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Laboratory Test Results of Hydrological Properties from Dry Drilled and Wet Drilled Cores in the Drift Scale Test Area and in the Single Heater Test Area of the Thermal Test Facility

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Abstract

Laboratory test results of saturation, porosity, bulk density, particle density, and gravimetric water content are presented for both dry drilled cores and wet drilled cores from the Thermal Test Facility (TTF) at Alcove 5 of the Exploratory Studies Facility (ESF). Core measurement is part of the hydrological characterization study to determine the amount of pore water available for evaporation and boiling during the heating phase. If thermally induced multiphase processes are sensitive to the saturation conditions in the rock formation, the system responses in the heater tests will be strongly influenced by the liquid and vapor flows in the rock matrix and through the prevailing fractures. The data reported here indicate that the liquid saturation of the wet drilled cores can differ from that of the dry drilled cores by 10%. The discrepancy may in part arise from spatial heterogeneity, and in part due to the different drilling methods.

Tabular Comparison of DST Dry Drilled and Wet Drilled Cores

The data from two sets of core measurements are tabulated in Table 1 for the dry drilled cores and in Table 2 for the wet drilled cores from the Drift

Scale Test (DST) area. Summaries of the averages and standard deviations of the measured values are presented at the end of each table to facilitate comparison between different data sets.

The first data set in Table 1 are based on cores from three permeability (PERM) holes dry drilled from an elevated platform at the end of the Connecting Drift (CD). The 20 m-long boreholes are oriented toward the easterly direction, away from the heated drift (HD). Borehole #183 or ESF-HD-PERM-2 is horizontal and the other two PERM holes are drilled at an incline angle of -20 degree (i.e., downward). Map 1 illustrates the layout of different drifts in the DST area of the TTF in ESF Alcove 5.

Included in the second set in Table 2 is one 46 m long MPBX (abbreviation for multi-point borehole extensiometer) borehole drilled horizontally from the same platform in the opposite direction toward the western direction, parallel to the HD axis. The other three 40 m long CHE (abbreviation for chemistry) holes are in a plane normal to the HD, drilled from the Access/Observation Drift (AOD), at incline angles of +24, +14, and -22 degrees. The wet drilled boreholes in Table 2 are more relevant to the DST since the boreholes are much closer to the HD than the PERM holes, with distances to the HD axis less than 10 m for three of the four holes in the second data set.

Graphic Comparison and Soft Information of DST Dry Drilled and Wet Drilled Cores

In addition to tables and summaries, the data of both sets are compared graphically in Figures 1 to 5, for saturation, porosity, bulk density, particle density, and gravitational water content (pore water weight divided by oven dried weight of the core), respectively. The property data points are plotted against the borehole depths. To facilitate the graphic comparison, some (but not all) of the data points from each borehole are connected by solid or dashed lines. The basis for this illustrative data trend analysis is discussed below.

Using the curve corresponding to Borehole #81, MPBX-1 in Figure 1 as an example (solid line with cross symbol), the particular data point with saturation value over 100% near 20 m is not connected to the solid curve passing through the other five points for cores deeper in the borehole. The footnote for this data point in Table 2 is the reason for questioning the validity of this high value. With a crumbled core having two open fractures, a "crushed" zone, and a porous looking, calcitic like intrusion in the core, the accuracy in measuring weights is not very high. The main source of error is in the estimate of the weight of water condensed in the walls of the core container. This is evaluated by absorbing the water from the container with a paper cloth and weighing the cloth. When large amount of fragments and powder is observed on the surfaces of the container, this measurement overestimates the water loss because it includes the weight of fine solids. Though the reason for this physically meaningless value of saturation over 100% is understood, yet there is no easy solution to a better measurement to arrive at a more accurate value.

For small core measurement, the water is usually assumed to be evenly distributed throughout the sample. For fractured samples, this assumption can introduce errors. For some of the cores which are processed long after drilling, water redistribution is much in evidence since the lower part of the core is observed to have darker color, indicating more water content. Cores with small, tight fractures generally introduce little error in the weight measurement. Larger fractures with porous infill material generally introduce greater inaccuracy. In the resaturation step needed to determine total pore volume with cores soaked in water, debris are sometimes observed.

Cyclic resaturation steps are used to quantify and to compensate for solid losses.

In the core processing procedure, any observations of factors potentially affecting the results are recorded. The abbreviated description for each core with abnormal features are included in the table footnotes. These "soft" information form the basis for distinguishing cores which yield reliable weight measurement from cores which give potentially abnormal and inaccurate measurement. Only those data points considered reliable are connected to its neighboring poiints. However, the determination of whether a data point should be connected to its neighboring points is subjective. The first two data points below 10 m borehole depth for borehole MPBX-1 are not connected because the first 10 m is located away from the heated drift. The cores are only collected in borehole depths beyond 10 m in the other three CHE holes from AOD. In any case, all data measured are plotted in the figures and included in the calculations of averages and standard deviations.

Alternative Interpretation Due to Spatial Variability

The graphic comparisons are also used to analyze whether the obvious saturation changes between these two data sets in Tables 1 and 2 are due to spatial variation instead of drilling method. It is important to describe obvious differences between the cores from the dry drilled PERM cores away from the HD and the wet drilled MPBX and CHE cores near the HD. The two most notable differences between the PERM batch of cores and the HD batch are (1) the samples are less fractured or crumbled in the PERM cores, and (2) the core surfaces and core containers of PERM cores are relatively drier. We also noted that the rock surfaces in the AOD parallel to the HD are "crumblier" than the rock surfaces along the Connecting Drift. The rock walls inside HD are also fairly rough.

In addition to Figure 1 for saturation, other figures for porosity (Figure 2), bulk density (Figure 3), gravitational water content (Figure 5), and even particle density (Figure 4) strongly suggest that the rocks in the vicinity of DST HD are less competent than the rocks east of the test area. The competent rocks have more uniform properties and less spatial variability or heterogeneity. The crumblier rocks have more heterogeneous variations with porous packets interlaced with highly fractured rock blocks.

Comparison of DST Properties with SHT Properties

The Single Heater Test (SHT) area is well characterized, with small discrete fractures controlling short range flow and transport processes and long range fracture continuum behavior superposed over the discrete responses (Level 4 Milestone SP918M4, Forecast of Thermal-Hydrological Conditions and Air Injection Test Results of the Single Heater Test, December 1996). The core measurement of three holes are tabulated in Table 3. The boreholes in SHT are shorter than the DST boreholes. It is obvious from the summary at the end of Table 3 that the saturation values in SHT block are in the 95% range. The SHT boreholes were also wet drilled and the variability of rock properties are comparable in magnitude with the DST HD data set.

The graphic presentations of the SHT data set are given in Figures 6 to 10 for the five properties: saturation, porosity, bulk density, particle density, and gravitational water content, respectively. The spatial scales (x-axis) are kept the same as the one used in the DST graphs. With the SHT results mainly in the first 12 m, we also include previously reported data points based on two grab samples collected along the AOD (Level 4 Milestone OS327322D1 "Letter Report on Hydrological Characterization of the Single Heater Test Area in the ESF", August 1996). Although only five subsamples are tested, it is interesting to note that one of the subsamples have 81%

saturation while the other four subsamples are all above 94%, as shown in Table 4. For completeness, the average values over 5 subsamples are included in the end of Table 4.

