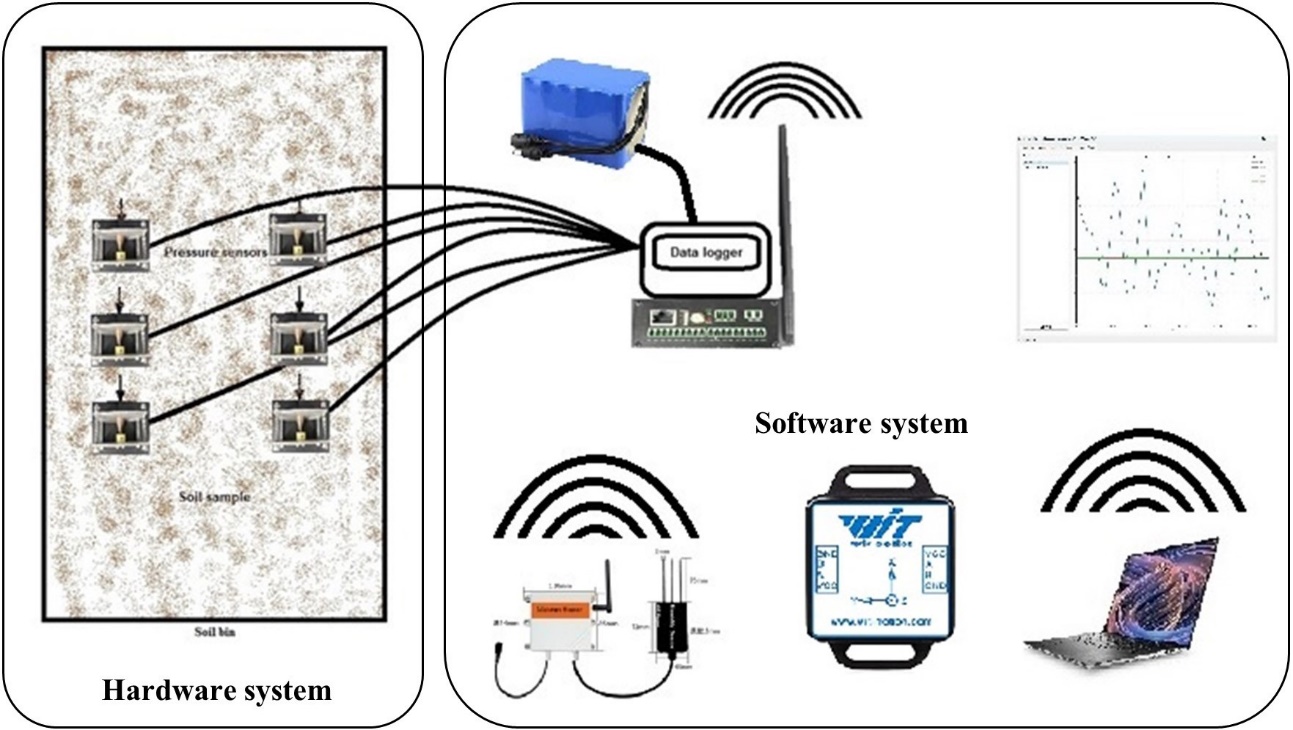
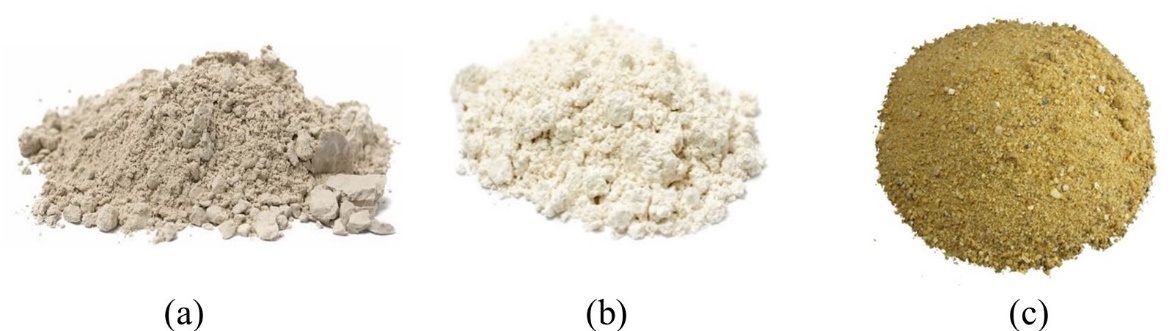
**Supplementary Information**

