

Kumamoto Eq. Ground Structure Survey

Report (Draft)

28 Feb. 2020



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1. Project Description

(1) Project Name

Kumamoto eq. ground structure survey

(2) Site Location

Site Location is shown at Fig. 1-1.

(3) Contents

a) In situ measurements

Boring: 39.0m

SPT: 38 times

Undisturbed sampling: Thin-walled tube sampling 3 samples

Rotary triple-tube sampling 2 samples

PS-logging (suspension method) 39m

b) Laboratory tests

Tests for physical properties 5 samples

Test for density of soil particles

Test for water content of soils

Test for particle size distribution of soils

Test for bulk density of soils

Tests for mechanical properties 5 samples

Cyclic triaxial test to determine deformation properties of geomaterials

(4) Field Survey Date

From: November 1,2019

To: November 23,2019

(5) Consultant

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Engineer: Yoichi Uto, Hiroki Watanabe



Figure1-1 Site Location

2. Results

PS logging results with Boing log are shown on fig. 2-1.

Laboratory test results are shown on table 2-1, 2.

Detailed results are shown on appendix.

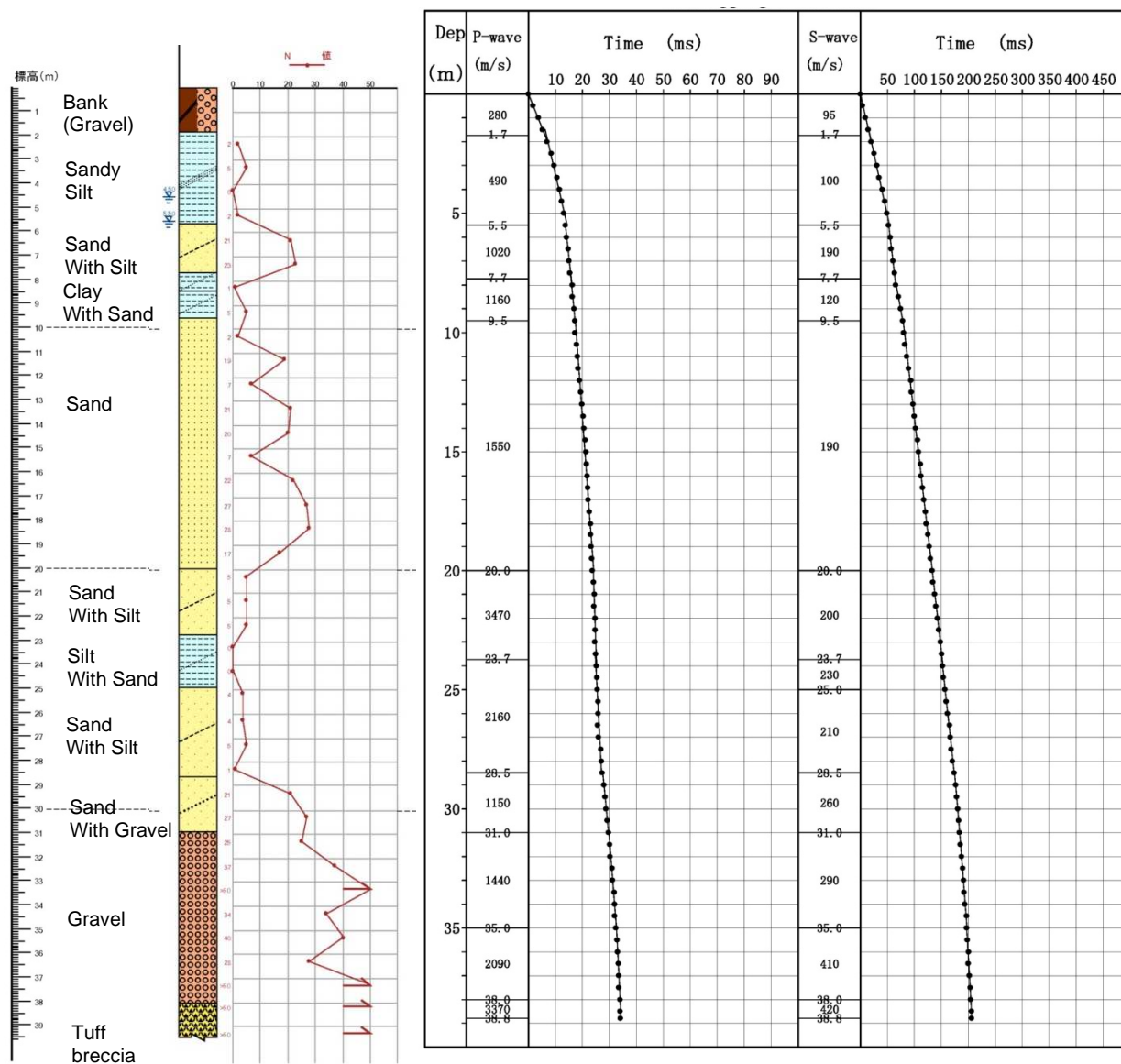


Fig.2-1 PS logging results with Boring log

Table 2-1 Soil condition

| depth (m) | thickness (m) | Soil |
|--------------|------------------|---------------------|
| 1.80 | 1.80 | Bank (Gravel) |
| 5.60 | 3.80 | Sandy Silt |
| 7.65 | 2.05 | Sand with Silt |
| 8.40 | 0.75 | Clay with Sand |
| 9.55 | 1.15 | Silt with Sand |
| 19.95 | 10.40 | Sand |
| 22.70 | 2.75 | Sand with Silt |
| 24.90 | 2.20 | Silt with Sand |
| 28.60 | 3.70 | Sand with Silt |
| 30.90 | 2.30 | Sand with Gravel |
| 38.00 | 7.10 | Gravel |
| 39.44 | 1.44 | Tuff breccia |

Table 2-2 PS logging result

| depth (m) | thickness (m) | P velocity (m/s) | S velocity (m/s) |
|--------------|------------------|---------------------|---------------------|
| 1.7 | 1.7 | 280 | 95 |
| 5.5 | 3.8 | 490 | 100 |
| 7.7 | 2.2 | 1020 | 190 |
| 9.5 | 1.8 | 1160 | 120 |
| 20.0 | 10.5 | 1550 | 190 |
| 23.7 | 3.7 | 3470 | 200 |
| 25.0 | 1.3 | 2160 | 230 |
| 28.5 | 3.5 | 2160 | 210 |
| 31.0 | 2.5 | 1150 | 260 |
| 35.0 | 4.0 | 1440 | 290 |
| 38.0 | 3.0 | 2090 | 410 |
| 38.8 | 0.8 | 3370 | 420 |

Table 2-3 Standards of Laboratory Tests

| tests | standards |
|--|------------|
| Test for density of soil particles | JIS A 1202 |
| Test for water content of soils | JIS A 1203 |
| Test for particle size distribution of soils | JIS A 1204 |
| Test for bulk density of soils | JIS A 1225 |
| Cyclic triaxial test to determine deformation properties of geomaterials | JGS 0542 |

JIS: Japanese Industrial Standard, JGS: Japanese Geotechnical Society Standard

Table 2-4 Summary of Laboratory Tests

| Sample No. | | T-1 | T-2 | Tr-3 | Tr-4 | T-5 |
|---|----------------------------|------------------------------------|--|-------------------------|------------------------------|--------------------------|
| Upper depth | m | 4.00 | 7.65 | 13.00 | 20.00 | 23.00 |
| Lower depth | m | 5.00 | 8.65 | 14.00 | 21.00 | 23.72 |
| Wet density | ρ_t g/cm ³ | 1.367 | 1.289 | 1.912 | 1.836 | 1.501 |
| Dry density | ρ_d g/cm ³ | 0.645 | 0.493 | 1.528 | 1.377 | 0.810 |
| Density of soil particles | ρ_s g/cm ³ | 2.701 | 2.479 | 2.831 | 2.782 | 2.693 |
| Natural water content of soil | w_n % | 111.9 | 161.7 | 25.1 | 33.3 | 85.4 |
| Void ratio | e | 3.188 | 4.028 | 0.853 | 1.02 | 2.325 |
| Degree of saturation | S_r % | 94.8 | 99.5 | 83.3 | 90.8 | 98.9 |
| Mass percentage of rock (more than 75mm) | % | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Mass percentage of gravel (2 to 75mm) | % | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 |
| Mass percentage of sand (0.075 to 2mm) | % | 13.2 | 5.5 | 84.8 | 78.1 | 3.1 |
| Mass percentage of silt (0.005 to 0.075mm) | % | 38.3 | 28.0 | 12.5 | 18.5 | 32.7 |
| Mass percentage of clay (not more than 0.005mm) | % | 48.5 | 66.5 | 2.4 | 3.4 | 64.2 |
| Maximum particle size | mm | 2 | 0.850 | 4.75 | 2 | 0.850 |
| Coefficient of uniformity | U_c | - | - | 7.32 | 5.27 | - |
| Particle size at 50% passing by mass | D_{50} mm | 0.00554 | - | 0.278 | 0.133 | 0.00119 |
| Particle size at 10% passing by mass | D_{10} mm | - | - | 0.0448 | 0.0283 | - |
| Liquid limit | w_L % | 103.9 | 189.2 | NP | NP | 100.4 |
| Plastic limit | w_p % | 56.0 | 68.7 | NP | NP | 47.7 |
| Plastic index | I_p | 47.9 | 120.5 | NP | NP | 52.7 |
| Classification of soil material | | Silt with sand (high liquid limit) | Organic clay with sand (high liquid limit) | Sand with fine fraction | Sand of fine fraction nature | Silt (high liquid limit) |
| Classification symbol | | (MH-S) | (OH-S) | (S-F) | (SF) | (MH) |
| Particle size at 20% passing by mass | D_{20} mm | - | - | 0.117 | 0.0678 | - |
| Maximum shear modulus | G_0 MN/m ² | 10.6 | 7.8 | 56.9 | 66.2 | 31.6 |

