations

Core recovery, CR = $\frac{\text{Total length of rock recovered}}{\text{Total core run length}}$

Example: $CR = \frac{(18 + 6 + 13 + 9 + 2 + 3 + 3)}{(60)}$

$CR = 90\%$

RQD = $\frac{\text{Sum of sound piece longer than 4 inches}}{\text{Total core run length}}$

RQD Percent	Rock Quality
< 25	very poor
25 < 50	poor
50 < 75	fair
75 < 90	good
90 < 100	excellent

Example: $RQD = \frac{(18 + 9 + 6)}{(60)}$

$RQD = 55\%$

Weathering

Unweathered: No evidence of chemical or mechanical alteration.

Slightly weathered: Slight discoloration on surface, slight alteration along discontinuities, less than 10% of rock volume altered.

Moderately Weathered: Discoloration evident, surface pitted and altered with alteration penetrating well below rock surfaces, weathering halos evident, 10% to 50% of the rock altered.

Highly Weathered: Entire mass discolored, alteration pervading nearly all of the rock, with some pockets of slightly weathered rock noticeable, some mineral leached away.

Hardness

Very soft:	Can be deformed by hand
Soft:	Can be scratched with a fingernail
Moderately hard:	Can be scratched easily with a knife
Hard:	Can be scratched with difficulty with a knife
Very hard:	Cannot be scratched with a knife

Thickness of Bedding

Massive:	3 ft. thick or greater
Thick bedded:	1 to 3 ft. thick
Medium bedded:	4 in. to 1 ft. thick
Thin bedded:	4 in. thick or less

Degree of Fracturing (jointing)

Unfractured:	Fracture spacing 6 ft. of more
Slightly fractured:	Fracture spacing 2 to 6 ft.
Moderately fractured:	Fracture spacing 8 in. to 2 ft.
Highly fractured:	Fracture spacing 2 to 8 in.
Intensely fractured:	Fracture spacing 2 in. or less

