

SO-Sieve

Version 1.2.8668.1

Scientific Manual

This software is developed by Soil Office Software Group. SO-Sieve includes sieve analysis, hydrometer and Atterberg limits tests. Soil type is also presented based on USCS (Unified Soil Classification System).



September 2023

Table of contents

1 INTRODUCTION..... 1

1-1 SOIL OFFICE 1

1-2 SO-SIEVE 1

1-3 SOFTWARE CAPABILITIES 1

 1-3-1 General features 1

 1-3-2 Sieve analysis 1

 1-3-3 Hydrometer test 2

 1-3-4 Atterberg limits tests 2

2 SOFTWARE INTERFACE 3

2-1 GENERAL 3

2-2 DETAILS ON MENUS 3

 2-2-1 File menu 3

 2-2-2 Main 4

 2-2-3 Test 5

 2-2-4 Export 13

 2-2-5 Settings 13

3 ERRORS 17

3-1 PRIMARY ERRORS 17

3-2 SECONDARY ERRORS 17

4 CALCULATION THEORIES 18

4-1 SIEVE ANALYSIS TEST 18

4-2 HYDROMETER TEST 19

 4-2-1 ASTM D7928 20

 4-2-2 ASTM D422 23

4-3 ATTERBERG LIMITS TESTS 26

 4-3-1 Liquid limit test 26

 4-3-2 Plastic limit test 27

 4-3-3 Plasticity index 27

5 CONTACT US 28

6 LIST OF SYMBOLS 29

1 INTRODUCTION

1-1 SOIL OFFICE

“Soil Office” is a developer of geotechnical engineering software since 2013. Our main objective is to develop functional and user friendly software, capable of performing precise calculations. The following software is currently considered:

- SO-Foundation: Bearing capacity of shallow foundations
- SO-Lab: Soil mechanics laboratory tests and boring logs including:
 - SO-Sieve: Sieve analysis, Hydrometer & Atterberg limits
 - SO-Shear: Direct shear
 - SO-Unconfined: Unconfined compression
 - SO-Triaxial: Triaxial compression
 - SO-Consolidation: One-dimensional consolidation
 - SO-Log: Geotechnical engineering boring logs

Feel free to contact us regarding any criticism, recommendation or additional information.

1-2 SO-SIEVE

“SO-Sieve” having a user-friendly interface, includes sieve analysis, hydrometer and Atterberg limits tests. It also presents soil type based on USCS (Unified Soil Classification System).

Sieve analysis and Atterberg limits may either be determined by test results or visual examination. Hydrometer test can be calculated using both ASTM D7928 and ASTM D422 (withdrawn 2016) standards. Note that sieve analysis and hydrometer tests could randomly be generated based on user-defined criteria.

Finally, in addition to test data and corresponding calculations, software outputs are presented in both landscape and portrait formats.

1-3 SOFTWARE CAPABILITIES

1-3-1 GENERAL FEATURES

- Supports “Metric” and “English” units.
- User is informed about the common ranges regarding input parameters.
- Software outputs are exported in both landscape and portrait formats.
- Test data and corresponding calculations are presented in a separate format.
- Blank laboratory data sheets may be used for test data input.
- Saving files with a minimal size.

1-3-2 SIEVE ANALYSIS

- Visual examination may be used for the determination of particle-size distribution.
- Random generation of sample sieve analysis tests based on user-defined criteria.
- Various sieve sets may be defined and used when needed.
- Test data can be edited using either graph or input table.

1-3-3 HYDROMETER TEST

- Random generation of sample hydrometer tests based on user-defined criteria.
- Hydrometer calculation using ASTM D7928:
 - Control cylinder correction: Correction value is measured using a control cylinder after each of the test readings.
 - Calibration relationship: is defined and automatically applied.
- Hydrometer calculation using ASTM D422:
 - Normal correction: Separate corrections are applied for the effect of temperature and dispersing agent. Temperature correction may be automatic or manually assigned by the user.
 - Composite correction: is measured at two temperatures (spanning the range of expected test temperatures) and corrections for other temperatures are calculated by the use of linear interpolation.
- The following may be defined through software settings and used when needed:
 - Time list.
 - Various 151H and 152H hydrometers.
 - Corrections regarding various hydrometers including composite correction and calibration relationship.

1-3-4 ATTERBERG LIMITS TESTS

- Visual examination may be used for the determination of soil type according to plasticity chart.
- User is warned when ASTM D4318 regulations are not satisfied.

2 SOFTWARE INTERFACE

2-1 GENERAL

After running SO-Sieve, the following menus are visible on the top ribbon:

File menu: Contains commands relating to the handling of files, such as creating a new project, save, etc.

Main: Project information, borings and samples are determined using this menu.

Test: Contains the following:

- **USCS:** Includes sieve analysis, hydrometer and Atterberg limits tests. Note that only final results regarding Atterberg limits tests can be assigned through this menu.
- **Atterberg limits:** Specifically used for Atterberg limits tests.
- **Edit:** Tests performed on a sample can be copied, moved or deleted using this menu.

Export: Contains the following:

- **Export:** Is used to export software outputs.
- **Blank:** Includes blank laboratory data sheets.

Settings: Program settings are determined through this menu.

Help: Contains the following:

- **Scientific manual:** Describes functionality of different parts of the software and the theories of the utilized methods.
- **Index:** Contains indexed help topics.

License: The permit to use the software and information on the client.

About: Contains general information.

- **SO-Sieve:** Brief description about the current software and its version.
- **Soil Office:** Introducing Soil Office Software Group.

Units: Switches between the available unit systems.

2-2 DETAILS ON MENUS

2-2-1 FILE MENU

This menu is consisted of the following:

New: Creation of a new project.

Open: Opens a previously defined project.

Save: Saves project (with *.sos extension).

Save as: Saves project with a different name.

Sample project: Sample project in order to demonstrate software features and easily work with it. Results regarding each of the sieve analysis, hydrometer and Atterberg limits tests are introduced or calculated by a variety of methods.

Close: Closes project.