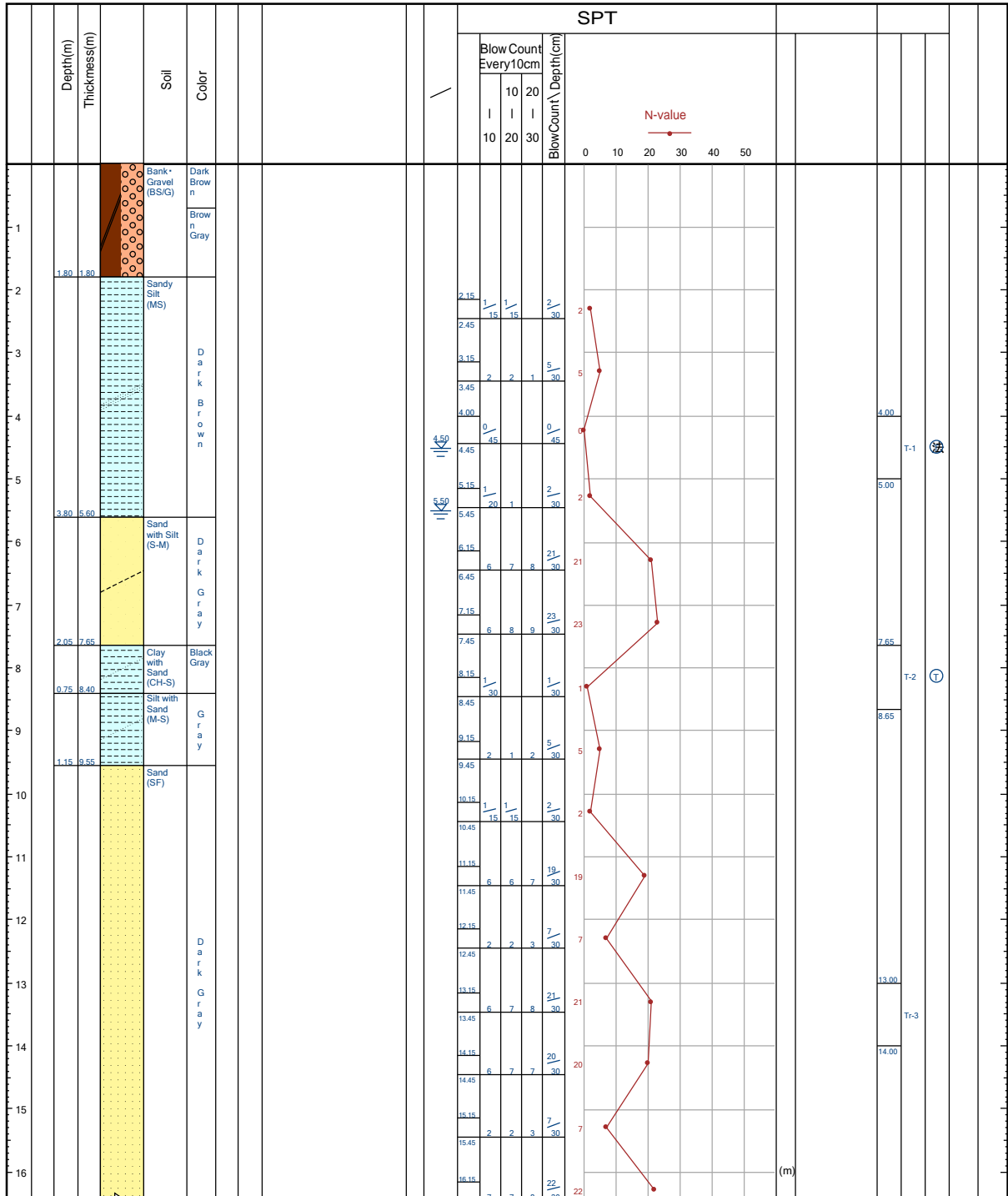
Appendix 1

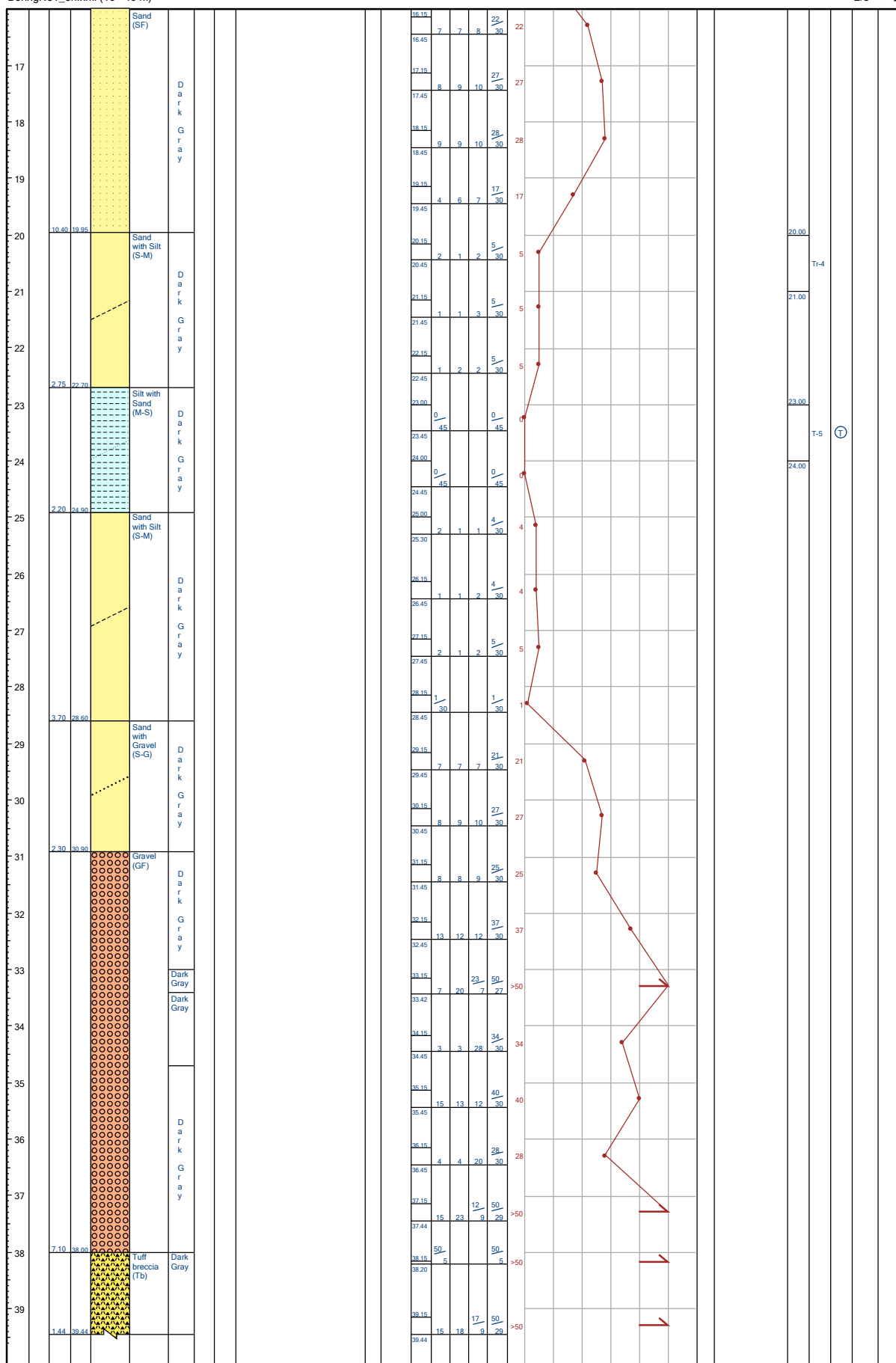
Borehole Log

ProjectName Kumamoto Eq. Ground Structure Survey

| | | | | | | | | | |