2/08

Concrete Core Photographs

Core #1

Core #1 Break

Core #2

Core #2 Break

Core #3

Core #3 Break – Before

Core #3 Break – After

Core #4

Core #4 Break

Core #5

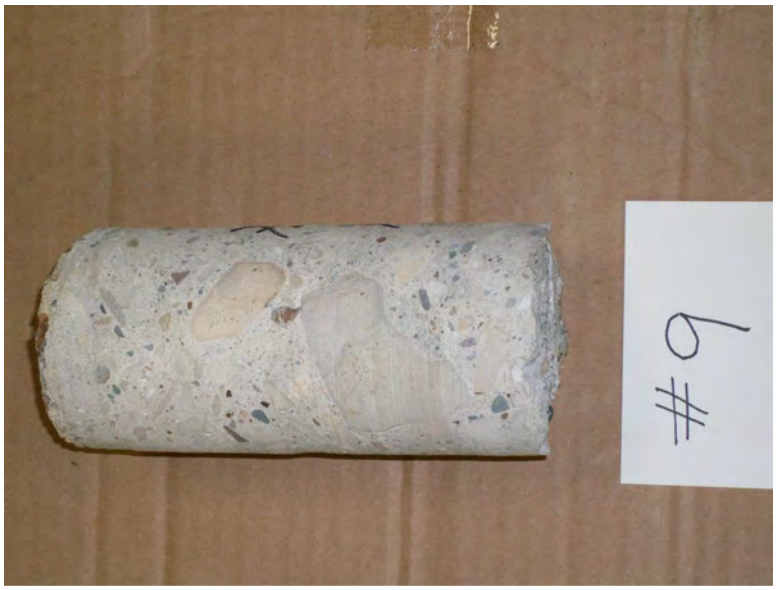
Core #6

Core #7

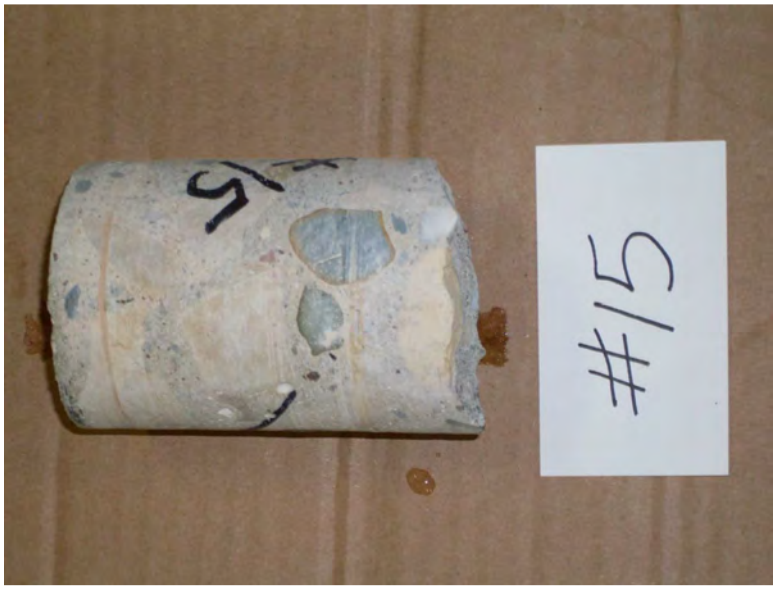
Core #7 Break

Core #8

Core #9



Core #9 Dry



Core #15 Dry

Core #16 Dry