Exit: Closes project and exits SO-Sieve

2-2-2 MAIN

2-2-2-1 PROJECT INFORMATION

Basic project information including name, client, location and code are entered in this section. A separate field is also dedicated for notes. The user can specify the project location on the map and the coordinates will be shown in the corresponding field. Project address is also presented by activating the “Reverse geocoding” option and the user may accept it or not.

2-2-2-2 TABLE OF BORINGS

Project borings are identified through this table. The input parameters are listed below:

Boring method: Whenever the boring is machine-drilled and the method is not included in the available options or the user prefers it not to be specified, the “-” option can be used.

Name: Boring name.

Depth: Boring depth.

Elev.: Ground elevation at top of boring.

GWT: Depth to water table measured from boring top (Ground Water Table).

Note: Notes regarding the boring such as weather conditions including recent rain or other events that could affect subsurface conditions.

Export: Defines whether the boring is included in the output or not. This option is active by default.

Contractor: Name of the drilling contractor.

Start date: Start date of drilling.

Finish date: Finish date of drilling.

2-2-2-3 TABLE OF SAMPLES

Samples obtained within each of the borings are introduced in this table. The input parameters are listed below:

Depth: Sample depth.

Sample category: Sample category including “Disturbed”, “Undisturbed” and “Rock core”.

Sample type: Varies by boring method and sample category. “-” may be used if empty for any reason.

Color: Sample color. Some colors are available by default and others can be defined by the user.

Code: Sample code.

Note: Notes regarding sample or its extrusion process.

2-2-3 TEST

The following are used in various parts of the software:

More ...: Is displayed as red when filled and contains:

Date: Test date.

Time: Test time.

Tested by: Name of the technician.

Note: Notes regarding the test.

Delete test: The test in the relevant section will be deleted.

Other parameters along with their usage are presented in their relevant sections. Note that some parameters are defined more than once for the ease of access.

2-2-3-1 USCS

2-2-3-1-1 SIEVE ANALYSIS

The grain-size distribution of coarse-grained soil is generally determined by means of sieve analysis. Some related parameters are presented below:

PEAT: is active whenever soil is of “peat” type. Activating this option, results in deactivation of others.

Cobble: is selected if “cobble” exist in the sample.

Boulder: is selected if “boulders” exist in the sample.

Organic: is related to the existence of organic fines in the soil sample.

Dry mass: Sample dry mass.

Load sieve set: using this option, various sieve sets can be loaded. Note that sieve sets are filtered considering used sieves (sieves where mass retained column is filled) in the sieve analysis table.

Used sieves: if active, only sieves that are used in the sieve analysis test are displayed.

Sieve analysis test table: has the following columns:

Sieve: Sieve name.

Opening: Sieve opening.

Mass retained: Soil mass retained on sieve in grams and percent, respectively.

Cumulative percent coarser: Cumulative percent of soil retained on a sieve.

Cumulative percent finer: Cumulative percent of soil passing a sieve.

Pan: Soil mass retained on the pan.

Note:

- 1- Whenever grain size corresponding to 100 [%] cumulative percent finer is not available in the test, one sieve size larger than the first used sieve (according to sieve list presented in ASTM E11) is considered as 100 [%] cumulative percent finer.
- 2- Soil mass retained on “No. 200” sieve has to be entered, otherwise, fines cannot be determined.

Visual examination: using this option, soil classification can be determined based on visual examination. Considering the sieve analysis test not being performed, the corresponding table is disabled and the following parameters are introduced:

USCS: Soil type according to USCS (Unified Soil Classification System) which is selectable by the user. Note that the possible choices are filtered considering the Atterberg limits.

Description: Sample description according to USCS not taking into account cobbles and boulders.

Generation: This option is mainly for the generation of random sieve analysis tests based on user-defined criteria. These criteria include the following parameters:

Gravel: Percentage of gravel.

Sand: Percentage of sand.

Fines: Percentage of fines.

W/P: Gradation type. “W” for well-graded and “P” for poorly-graded. This option is available only where “Fines” are equal to or less than 12 [%].

1st sieve: Largest sieve used in sieve analysis test.

By every single click on “Generate”, a new sieve analysis test is randomly generated considering the mentioned criteria. If the test fully matches the desired conditions, “Synced” is displayed, otherwise, “Not synced” is displayed.

Note: Coarse-grained soils (with fines equal to or less than 12 [%]) with C_u greater than or equal to 4.0 in gravels and 6.0 in sands where C_c is at least 1.0 but not more than 3.0, are considered as well-graded, otherwise poorly-graded.

Calculation of C_u and C_c is presented in section 2-2-3-1-5.

2-2-3-1-2 HYDROMETER

The sedimentation or hydrometer method is used to determine the particle-size distribution (gradation) of the material that is finer than the No. 200 (75- μ m) sieve and larger than about 0.2 [μ m]. By choosing the corresponding option, hydrometer test is activated and can be calculated using both ASTM D7928 and ASTM D422 (withdrawn 2016) standards. The following are common in both standards:

Type: Hydrometer type (151H or 152H).

Hydrometer details: are displayed by clicking. A default hydrometer is defined for each case.

Load hydrometer: various hydrometers can be loaded using this option.

Dispersant: a field for specifying the dispersing agent used in the test.

Separation sieve: the sieve that the hydrometer test material is passed through.

Passing: Cumulative percent finer of the sample corresponding to the separation sieve, which is automatically calculated (if possible) and as a result, hydrometer graph is attached to sieve analysis graph.

Generation: This option is mainly for the generation of random hydrometer tests based on user-defined criterion. The user may choose between the three options CL/CH, CL-ML and ML/MH as fines type and by every single click on “Generate”, a new hydrometer test is randomly generated considering the user’s choice. If the test matches the desired condition, “Synced” is displayed, otherwise, “Not synced” is displayed.

Note: Sand, silt and clay percentages are displayed beneath the hydrometer table. Particles finer than 0.002 [mm] are considered as clay by default. This criterion can be altered to 0.005 [mm] through the software settings.

❖ ASTM D7928

Current method contains the following parameters:

G_s : Specific gravity of soil solids.

M_d : Mass of dry soil.

V_{sp} : Volume of suspension.

Temp.: Temperature.

Constant: Temperature is constant during test. Using this option, the temperature column is disabled in the hydrometer test table and the specified value is assigned to all readings.