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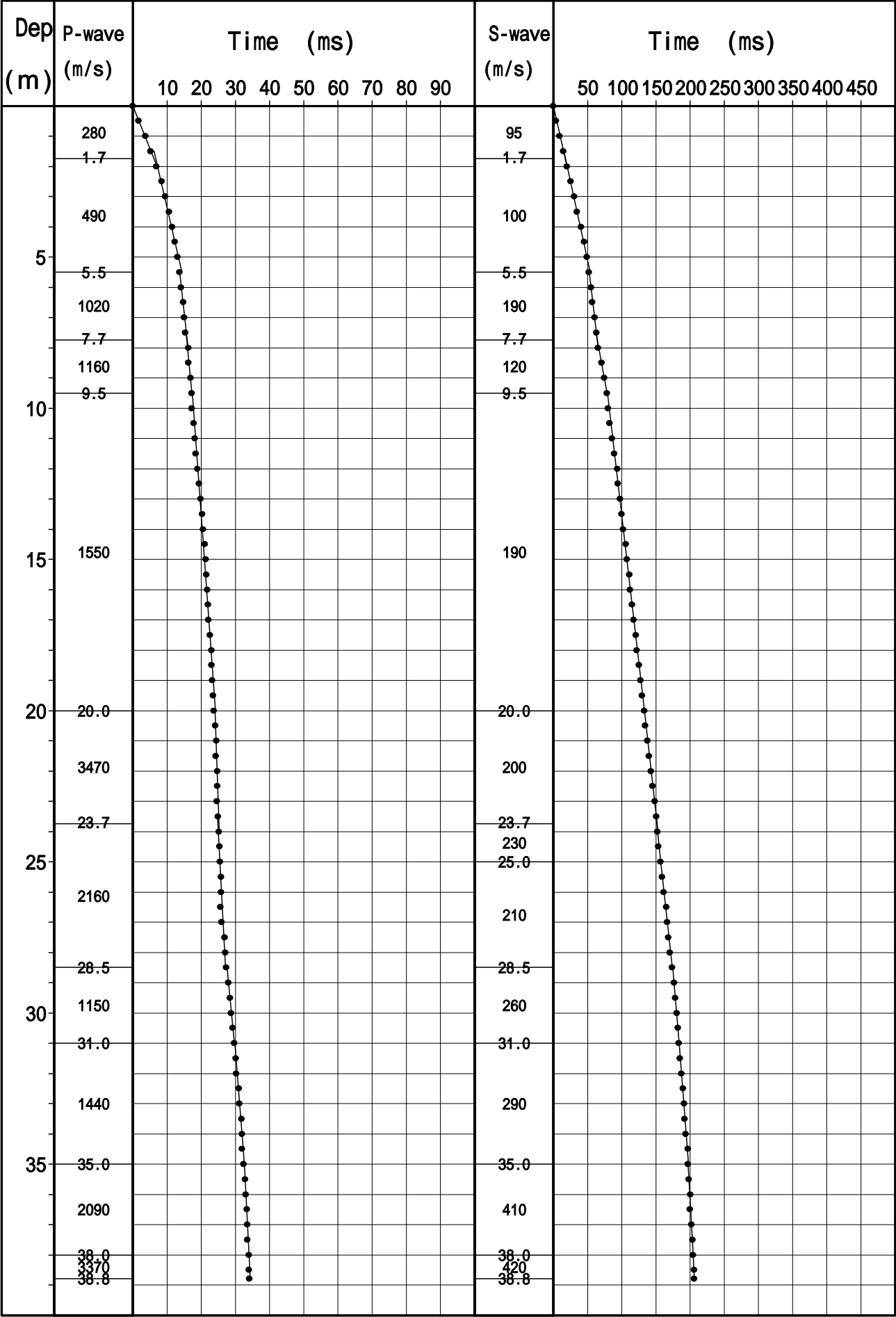
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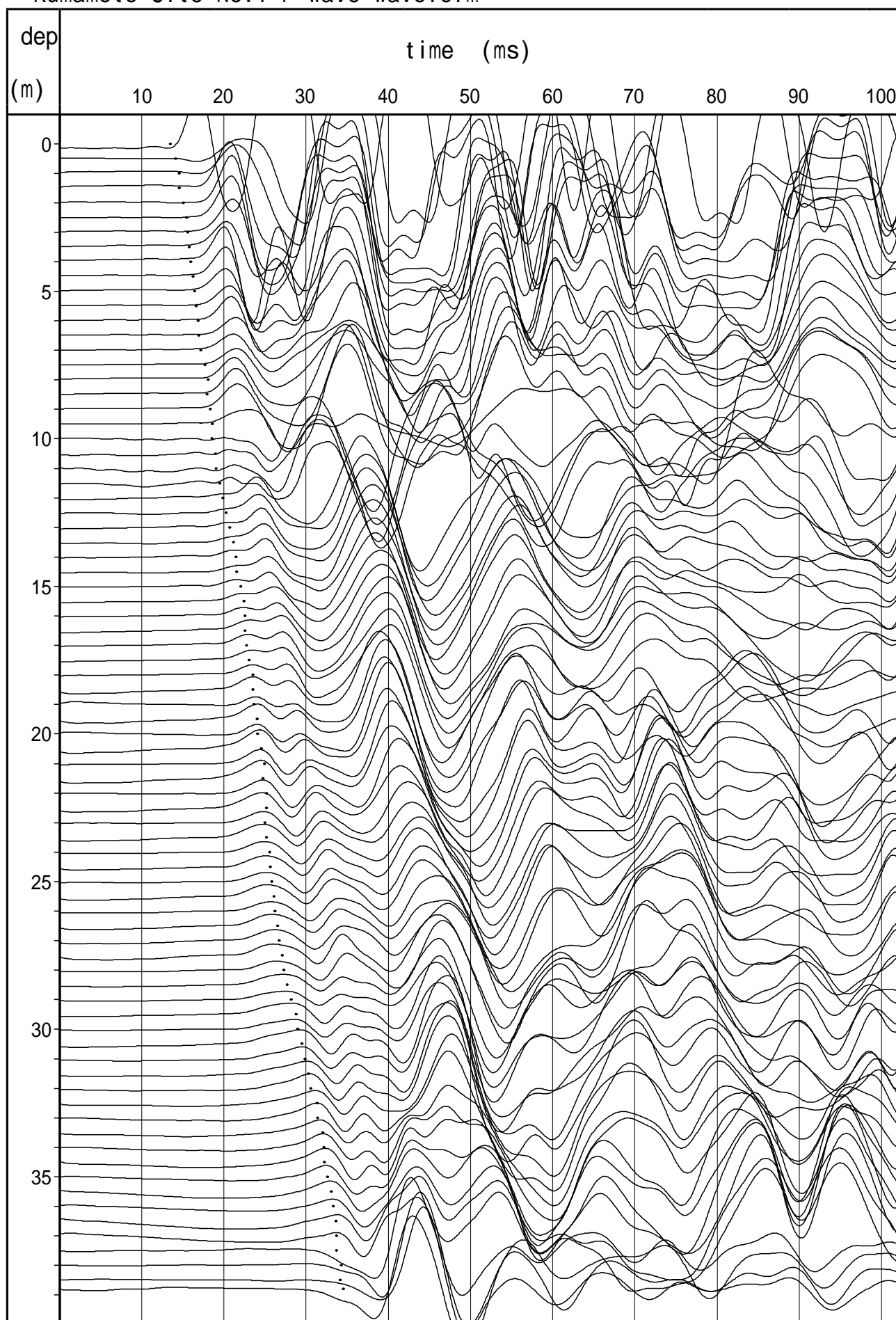