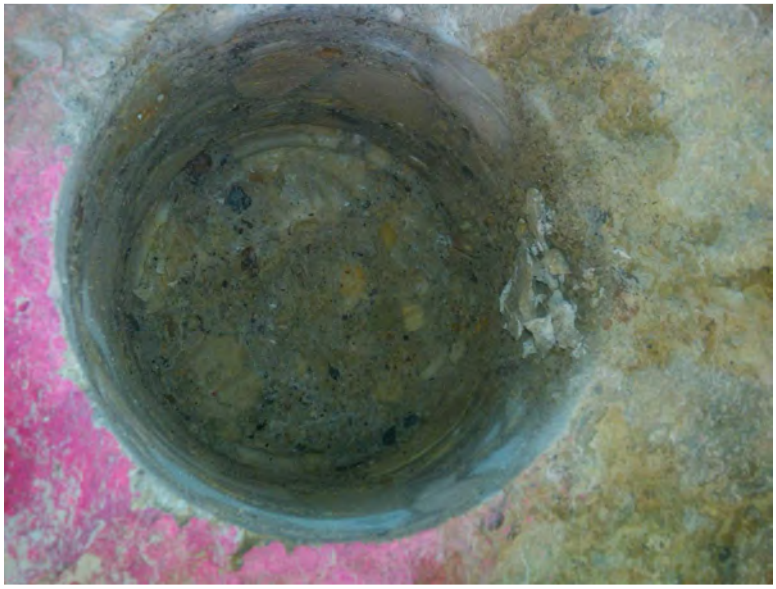
Core #17 Dry

Hole #2

Hole #3

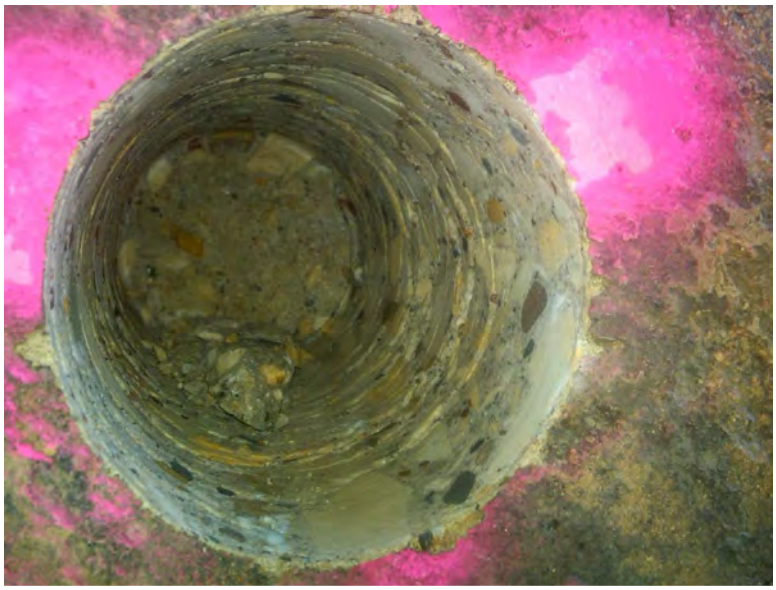
Hole #4

Hole #5 – 1



Hole #5 – 2

Hole #6



Hole #8

Hole #9

ST-11 Core Photographs

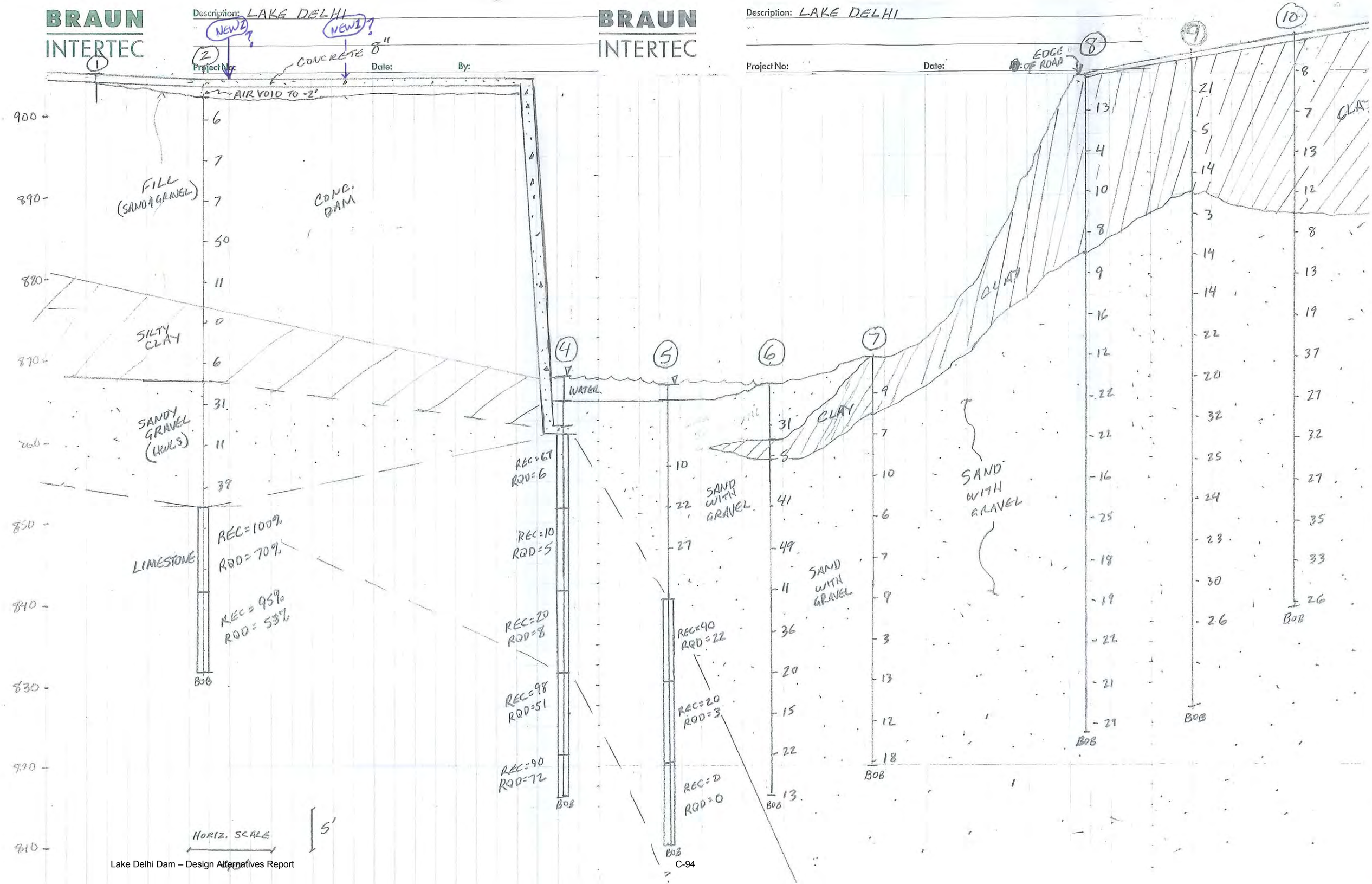
ST-11 50’ to 60’

ST-11 50’ to 60’ – Interface 1

ST-11 50’ to 60’ – Interface 2

ST-11 87’ to 97’