Conclusions and Recommendations

As noted in Milestone OS327322D1, the average saturation value compiled from all surface-based boreholes for Topopah Spring crystal poor middle nonlithophysal tuff (TMN, 266 samples) is 85 ± 12% (L. E. Flint, USGS, Matrix Properties of Hydrogeologic Units at Yucca Mountain, Nevada, U. S. Geological Survey Open-File Report, MOL.19970324.0046, GS950308312231.002 (Q), U. S. Geological Survey, Denver, CO, 1996). In this report, the average value for the dry drilled DST PERM cores is 84% and the wet drilled DST HD value is 93%. The corresponding surface-based borehole porosity value is 11 ± 2%, as compared to the average values from 11% for dry cores to 13% for wet cores.

Therefore, the 10% difference in liquid saturation between the dry drilled and the wet drilled data sets in the thermal test area is within the standard deviation of 12% for all the surface based samples. From an optimistic viewpoint, the core study reported here confirms our site wide understanding of the Topopah Spring welded tuff saturation variation.

On the other hand, for the Drift Scale Test with complex multiphase processes confined to within a few meters around the heated drift, it is important to quantify the amount of pore water available for boiling that controls the vapor transport and heat transfer processes in the near field. The finding in this report that the saturation in DST rocks differ by 10% due in part to different drilling methods may be worrisome.

Since boreholes are still being drilled in the DST area, we recommend to make one change in the DST drilling plan and use the dry drilling method for one of the remaining planned boreholes from the AOD or from HD to collect one set of dry drilled cores in the immediate vicinity of the DST HD. An analysis of these cores may provide better understanding in liquid saturation difference reported here is purely due to drilling method-related effect or if the saturation variation depends sensitively on the local rock condition.

Data Status and Quality Assurance

All the measurement and analysis in this study were performed by qualified personnel and the equipment used to obtain them was calibrated under the LBNL QA program. All data presented are to be considered qualified data.

Acknowledgment:

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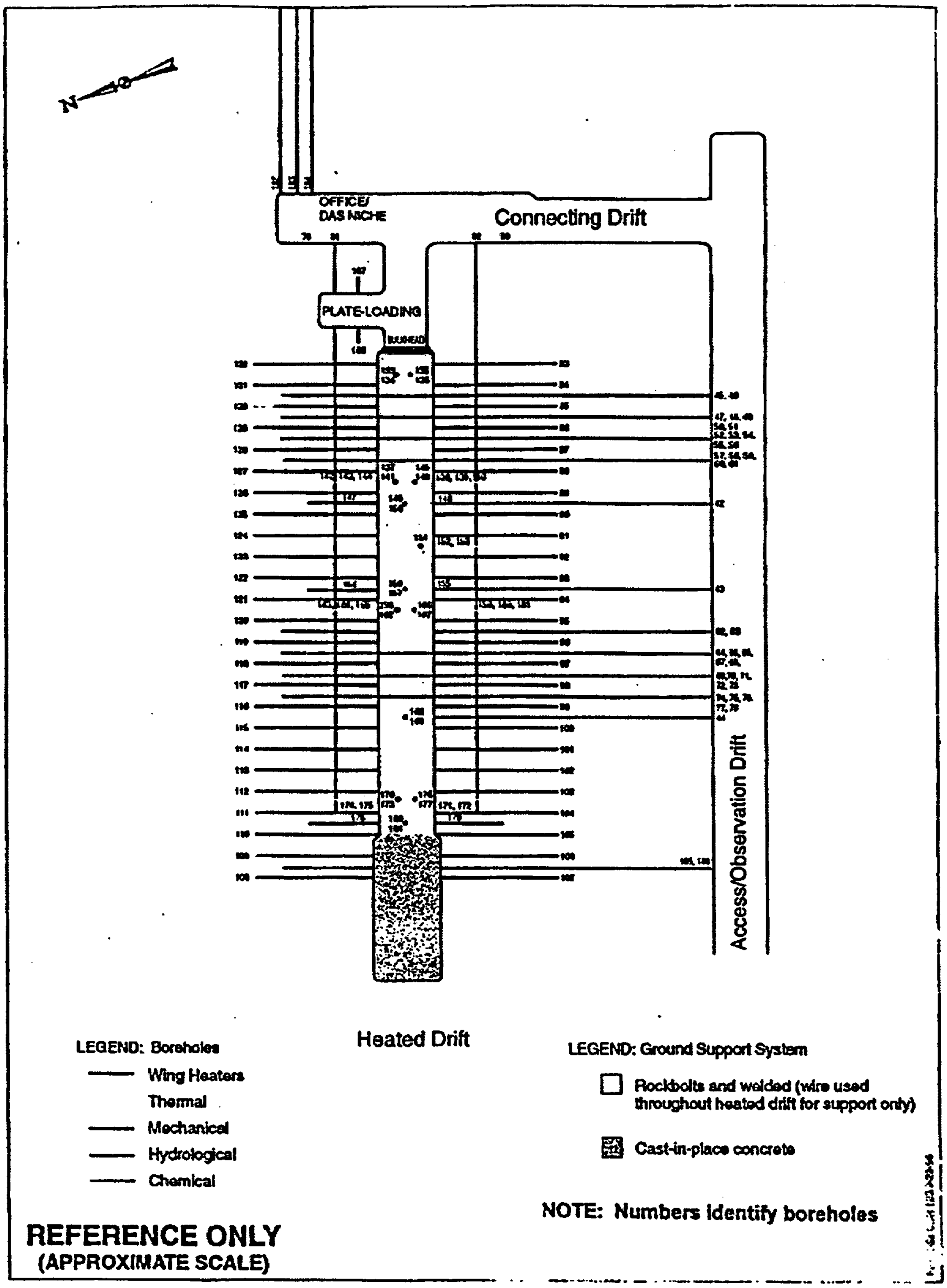


MAP 1: Layout of the Drift Scale Test Area

Table 1. Laboratory Measurement of Dry Drilled Cores from Permeability Holes of the Drift Scale Test Area

Borehole #182, ESF-HD-PERM-1					
sample location (m)	saturation (%)	porosity (%)	bulk density (g/cc)	particle density (g/cc)	gravimetric water content (g/g)
5.5	86.67	9.61	2.27	2.51	0.037
9.9	89.67	11.02	2.24	2.52	0.044
15.5	85.08	10.27	2.25	2.51	0.039
19.8	86.72	10.27	2.25	2.51	0.039

Borehole #183, ESF-HD-PERM-2					
sample location (m)	saturation (%)	porosity (%)	bulk density (g/cc)	particle density (g/cc)	gravimetric water content (g/g)
5.2	83.84	9.62	2.27	2.51	0.035
10.1	82.86	12.02	2.21	2.51	0.045
15.3	76.61	13.35	2.19	2.53	0.046
19.9	79.21	10.89	2.24	2.51	0.038

Borehole #184, ESF-HD-PERM-3					
sample location (m)	saturation (%)	porosity (%)	bulk density (g/cc)	particle density (g/cc)	gravimetric water content (g/g)
5.1	81.40	9.87	2.25	2.50	0.035
10.0	86.61	10.91	2.24	2.51	0.042
15.5	85.80	9.43	2.27	2.51	0.035
18.9	81.76	10.17	2.26	2.52	0.037

DST PERM Borehole Summary

	saturation (%)	porosity (%)	bulk density (g/cc)	particle density (g/cc)	gravimetric water content (g/g)
DST PERM average:	**83.85**	**10.62**	**2.25**	**2.51**	**0.039**
standard deviation	3.67	1.14	0.02	0.01	0.004

Table 2. Laboratory Measurement of Wet Drilled Cores from Holes Around Heated Drift of the Drift Scale Test Area