Appendix 2
PS Logging Data

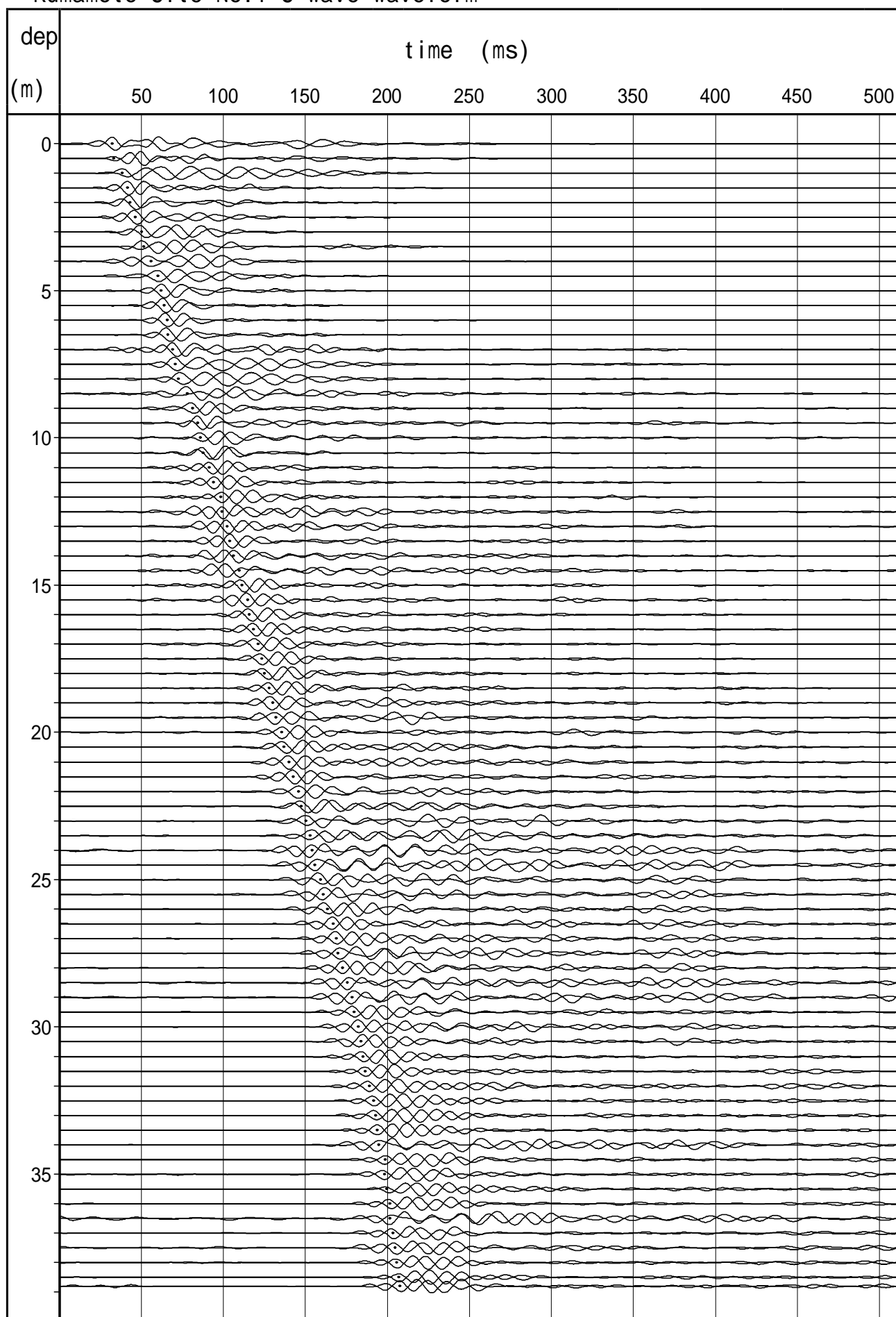
PS_Logging_TravelTime



Kumamoto Site No.1 P-wave waveform



Kumamoto Site No.1 S-wave waveform



Appendix 3

Laboratory test Data

Table A3-1 Summary of particle size distribution of soils

| Sample No. | T-1 | T-2 | Tr-3 | Tr-4 | T-5 |
|--------------------|----------------------|-------|-------|-------|-------|
| Upper Depth(m) | 4.00 | 7.65 | 13.00 | 20.00 | 23.00 |
| Bottom Depth (m) | 5.00 | 8.65 | 14.00 | 21.00 | 23.72 |
| particle size (mm) | mass percentages (%) | | | | |
| 75 | | | | | |
| 53 | | | | | |
| 37.5 | | | | | |
| 26.5 | | | | | |
| 19 | | | | | |
| 9.5 | | | | | |
| 4.75 | | | 100.0 | | |
| 2 | 100.0 | | 99.7 | 100.0 | |
| 0.85 | 99.7 | 100.0 | 95.2 | 99.8 | 100.0 |
| 0.425 | 98.3 | 99.6 | 75.1 | 99.2 | 99.7 |
| 0.25 | 95.8 | 98.8 | 44.2 | 96.7 | 99.4 |
| 0.106 | 90.2 | 96.9 | 18.5 | 33.2 | 98.5 |
| 0.075 | 86.8 | 94.5 | 14.9 | 21.9 | 96.9 |
| 0.0548 | 83.4 | 92.2 | 11.7 | 17.2 | 93.9 |
| 0.039 | 79.0 | 88.9 | 9.2 | 13.3 | 90.0 |
| 0.0248 | 72.9 | 84.3 | 6.6 | 9.4 | 85.0 |
| 0.0144 | 65.2 | 79.1 | 4.8 | 6.8 | 78.2 |
| 0.0103 | 59.6 | 75.2 | 3.8 | 5.5 | 73.7 |
| 0.0073 | 54.1 | 71.2 | 2.8 | 4.2 | 68.8 |
| 0.00362 | 44.2 | 64.0 | 2.0 | 2.9 | 60.0 |
| 0.00149 | 34.8 | 56.8 | 1.3 | 1.6 | 51.1 |
| 0.001 | 32.6 | 54.9 | 1.1 | 1.3 | 49.1 |

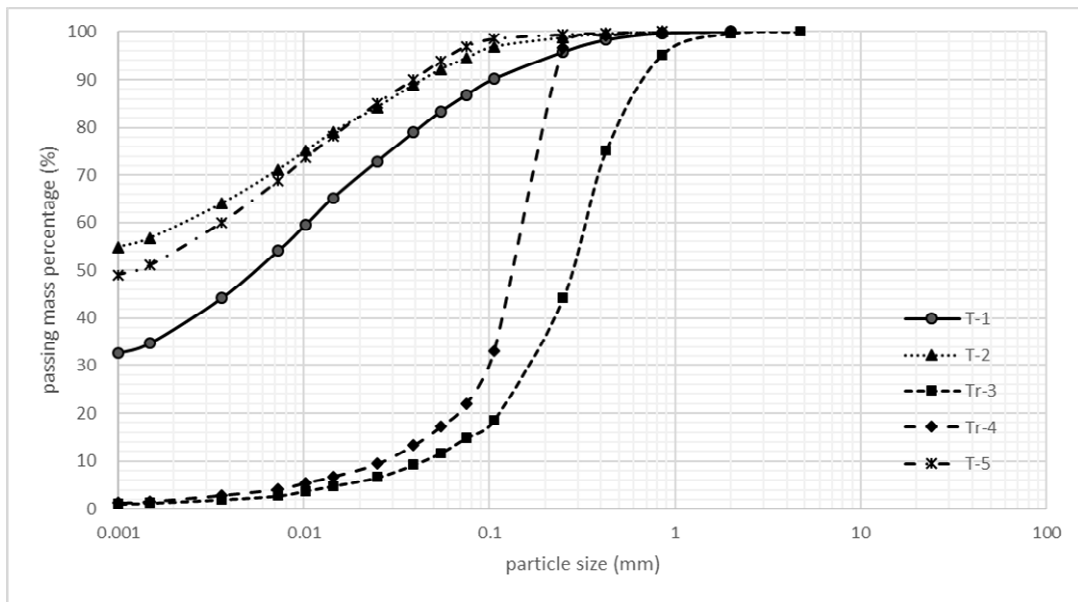


Figure A3-1 Particle size accumulation curve

Table A3-2 Cyclic triaxial test to determine deformation properties of geomaterials: specimen conditions and test results