Geotechnical Parameters


BRAUN INTERTEC
Description: LAKE DELHI
Project No:
Date:
By:
NEW2 ?
NEW1 ?
CONCRETE 8"
AIR VOID TO -2'
FILL (SAND & GRAVEL)
CONC. DAM
SILTY CLAY
SANDY GRAVEL (HWLS)
LIMESTONE
REC=100%
RQD=70%
REC=95%
RQD=53%
BOB
WATER
REC=67
RQD=6
REC=10
RQD=5
REC=20
RQD=8
REC=98
RQD=51
REC=90
RQD=72
REC=40
RQD=22
REC=20
RQD=3
REC=0
RQD=0
SAND WITH GRAVEL
CLAY
EDGE OF ROAD
HORIZ. SCALE
5'
900
890
880
870
860
850
840
830
820
810

CLAY BORROW : TOTAL STRESS PARAMETERS

Table 3-2
Ratio of ϕ/δ (After Allen, Duncan, and Snacio 1988)

Soil Type	Steel	Wood	Concrete
Sand	$\delta/\phi = 0.54$	$\delta/\phi = 0.76$	$\delta/\phi = 0.76$
Silt & Clay	$\delta/\phi = 0.54$	$\delta/\phi = 0.55$	$\delta/\phi = 0.50$

Table 3-3
Values of δ for Various Interfaces
(after U.S. Department of the Navy 1982)

Soil Type	δ (deg)
(a) Steel sheet piles	
Clean gravel, gravel sand mixtures, well-graded rockfill with spalls	22
Clean sand, silty sand-gravel mixture, single-size hard rockfill	17
Silty sand, gravel or sand mixed with silt or clay	14
Fine sandy silt, nonplastic silt	11
(b) Concrete sheet piles	
Clean gravel, gravel sand mixtures, well-graded rockfill with spalls	22-26
Clean sand, silty sand-gravel mixture, single-size hard rockfill	17-22
Silty sand, gravel or sand mixed with silt or clay	17
Fine sandy silt, nonplastic silt	14

Table 3-4
Correlation of Undrained Shear Strength of Clay (q_u=2c)

Consistency	q_u (psf)	SPT (blows/ft)	Saturated Unit Weight (psf)
Very Soft	0-500	0-2	<100-110
Soft	500-1,000	3-4	100-120
Medium	1,000-2,000	5-8	110-125
Stiff	2,000-4,000	9-16	115-130
Very Stiff	4,000-8,000	16-32	120-140
Hard	>8,000	>32	>130

LOESS
TILL

(5) Since an undrained condition may be expected to occur under "fast" loading in the field, it represents a "short-term" condition; in time, drainage will occur, and the drained strength will govern (the "long-term" condition). To model these conditions in the laboratory, three types of tests are generally used; unconsolidated undrained (Q or UU), consolidated undrained (R or CU), and consolidated drained (S or CD). Undrained shear strength in the laboratory is determined from either Q or R tests and drained shear strength is established from S tests or from consolidated undrained tests with pore pressure measurements ($\bar{R}$).

(6) The undrained shear strength, S_u, of a normally consolidated clay is usually expressed by only a cohesion intercept; and it is labeled c_u to indicate that ϕ was taken as zero. c_u decreases dramatically with water content; therefore, in design it is common to consider the fully saturated condition even if a clay is partly saturated in the field. Typical undrained shear strength values are presented in Table 3-4. S_u increases with depth (or effective stress) and this is commonly expressed with the ratio "S_u/p" (p denotes the effective vertical stress). This ratio correlates roughly with plasticity index and overconsolidation ratio (Figures 3-2, 3-3, respectively). The undrained shear strength of many overconsolidated soils is further complicated due to the presence of fissures; this leads to a lower field strength than tests on small laboratory samples indicate.

(7) The drained shear strength of normally consolidated clays is similar to that of loose sands ($c' = O$), except that ϕ is generally lower. An empirical correlation of the effective angle of internal friction, ϕ', with plasticity index for normally consolidated clays is shown in Figure 3-4. The drained shear strength of over-consolidated clays is similar to that of dense sands (again with lower ϕ'), where there is a peak strength (c' nonzero) and a "residual" shear strength ($c' = O$).