Borehole #81, ESF-HD-MPBX-1					
sample location (m)	saturation (%)	porosity (%)	bulk density (g/cc)	particle density (g/cc)	gravimetric water content (g/g)
4.6#	96.43	10.15	2.25	2.50	0.043
6.8	84.97	9.73	2.27	2.51	0.036
12.3**	96.02	10.16	2.26	2.52	0.043
17.8##	96.80	9.46	2.26	2.49	0.040
20.8*	103.77	15.34	2.14	2.53	0.073
24.1	94.10	8.77	2.28	2.50	0.036
32.0	95.42	9.67	2.28	2.52	0.040
35.1^	92.97	11.81	2.21	2.51	0.050
39.4	92.82	10.31	2.26	2.52	0.042
45.3	94.57	9.27	2.28	2.51	0.038

* two open fractures + "crushed zone" + porous looking calcite inclusion
# entire surface of core was wet
^ large open fracture down center of upper half
** closed vertical fracture along core axis
two fractures with small aperture

Borehole #52, ESF-HD-CHE-1					
sample location (m)	saturation (%)	porosity (%)	bulk density (g/cc)	particle density (g/cc)	gravimetric water content (g/g)
15.3^	87.56	11.73	2.22	2.52	0.046
18#	95.91	17.32	2.09	2.52	0.079
26.5^	87.89	11.04	2.24	2.51	0.043
29.9*	97.32	13.98	2.16	2.51	0.063
35.0	96.98	18.19	2.07	2.53	0.085
38.2**	98.58	16.57	2.11	2.53	0.077

* contains large open vug on side surface
# large fracture exposed on surface
^ water drop loss during transfer
** contains fracture on side surface

Borehole #53, ESF-HD-CHE-2					
sample location (m)	saturation (%)	porosity (%)	bulk density (g/cc)	particle density (g/cc)	gravimetric water content (g/g)
10.7#	95.31	11.67	2.22	2.51	0.050
16.7#	96.84	12.94	2.19	2.51	0.057
22.2	94.96	11.52	2.22	2.51	0.049
28.2*	74.03	15.62	2.11	2.50	0.055
36.5*	95.47	12.80	2.21	2.53	0.055

* large amount of water condensed in container

\# contains fracture on side surface

Borehole #56, ESF-HD-CHE-5					
sample location (m)	saturation (%)	porosity (%)	bulk density (g/cc)	particle density (g/cc)	gravimetric water content (g/g)
10.6	94.99	14.57	2.15	2.52	0.064
18.0*	94.34	12.33	2.20	2.51	0.053
23.2	95.58	16.02	2.11	2.51	0.072
29.6	92.79	15.91	2.14	2.54	0.069
35.7	86.21	11.65	2.21	2.51	0.045
38.9	82.40	10.09	2.25	2.51	0.037

* contains fracture on side surface

DST HD Borehole Summary

	saturation (%)	porosity (%)	bulk density (g/cc)	particle density (g/cc)	gravimetric water content (g/g)
DST HD average:	**93.15**	**12.54**	**2.20**	**2.51**	**0.053**
standard deviation	5.93	2.75	0.06	0.01	0.015

