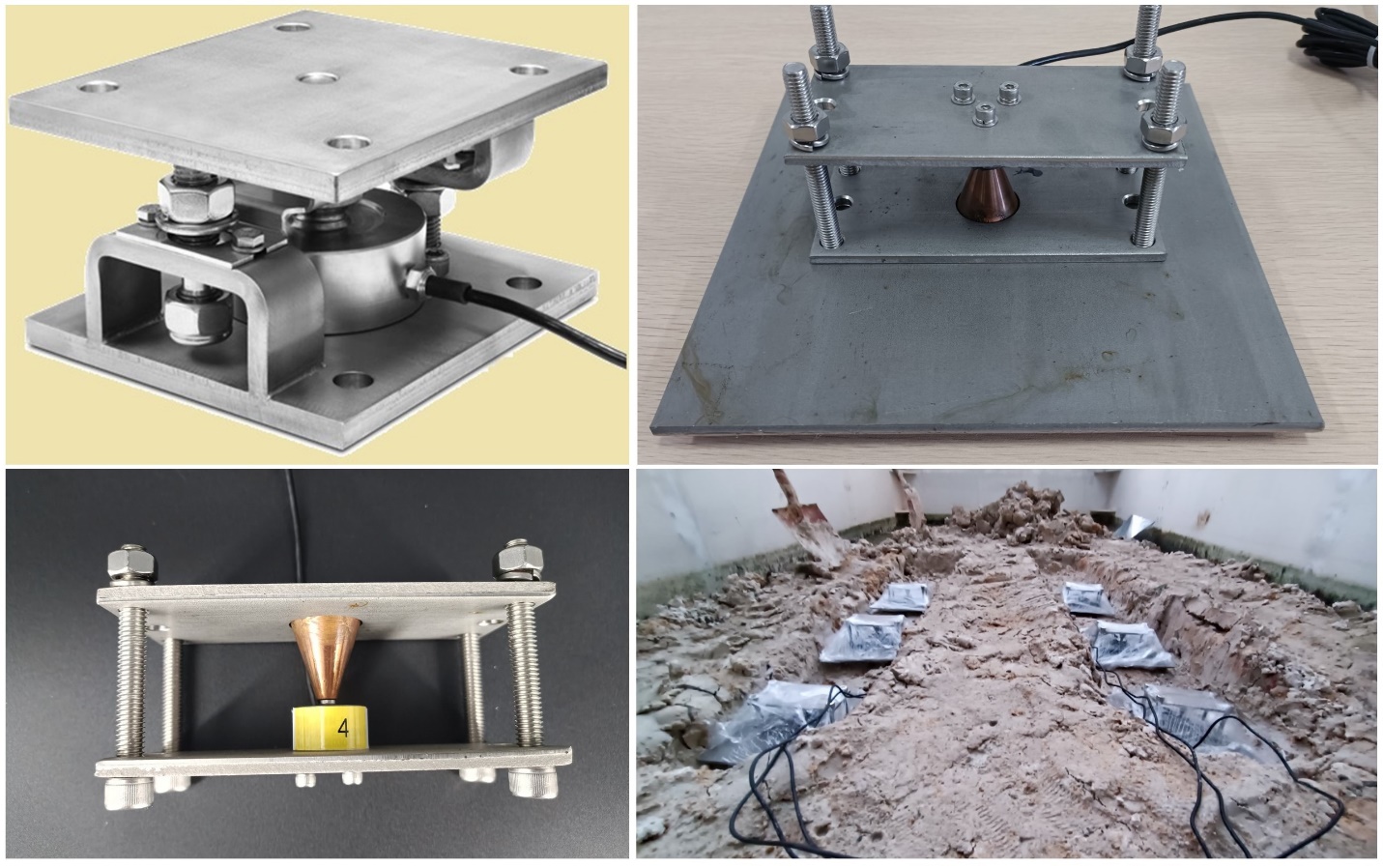
**Supplementary Information**

***Pressure sensor***



**Supplementary Figure 1.** Pressure sensor, including sensor bracket.

***Soil bin***



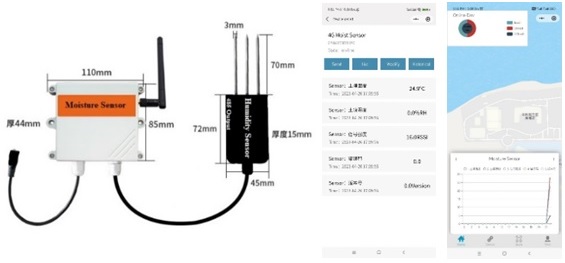
**Supplementary Figure 2.** Soil bin setup for the experiment.