Variable: Temperature is variable during test. In this case, temperature should also be entered along with each hydrometer reading.

According to ASTM D7928, two methods are introduced for the correction of readings:

Control cylinder: In this method a control cylinder filled with the reference solution is used in conjunction with the soil suspension cylinder to obtain the correction. Thus the following two parameters are involved in the correction process:

C_m : Meniscus correction.

Offset (R_{dt}): Hydrometer offset reading from reference solution at same temperature as reading.

Calibration relationship: In this method, corrections are performed by the use of calibration relationship, which is once defined and afterwards automatically applied to all readings. Below parameters are used in this method:

C_m : Meniscus correction.

T_i : Temperature corresponding to each correction reading.

151H:

$R_{151,t}$: each calibration relationship reading in 151H hydrometers.

A_i : is calculated as $A_t = R_{151,t} + (7.784 \times 10^{-6} \times T_t) + (4.959 \times 10^{-6} \times T_t^2)$.

A : average of A_i values.

Std. Dev.: Standard deviation of A_i values.

Offset (R_{dt}): is calculated as $R_{dt} = A - (7.784 \times 10^{-6} \times T) - (4.959 \times 10^{-6} \times T^2)$. Note that “ T ” is the temperature corresponding to the reading to be corrected.

152H:

$R_{152,t}$: each calibration relationship reading in 152H hydrometers.

B_t : is calculated as $B_t = R_{152,t} + (1.248 \times 10^{-2} \times T_t) + (7.950 \times 10^{-3} \times T_t^2)$.

B : average of B_t values.

Std. Dev.: Standard deviation of B_t values.

Offset (R_{dt}): is calculated as $R_{dt} = B - (1.248 \times 10^{-2} \times T) - (7.950 \times 10^{-3} \times T^2)$. Note that “ T ” is the temperature corresponding to the reading to be corrected.

Hydrometer test table: has the following columns in ASTM D7928 mode:

Elapsed time (t): Elapsed time.

Temp. (T): Temperature.

Reading (R): Hydrometer reading.

Offset (R_{dt}): Hydrometer offset due to temperature and dispersant.

Corrected readings ($R - R_{dt}$): Readings corrected for temperature and dispersant.

Corrected readings (R_{cL}): Meniscus-corrected readings.

Fall distance (H): Particle fall distance.

Diameter (D): Particle diameter.

Percent finer (Partial): Partial cumulative percent finer.

Percent finer (Total): Total cumulative percent finer.

❖ ASTM D422

Current method contains the following parameters:

G_s : Specific gravity of soil solids.

M_d : Mass of dry soil.

$Temp.$: Temperature.

Constant: Temperature is constant during test. Using this option, the temperature column is disabled in the hydrometer test table and the specified value is assigned to all readings.

Variable: Temperature is variable during test. In this case, temperature should also be entered along with each hydrometer reading.

According to ASTM D422, two methods are introduced for the correction of readings:

Normal correction: Each of the corrections are separately determined in this mode:

C_m : Meniscus correction.

C_t - *Manual*: User-defined temperature correction. This option is available only when the temperature is constant during the test.

C_t - *Automatic*: Automatic temperature correction. There is no limitation to using this option.

C_d : Dispersant correction.

Composite correction: is measured at two temperatures (spanning the range of expected test temperatures) and corrections for other temperatures are calculated by the use of linear interpolation. Linear extrapolation is also used in case the temperature is not within the defined values. Composite correction is defined using the following:

C_m : Meniscus correction.

T_i : Temperature corresponding to each correction reading. The two temperatures are preferred to be spanning the expected test temperatures.

$C_{c,i}$: Composite correction corresponding to each correction reading.

Hydrometer test table: has the following columns in ASTM D422 mode:

Elapsed time (t): Elapsed time.

Temp. (T): Temperature.

Reading (R): Hydrometer reading.

Corrected readings (R_{cp}): Readings corrected for temperature and dispersant.

Corrected readings (R_{cL}): Meniscus-corrected readings.

Fall distance (H): Particle fall distance.

Diameter (D): Particle diameter.

Percent finer (Partial): Partial cumulative percent finer.

Percent finer (Total): Total cumulative percent finer.

2-2-3-1-3 ATTERBERG LIMITS

The following five options are available for the determination of Atterberg limits:

- Atterberg limits tests are not performed: This option is only available when fines are less than 5 [%].
- NP: Nonplastic. If either the liquid limit or plastic limit could not be determined, or if the plastic limit is equal to or greater than the liquid limit.
- Visual examination: Fines type according to the plasticity chart is determined by visual examination. Available options are: ML, CL-ML, CL, MH and CH.
- Free input: LL (Liquid Limit) and PL (Plastic Limit) can be determined directly. PI (Plasticity Index) is the difference between the LL and the PL.
- Test data: Using this option (which is not accessible through USCS tab), full Atterberg limits tests data has to be entered. In case the mentioned data is entered through the Atterberg limits tab, other options are disabled.

2-2-3-1-4 GRAPH

The illustrated graph corresponds to the sieve analysis and the hydrometer tests. In addition to the graph being continuously synced with the test results, the user can move each of the graph points within the range of sieve analysis test (coarser than No. 200 sieve) and the table is correspondingly updated.

2-2-3-1-5 RESULTS SUMMARY

The results summary of the performed tests are presented in this section, including:

BH/TP: Borehole or test pit name.

Depth: Sample depth.

Organic: defines the existence of organic fines.

Cobble: Particles of rock that will pass a 12-in. (300-mm) square opening and be retained on a 3-in. (75-mm) U.S. standard sieve.

Boulder: Particles of rock that will not pass a 12-in. (300-mm) square opening.

Plus 3-in.: Particles retained on a 3-in. (75-mm) U.S. standard sieve, during sieve analysis test.

Gravel: Percentage of gravel.

Coarse: passes a 3-in. (75-mm) sieve and is retained on a 0.75-in. (19-mm) sieve.

Fine: passes a 0.75-in. (19-mm) sieve and is retained on a No. 4 (4.75-mm) sieve.

Sand: Percentage of sand.

Coarse: passes a No. 4 (4.75-mm) sieve and is retained on a No. 10 (2.00-mm) sieve.