***Terramechanics and Experimental Setup***



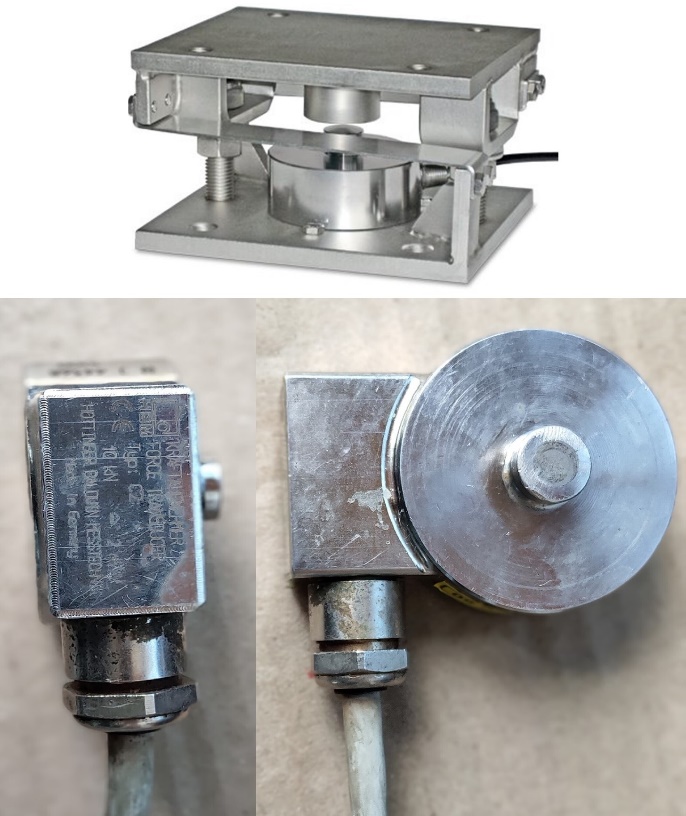
**Supplementary Figure 1.** Schematic drawing of the model experiment (soil bin, pressure sensors, wireless data logger equipment, signal amplifier, 12V/24V power supply, the 9-axis attitude sensor, communication module, and software).

***Soil Sample and Preparation of soil bed***



**Supplementary Figure 2.** (a) Bentonite clay (-0.063mm), (b) Diatom soils (>20μm), and (c) Sand (2mm~5mm) were used.

***Pressure sensor***



**Supplementary Figure 3.** Pressure sensor including sensor bracket.

***Soil bin***



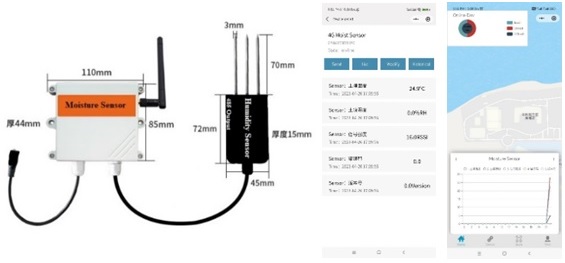
**Supplementary Figure 4.** Experimental setup for Soil Bin Test.

***9-axis attitude sensor***

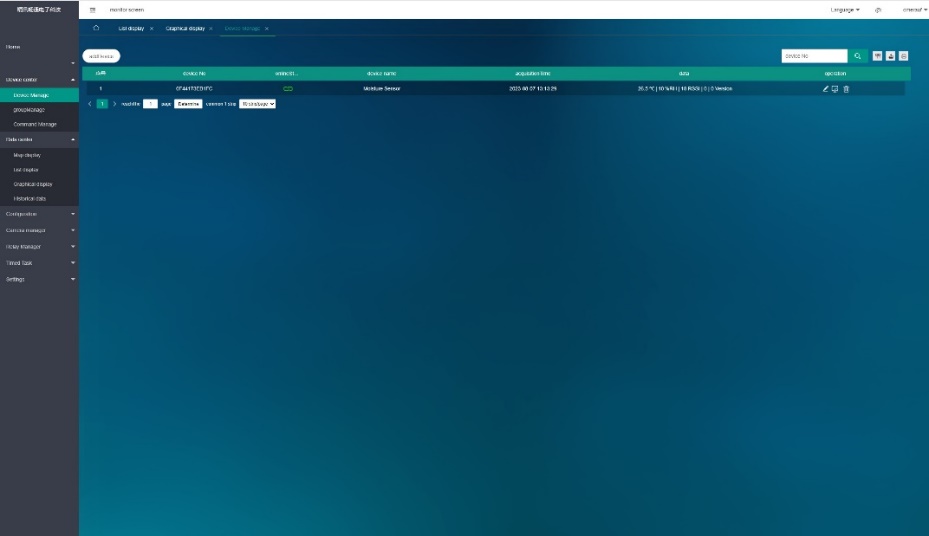


**Supplementary Figure 5.** Attitude sensor (WitMotion Bluetooth BLE 5.0 9 Axis Low-consumption Sensor WT901BLECL Angle + Acceleration + Gyro + Mag MPU9250 on PC/Android, China)