Fig. 1 DST Saturation

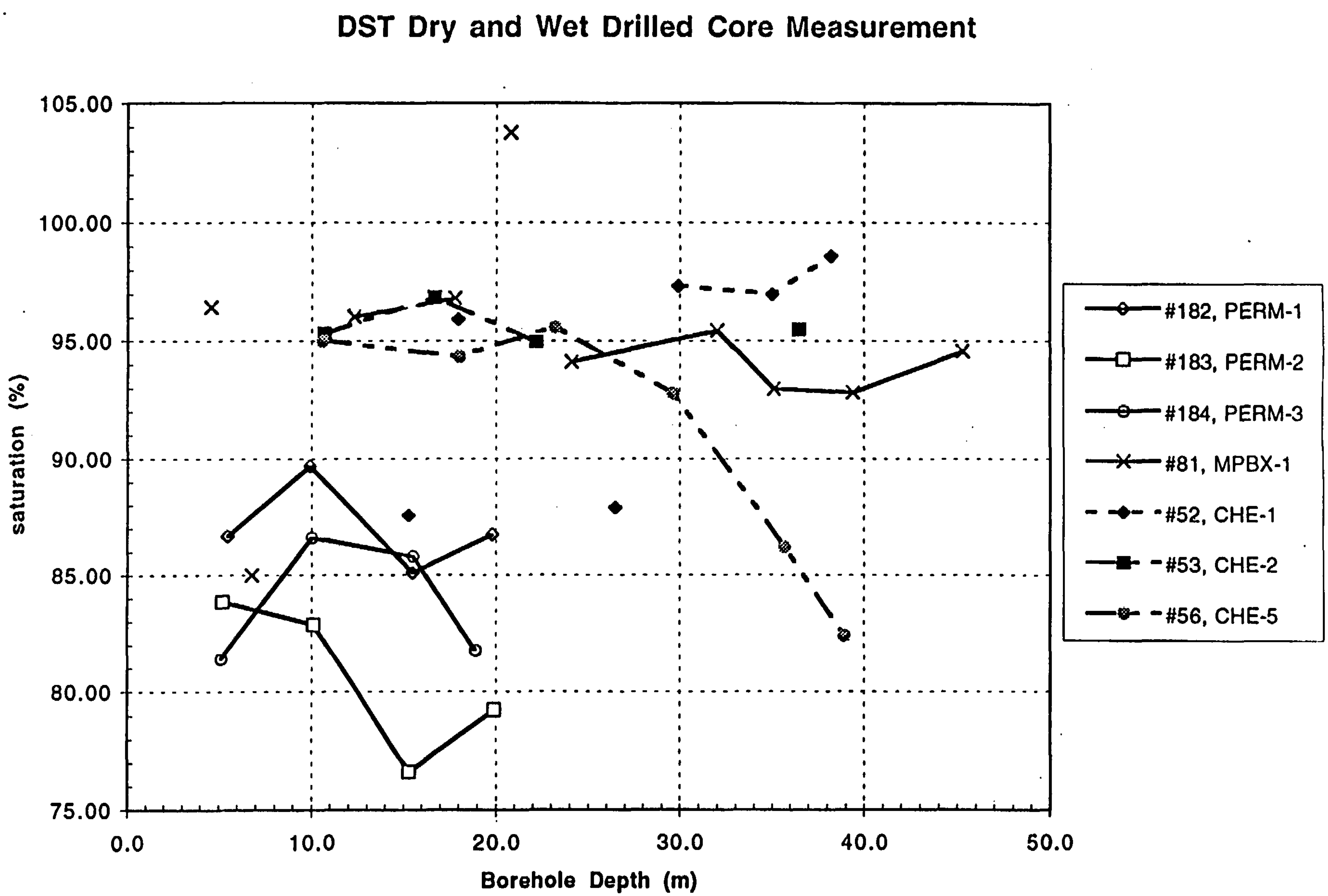


Fig. 2 DST Porosity

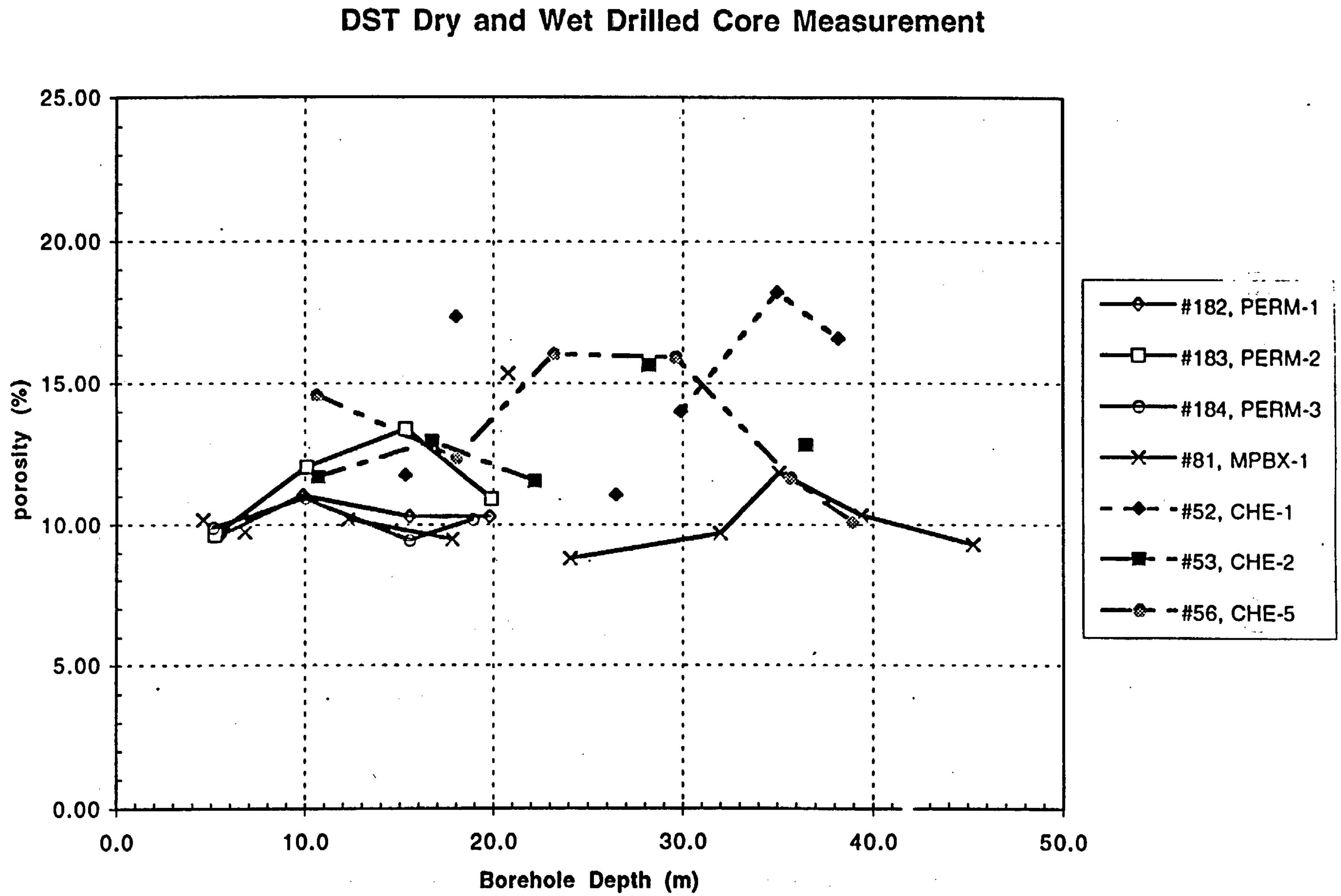


Fig. 3 DST Bulk Density

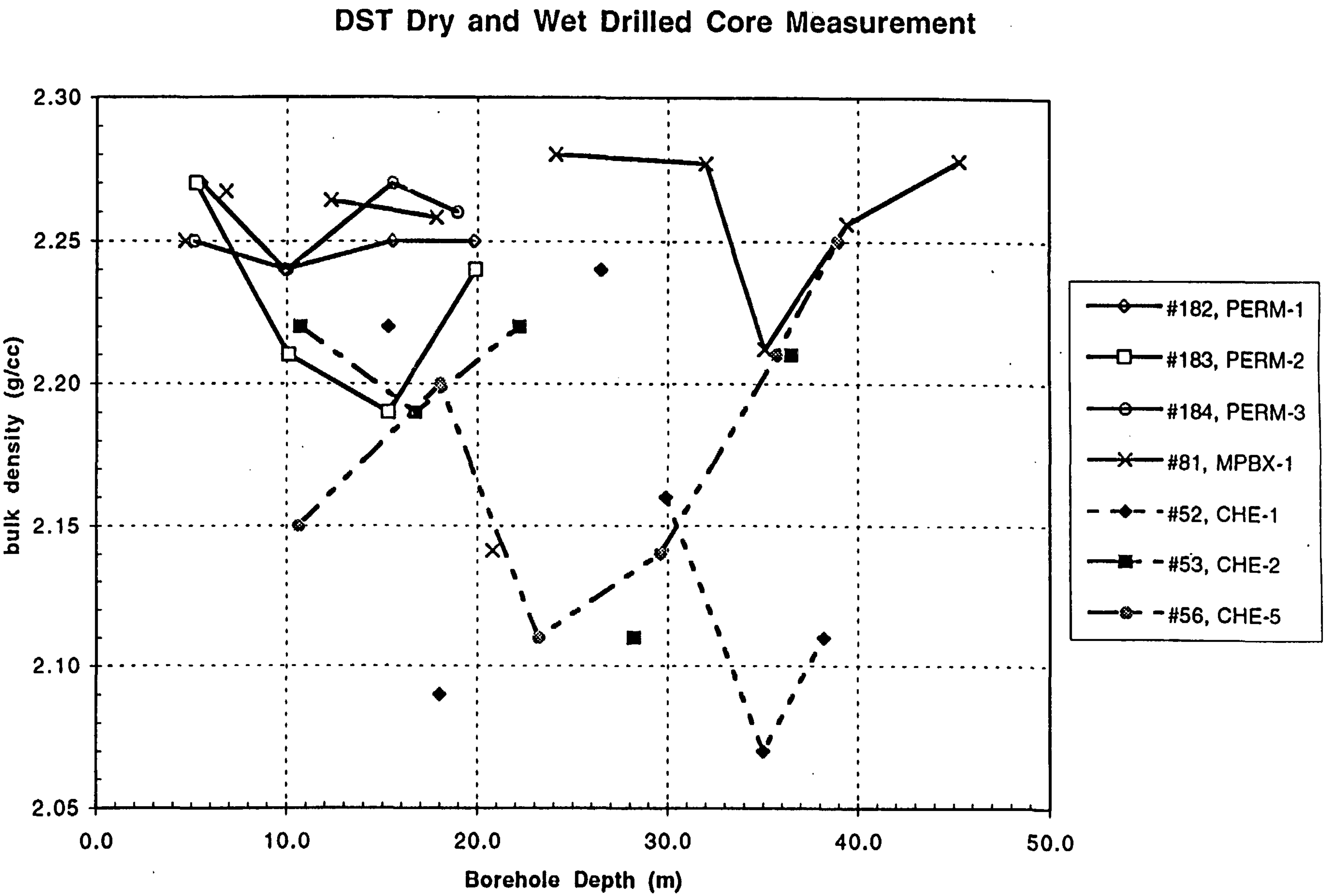


Fig. 4 DST Particle Density