Medium: passes a No. 10 (2.00-mm) sieve and is retained on a No. 40 (425- μ m) sieve.

Fine: passes a No. 40 (425- μ m) sieve and is retained on a No. 200 (75- μ m) sieve.

Silt: Percentage of silt.

Clay: Percentage of clay.

D₁₀, D₃₀ & D₆₀: the particle sizes corresponding to 10, 30 & 60 [%] passing on the cumulative particle-size distribution curve, respectively. *D₁₀* is also called the “effective size”.

D_{50} : the particle size corresponding to 50 [%] passing on the cumulative particle-size distribution curve. D_{50} is also called the “median size”.

C_u : Coefficient of uniformity defined as $\frac{D_{60}}{D_{10}}$.

C_c : Coefficient of curvature defined as $\frac{(D_{30})^2}{D_{10} \times D_{60}}$.

LL : Liquid Limit.

PI : Plasticity Index.

$USCS$: Unified Soil Classification System.

Description: Sample description according to USCS.

Note: Sub-divisions of gravels and sands are presented in the results summary by default. By clicking on each of the “Gravel” and “Sand” phrases, sub-division cells will be merged and the total value is reported.

2-2-3-2 ATTERBERG LIMITS

This tab is dedicated to the determination of Atterberg limits and is described in section 2-2-3-1-3. The only difference is that unlike USCS tab, the “Test data” option is accessible.

2-2-3-2-1 LIQUID LIMIT

This section includes liquid limit test data which can be performed either by multipoint method or one-point method. In case the liquid limit could not be determined, the “Liquid limit test could not be performed” option may be used. As a result, all liquid limit related fields are disabled and regardless of the plastic limit test result, soil is reported as NP.

❖ Multipoint method

Using this option, by performing the liquid limit test a minimum of 3 up to 5 times and entering the results in the corresponding table:

- 1- Each test result is illustrated as a single point on the semi logarithmic graph below.
- 2- The best linear interpolation is drawn.
- 3- The water content corresponding to the intersection of the interpolation line with the 25-drop abscissa, is considered as the liquid limit.

Table rows are as follows:

Number of blows (N): Number of drops causing closure of the groove.

Container No.

Mass of container + moist soil (M_{cms})

Mass of container + dry soil (M_{cds})

Mass of container (M_c)

Mass of water (M_w)

Mass of dry soil (M_{ds})

Water content (w)

Note: at least three trials with [25,35], [20,30] and [15,25] blows (N) are required in this method.

❖ One-point method

The test is performed twice in this method. The liquid limit is calculated by the given formula and afterwards, the average is reported as the liquid limit of the soil sample. All of the table parameters are introduced earlier in the current section.

Note:

- 1- Two tests are required to gain result.
- 2- Number of blows in the tests should not differ more than 2.
- 3- Difference between two trial liquid limits should not exceed 1 [%].

2-2-3-2-2 PLASTIC LIMIT

This section includes plastic limit test data. In case the plastic limit could not be determined, the “Plastic limit test could not be performed” option may be used. As a result, all plastic limit related fields are disabled and regardless of the liquid limit test result, soil is reported as NP.

According to ASTM D4318, soil is rolled into 3.2 [mm] (0.125-in.) diameter threads with moisture content equal to the plastic limit. Two containers are filled with threads and the moisture content of each is calculated. The average moisture content of the two containers is reported as the plastic limit. All of the table parameters are introduced in section 2-2-3-2-

1.

Note:

- 1- Two containers have to be filled with soils in plastic limit condition.
- 2- Each container should at least have 6 [g] of moist soil.

2-2-3-2-3 RESULTS SUMMARY

The results summary of the Atterberg limits tests are presented in this section, including:

BH/TP: Borehole or test pit name.

Depth: Sample depth.

LL: Liquid Limit.

PL: Plastic Limit.

PI: Plasticity Index.

Plasticity chart classification: Fines type according to plasticity chart.

2-2-3-3 EDIT

Tests performed on a sample can be copied, moved or deleted using this menu.

Whenever the destination sample contains some data, the user is asked for overwrite confirmation. Checking the corresponding option prior to copying or moving, eliminates the confirmation step.

2-2-4 EXPORT

2-2-4-1 EXPORT

Is used to export software outputs, including:

Output: Final test results

- Particle-Size Distribution
- Atterberg Limits

Test data: Test data and corresponding calculations

- Sieve Analysis
- Hydrometer
- Atterberg Limits

2-2-4-2 BLANK

Blank laboratory data sheets are accessible through this menu. Note that separate sheets are considered for various hydrometers (151H or 152H), standards (ASTM D7928 or ASTM D422) and correction methods.

2-2-5 SETTINGS

Program settings are determined through this menu, including the following three sections:

2-2-5-1 SIEVE ANALYSIS

- Sieve set: Sieve sets along with editing capabilities are accessible.
- When fines $\in (10,12]$ and D_{10} is not reached:
 - Minimum particle size is considered as D_{10}
 - Sample is considered as “Poorly-graded”

2-2-5-2 HYDROMETER

- Particles finer than 0.002/0.005 [mm] are considered as clay: 0.002 [mm] is considered as default but can be altered by user's will.
- Default mode: Default test mode (including the standard and the hydrometer type) is determined through this option.
- Time list.