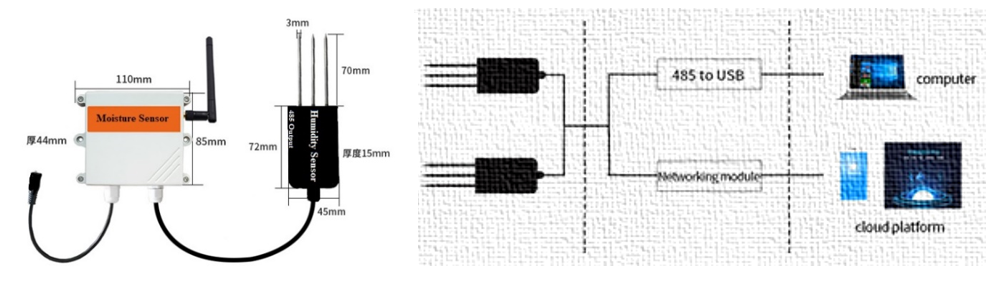
***Soil moisture and measurement system***



**Supplementary Figure 6**. Moisture sensor wireless interface and WeChat Mini app interface.



**Supplementary Figure 7.** Soil moisture 4G wireless web interface.



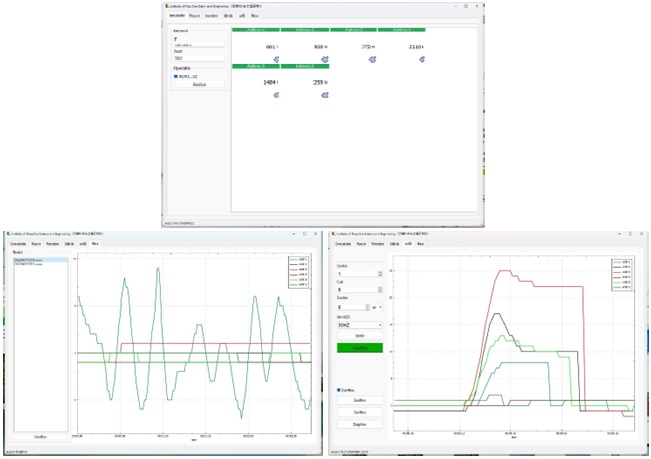
(a) (b)

**Supplementary Figure 8.** (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 correctly install, set up, and calibrate both the FD0843 and the pressure sensors. For optimal setup and operation, always adhere to the manufacturer's instructions or seek advice from technical specialists.

**Supplementary Figure 9.** 6-channel wireless Data Acquisition System.



**Supplementary Figure 10.** 6-Channel Computer-Enabled Ground Pressure Measurement Software.

**Supplementary Table 1.** 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 |

**Supplementary Table 2.** 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 3.** The physical properties of Bentonite and Diatom soil.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| 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 |

***Tracked vehicle***

**Supplementary Table 4.** A tracked vehicle was used for the experiment's basic parameters.

|  |  |  |
| --- | --- | --- |
| Parameter name | Symbol | Parameter content |
| Track length × width × Height (cm) | Lx×Ly×Lz | 120 × 90 × 80 |
| Contact length of rubber track | cm | 90 |
| Width of single rubber track | cm | 20 |
| Drive wheel diameter | cm | 26 |
| Front idler diameter | cm | 32 |
| Lugs | cm | 19 |
| Weight of the tracked vehicle | *W* (kg) | 530 |
| Weight of the vehicle in the water | *Ww* (kg) | -470 |
| Contact Pressure | *P* (kPa) | 13.889 |
| Contact Pressure in the water | *Pw* (kPa) | 12.5 |

***Soil bin***

**Supplementary Table 5.** Soil bin parameters.

|  |  |
| --- | --- |
| **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 |

**Supplementary Table 6.** 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 |

**Supplementary Table 7.** Rubber Tracked Vehicle Motion Test on Diatom and Bentonite Soil

|  |  |  |
| --- | --- | --- |
| **Soil Type** | **Speed (m/sec)** | **Motion Observation** |
| Bentonite | 0.1 | Smooth |
| 0.2 | Steady |
| 0.3 | Unstable |
| Diatom | 0.1 | Smooth |
| 0.2 | Stable |
|  | 0.3 | Unstable |