| sample no. | depth | | | consoli- dation pressure | density of soil particles | specimen status | initial condition | | | | before consolidation | | after consolidation | | test results | | | |
|------------|-------|-----|-------|--------------------------------|---------------------------------|--------------------|----------------------|---------------------|----------------------|------------|----------------------|------------|----------------------|------------|----------------------|-----------------|----------------------|------------|
| | | | | | | | wet density | water content of | dry density | void ratio | dry density | void ratio | dry density | void ratio | E_0 | ε_r | G_0 | γ_r |
| | | (m) | | (kN/m ²) | (g/cm ³) | | (g/cm ³) | (%) | (g/cm ³) | | (g/cm ³) | | (g/cm ³) | | (MN/m ²) | (%) | (MN/m ²) | (%) |
| T-1 | 4.00 | ~ | 5.00 | 65 | 2.701 | bulk | 1.367 | 125.9 | 0.605 | 3.464 | 0.608 | 3.442 | 0.638 | 3.236 | 31.7 | 1.01E-01 | 10.6 | 1.52E-01 |
| T-2 | 7.65 | ~ | 8.65 | 90 | 2.479 | bulk | 1.289 | 164.3 | 0.488 | 4.080 | 0.490 | 4.059 | 0.523 | 3.736 | 23.3 | 2.45E-01 | 7.8 | 3.67E-01 |
| Tr-3 | 13.00 | ~ | 14.00 | 130 | 2.831 | frozen | 1.912 | 25.9 | 1.519 | 0.864 | 1.536 | 0.843 | 1.558 | 0.817 | 170.7 | 4.48E-02 | 56.9 | 6.72E-02 |
| Tr-4 | 20.00 | ~ | 21.00 | 200 | 2.782 | frozen | 1.836 | 33.9 | 1.371 | 1.029 | 1.412 | 0.970 | 1.442 | 0.929 | 198.6 | 6.99E-02 | 66.2 | 1.05E-01 |
| T-5 | 23.00 | ~ | 23.72 | 50 | 2.693 | bulk | 1.501 | 86.3 | 0.806 | 2.341 | 0.807 | 2.337 | 0.850 | 2.168 | 94.7 | 1.34E-01 | 31.6 | 2.01E-01 |