***9-axis attitude sensor***

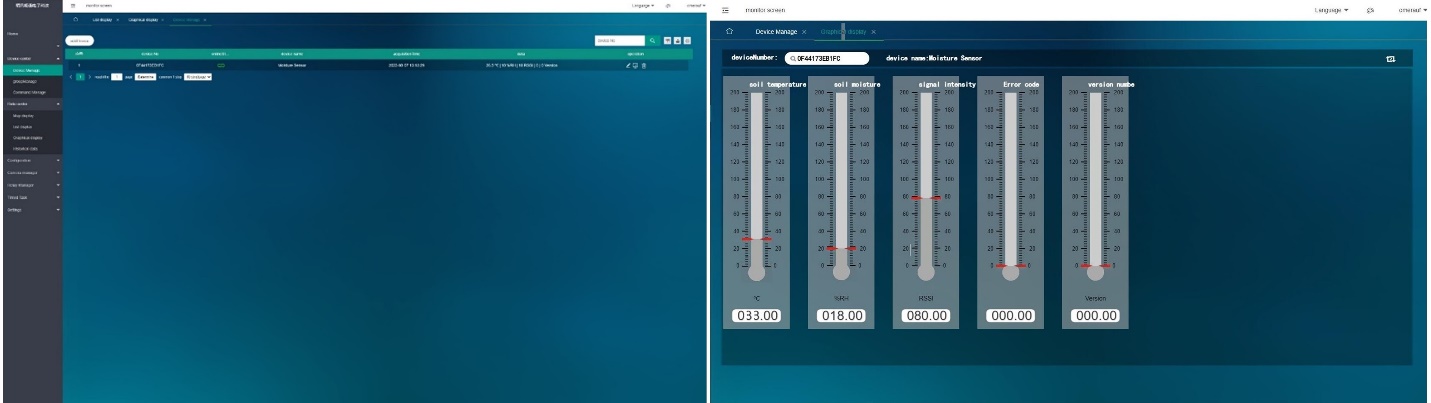


**Supplementary Figure 3.** Attitude sensor (WitMotion Bluetooth BLE 5.0 9 Axis Low-consumption Sensor WT901BLECL Angle + Acceleration + Gyro + Mag MPU9250 on PC/Android, China)

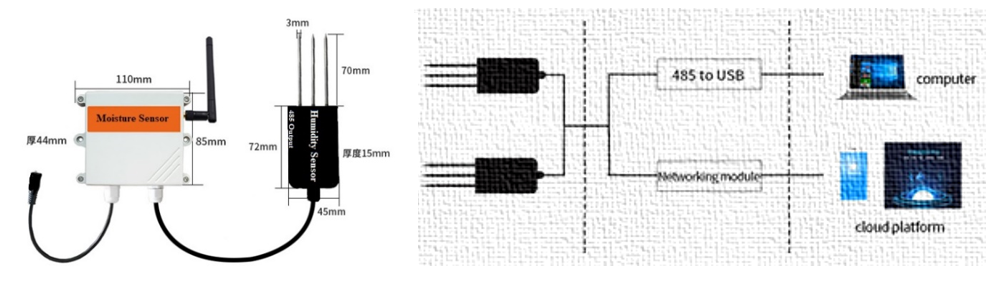
***Soil moisture and measurement system***



**Supplementary Figure 4**. Moisture sensor wireless interface and WeChat Mini app interface.



**Supplementary Figure 5. Soil** moisture sensors' real-time data monitoring web-based interface tool shows temperature, humidity, and signal strength.