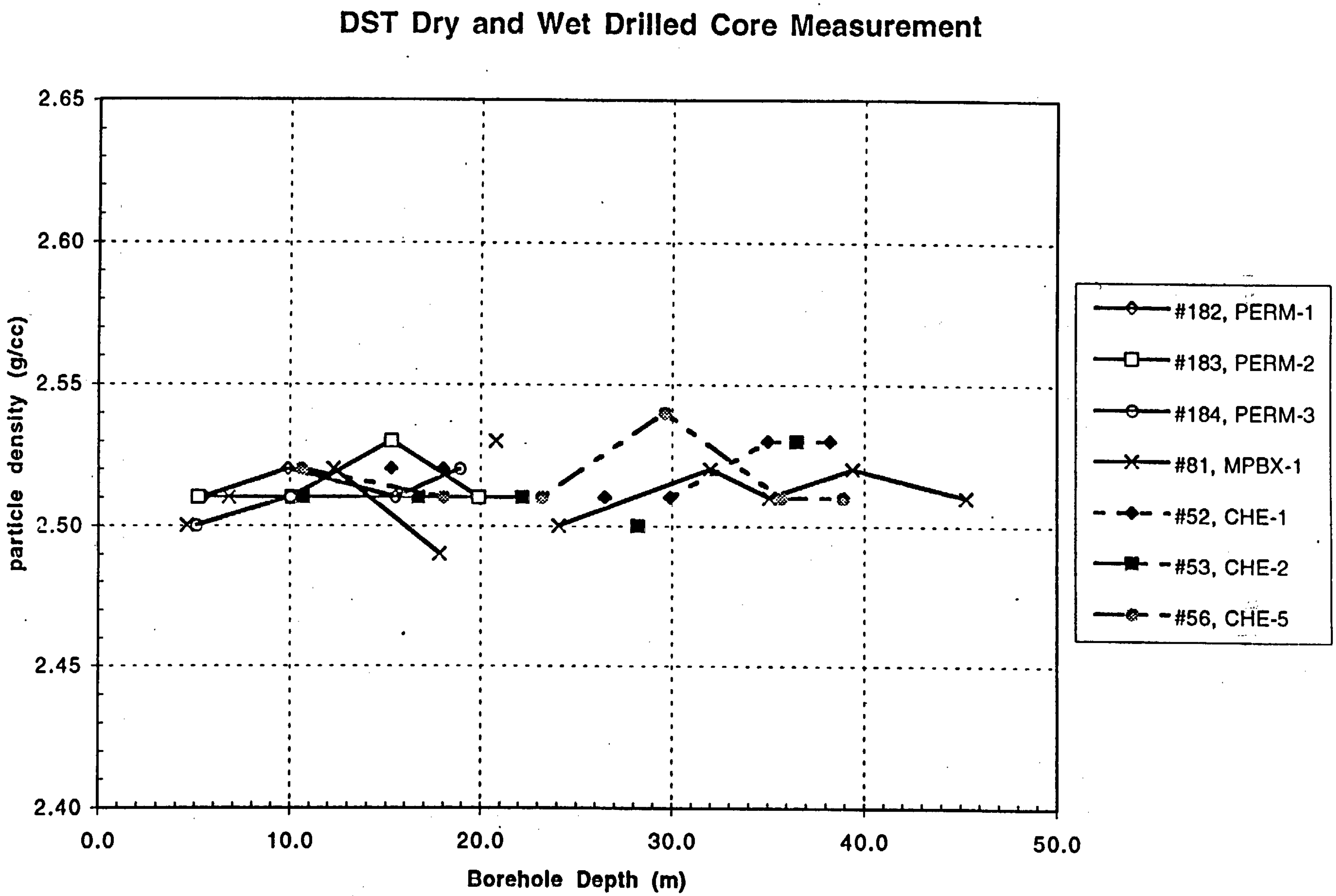


Fig. 5 DST Grav. Water Content

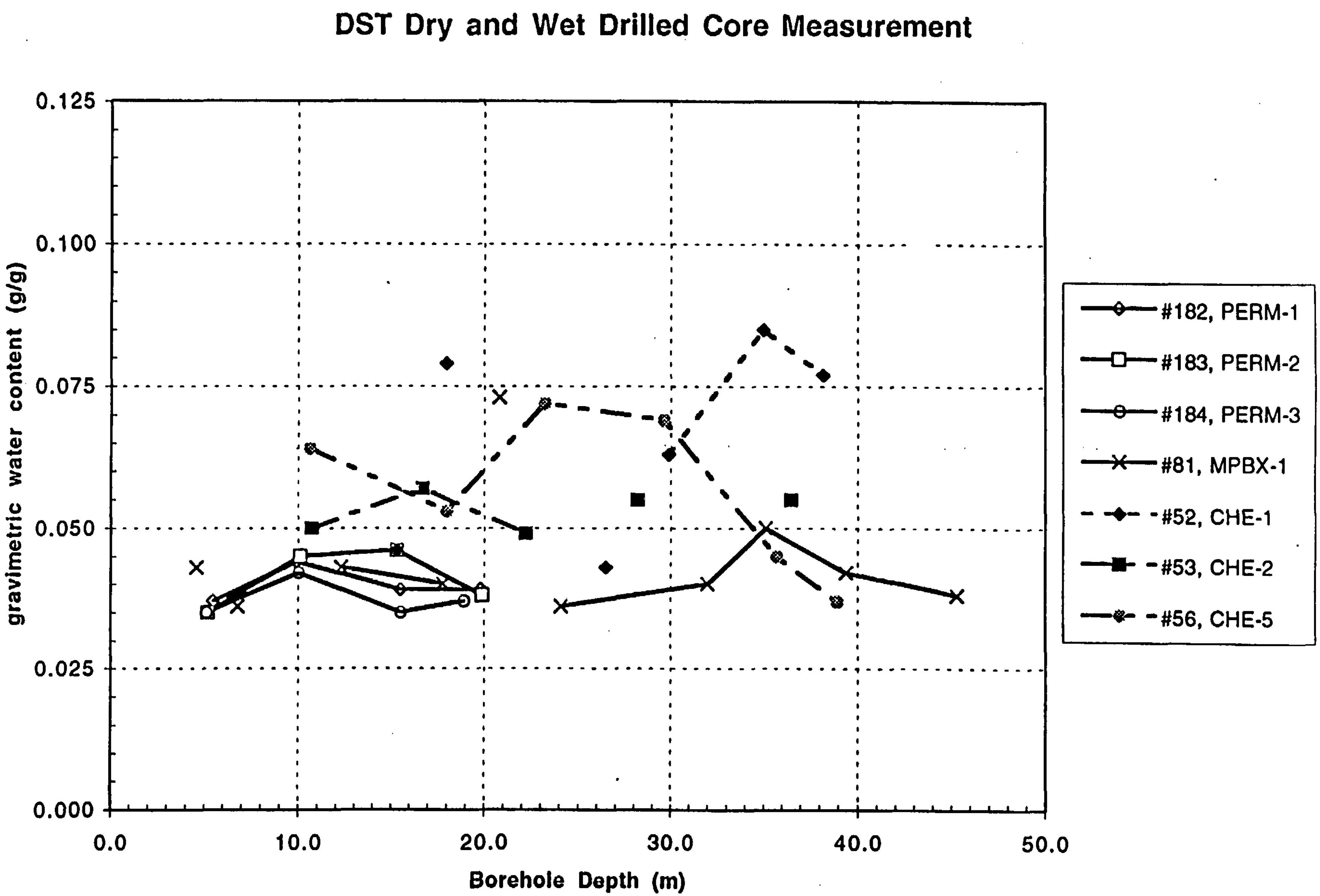


Table 3. Laboratory Measurement of Wet Drilled Cores from Holes in the Single Heater Test Area