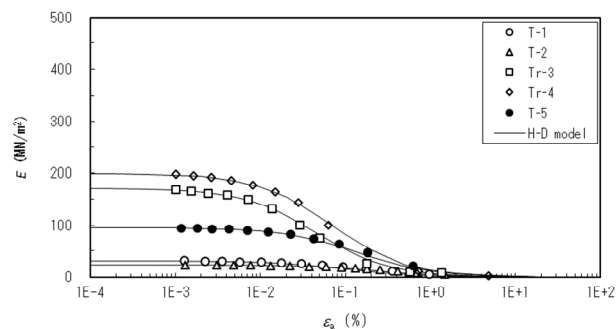


Figure $E - \varepsilon_0$ relations

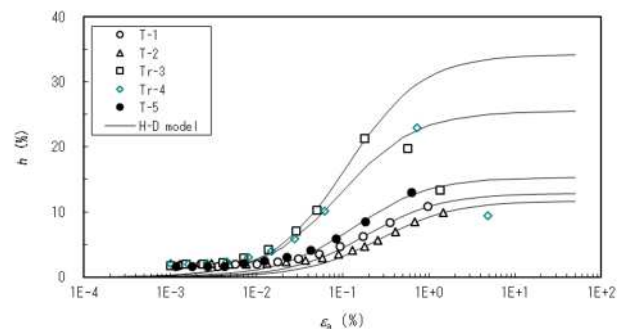


Figure $h - \varepsilon_0$ relations

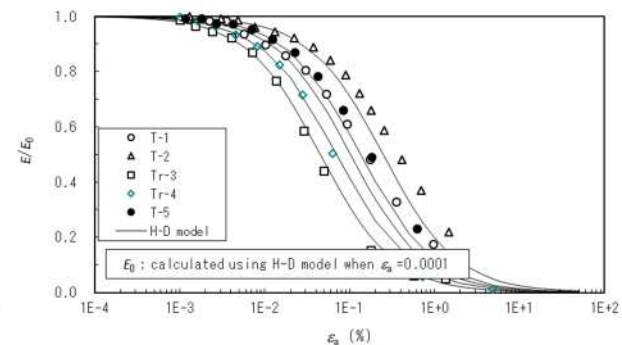


図 $E/E_0 \sim \varepsilon_0$ 関係

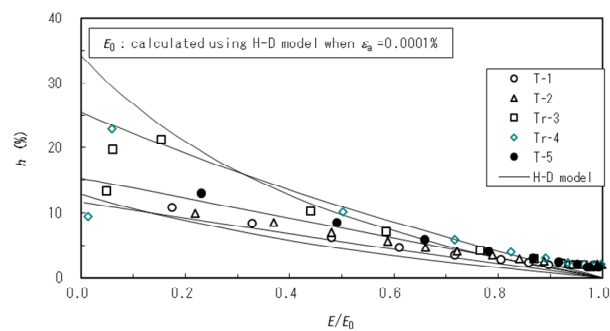


Figure $h - E/E_0$ relations

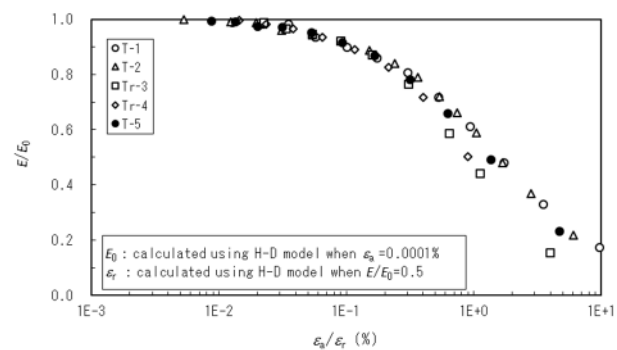


Figure $E/E_0 \sim \varepsilon_0/\varepsilon_r$ relations

Figure A3-2 E, h relations

Table A3-3 E, h relations

| test data | | | | | H-D model | | | | |
|---------------|-------|------|-----------------------------|---------|-----------------------------|---------------|---------------|---------|---------|
| | | | | | ε_r | E_{\max} | ε | E | E/E_0 |
| ε | E | h | $\varepsilon/\varepsilon_r$ | E/E_0 | $\varepsilon/\varepsilon_r$ | ε | E | E/E_0 | h |
| Tr-1 | | | | | | | | | |
| 1.28E-03 | 31.3 | 1.7 | 1.27E-02 | 0.989 | 9.89E-04 | 1.00E-04 | 31.7 | 1.000 | 0.0 |
| 2.25E-03 | 31.1 | 1.9 | 2.23E-02 | 0.982 | 1.98E-03 | 2.00E-04 | 31.6 | 0.999 | 0.0 |
| 3.54E-03 | 31.1 | 1.6 | 3.50E-02 | 0.982 | 4.95E-03 | 5.00E-04 | 31.5 | 0.996 | 0.0 |
| 5.75E-03 | 29.6 | 1.9 | 5.69E-02 | 0.935 | 9.89E-03 | 1.00E-03 | 31.4 | 0.991 | 0.1 |
| 1.02E-02 | 28.4 | 1.9 | 1.01E-01 | 0.897 | 1.98E-02 | 2.00E-03 | 31.1 | 0.982 | 0.1 |
| 1.77E-02 | 27.2 | 2.3 | 1.75E-01 | 0.859 | 4.95E-02 | 5.00E-03 | 30.2 | 0.954 | 0.3 |
| 3.06E-02 | 25.5 | 2.8 | 3.03E-01 | 0.805 | 9.89E-02 | 1.00E-02 | 28.8 | 0.911 | 0.7 |
| 5.32E-02 | 22.7 | 3.5 | 5.26E-01 | 0.717 | 1.98E-01 | 2.00E-02 | 26.5 | 0.836 | 1.2 |
| 9.42E-02 | 19.3 | 4.7 | 9.32E-01 | 0.610 | 4.95E-01 | 5.00E-02 | 21.2 | 0.670 | 2.7 |
| 1.73E-01 | 15.2 | 6.2 | 1.72E+00 | 0.480 | 9.89E-01 | 1.00E-01 | 15.9 | 0.503 | 4.5 |
| 3.54E-01 | 10.4 | 8.3 | 3.50E+00 | 0.328 | 1.98E+00 | 2.00E-01 | 10.6 | 0.336 | 6.6 |
| 9.74E-01 | 5.5 | 10.9 | 9.64E+00 | 0.174 | 4.95E+00 | 5.00E-01 | 5.3 | 0.168 | 9.4 |
| | | | | | 9.89E+00 | 1.00E+00 | 2.9 | 0.092 | 10.8 |
| | | | | | 1.98E+01 | 2.00E+00 | 1.5 | 0.048 | 11.8 |
| | | | | | 4.95E+01 | 5.00E+00 | 0.6 | 0.020 | 12.4 |
| | | | | | 9.89E+01 | 1.00E+01 | 0.3 | 0.010 | 12.6 |
| | | | | | 1.98E+02 | 2.00E+01 | 0.2 | 0.005 | 12.7 |
| | | | | | 4.95E+02 | 5.00E+01 | 0.1 | 0.002 | 12.8 |
| test data | | | | | H-D model | | | | |
| | | | | | ε_r | E_{\max} | ε | E | E/E_0 |
| ε | E | h | $\varepsilon/\varepsilon_r$ | E/E_0 | $\varepsilon/\varepsilon_r$ | ε | E | E/E_0 | h |
| Tr-4 | | | | | | | | | |
| 1.01E-03 | 198.0 | 2.1 | 1.44E-02 | 0.997 | 1.43E-03 | 1.00E-04 | 198.6 | 1.000 | 0.0 |
| 1.64E-03 | 195.1 | 1.9 | 2.35E-02 | 0.982 | 2.86E-03 | 2.00E-04 | 198.4 | 0.999 | 0.1 |
| 2.66E-03 | 191.7 | 2.1 | 3.80E-02 | 0.965 | 7.15E-03 | 5.00E-04 | 197.5 | 0.994 | 0.1 |
| 4.53E-03 | 185.4 | 2.3 | 6.48E-02 | 0.933 | 1.43E-02 | 1.00E-03 | 196.1 | 0.987 | 0.3 |
| 8.08E-03 | 177.0 | 3.0 | 1.16E-01 | 0.891 | 2.86E-02 | 2.00E-03 | 193.4 | 0.974 | 0.5 |
| 1.49E-02 | 163.8 | 4.0 | 2.13E-01 | 0.825 | 7.15E-02 | 5.00E-03 | 185.6 | 0.935 | 1.3 |
| 2.80E-02 | 142.4 | 5.9 | 4.01E-01 | 0.717 | 1.43E-01 | 1.00E-02 | 174.0 | 0.876 | 2.5 |
| 6.25E-02 | 99.9 | 10.1 | 8.94E-01 | 0.503 | 2.86E-01 | 2.00E-02 | 154.7 | 0.779 | 4.5 |
| 7.22E-01 | 11.6 | 22.9 | 1.03E+01 | 0.058 | 7.15E-01 | 5.00E-02 | 116.0 | 0.584 | 8.9 |
| 4.80E+00 | 2.5 | 9.4 | 6.86E+01 | 0.013 | 1.43E+00 | 1.00E-01 | 81.9 | 0.412 | 13.2 |
| | | | | | 2.86E+00 | 2.00E-01 | 51.5 | 0.259 | 17.4 |
| | | | | | 7.15E+00 | 5.00E-01 | 24.4 | 0.123 | 21.5 |
| | | | | | 1.43E+01 | 1.00E+00 | 13.0 | 0.065 | 23.3 |
| | | | | | 2.86E+01 | 2.00E+00 | 6.7 | 0.034 | 24.3 |
| | | | | | 7.15E+01 | 5.00E+00 | 2.7 | 0.014 | 25.0 |
| | | | | | 1.43E+02 | 1.00E+01 | 1.4 | 0.007 | 25.2 |
| | | | | | 2.86E+02 | 2.00E+01 | 0.7 | 0.003 | 25.4 |
| | | | | | 7.15E+02 | 5.00E+01 | 0.3 | 0.001 | 25.4 |
| test data | | | | | H-D model | | | | |
| | | | | | ε_r | E_{\max} | ε | E | E/E_0 |
| ε | E | h | $\varepsilon/\varepsilon_r$ | E/E_0 | $\varepsilon/\varepsilon_r$ | ε | E | E/E_0 | h |
| Tr-5 | | | | | | | | | |
| 1.17E-03 | 94.0 | 1.6 | 8.73E-03 | 0.992 | 7.46E-04 | 1.00E-04 | 94.7 | 1.000 | 0.0 |
| 1.81E-03 | 93.9 | 1.6 | 1.35E-02 | 0.991 | 1.49E-03 | 2.00E-04 | 94.6 | 0.999 | 0.0 |
| 2.71E-03 | 92.3 | 1.6 | 2.02E-02 | 0.975 | 3.73E-03 | 5.00E-04 | 94.4 | 0.997 | 0.1 |
| 4.24E-03 | 92.0 | 1.6 | 3.16E-02 | 0.971 | 7.46E-03 | 1.00E-03 | 94.1 | 0.993 | 0.1 |
| 7.10E-03 | 90.1 | 2.1 | 5.30E-02 | 0.951 | 1.49E-02 | 2.00E-03 | 93.4 | 0.986 | 0.2 |
| 1.25E-02 | 86.7 | 2.4 | 9.30E-02 | 0.915 | 3.73E-02 | 5.00E-03 | 91.4 | 0.965 | 0.5 |
| 2.25E-02 | 82.2 | 3.0 | 1.68E-01 | 0.868 | 7.46E-02 | 1.00E-02 | 88.2 | 0.931 | 1.1 |
| 4.24E-02 | 74.0 | 4.1 | 3.17E-01 | 0.781 | 1.49E-01 | 2.00E-02 | 82.5 | 0.871 | 2.0 |
| 8.35E-02 | 62.4 | 5.9 | 6.24E-01 | 0.659 | 3.73E-01 | 5.00E-02 | 69.0 | 0.729 | 4.1 |
| 1.82E-01 | 46.4 | 8.5 | 1.36E+00 | 0.490 | 7.46E-01 | 1.00E-01 | 54.3 | 0.573 | 6.5 |
| 6.31E-01 | 21.8 | 13.0 | 4.71E+00 | 0.230 | 1.49E+00 | 2.00E-01 | 38.0 | 0.401 | 9.1 |
| | | | | | 3.73E+00 | 5.00E-01 | 20.0 | 0.211 | 12.0 |
| | | | | | 7.46E+00 | 1.00E+00 | 11.2 | 0.118 | 13.5 |
| | | | | | 1.49E+01 | 2.00E+00 | 6.0 | 0.063 | 14.3 |
| | | | | | 3.73E+01 | 5.00E+00 | 2.5 | 0.026 | 14.9 |
| | | | | | 7.46E+01 | 1.00E+01 | 1.3 | 0.013 | 15.1 |
| | | | | | 1.49E+02 | 2.00E+01 | 0.6 | 0.007 | 15.2 |
| | | | | | 3.73E+02 | 5.00E+01 | 0.3 | 0.003 | 15.3 |