(8) The general approach in solving problems involving clay is that, unless the choice is obvious, both undrained and drained conditions are analyzed separately. The more critical condition governs the design. Total stresses are used in an analysis with undrained shear strength (since pore pressures are "included" in the undrained shear strength) and effective stresses in a drained case; thus such analyses are usually called total and effective stress analyses, respectively.

(9) At low stress levels, such as near the top of a wall, the undrained strength is greater than the drained

LOESS : assume q_u = 2000 psf ; c = 1000 psf (compacted)
TILL : assume q_u = 4000 psf ; c = 2000 psf (compacted)

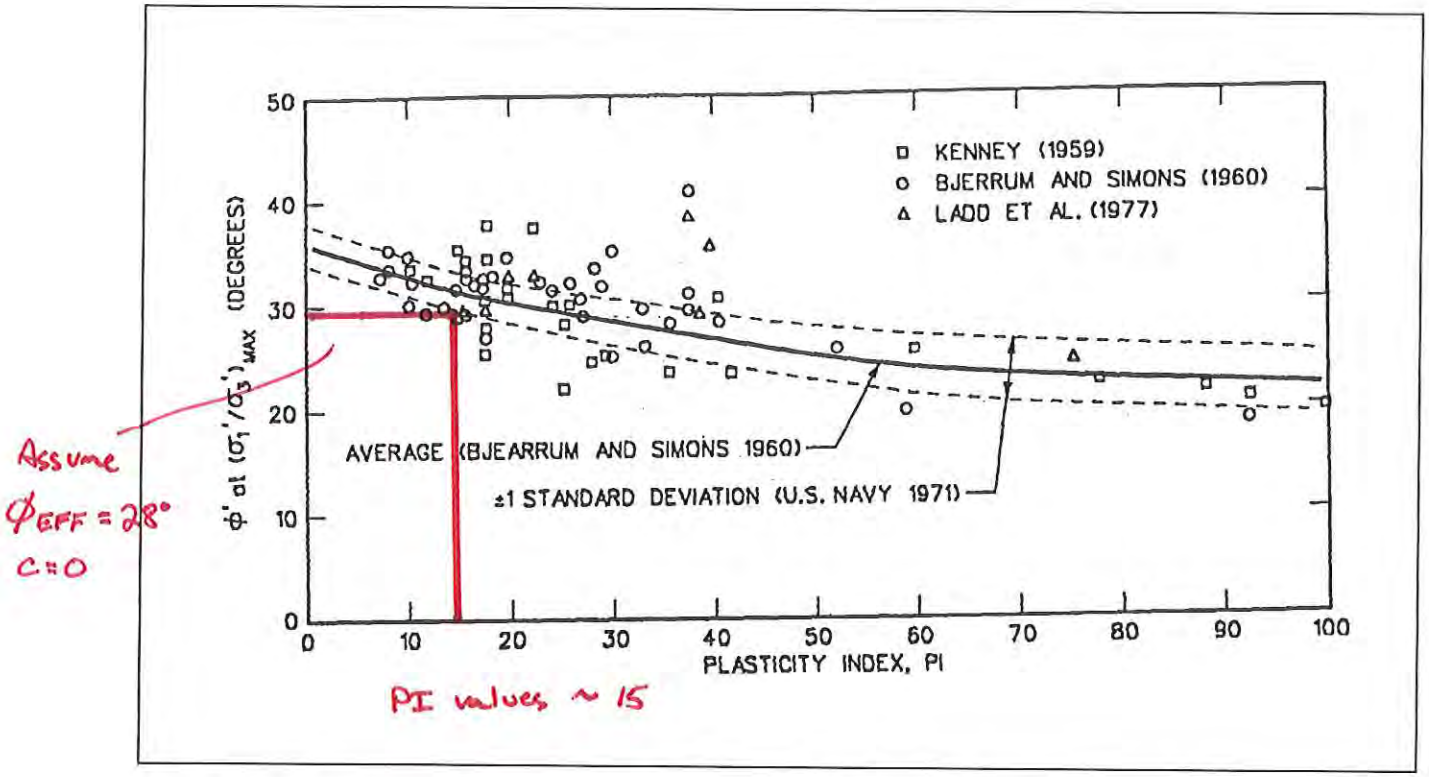


Figure 3-4. Empirical correlation between friction angle and PI from triaxial tests on normally consolidated clays

stress of 1 ton per square foot using an equation of the form:

$$N' = C_N N \tag{3-1}$$

where

N' = corrected resistance

C_N = correction factor

N = measured resistance

Table 3-5 and Figure 3-5 summarize the some most commonly proposed values for C_N. Whitman and Liao (1984) developed the following expression for C_N:

$$C_N = \sqrt{\frac{1}{\sigma'_{vo}}} \tag{3-2}$$

where effective stress due to overburden, σ'_{vo}, is expressed in tons per square foot. The drained friction angle ϕ' can be estimated from N' using Figure 3-6. The relative density of normally consolidated sands can be estimated from the correlation obtained by Marcuson and Bieganousky (1977):

$$D_r = 11.7 + 0.76[|222(N) + 1600 - 53(p'_{vo}) - 50(C_u)^2|]^{1/2} \tag{3-3}$$

where

p'_{vo} = effective overburden pressure in pounds per square inch

C_u = coefficient of uniformity (D_{60}/D_{10})

Correlations have also been proposed between the SPT and the undrained strength of clays (see Table 3-4). However, these are generally unreliable and should be used for very preliminary studies only and for checking the reasonableness of SPT and lab data.

c. Cone penetration test. The CPT (ASTM D 3441-79 (1986a)) is widely used in Europe and is gaining

From Brown. Ref. unknown

Clay borrow; effective strength parameters

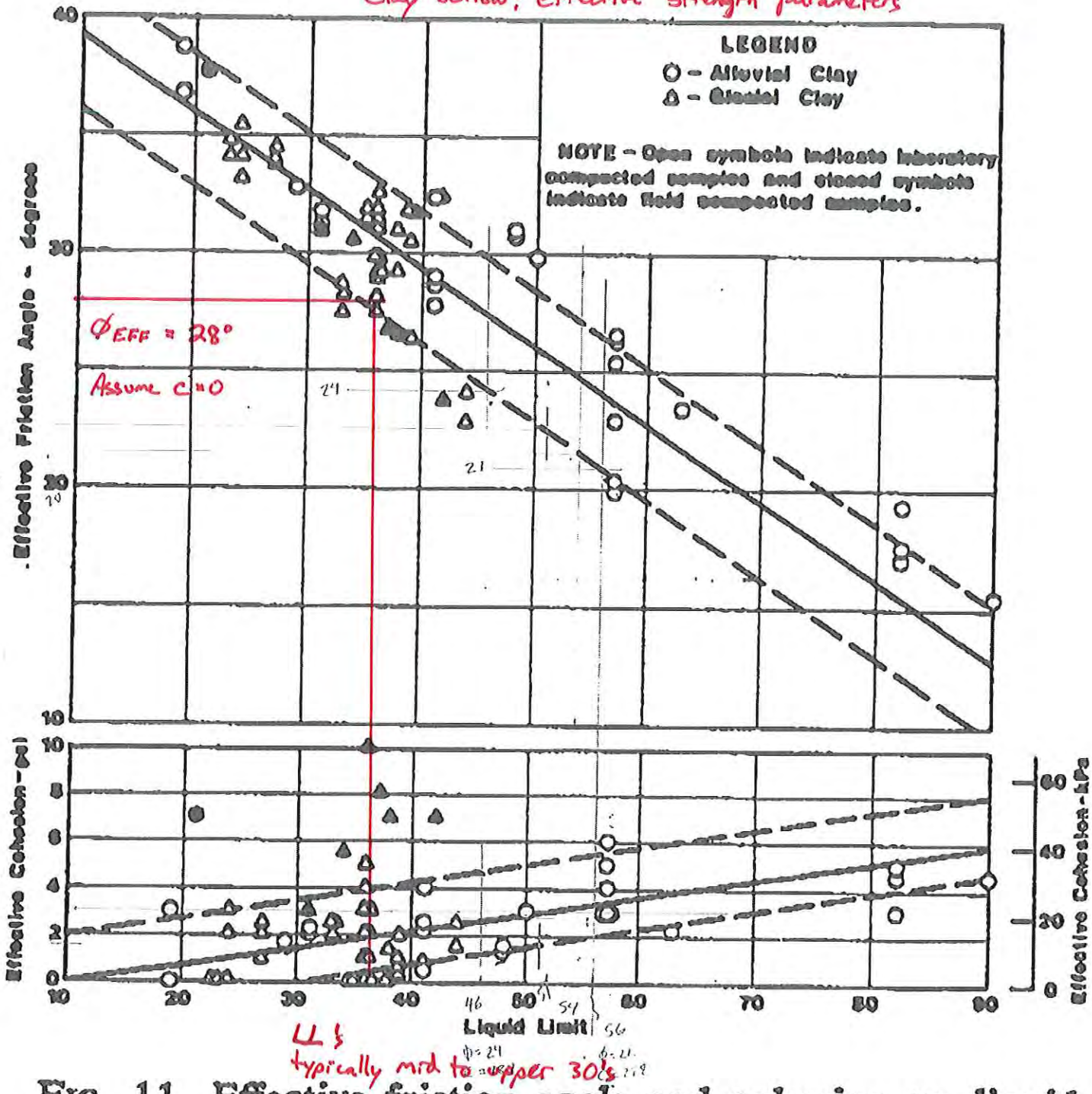


FIG. 11. Effective friction angle and cohesion vs. liquid limit for consolidated undrained tests on compacted clays.

Sand/Gravel Strength Parameters

Table 3-1
Granular Soil Properties (after Teng 1962)

Compactness	Relative Density (%)	SPT N (blows per ft)	Angle of Internal Friction (deg)	Unit Weight	
				Moist (pcf)	Submerged (pcf)
Very Loose	0-15	0-4	<28	<100	<60
Loose	16-35	5-10	28-30	95-125	55-65
Medium	36-65	11-30	31-36	110-130	60-70
Dense	66-85	31-50	37-41	110-140	65-85
Very Dense	86-100	>51	>41	>130	>75

Blow Count Range

Assume $\phi = 30°$

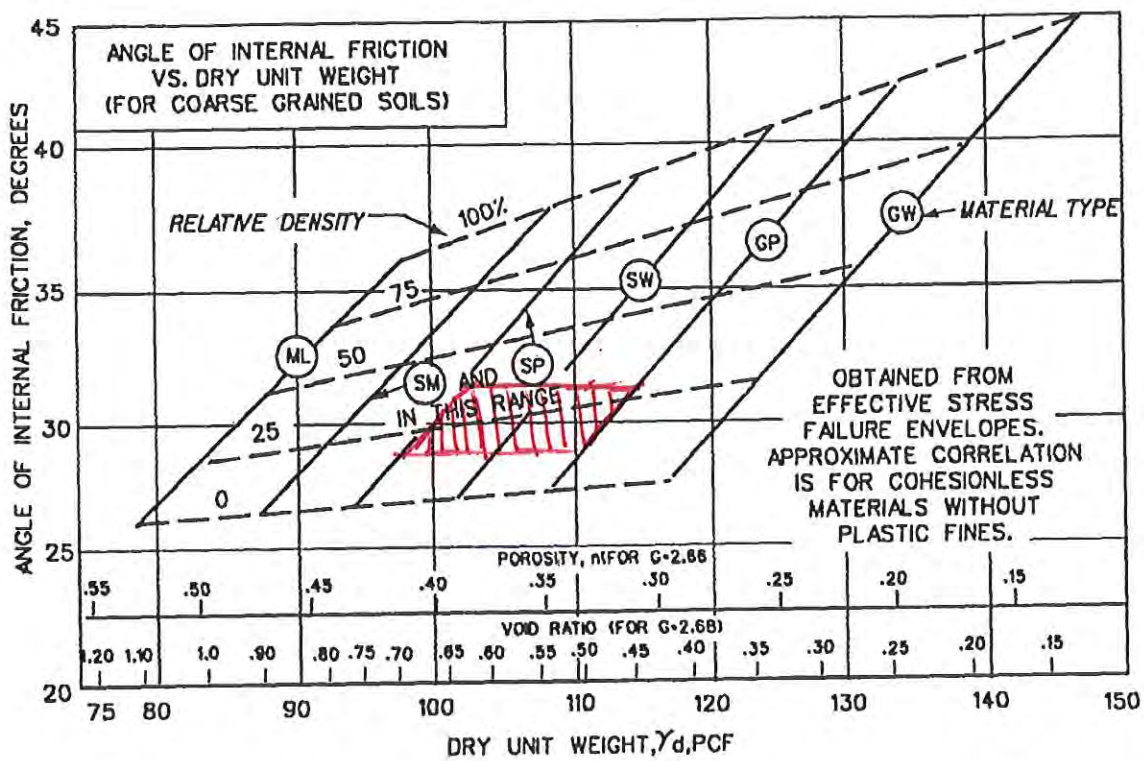


Figure 3-1. Cohesionless Soil Properties (after U.S. Department of the Navy 1971)