❖ Hydrometer

Various hydrometers can be defined through this section. Schematic view of the hydrometers along with default dimensions are presented below:

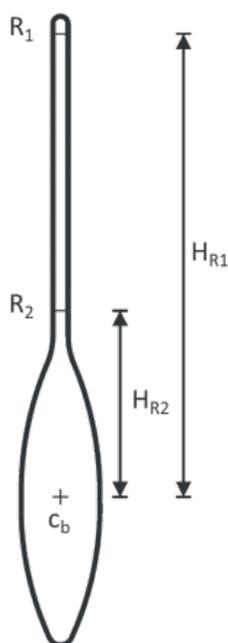


Fig. 2-1 – Hydrometer parameters according to ASTM D7928

Table 2-1 – Default values of hydrometer parameters according to ASTM D7928

Parameter	Description	151H	152H
V_{hb}	Volume of the hydrometer bulb up to the base of the stem	54.0 [cm ³]	54.0 [cm ³]
A	Cross-sectional area of the sedimentation cylinder	28.1 [cm ²]	28.1 [cm ²]
H_{R2}	Distance between the center of buoyancy and the maximum hydrometer reading	7.0 [cm]	7.0 [cm]
H_{R1}	Distance between the center of buoyancy and the minimum hydrometer reading	18.6 [cm]	18.6 [cm]
R_2	Maximum hydrometer reading	1.038 [-]	60 [g/L]
R_1	Minimum hydrometer reading	0.095 [-]	-5 [g/L]

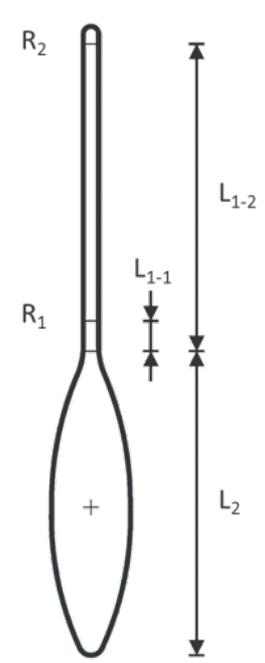


Fig. 2-2 – Hydrometer parameters according to ASTM D422

Table 2-2 - Default values of hydrometer parameters according to ASTM D422

Parameter	Description	151H	152H
V_{hb}	Volume of the hydrometer bulb up to the base of the stem	67.0 [cm ³]	67.0 [cm ³]
A	Cross-sectional area of the sedimentation cylinder	27.8 [cm ²]	27.8 [cm ²]
L_{1-1}	Distance between the top of the bulb and the maximum hydrometer reading	2.3 [cm]	2.3 [cm]
L_{1-2}	Distance between the top of the bulb and the minimum hydrometer reading	10.5 [cm]	10.5 [cm]
R_1	Maximum hydrometer reading	1.031 [-]	50 [g/L]
R_2	Minimum hydrometer reading	1.000 [-]	0 [g/L]
L_2	Overall length of the hydrometer bulb	14.0 [cm]	14.0 [cm]

❖ Correction

Various hydrometer corrections can be defined and saved in this section. Corresponding parameters (regarding calibration relationship and composite methods according to ASTM D7928 and ASTM D422 standards, respectively) are previously defined in section 2-2-3-1-2.

2-2-5-3 ATTERBERG LIMITS

- Round results to the nearest whole number.

❖ Liquid limit (LL)

- Multipoint method:
 - At least three trials with [25,35], [20,30] and [15,25] blows (N) are required.
- One-point method:
 - 2 tests are required to gain result.
 - Number of blows in the tests should not differ more than 2.

- Difference between 2 trial liquid limits should not exceed 1 [%].

❖ Plastic limit (PL)

- 2 containers have to be filled with soils in plastic limit condition.
- Each container should at least have 6 [g] of moist soil.

3 ERRORS

Possible errors in the software are divided to primary and secondary errors which are described in the current chapter.

3-1 PRIMARY ERRORS

Whenever wrong or illogical data are entered, the corresponding cells' colors are altered and a message is shown in the bottom ribbon to guide the user. The utilized colors are described below:

Red: The cell is empty or of the wrong data type.

Orange: The entered value is not acceptable.

Green: Calculations may be performed, but the cell value seems to be illogical.

Pink: Demo version limitations.

Note: Project data cannot be saved while primary errors (except green type) exist.

3-2 SECONDARY ERRORS

Unlike primary errors, secondary errors do not apply any limitations on saving project data and are mostly encountered when changes in some data, cause some others to be inaccurate or incompatible. These errors are of 2 types; compatibility and depth:

Compatibility errors: Identify incompatibility among input data.

Depth errors: Identify errors due to depth values.

Secondary errors have the following advantages:

- Software does not crash.
- All errors regarding each input data are individually specified.

Note: By clicking on the error types located beneath the tables, a message is shown and the user is informed about the probable cause or causes of the errors.

4 CALCULATION THEORIES

In this chapter, brief descriptions regarding sieve analysis, hydrometer and Atterberg limits tests are presented. Also utilized parameters along with calculation methods are fully described. Note that all parameters are defined in this chapter for the ease of access and the calculational parameters are marked with an asterisk (*).

4-1 SIEVE ANALYSIS TEST

The grain-size distribution of coarse-grained soil is generally determined by means of sieve analysis. A sieve analysis is conducted by taking a measured amount of dry, well-pulverized soil and passing it through a stack of progressively finer sieves with a pan at the bottom. The amount of soil retained on each sieve is measured, and the cumulative percentage of soil passing through each is determined. This percentage is generally referred to as percent finer.

The percent finer for each sieve is plotted on semilogarithmic graph. Note that the grain diameter is plotted on the logarithmic scale and the percent finer is plotted on the arithmetic scale.

Sieve analysis test includes the following parameters:

Dry mass: Sample dry mass, [g].

Sieve: Sieve name.

Opening: Sieve opening, [mm].

Mass retained: Soil mass retained on sieve, [g].

Pan: Soil mass retained on the pan, [g].

(* Mass retained [%]: Soil mass retained on sieve, [%].

(* Cumulative percent coarser: Cumulative percent of soil retained on a sieve, [%].

(* Cumulative percent finer: Cumulative percent of soil passing a sieve, [%].

Calculations are as below:

$$\text{Mass retained [\%]} = \frac{\text{Mass retained}}{\text{Dry mass}} \times 100$$

$$\text{Cumulative percent coarser (than } i^{\text{th}} \text{ sieve)} = \sum_{i=1}^i (\text{Mass retained [\%]})$$

$$\text{Cumulative percent finer (than } i^{\text{th}} \text{ sieve)} = 100 - \sum_{i=1}^i (\text{Mass retained [\%]})$$

4-2 HYDROMETER TEST

Hydrometer test is based on the principle of sedimentation of soil particles in water and is used to determine the particle-size distribution of the material that is finer than the No. 200 (75- μm) sieve and larger than about 0.2 [μm]. The test is performed on material passing the No. 10 (2.0-mm) or finer sieve. The test specimen is mixed with a dispersing agent and test water. The slurry is allowed to condition and is then thoroughly mixed and placed in a cylinder with additional test water. Readings are taken with a hydrometer and thermometer over specific time intervals. Calculations are performed and the results are presented as the mass percent finer versus the log of the particle diameter.