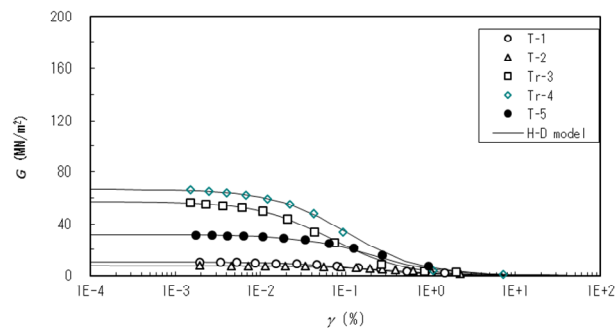


Figure G - γ relations

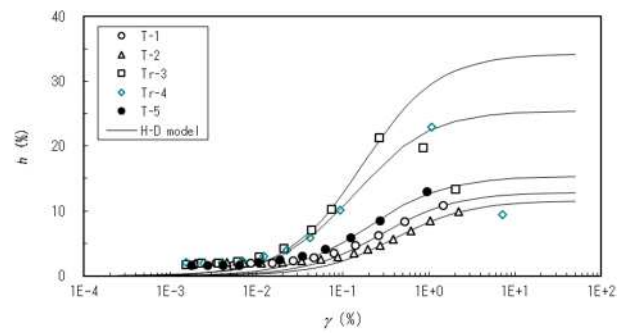


Figure h - γ relations

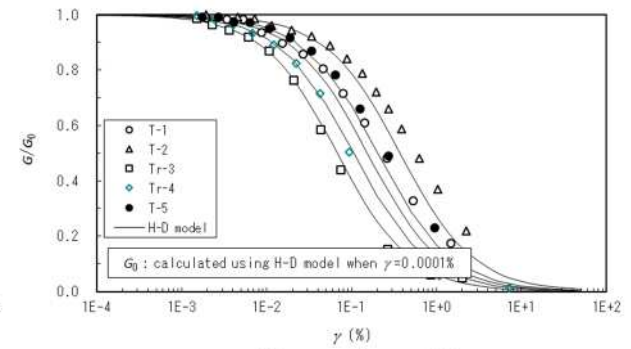


Figure G/G_0 - γ relations

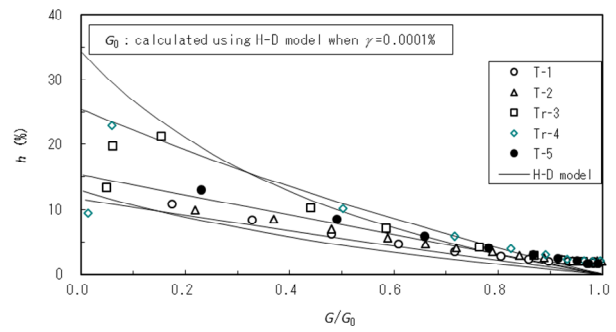


Figure h - G/G_0 relations

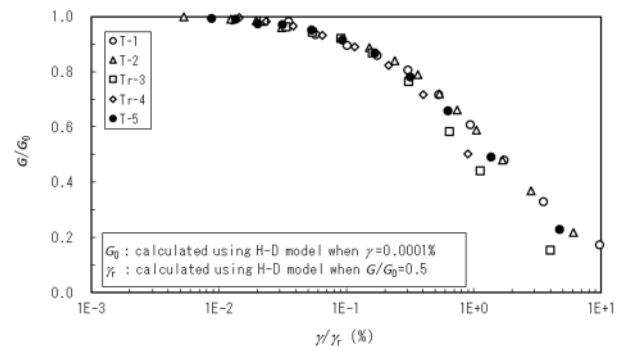


Figure G/G_0 - γ/γ_r relations

Figure A3-3 G , h relations

Table A3-4 G, h relations

| test data | | | | | H-D model | | | | | test data | | | | | H-D model | | | | | test data | | | | | H-D model | | | | | | | |
|-----------|------|------|-------------------|---------|-------------------|----------|------|-----------|----------|-----------|-----|-----|-------------------|---------|-------------------|------------|----------|---------|-----------|-----------|------|------|-------------------|---------|-------------------|----------|------------|----------|------|-----------|----------|--|
| | | | | | γ_t | 1.52E-01 | | γ | 2.82E-01 | | | | | | | γ_t | 3.67E-01 | | γ | 4.04E-01 | | | | | | | γ_t | 6.72E-02 | | γ | 1.70E-01 | |
| | | | | | G_{max} | 10.6 | | h_{max} | 12.9 | | | | | | | G_{max} | 7.8 | | h_{max} | 11.6 | | | | | | | G_{max} | 57.0 | | h_{max} | 34.2 | |
| γ | G | h | γ/γ_t | G/G_0 | γ/γ_t | γ | G | G/G_0 | h | γ | G | h | γ/γ_t | G/G_0 | γ/γ_t | γ | G | G/G_0 | h | γ | G | h | γ/γ_t | G/G_0 | γ/γ_t | γ | G | G/G_0 | h | | | |
| Tr-1 | | | | | Tr-2 | | | | | Tr-3 | | | | | Tr-4 | | | | | Tr-5 | | | | | | | | | | | | |
| 1.92E-03 | 10.4 | 1.7 | 1.27E-02 | 0.988 | 6.60E-04 | 1.00E-04 | 10.6 | 1.000 | 0.0 | 1.94E-03 | 7.8 | 1.9 | 5.27E-03 | 0.999 | 2.72E-04 | 1.00E-04 | 7.8 | 1.000 | 0.0 | 1.52E-03 | 56.1 | 1.7 | 2.25E-02 | 0.985 | 1.49E-03 | 1.00E-04 | 56.9 | 1.000 | 0.0 | | | |
| 3.98E-03 | 10.4 | 1.9 | 2.23E-02 | 0.982 | 1.32E-04 | 2.00E-04 | 10.6 | 0.999 | 0.0 | 4.55E-03 | 7.7 | 2.1 | 1.24E-02 | 0.990 | 5.45E-04 | 2.00E-04 | 7.8 | 1.000 | 0.0 | 2.28E-03 | 54.8 | 1.9 | 3.39E-02 | 0.963 | 2.98E-03 | 2.00E-04 | 56.8 | 0.999 | 0.0 | | | |
| 5.31E-03 | 10.4 | 1.6 | 3.50E-02 | 0.982 | 3.30E-03 | 5.00E-04 | 10.5 | 0.997 | 0.0 | 7.19E-03 | 7.7 | 2.0 | 1.96E-02 | 0.986 | 1.36E-03 | 5.00E-04 | 7.8 | 0.999 | 0.0 | 3.63E-03 | 53.7 | 2.0 | 5.40E-02 | 0.944 | 7.44E-03 | 5.00E-04 | 56.6 | 0.994 | 0.0 | | | |
| 8.63E-03 | 9.9 | 1.9 | 5.69E-02 | 0.935 | 6.60E-03 | 1.00E-03 | 10.5 | 0.994 | 0.0 | 1.14E-02 | 7.5 | 2.0 | 3.30E-02 | 0.960 | 2.72E-03 | 1.00E-03 | 7.8 | 0.998 | 0.0 | 6.11E-03 | 52.4 | 2.2 | 9.09E-02 | 0.920 | 1.49E-02 | 1.00E-03 | 56.2 | 0.987 | 0.2 | | | |
| 1.53E-02 | 9.5 | 2.9 | 1.01E-01 | 0.897 | 1.32E-02 | 2.00E-03 | 10.4 | 0.988 | 0.0 | 1.98E-02 | 7.3 | 2.1 | 5.39E-02 | 0.943 | 5.45E-03 | 2.00E-03 | 7.7 | 0.995 | 0.1 | 1.07E-02 | 49.4 | 2.9 | 1.60E-01 | 0.868 | 2.98E-02 | 2.00E-03 | 55.4 | 0.973 | 0.4 | | | |
| 2.65E-02 | 9.1 | 1.3 | 7.5E-01 | 0.859 | 3.30E-02 | 5.00E-03 | 10.3 | 0.969 | 0.0 | 3.35E-02 | 7.2 | 2.3 | 9.11E-02 | 0.922 | 9.72E-03 | 5.00E-02 | 7.7 | 0.987 | 0.0 | 7.64E-02 | 43.5 | 4.2 | 3.08E-01 | 0.784 | 7.44E-02 | 5.00E-03 | 53.1 | 0.932 | 1.0 | | | |
| 4.60E-02 | 8.5 | 2.8 | 3.03E-01 | 0.805 | 6.60E-02 | 1.00E-02 | 9.9 | 0.939 | 0.4 | 5.58E-02 | 6.9 | 2.5 | 1.52E-01 | 0.887 | 2.72E-02 | 5.00E-02 | 7.6 | 0.974 | 0.3 | 4.34E-02 | 33.3 | 7.0 | 6.47E-01 | 0.564 | 1.49E-01 | 1.00E-02 | 49.6 | 0.872 | 1.9 | | | |
| 7.98E-02 | 7.6 | 3.5 | 5.26E-01 | 0.717 | 1.32E-01 | 2.00E-02 | 9.3 | 0.884 | 0.9 | 8.78E-02 | 6.5 | 2.9 | 2.39E-01 | 0.840 | 5.45E-02 | 2.00E-02 | 7.4 | 0.949 | 0.5 | 7.50E-02 | 25.1 | 10.3 | 1.12E+00 | 0.450 | 2.98E-01 | 2.00E-02 | 43.9 | 0.772 | 3.6 | | | |
| 1.41E-01 | 6.4 | 4.7 | 9.32E-01 | 0.609 | 3.30E-01 | 5.00E-02 | 7.9 | 0.752 | 1.9 | 1.34E-01 | 6.1 | 3.5 | 3.65E-01 | 0.789 | 1.36E-01 | 5.00E-02 | 6.8 | 0.880 | 1.3 | 2.69E-01 | 8.7 | 21.3 | 3.99E+00 | 0.143 | 7.44E-01 | 5.00E-02 | 32.7 | 0.574 | 7.8 | | | |
| 2.60E-01 | 5.1 | 6.2 | 1.72E+00 | 0.480 | 6.60E-01 | 1.00E-01 | 6.4 | 0.603 | 3.4 | 1.96E-01 | 5.6 | 4.1 | 5.34E-01 | 0.720 | 2.72E-01 | 1.00E-01 | 6.1 | 0.786 | 2.3 | 8.61E-01 | 3.4 | 19.7 | 1.28E+01 | 0.060 | 1.49E+00 | 1.00E-01 | 22.9 | 0.402 | 12.7 | | | |
| 5.30E-01 | 3.5 | 8.3 | 3.50E+00 | 0.328 | 1.32E+00 | 2.00E-01 | 4.6 | 0.431 | 5.3 | 2.70E-01 | 5.1 | 4.7 | 7.36E-01 | 0.660 | 5.45E-01 | 2.00E-01 | 5.0 | 0.648 | 3.8 | 2.03E+00 | 2.8 | 13.3 | 3.02E+01 | 0.049 | 2.98E+00 | 2.00E-01 | 14.3 | 0.252 | 18.5 | | | |
| 1.46E+00 | 1.8 | 10.9 | 9.64E+00 | 0.174 | 3.30E+00 | 5.00E-01 | 2.5 | 0.233 | 8.2 | 3.83E-01 | 4.6 | 5.6 | 1.04E+00 | 0.587 | 1.36E+00 | 5.00E-01 | 3.3 | 0.424 | 6.4 | | | | | | | | | | | | | |
| | | | | | 6.60E+00 | 1.00E+00 | 1.4 | 0.132 | 10.0 | 6.19E-01 | 3.7 | 6.9 | 1.69E+00 | 0.480 | 2.72E+00 | 1.00E+00 | 2.1 | 0.269 | 8.3 | | | | | | | | | | | | | |
| | | | | | 1.32E+01 | 2.00E+00 | 0.7 | 0.071 | 11.3 | 1.04E+00 | 2.9 | 8.5 | 2.82E+00 | 0.369 | 5.45E+00 | 2.00E+00 | 1.2 | 0.155 | 9.7 | | | | | | | | | | | | | |
| | | | | | 3.30E+01 | 5.00E+00 | 0.3 | 0.029 | 12.2 | 2.22E+00 | 1.7 | 9.9 | 6.04E+00 | 0.219 | 1.36E+01 | 5.00E+00 | 0.5 | 0.068 | 10.8 | | | | | | | | | | | | | |
| | | | | | 6.60E+01 | 1.00E+01 | 0.2 | 0.015 | 12.5 | | | | | | 2.72E+01 | 1.00E+01 | 0.3 | 0.035 | 11.2 | | | | | | | | | | | | | |
| | | | | | 1.32E+02 | 2.00E+01 | 0.1 | 0.008 | 12.7 | | | | | | 5.45E+01 | 2.00E+01 | 0.1 | 0.018 | 11.4 | | | | | | | | | | | | | |
| | | | | | 3.30E+02 | 5.00E+01 | 0.0 | 0.003 | 12.8 | | | | | | 1.36E+02 | 5.00E+01 | 0.1 | 0.007 | 11.5 | | | | | | | | | | | | | |