SEEPAGE PARAMETERS

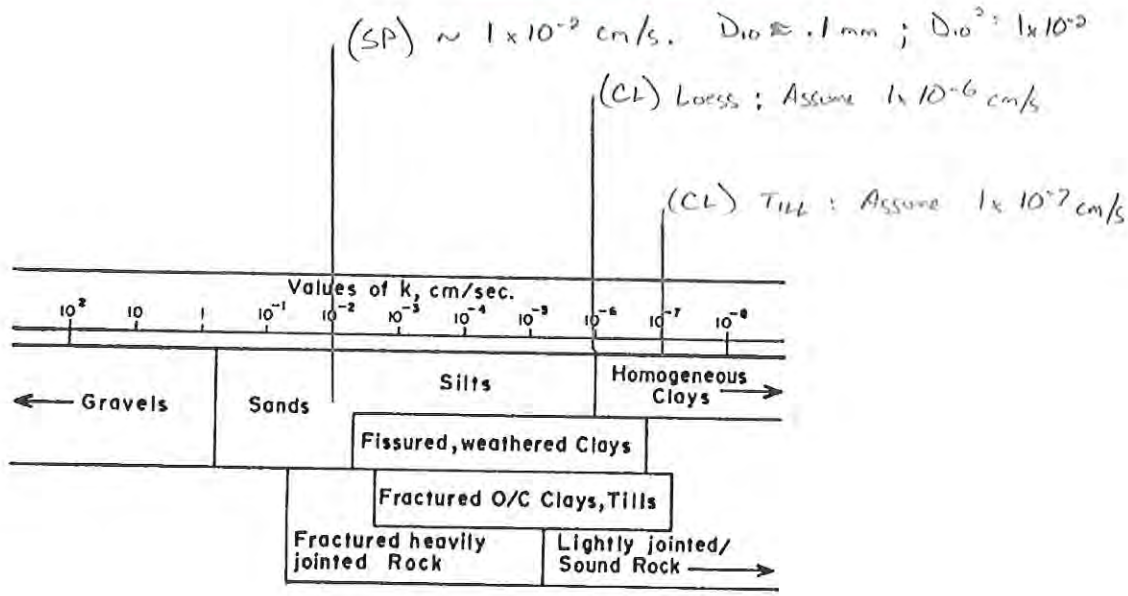


Figure 2-5. Approximate range in coefficient of permeability of soils and rocks (from Milligan[224])

ordinary gravel or soil and have tremendous influence on the watertightness of dam foundations and abutments as shown in figure 2-6 (Cedergren 1977). Figure 2-6a shows a soil profile surmised from several drill holes. The grain size analysis of soil samples taken at frequent intervals erroneously indicated that the deposit was composed of relatively uniform sandy gravels. Laboratory permeability tests on disturbed samples produced coefficients of permeability of about 1 x 10^{-6} cm/sec. Using this value of permeability, the probable seepage loss beneath the proposed dam was estimated to be 3 cu ft/day, which is an insignificant quantity. However, the design engineer had observed many openwork streaks in which the fines fraction of the material was almost completely absent along the banks of the river and noted that the ground-water table was level for several hundred feet away from the river and fluctuated rapidly with changes in river stage. Field pumping tests were conducted which indicated somewhat variable permeabilities but none approaching the magnitude of openwork gravels. Based upon the available data, the dam was designed with a cutoff trench to bedrock. During the excavation of the cutoff trench, streaks of openwork gravel were found throughout the foundation. A revised seepage computation based on a permeability of 30 cm/sec indicated that without the cutoff trench, the theoretical underseepage would be about 1,000,000 cu ft/day. If openwork gravel or other important discontinuities in earth dam foundations remain undetected, serious problems from excessive seepage and hydrostatic pressures will develop. This example illustrates the potential serious effects of deviations between the design assumptions and the as-built dam (Cedergren 1977). Also, thin continuous seams of cohesive soil can drastically alter the vertical flow through what would otherwise be a highly permeable site.