Hydrometer test could be performed and calculated using both ASTM D7928 and ASTM D422 (withdrawn 2016) standards with the following parameters in common:

Type: Hydrometer type (151H or 152H).

Separation sieve: the sieve that the hydrometer test material is passed through.

Passing: Cumulative percent finer of the sample corresponding to the separation sieve, which is automatically calculated (if possible) and as a result, hydrometer graph is attached to sieve analysis graph, [%].

4-2-1 ASTM D7928

Schematic view of the hydrometer along with default dimensions according to ASTM D7928, are presented:

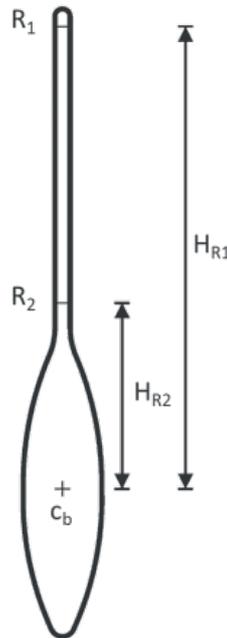


Fig. 4-1 – Hydrometer parameters according to ASTM D7928

Table 4-1 – Default values of hydrometer parameters according to ASTM D7928

Parameter	Description	151H	152H
V_{hb}	Volume of the hydrometer bulb up to the base of the stem	54.0 [cm ³]	54.0 [cm ³]
A	Cross-sectional area of the sedimentation cylinder	28.1 [cm ²]	28.1 [cm ²]
H_{R2}	Distance between the center of buoyancy and the maximum hydrometer reading	7.0 [cm]	7.0 [cm]
H_{R1}	Distance between the center of buoyancy and the minimum hydrometer reading	18.6 [cm]	18.6 [cm]
R_2	Maximum hydrometer reading	1.038 [-]	60 [g/L]
R_1	Minimum hydrometer reading	0.095 [-]	-5 [g/L]

Current method contains the following parameters:

G_s : Specific gravity of soil solids, [-].

M_d : Mass of dry soil, [g].

V_{sp} : Volume of suspension, [cm³].

$Temp.$: Temperature.

Constant: Temperature is constant during test. Using this option, the temperature column is disabled in the hydrometer test table and the specified value is assigned to all readings, [°C].

Variable: Temperature is variable during test. In this case, temperature should also be entered along with each hydrometer reading.

According to ASTM D7928, two methods are introduced for the correction of readings:

Control cylinder: In this method a control cylinder filled with the reference solution is used in conjunction with the soil suspension cylinder to obtain the correction. Thus the following two parameters are involved in the correction process:

C_m : Meniscus correction, 151H: [-] 152H: [g/L].

Offset (R_{dt}): Hydrometer offset reading from reference solution at same temperature as reading, 151H: [-] 152H: [g/L].

Calibration relationship: In this method, corrections are performed by the use of calibration relationship, which is once defined and afterwards automatically applied to all readings. Below parameters are used in this method:

C_m : Meniscus correction, 151H: [-] 152H: [g/L].

T_i : Temperature corresponding to each correction reading, [°C].

151H:

$R_{151,t}$: each calibration relationship reading in 151H hydrometers, [-].

(*) A_t : is calculated as $A_t = R_{151,t} + (7.784 \times 10^{-6} \times T_t) + (4.959 \times 10^{-6} \times T_t^2)$.

(*) A : average of A_t values.

(*) *Std. Dev.*: Standard deviation of A_t values which has to be less than 0.0005.

(*) Offset (R_{dt}): is calculated as $R_{dt} = A - (7.784 \times 10^{-6} \times T) - (4.959 \times 10^{-6} \times T^2)$. Note that "T" is the temperature corresponding to the reading to be corrected.

152H:

$R_{152,t}$: each calibration relationship reading in 152H hydrometers, [g/L].

(*) B_t : is calculated as $B_t = R_{152,t} + (1.248 \times 10^{-2} \times T_t) + (7.950 \times 10^{-3} \times T_t^2)$.

(*) B : average of B_t values.

(*) *Std. Dev.*: Standard deviation of B_t values which has to be less than 0.5.

(*) Offset (R_{dt}): is calculated as $R_{dt} = B - (1.248 \times 10^{-2} \times T) - (7.950 \times 10^{-3} \times T^2)$. Note that "T" is the temperature corresponding to the reading to be corrected.

Hydrometer test table: has the following columns in ASTM D7928 mode:

Elapsed time (t): Elapsed time, [min].

Temp. (T): Temperature, [$^{\circ}$ C].

Reading (R): Hydrometer reading, 151H: [-] 152H: [g/L].

(*) Offset (R_{dt}): Hydrometer offset due to temperature and dispersant, 151H: [-] 152H: [g/L].

(*) Corrected readings ($R - R_{dt}$): Readings corrected for temperature and dispersant, 151H: [-] 152H: [g/L].

(*) Corrected readings (R_{cL}): Meniscus-corrected readings, 151H: [-] 152H: [g/L].

(*) Fall distance (H): Particle fall distance, [cm].

(*) Diameter (D): Particle diameter, [mm].

(*) Percent finer (Partial): Partial cumulative percent finer, [%].

(*) Percent finer (Total): Total cumulative percent finer, [%].