| test data | | | | | H-D model | | | | | test data | | | | | H-D model | | | | | | |
|-----------|------|------|-------------------|---------|-------------------|----------|------|-----------|----------|-----------|------|------|-------------------|---------|-------------------|------------|----------|---------|-----------|----------|--|
| | | | | | γ_t | 1.05E-01 | | γ | 1.40E-01 | | | | | | | γ_t | 2.01E-01 | | γ | 2.02E-01 | |
| | | | | | G_{max} | 66.3 | | h_{max} | 25.5 | | | | | | | G_{max} | 31.6 | | h_{max} | 15.3 | |
| γ | G | h | γ/γ_t | G/G_0 | γ/γ_t | γ | G | G/G_0 | h | γ | G | h | γ/γ_t | G/G_0 | γ/γ_t | γ | G | G/G_0 | h | | |
| Tr-4 | | | | | Tr-5 | | | | | Tr-6 | | | | | Tr-7 | | | | | | |
| 1.52E-03 | 66.0 | 2.1 | 1.44E-02 | 0.996 | 9.53E-04 | 1.00E-04 | 66.2 | 1.000 | 0.0 | 1.76E-03 | 31.3 | 1.6 | 8.73E-03 | 0.992 | 4.98E-04 | 1.00E-04 | 31.6 | 1.000 | 0.0 | | |
| 2.46E-03 | 65.0 | 1.9 | 2.35E-02 | 0.982 | 1.91E-03 | 2.00E-04 | 66.2 | 0.999 | 0.0 | 2.72E-03 | 31.3 | 1.6 | 1.35E-02 | 0.991 | 9.95E-04 | 2.00E-04 | 31.6 | 1.000 | 0.0 | | |
| 3.99E-03 | 63.9 | 2.1 | 3.80E-02 | 0.965 | 4.77E-03 | 5.00E-04 | 66.0 | 0.996 | 0.1 | 4.07E-03 | 30.8 | 1.6 | 2.02E-02 | 0.974 | 2.49E-03 | 5.00E-04 | 31.5 | 0.998 | 0.0 | | |
| 6.80E-03 | 61.8 | 2.3 | 6.48E-02 | 0.933 | 9.53E-03 | 1.00E-03 | 65.7 | 0.991 | 0.2 | 6.36E-03 | 30.7 | 1.6 | 3.16E-02 | 0.971 | 4.98E-03 | 1.00E-03 | 31.4 | 0.996 | 0.1 | | |
| 1.21E-02 | 59.0 | 3.0 | 1.16E-01 | 0.891 | 1.91E-02 | 2.00E-03 | 65.1 | 0.982 | 0.4 | 1.07E-02 | 30.0 | 2.1 | 5.30E-02 | 0.951 | 9.95E-03 | 2.00E-03 | 31.3 | 0.991 | 0.1 | | |
| 2.24E-02 | 54.6 | 4.0 | 2.13E-01 | 0.824 | 4.77E-02 | 5.00E-03 | 63.3 | 0.955 | 0.9 | 1.87E-02 | 28.9 | 2.4 | 9.30E-02 | 0.915 | 2.49E-02 | 5.00E-03 | 30.8 | 0.976 | 0.4 | | |
| 4.20E-02 | 47.5 | 5.9 | 4.01E-01 | 0.717 | 9.53E-02 | 1.00E-02 | 60.5 | 0.914 | 1.7 | 3.38E-02 | 27.4 | 3.0 | 1.68E-01 | 0.868 | 4.98E-02 | 1.00E-02 | 30.1 | 0.953 | 0.7 | | |
| 9.37E-02 | 33.3 | 10.1 | 8.94E-01 | 0.503 | 2.91E-02 | 2.00E-02 | 55.7 | 0.781 | 3.2 | 6.36E-02 | 24.7 | 4.1 | 1.17E-01 | 0.791 | 9.95E-02 | 2.00E-02 | 28.7 | 0.910 | 1.0 | | |
| 1.08E+00 | 3.9 | 22.9 | 3.03E+01 | 0.058 | 4.77E-01 | 5.00E-02 | 44.9 | 0.678 | 10.0 | 1.25E-01 | 20.8 | 5.9 | 2.24E-01 | 0.659 | 2.49E-01 | 5.00E-02 | 25.7 | 0.801 | 3.0 | | |
| 7.19E+00 | 0.8 | 9.4 | 6.86E+01 | 0.013 | 9.53E-01 | 1.00E-01 | 33.9 | 0.512 | 10.6 | 2.73E-01 | 15.5 | 8.5 | 1.36E+00 | 0.490 | 4.98E-01 | 1.00E-01 | 21.1 | 0.669 | 5.1 | | |
| | | | | | 1.91E+00 | 2.00E-01 | 22.8 | 0.344 | 15.0 | 9.46E-01 | 7.3 | 13.0 | 4.71E+00 | 0.230 | 9.95E-01 | 2.00E-01 | 15.8 | 0.501 | 7.6 | | |
| | | | | | 4.77E+00 | 5.00E-01 | 11.5 | 0.174 | 19.9 | | | | | | 2.49E+00 | 5.00E-01 | 9.1 | 0.287 | 10.9 | | |
| | | | | | 9.53E+00 | 1.00E+00 | 6.3 | 0.095 | 22.3 | | | | | | 4.98E+00 | 1.00E+00 | 5.3 | 0.167 | 12.7 | | |
| | | | | | 1.91E+01 | 2.00E+00 | 3.3 | 0.050 | 23.8 | | | | | | 9.95E+00 | 2.00E+00 | 2.9 | 0.091 | 13.9 | | |
| | | | | | 4.77E+01 | 5.00E+00 | 1.4 | 0.021 | 24.8 | | | | | | 2.49E+01 | 5.00E+00 | 1.2 | 0.039 | 14.7 | | |
| | | | | | 9.53E+01 | 1.00E+01 | 0.7 | 0.010 | 25.1 | | | | | | 4.98E+01 | 1.00E+01 | 0.6 | 0.020 | 15.0 | | |
| | | | | | 1.91E+02 | 2.00E+01 | 0.3 | 0.005 | 25.3 | | | | | | 9.95E+01 | 2.00E+01 | 0.3 | 0.010 | 15.1 | | |
| | | | | | 4.77E+02 | 5.00E+01 | 0.1 | 0.002 | 25.4 | | | | | | 2.49E+02 | 5.00E+01 | 0.1 | 0.004 | 15.2 | | |