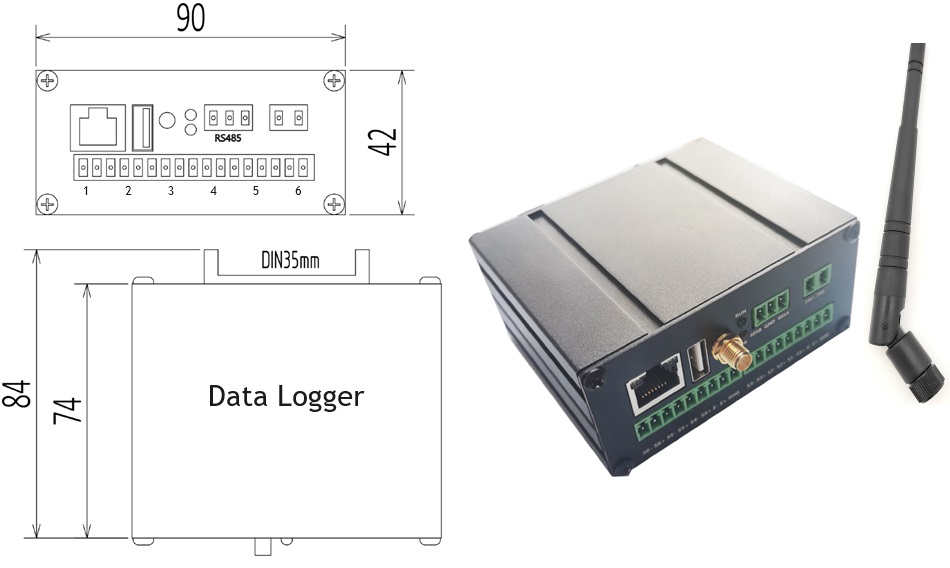


(a) (b)

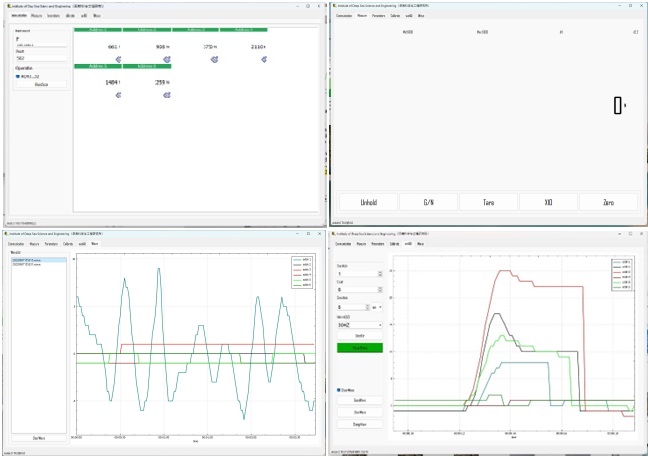
**Supplementary Figure 6.** (a) 4G wireless soil temperature and moisture sensor (b) Wireless communication module.

***Data acquisition FD0843 (6 Channel)***

The FD0843, with its integrated Wireless Serial Communication Module, serves as a data collection hub, adept at gathering and transmitting information from sensors through its 6 channels. When pressure sensors are connected to the FD0843, each sensor's data flows into one of these channels, simplifying data aggregation and transmission. Its wireless capability enhances the ease and versatility of data retrieval, facilitating both real-time monitoring and subsequent analysis on a computer. By analyzing this data, we can gain deeper insights into how different loads impact sinkage, enriching our knowledge of pressure sinkage behaviour. To ensure precision in data collection, it's essential to install, set up, and calibrate both the FD0843 and the pressure sensors correctly. For optimal setup and operation, always adhere to the manufacturer's instructions or seek advice from technical specialists.



**Supplementary Figure 7.** 6-channel Wireless Data Acquisition System.



**Supplementary Figure 8.** 6-Channel Computer-Enabled Ground Pressure Measurement Software.

***Data logger specifications***

**Supplementary Table 1.** Data logger detailed specifications.

|  |  |
| --- | --- |
| Parameters | Specifications |
| Body | Aluminum alloy housing |
| Size | 90mm×42mm×84mm |
| Use environment | Temperature: －30°～ 65 ℃;  Relative humidity: 10% ～ 95% |
| Protection | IP20 |
| Operating Voltage | 9～24 VDC, Power ＜10W |
| Supporting sensor | 1～6 |
| Maximum input signal | 5mV/V |
| A/D update rate | 1600Hz |
| Measurement rate | 100/200/400/800/1600 |
| Data transfer rate | 100Mb/s |
| Sensor excitation voltage | 5VDC |
| Minimum input sensitivity | 0.5μV/d |
| Serial port | RS-485, 4800 ～ 115, 200 Baud rate |
| Wireless transmission | WiFi communication |
| Software | Computer-based software |
| Supporting protocol | MODBUS-RTU、MODBUS-UDP、Ether-CAT |
| Interface type | Ethernet |