**Supplementary Table 8.** Parameters for Soil bin 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 |

**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 |

***Track Vehicle Sinkage Observations***

**Supplementary Table 10.** Observations Table for Rubber Tracked Vehicle Pressure Sinkage Test

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Soil | Moisture (%) | Speed (m/s) | Sinkage (cm) | Track-Soil Observations |
| Bentonite | 5 | 0.1 | 1.10 | Normal wear and tear on tracks |
| Bentonite | 10 | 0.1 | 1.50 | Rutting beginning tracks deforming |
| Bentonite | 15 | 0.1 | 2.40 | Deep rutting, tracks digging in |
| Bentonite | 20 | 0.1 | 2.70 | Severe rutting, tracks stuck |
| Bentonite | 25 | 0.1 | 3.20 | Severe track deformation and sinking |
| Bentonite | 30 | 0.1 | 3.80 | Increased track slippage |
| Diatom | 5 | 0.1 | 0.55 | Normal wear and tear on tracks |
| Diatom | 10 | 0.1 | 0.80 | Minor rutting |
| Diatom | 15 | 0.1 | 0.83 | Rutting |
| Diatom | 20 | 0.1 | 0.90 | Deep Rutting |
| Diatom | 25 | 0.1 | 1.21 | Soil very soft, tracks dug in |
| Diatom | 30 | 0.1 | 1.30 | Severe track deformation and sinking |

***Cone index measurement***

**Supplementary Table 11.** 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 12.** 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 13.** 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 |

**Supplementary Table 14** Data Logging Table Showing Pressure Sensor Readings Recorded During Vehicle Track Testing on Bentonite and Diatom Soil Bed with 2-5mm Sand-Gravel Mixture at 10%, 20%, and 30% Moisture Levels and Speed is Set to Be 0.1, 0.2 and 0.3m/sec.

**Table 14 (a):** Data Logging Table @ 0.1 m/sec velocity.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Soil Type | Moisture Level (%) | Speed (m/sec) | Sensor 1 (kPa) | Sensor 2 (kPa) | Sensor 3 (kPa) | Sensor 4 (kPa) | Sensor 5 (kPa) | Sensor 6 (kPa) |
| Bentonite | 10 | 0.1 | 35 | 38 | 36 | 39 | 37 | 34 |
| Bentonite | 20 | 0.1 | 39 | 42 | 40 | 43 | 41 | 38 |
| Bentonite | 30 | 0.1 | 43 | 46 | 44 | 47 | 45 | 42 |
| Diatom | 10 | 0.1 | 36 | 39 | 37 | 40 | 38 | 35 |
| Diatom | 20 | 0.1 | 39 | 42 | 40 | 43 | 41 | 38 |
| Diatom | 30 | 0.1 | 43 | 46 | 44 | 47 | 45 | 42 |

**Table 14 (b):** Data Logging Table @ 0.2 m/sec velocity.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Soil Type | Moisture Level (%) | Speed (m/sec) | Sensor 1 (kPa) | Sensor 2 (kPa) | Sensor 3 (kPa) | Sensor 4 (kPa) | Sensor 5 (kPa) | Sensor 6 (kPa) |
| Bentonite | 10 | 0.2 | 41 | 44 | 42 | 45 | 43 | 40 |
| Bentonite | 20 | 0.2 | 44 | 47 | 45 | 48 | 46 | 43 |
| Bentonite | 30 | 0.2 | 48 | 51 | 49 | 52 | 50 | 47 |
| Diatom | 10 | 0.2 | 42 | 45 | 43 | 46 | 44 | 41 |
| Diatom | 20 | 0.2 | 44 | 47 | 45 | 48 | 46 | 43 |
| Diatom | 30 | 0.2 | 48 | 51 | 49 | 52 | 50 | 47 |

**Table 14 (c):** Data Logging Table @ 0.3 m/sec velocity.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Soil Type | Moisture Level (%) | Speed (m/sec) | Sensor 1 (kPa) | Sensor 2 (kPa) | Sensor 3 (kPa) | Sensor 4 (kPa) | Sensor 5 (kPa) | Sensor 6 (kPa) |
| Bentonite | 10 | 0.3 | 47 | 50 | 48 | 51 | 49 | 46 |
| Bentonite | 20 | 0.3 | 50 | 53 | 51 | 54 | 52 | 49 |
| Bentonite | 30 | 0.3 | 54 | 57 | 55 | 58 | 56 | 53 |
| Diatom | 10 | 0.3 | 48 | 51 | 49 | 52 | 50 | 47 |
| Diatom | 20 | 0.3 | 50 | 53 | 51 | 54 | 52 | 49 |
| Diatom | 30 | 0.3 | 54 | 57 | 55 | 58 | 56 | 53 |