Borehole #1, ESF-TMA-H1					
sample location (m)	saturation (%)	porosity (%)	bulk density (g/cc)	particle density (g/cc)	gravimetric water content (g/g)
1.0	89.46	10.66	2.25	2.51	0.043
2.5*	88.04	13.30	2.18	2.52	0.054
3.7	93.60	8.87	2.29	2.52	0.036
4.7	97.27	11.83	2.22	2.51	0.051
5.7	93.97	13.83	2.16	2.51	0.061
6.7	96.03	11.89	2.21	2.51	0.052

* contains small voids

Borehole #6, ESF-TMA-OMPBX-1					
sample location (m)	saturation (%)	porosity (%)	bulk density (g/cc)	particle density (g/cc)	gravimetric water content (g/g)
0.2	94.82	11.00	2.24	2.51	0.047
2.4	94.75	10.43	2.25	2.51	0.044
4.4	93.58	10.18	2.26	2.51	0.042
7.5*	96.87	23.62	1.96	2.57	0.104
subcore		20.44	2.02	2.53	
9.3	96.17	11.55	2.22	2.52	0.050
11.3	93.07	9.74	2.27	2.51	0.040

* split along axis during oven drying

Borehole #5, ESF-TMA-MPBX-4					
sample location (m)	saturation (%)	porosity (%)	bulk density (g/cc)	particle density (g/cc)	gravimetric water content (g/g)
0.7*	95.85	17.03	2.05	2.48	0.079
2.1*	101.61	9.69	2.25	2.49	0.044
2.6#	102.17	13.33	2.17	2.50	0.063
3.8#	96.74	10.58	2.24	2.50	0.046
subcore		10.44	2.24	2.50	
5.4	97.65	9.60	2.27	2.51	0.040

* contains open fractures and large vugs.
# received in fragments

SHT Borehole Summary

	saturation (%)	porosity (%)	bulk density (g/cc)	particle density (g/cc)	gravimetric water content (g/g)
SHT average:	**95.39**	**12.53**	**2.20**	**2.51**	**0.053**
standard deviation	3.56	3.89	0.09	0.02	0.017

Table 4. Laboratory Measurement of Grab Samples from Wet Excavation of the Access/Observation Drift of the Thermal Test Facility

AOD Grab Samples					
CS location (m)	saturation (%)	porosity (%)	bulk density (g/cc)	particle density (g/cc)	gravimetric water content (g/g)
30.0	99.00	8.60	2.26	2.47	0.038
sub-sample	94.90	8.30	2.27	2.47	0.035
40.0	95.40	9.30	2.27	2.50	0.039
sub-sample	93.80	10.10	2.24	2.49	0.042
sub-sample	80.50	10.40	2.24	2.50	0.037

AOD Grab Sample Summary

	saturation (%)	porosity (%)	bulk density (g/cc)	particle density (g/cc)	gravimetric water content (g/g)
AOD average:	**92.72**	**9.34**	**2.26**	**2.49**	**0.038**
standard deviation:	7.10	0.91	0.02	0.02	0.003