Finally, test calculations are as below:

$$R_{cL} = R + C_m$$

$$H = H_{R2} + \left(\frac{(H_{R1} - H_{R2})}{(R_2 - R_1)} \times (R_2 - R - C_m) \right) - \left(\frac{V_{hb}}{2A} \right)$$

$$D = \left(\sqrt{\frac{18\mu}{\rho_w g (G_s - 1)} \times \frac{H}{t}} \right) \times 10; \begin{cases} \mu: \text{Viscosity of water at } 20 [^{\circ}\text{C}], & \mu = 0.01 [g/(cm.s)] \\ \rho_w: \text{Mass density of water at } 20 [^{\circ}\text{C}], & \rho_w = 0.99821 [g/cm^3] \end{cases}$$

$$\text{Percent finer (Partial)} = \begin{cases} \left(\frac{G_s}{G_s - 1} \right) \left(\frac{V_{sp}}{M_d} \right) \rho_w \times (R - R_{dt}) \times 100 & 151H \\ 0.6226 \times \left(\frac{G_s}{G_s - 1} \right) \left(\frac{V_{sp}}{M_d} \right) \rho_w \times (R - R_{dt}) \times \frac{100}{1000} & 152H \end{cases}$$

$$\text{Percent finer (Total)} = \text{Percent finer (Partial)} \times \text{Passing}$$

Note: Sand, silt and clay percentages are displayed beneath the hydrometer table. Particles finer than 0.002 [mm] are considered as clay by default. This criterion can be altered to 0.005 [mm] through the software settings.

4-2-2 ASTM D422

Schematic view of the hydrometer along with default dimensions according to ASTM D422, are presented:

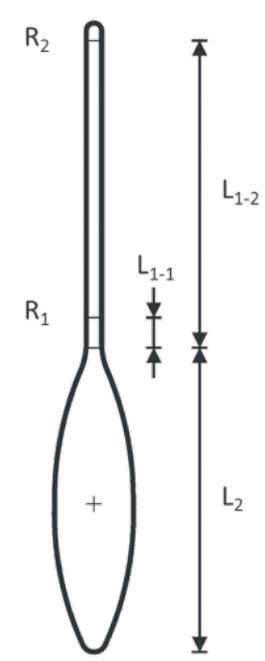


Fig. 4-2 – Hydrometer parameters according to ASTM D422

Table 4-2 - Default values of hydrometer parameters according to ASTM D422

Parameter	Description	151H	152H
V_{hb}	Volume of the hydrometer bulb up to the base of the stem	67.0 [cm ³]	67.0 [cm ³]
A	Cross-sectional area of the sedimentation cylinder	27.8 [cm ²]	27.8 [cm ²]
L_{1-1}	Distance between the top of the bulb and the maximum hydrometer reading	2.3 [cm]	2.3 [cm]
L_{1-2}	Distance between the top of the bulb and the minimum hydrometer reading	10.5 [cm]	10.5 [cm]
R_1	Maximum hydrometer reading	1.031 [-]	50 [g/L]
R_2	Minimum hydrometer reading	1.000 [-]	0 [g/L]
L_2	Overall length of the hydrometer bulb	14.0 [cm]	14.0 [cm]

Current method contains the following parameters:

G_s : Specific gravity of soil solids, [-].

M_d : Mass of dry soil, [g].

$Temp.$: Temperature.

Constant: Temperature is constant during test. Using this option, the temperature column is disabled in the hydrometer test table and the specified value is assigned to all readings, [°c].

Variable: Temperature is variable during test. In this case, temperature should also be entered along with each hydrometer reading.

According to ASTM D422, two methods are introduced for the correction of readings:

Normal correction: Each of the corrections are separately determined in this mode:

C_m : Meniscus correction, 151H: [-] 152H: [g/L].

C_t - *Manual*: User-defined temperature correction. This option is available only when the temperature is constant during the test, 151H: [-] 152H: [g/L].

C_t - *Automatic*: Automatic temperature correction. There is no limitation to using this option, 151H: [-] 152H: [g/L].

$$151H: C_t = (7.784 \times 10^{-6} \times T + 4.959 \times 10^{-6} \times T^2) - (7.784 \times 10^{-6} \times 20 + 4.959 \times 10^{-6} \times 20^2)$$

$$152H: C_t = (1.248 \times 10^{-2} \times T + 7.95 \times 10^{-3} \times T^2) - (1.248 \times 10^{-2} \times 20 + 7.95 \times 10^{-3} \times 20^2)$$

C_d : Dispersant correction, 151H: [-] 152H: [g/L].

Composite correction: is measured at two temperatures (spanning the range of expected test temperatures) and corrections for other temperatures are calculated by the use of linear interpolation. Linear extrapolation is also used in case the temperature is not within the defined values. Composite correction is defined using the following:

C_m : Meniscus correction, 151H: [-] 152H: [g/L].

T_i : Temperature corresponding to each correction reading. The two temperatures are preferred to be spanning the expected test temperatures, [°C].

$C_{c,i}$: Composite correction corresponding to each correction reading, 151H: [-] 152H: [g/L].

Hydrometer test table: has the following columns in ASTM D422 mode:

Elapsed time (t): Elapsed time, [min].

Temp. (T): Temperature, [$^{\circ}$ C].

Reading (R): Hydrometer reading, 151H: [-] 152H: [g/L].

(*) Corrected readings (R_{cp}): Readings corrected for temperature and dispersant, 151H: [-] 152H: [g/L].

(*) Corrected readings (R_{cl}): Meniscus-corrected readings, 151H: [-] 152H: [g/L].

(*) Fall distance (H): Particle fall distance, [cm].

(*) Diameter (D): Particle diameter, [mm].

(*) Percent finer (Partial): Partial cumulative percent finer, [%].

(*) Percent finer (Total): Total cumulative percent finer, [%].

Finally, test calculations are as below:

$$R_{cp} = \begin{cases} R - C_d + C_t & \text{Normal correction} \\ R - C_c & \text{Composite correction} \end{cases}$$

$$R_{cl} = R + C_m$$

$$H = L_1 + \frac{1}{2} \left(L_2 - \frac{V_b}{A} \right)$$

Note: L_l is calculated using linear interpolation as follows:

$$L_1 = m \times R_{cl} + b \quad ; \quad m = \frac{L_{1-1} - L_{1-2}}{R_1 - R_2} \quad ; \quad b = L_{1-1} - m \times R_1$$

$$D = k \sqrt{\frac{H}{t}} \quad ; \quad k = \sqrt{\frac{30n}{980(G_s - G_1)}} \quad ; \quad \begin{cases} G_1: \text{Specific gravity of the suspending medium } (G_1 = 1.0) \\ n: \text{Viscosity of the suspending medium (in this case water) [g/(cm.s)]} \end{cases}$$

$$\text{Percent finer (Partial)} = \begin{cases} \left[\frac{100,000}{M_d} \times \frac{G_s}{G_s - G_1} \right] \times (R_{cp} - G_1) & 151H \\ \left(\frac{R_{cp} \times a}{M_d} \right) \times 100 & 152H \end{cases}$$

$$\text{Percent finer (Total)} = \text{Percent finer (Partial)} \times \text{Passing}$$

Note: Sand, silt and clay percentages are displayed beneath the hydrometer table. Particles finer than 0.002 [mm] are considered as clay by default. This criterion can be altered to 0.005 [mm] through the software settings.