***Soil Properties***

**Supplementary Table 2.** Mechanical Soil Properties for Bentonite and Diatom Soils

|  |  |  |
| --- | --- | --- |
| **Mechanical Soil Property** | **Bentonite** | **Diatom** |
| Compressibility | High | Low |
| Shear Strength | Low | High |
| Friction Angle | Low | High |
| Cohesion | High | Low |
| Dilatancy | High | Low |
| Plasticity | High | Low |

***Loose Soil Properties***

**Supplementary Table 3.** Loose Soil Properties for the Tracked Vehicle, Soil Bin Experiment

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Parameter** | **Unit** | **Bentonite** | | | **Diatom** | | |
| Condition | - | Loose | Loose | Loose | Loose | Loose | Loose |
| Moisture Content (±) | % | 10 | 20 | 30 | 10 | 20 | 30 |
| Normal Stiffness | kPa | 26 | 35 | 32 | 43 | 67.7 | 78 |
| Terrain Stiffness (k∅) | kN/m | 18 | 17.1 | 20 | 27 | 32 | 37 |
| Ground Pressure | PSI | 23 | 28 | 32 | 28 | 32 | 37 |
| Sinkage | cm | 2.5 | 3.6 | 4.8 | 1.8 | 2.6 | 3.8 |
| Sinkage Ratio (s/D) | - | 0.19 | 0.18 | 0.16 | 0.13 | 0.1 | 0.8 |
| Shear Stiffness | kPa | 12 | 17 | 19 | 26 | 31 | 37 |
| Cohesion | kPa | 6.5 | 8.7 | 10.5 | 4.2 | 5.5 | 6.3 |
| Friction Angle | ° | 26 | 28.5 | 30 | 33 | 34.5 | 37 |
| Hardening Ratio | - | 1.7 | 2.1 | 2.32 | 1.5 | 2.15 | 2.6 |
| Dilation Angle | ° | 6 | 5.5 | 6.5 | 3.5 | 5 | 6.5 |
| Fluid Content | % | 10 | 15 | 20 | 12 | 16 | 19 |
| Ground Pressure | kPa | 23 | 29 | 34 | 36 | 42 | 46 |

***Compact Soil Properties***

**Supplementary Table 4.** Compact Soil Properties for the Tracked Vehicle, Soil Bin Experiment

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Parameter** | **Unit** | **Bentonite** | | | **Diatom** | | |
| Condition | - | Compact | Compact | Compact | Compact | Compact | Compact |
| Moisture Content (±) | % | 10 | 20 | 30 | 10 | 20 | 30 |
| Normal Stiffness | kPa | 37 | 46 | 61 | 58 | 84 | 91 |
| Terrain Stiffness (k∅) | kN/m | 16.3 | 18.9 | 26 | 35 | 43 | 46 |
| Ground Pressure | PSI | 26 | 31 | 37 | 33 | 37 | 42 |
| Sinkage | cm | 1.1 | 2.3 | 3.1 | 0.8 | 1.3 | 2.1 |
| Sinkage Ratio (s/D) | - | 0.11 | 0.09 | 0.06 | 0.12 | 0.07 | 0.06 |
| Shear Stiffness | kPa | 16 | 19 | 26 | 37 | 41.6 | 48.5 |
| Cohesion | kPa | 8.5 | 12.7 | 14.5 | 7.3 | 8.2 | 9.5 |
| Friction Angle | ° | 28 | 31 | 35 | 35 | 37 | 41 |
| Hardening Ratio | - | 2.3 | 2.5 | 2.7 | 2.6 | 3.3 | 3.8 |
| Dilation Angle | ° | 7 | 7.9 | 8.8 | 6 | 7.5 | 8.7 |
| Friction Coefficient | μ | 0.8 | 0.65 | 0.58 | 0.9 | 0.84 | 0.76 |
| Ground Pressure | kPa | 31 | 38 | 45 | 33 | 46 | 52 |