Fig. 6 SHT Saturation

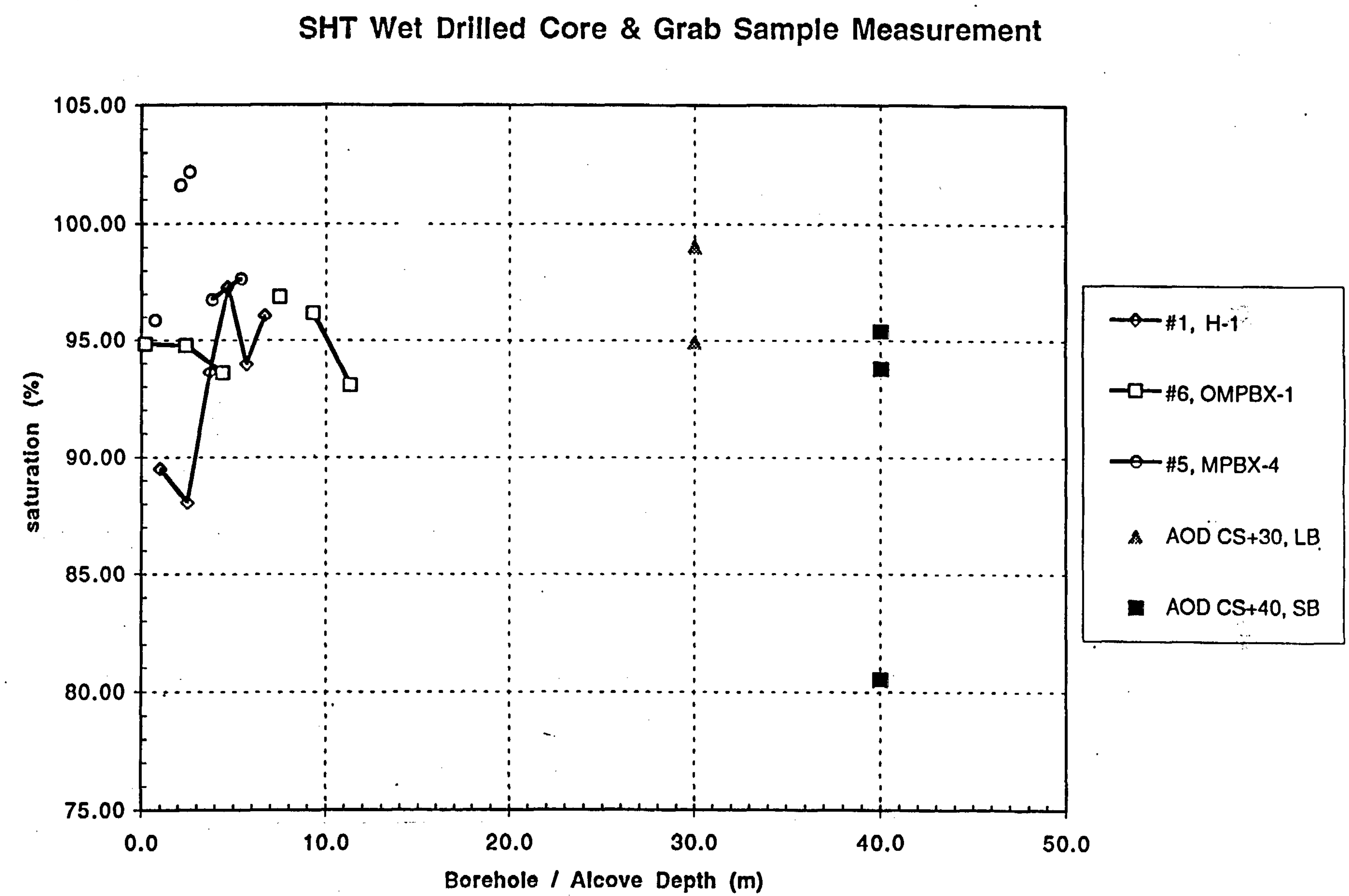


Fig. 7 SHT Porosity

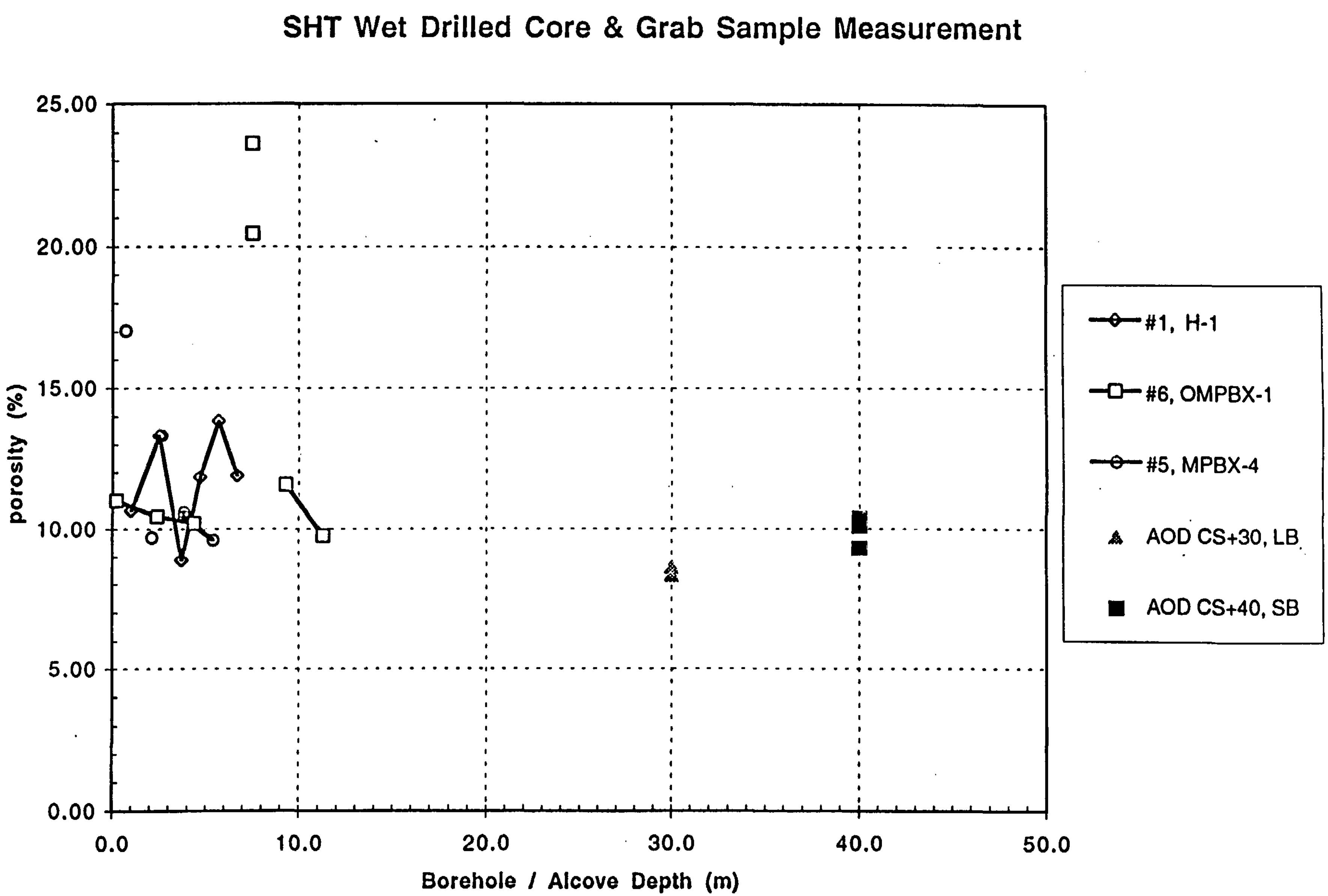


Fig. 8 SHT Bulk Density

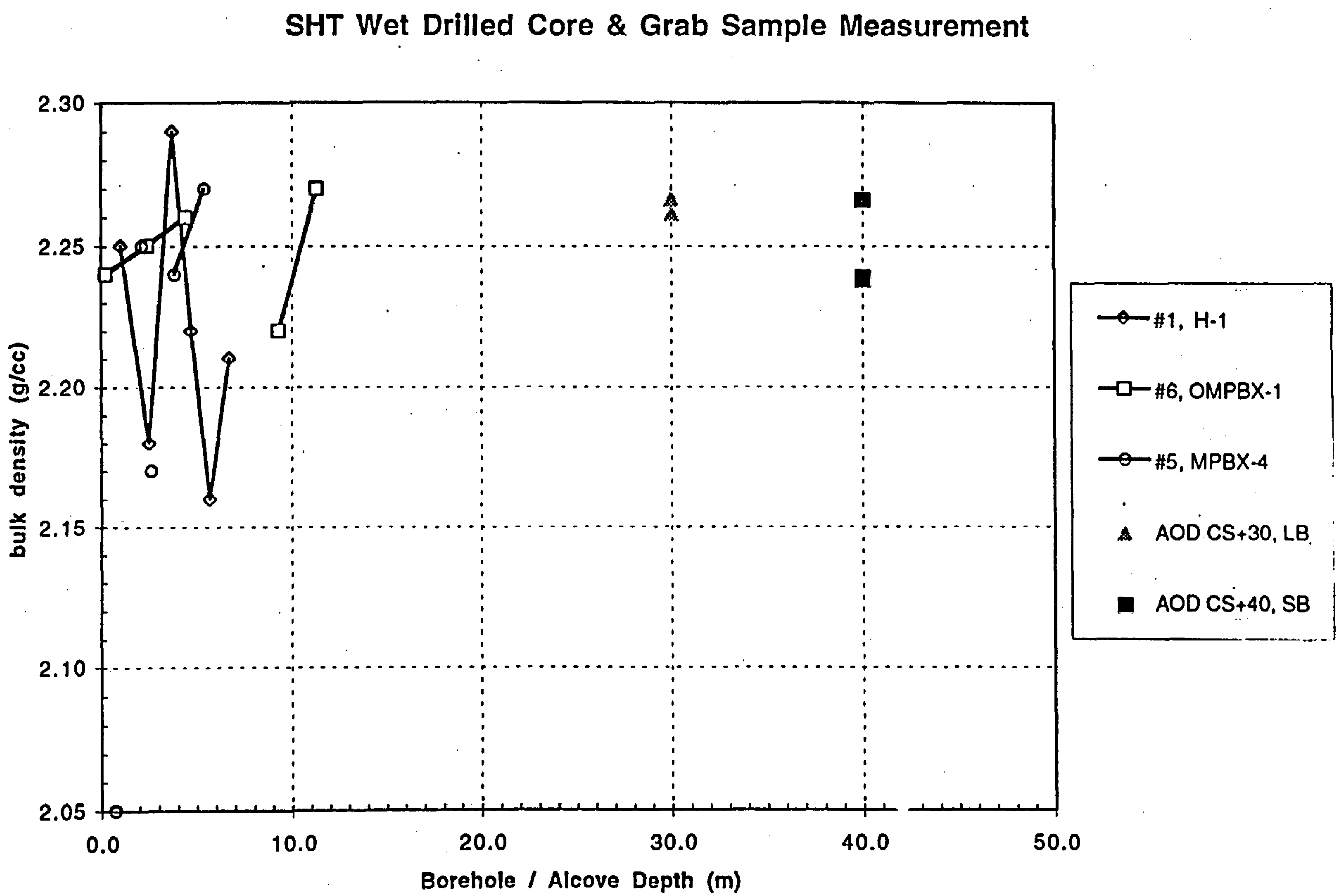