4-3 ATTERBERG LIMITS TESTS

In cohesive soils, originally, six “limits of consistency” of fine-grained soils were defined by Albert Atterberg. In current engineering usage, the term usually refers only to the liquid limit, plastic limit, and in some references, the shrinkage limit. The methods described herein are performed only on that portion of a soil that passes the No. 40 (425- μm) sieve.

Note: Both liquid limit and plastic limit are whole numbers.

4-3-1 LIQUID LIMIT TEST

In cohesive soils, liquid limit (LL) is the water content, in percent, of a soil at the arbitrarily defined boundary between the semi-liquid and plastic states. The undrained shear strength of soil at the liquid limit is considered to be approximately

2 [kPa]. The liquid limit is determined by performing trials in which a portion of the specimen is spread in a brass cup, divided in two by a grooving tool, and then allowed to flow together from the shocks caused by repeatedly dropping the cup in a standard mechanical device.

Liquid limit table rows are as follows:

- Number of blows (N): Number of drops causing closure of the groove.
- Container No.
- Mass of container + moist soil (M_{cms})
- Mass of container + dry soil (M_{cds})
- Mass of container (M_c)
- (* Mass of water (M_w))
- (* Mass of dry soil (M_{ds}))
- (* Water content (w))

Calculations are performed as follows:

$$M_w = M_{cms} - M_{cds}$$

$$M_{ds} = M_{cds} - M_c$$

$$w = \frac{M_w}{M_{ds}}$$

This test is performed by the following two methods:

4-3-1-1 MULTIPOINT METHOD

In this method at least three trials with [25,35], [20,30] and [15,25] blows (N) are required. In order to determine the liquid limit, the relationship between the water content (w) and the corresponding numbers of drops (N) of the cup, are plotted on a semilogarithmic graph with the water content as ordinates on the arithmetical scale, and the number of drops as abscissas on a logarithmic scale. Afterwards, the best straight line is drawn through the plotted points. The water content corresponding to the intersection of the line with the 25-drop abscissa is considered as the liquid limit.

4-3-1-2 ONE-POINT METHOD

In this method two trials with [20,30] blows (N) are required. The liquid limit regarding each trial is calculated using the following equation:

$$LL_n = w_n \times \left(\frac{N_n}{25}\right)^{0.121}$$

Where the subscripts indicate the test number. The liquid limit is the average of the two trial liquid limit values.

Note:

- 1- Number of blows in the tests should not differ more than 2.
- 2- Difference between two trial liquid limits should not exceed 1 [%].

4-3-2 PLASTIC LIMIT TEST

The plastic limit (PL) is determined by alternately pressing together and rolling into a 3.2 [mm] (0.125-in.) diameter thread a small portion of plastic soil until its water content is reduced to a point at which the thread crumbles and can no longer be pressed together and re-rolled. The water content of the soil at this point is reported as the plastic limit. Threads with the mentioned criteria are placed in two containers and the average water content of the threads are calculated in each. Plastic limit is the average water content of the two containers. All table parameters are previously defined in section 4-3-1.

Note: Each container should at least have 6 [g] of moist soil.

4-3-3 PLASTICITY INDEX

Plasticity index is the difference between the liquid limit and the plastic limit.

$$PI = LL - PL$$

Note: If either the liquid limit or plastic limit could not be determined, or if the plastic limit is equal to or greater than the liquid limit, the soil is reported as nonplastic (NP).

5 CONTACT US

Feel free to contact us regarding any criticism, recommendation or additional information.

- 1- Visit www.soiloffice.com/ContactUs
- 2- Send an e-mail to info@soiloffice.com
- 3- Call (+98) 912 313 4107 – Emad Zargaran.
(Also available on WhatsApp)
- 4- Call “Emad.Zargaran” via Skype.

6 LIST OF SYMBOLS

Symbol	Description
1 st sieve	largest sieve used in sieve analysis test
A	average of A_i values
A_t	of the parameters used in the calibration relationship of 151H hydrometers
B	average of B_i values
B_t	of the parameters used in the calibration relationship of 152H hydrometers
C_c	coefficient of curvature
C_c	composite correction corresponding to each test reading
$C_{c,t}$	composite correction corresponding to each correction reading
C_d	dispersant correction
C_m	meniscus correction
C_t	temperature correction
C_u	coefficient of uniformity
D	particle diameter
D_{10}, D_{30} & D_{60}	the particle sizes corresponding to 10, 30 & 60 [%] passing on the cumulative particle-size distribution curve, respectively. D_{10} is also called the “effective size”.
D_{50}	the particle size corresponding to 50 [%] passing on the cumulative particle-size distribution curve. D_{50} is also called the “median size”.
Elev.	ground elevation at top of boring
G_s	specific gravity of soil solids
GWT	depth to water table measured from boring top (Ground Water Table)
H	particle fall distance
LL	Liquid Limit
M_d	mass of dry soil
NP	Nonplastic
PI	Plasticity Index
PL	Plastic Limit
R	hydrometer reading
$R_{151,t}$	each calibration relationship reading in 151H hydrometers
$R_{152,t}$	each calibration relationship reading in 152H hydrometers
R_{cl}	meniscus-corrected readings
R_{cp}	readings corrected for temperature and dispersant
R_{at}	hydrometer offset due to temperature and dispersant
R_{at}	hydrometer offset reading from reference solution at same temperature as reading (in control cylinder method)
t	elapsed time
T	temperature
T_t	temperature corresponding to each correction reading
USCS	Unified Soil Classification System
V_{sp}	volume of suspension
W/P	gradation type. “W” for well-graded and “P” for poorly-graded