***Mechanics of track soil interaction***

**Supplementary Table 5.** The Physical Properties of Bentonite, Diatom, and Sand Gravel Mixture

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Parameter | Unit | Bentonite | Diatom | Sand Gravel mixture |
| Classification | - | Clay soil | Sedimentary deposit/rock | Silty gravel |
| Bulk density | g/cm³ | 1.4 (Loose)  1.5 (Compact) | 1.1 (Loose)  1.2 (Compact) | 1.6 (Loose)  1.7 (Compact) |
| Water Moisture content | % | 29 | 23 | 11 |
| Internal friction angle | ° | 21 | 27 | 35 |
| Cohesion | kPa | High | Low | Very low |
| Porosity | % | 54 | 62 | 31 |
| Swelling Capacity | % | High | Low | Very low |
| Specific gravity | - | 2.4 | 2.2 | 2.6 |
| Soil cone index (dry) | MPa | 1.7 | 1.0 | 3.4 |
| Soil cone index (wet) | MPa | 1.1 | 0.6 | 1.9 |

***Soil bin***

**Supplementary Table 6.** The Parameters for the Soil Bin are Used for Pressure Sinkage and Bearing Capacity

|  |  |
| --- | --- |
| Soil Bin Specifications | Values |
| Length | 610 cm |
| Width | 245 cm |
| Height | 180 cm |
| Thickness | 0.4 cm |
| Depth | 175 cm |
| Material | Steel |
| Capacity | Adequate for accommodating small to medium rubber-tracked vehicles |
| Drainage System | Installed to control surplus water and soil saturation efficiently. |
| Side Walls | Smooth and vertical to reduce vehicle motion interference |
| Floor Surface | Even and level for uniform testing |
| Lighting | Adequate lighting for assessing visibility |
| Safety Features | Guardrails or obstacles for operator safety |
| Data Collection | Integration of sensor and data acquisition equipment |

***Soil’s Detailed Properties***

**Supplementary Table 7.** Detailed Properties of Test Soils

|  |  |  |
| --- | --- | --- |
| **Parameter name** | **Unit** | **Value** |
| Soil particle density   * Bentonite * Diatom * Sand gravel mixture | g/cm3 | 2.7  2.3  2.7 |
| Natural moisture content   * Bentonite * Diatom * Sand gravel mixture | % | 21  8  9 |
| Grain size distribution   * Bentonite * Diatom * Sand gravel mixture | mm | < 0.002  0.1  2 ~ 5 |
| Maximum dry density   * Bentonite * Diatom * Sand gravel mixture | g/cm3 | 1.2  1.7  1.8 |
| Optimum moisture content   * Bentonite * Diatom * Sand gravel mixture | % | 19  13  8 |

***Tracked Vehicle Motion Test***

**Supplementary Table 8.** Rubber Tracked Vehicle Motion Test on Diatom and Bentonite Soil

|  |  |  |  |
| --- | --- | --- | --- |
| **Soil Type** | **Soil Density** | **Speed (m/sec)** | **Motion Observation** |
| Diatom soil | Loose (g/cm3) | 0.1 | High sinkage, low traction |
| Diatom soil | Loose (g/cm3) | 0.2 | Higher sinkage, difficulty moving |
| Diatom soil | Loose (g/cm3) | 0.3 | Unable to move, gets stuck |
| Diatom soil | Compacted (g/cm3) | 0.1 | Low sinkage, good traction |
| Diatom soil | Compacted (g/cm3) | 0.2 | Moderate sinkage, able to move |
| Diatom soil | Compacted (g/cm3) | 0.3 | High sinkage, difficulty moving |
| Bentonite soil | Loose (g/cm3) | 0.1 | Very high sinkage, unable to move |
| Bentonite soil | Loose (g/cm3) | 0.2 | N/A, unable to achieve speed |
| Bentonite soil | Loose (g/cm3) | 0.3 | N/A, unable to achieve speed |
| Bentonite soil | Compacted (g/cm3) | 0.1 | Moderate sinkage, able to move |
| Bentonite soil | Compacted (g/cm3) | 0.2 | High sinkage, difficulty moving |
| Bentonite soil | Compacted (g/cm3) | 0.3 | Unable to move, gets stuck |

***Cone Penetration Resistance***

**Supplementary Table 9.** Cone penetration resistance at different moistures

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Soil** | **Depth (cm)** | **Cone penetration resistance kPa @ Moisture (± %)** | | |
| **10 ± %** | **20 ± %** | **30 ± %** |
| Bentonite | 0-5 | 10 kPa | 20 kPa | 40 kPa |
| 5-15 | 15 kPa | 30 kPa | 45 kPa |
| 15-30 | 20 kPa | 25 kPa | 50 kPa |
| Diatom | 0-5 | 15 kPa | 18 kPa | 20 kPa |
| 5-15 | 18 kPa | 20 kPa | 22 kPa |
| 15-30 | 20 kPa | 22 kPa | 25 kPa |