Fig. 9 SHT Particle Density

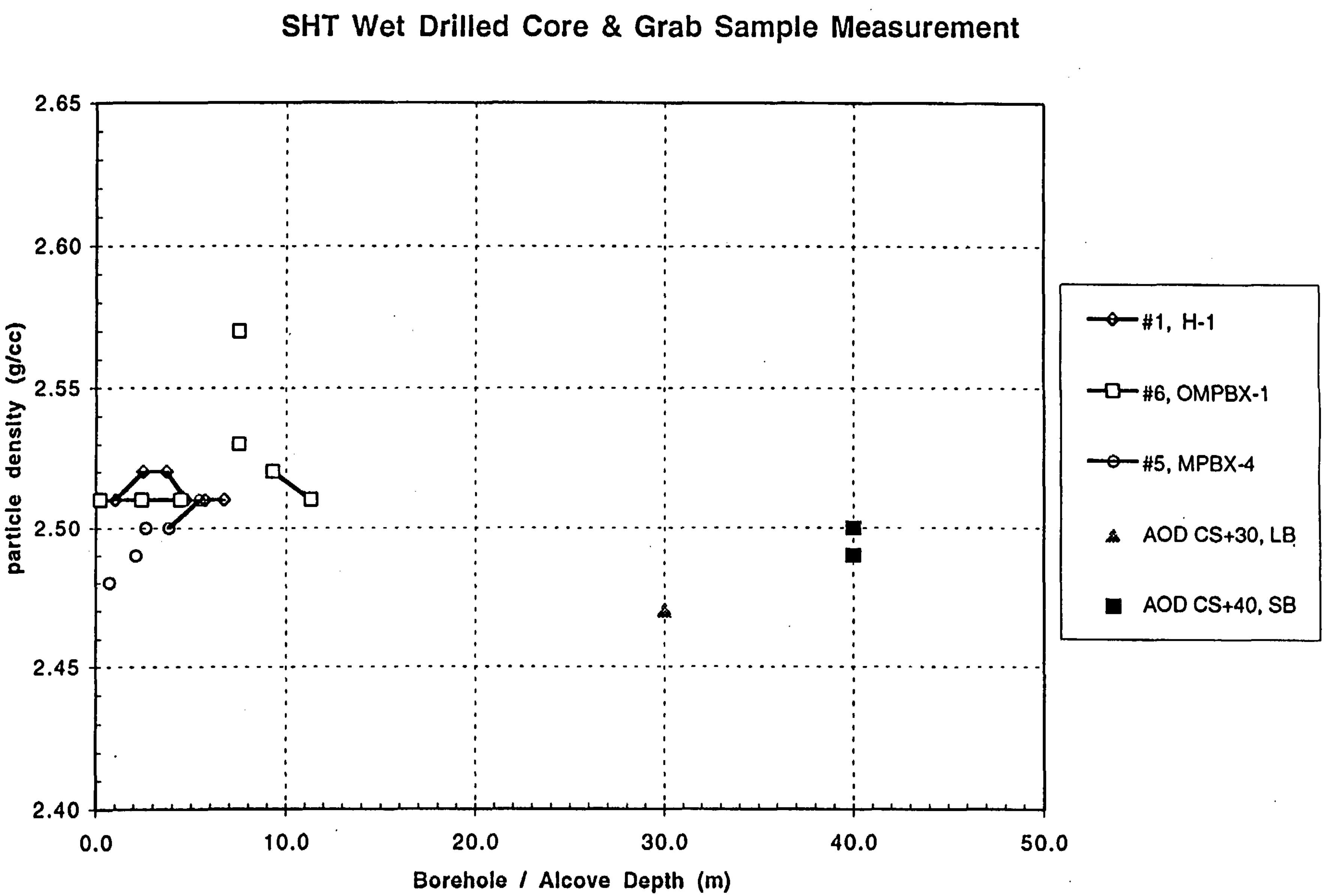
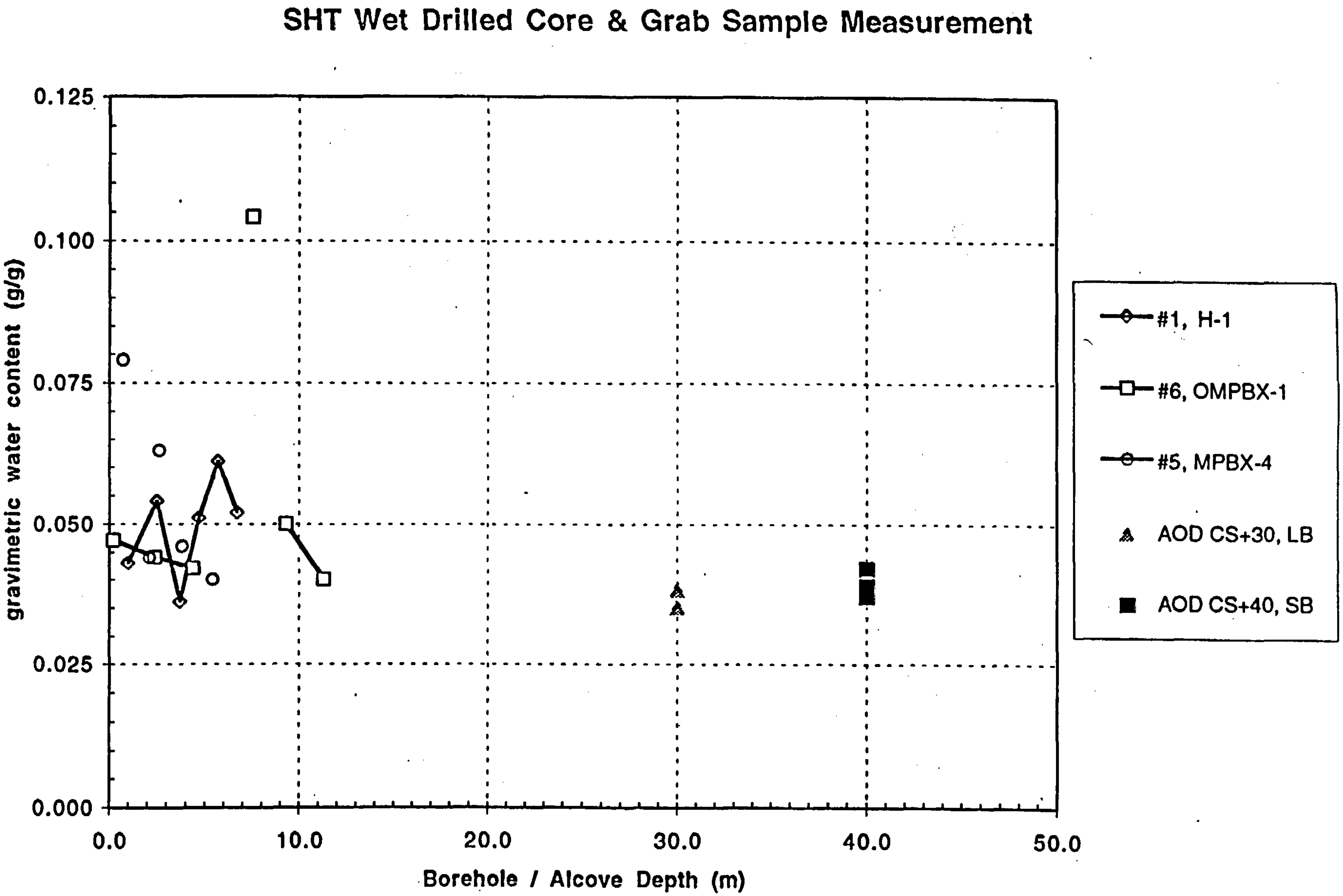


Fig.10 SHT Grav. Water Content



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