***Cone index measurement***

**Supplementary Table 10.** Experimental Soil Properties and Cone Index Measurement for Bentonite and Diatom

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Soil type | Moisture content ± % | Loose Density 3g/cm³ | Compacted Density g/cm³ | Compaction % | Depth cm | Cone Index kPa |
| Bentonite | 10 | 1.3 | 1.5 | 15.38 | 10 | 94.12 |
| 20 | 215.25 |
| 30 | 127.36 |
| 40 | 179.48 |
| Bentonite | 20 | 1.2 | 1.4 | 17.67 | 10 | 184.16 |
| 20 | 94.28 |
| 30 | 179.4 |
| 40 | 127.52 |
| Bentonite | 30 | 1.1 | 1.3 | 18.18 | 10 | 94.44 |
| 20 | 162.36 |
| 30 | 127.6 |
| 40 | 215.72 |
| Diatom | 10 | 0.9 | 1.1 | 22.29 | 10 | 269.14 |
| 20 | 293.62 |
| 30 | 318.11 |
| 40 | 342.59 |
| Diatom | 20 | 0.8 | 1.0 | 25.4 | 10 | 219.38 |
| 20 | 238.12 |
| 30 | 257.86 |
| 40 | 278.59 |
| Diatom | 30 | 0.7 | 0.9 | 28.57 | 10 | 175.21 |
| 20 | 192.44 |
| 30 | 212.67 |
| 40 | 231.89 |

***Rubber Tracked Vehicle Ground Pressure and Sinkage Test Results***

**Supplementary Table 11.** Rubber-Tracked Vehicle Sinkage, Ground Pressure, Speed Test Results

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Soil Type | Speed (m/s) | Moisture Content (± %) | Ground Pressure (kPa) | Sinkage (cm) |
| Bentonite | 0.1 | 10 | 23 | 1.5 |
| Bentonite | 0.1 | 20 | 25 | 2.7 |
| Bentonite | 0.1 | 30 | 27 | 3.8 |
| Bentonite | 0.2 | 10 | 21 | 2.6 |
| Bentonite | 0.2 | 20 | 23 | 3.7 |
| Bentonite | 0.2 | 30 | 25 | 4.3 |
| Bentonite | 0.3 | 10 | 19 | 3.2 |
| Bentonite | 0.3 | 20 | 21 | 4.4 |
| Bentonite | 0.3 | 30 | 23 | 5.2 |
| Diatom | 0.1 | 10 | 29 | 0.8 |
| Diatom | 0.1 | 20 | 31 | 0.9 |
| Diatom | 0.1 | 30 | 33 | 1.3 |
| Diatom | 0.2 | 10 | 27 | 0.6 |
| Diatom | 0.2 | 20 | 29 | 1.8 |
| Diatom | 0.2 | 30 | 31 | 1.6 |
| Diatom | 0.3 | 10 | 25 | 1.9 |
| Diatom | 0.3 | 20 | 27 | 1.7 |
| Diatom | 0.3 | 30 | 29 | 2.8 |

**Supplementary Table 12.** Moisture Content, Cohesive Modulus, and Sinkage Exponent of Bentonite and Diatom

|  |  |  |  |
| --- | --- | --- | --- |
| **Soil Type** | **Moisture Content (± %)** | **Sinkage Exponent** | **Cohesive Modulus (kPa)** |
| Bentonite | 5 | 0.3 | 150 |
| Bentonite | 10 | 0.5 | 100 |
| Bentonite | 15 | 0.7 | 75 |
| Bentonite | 20 | 0.9 | 50 |
| Bentonite | 25 | 1.1 | 25 |
| Bentonite | 30 | 1.3 | 12.5 |
| Diatom | 5 | 0.1 | 75 |
| Diatom | 10 | 0.3 | 50 |
| Diatom | 15 | 0.5 | 37.5 |
| Diatom | 20 | 0.7 | 25 |
| Diatom | 25 | 0.9 | 12.5 |
| Diatom | 30 | 1.1 | 6.25 |