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Soil Impact Attenuation Performance: A Field Study

William B. Beine
John R. Sorrells

Product Safety Technology Division
Center for Consumer Product Technology
National Engineering Laboratory
National Bureau of Standards
U.S. Department of Commerce
Washington, D.C. 20234

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Final

Prepared for

Consumer Product Safety Commission
5401 Westbard Avenue
Bethesda, MD 20016

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U.S. DEPARTMENT OF COMMERCE, Philip M. Klutznick, *Secretary*
Luther H. Hodges, Jr., *Deputy Secretary*
Jordan J. Baruch, *Assistant Secretary for Productivity, Technology, and Innovation*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

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Soil Impact Attenuation Performance: A Field Study

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I. INTRODUCTION

Background

Recently the Center for Consumer Product Technology of the National Bureau of Standards (NBS) completed a laboratory investigation of the impact attenuation performance of playground surfacing materials.* Specifically, the objectives of that research were (1) to develop a methodology for assessing the impact attenuation performance of surfaces in relation to head injury, and (2) to test surfacing materials commonly installed under playground equipment to determine which surfacing materials, if any, are capable of providing reasonable protection against head injury. Eleven surfacing materials were tested in that study. However, soil, because of its indefinite composition, was not included in the test.

More recently the Consumer Product Safety Commission (CPSC) requested that the NBS conduct a very limited field study of the impact attenuation capability of soil. This work began in late August of 1979 and is the subject of this report.

Purpose and Scope

The objective of this research is to provide the CPSC with an appraisal of the impact attenuation performance of different soils and asphalt. The scope of this investigation was limited to testing four soils and one asphalt surface at playground sites in the Washington, D.C., metropolitan area.

II. TEST METHOD AND EQUIPMENT

There is a history of test method development for investigating the ability of various products to attenuate an impact, especially in protective headgear research. All of the recent test methods require dropping an instrumented headform in guided free fall and measuring the linear acceleration of the headform during impact. This was the method used in the earlier laboratory testing of playground surfacing materials and in this study of soil and asphalt.

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*This effort was funded by the Consumer Product Safety Commission. Documentation of that study can be found in the report, "Impact Attenuation Performance of Surfaces Installed Under Playground Equipment," NBSIR 79-1707.

The equipment required by this test method consists of a headform to impact the test material, an accelerometer mounted at the center of gravity of the headform, a monorail to guide the headform as it falls, instrumentation to record and display the results of each test, and a velocity meter. Also, because these tests were conducted on playgrounds, a vehicle to transport the equipment, a mount to attach the monorail to the vehicle and hold the monorail stationary during tests, and an AC power source were required. The field test equipment is shown in figures 1 and 2.

To facilitate mobility, the length of the existing monorail was shortened to 9 feet. This permitted tests to be made from drop heights up to 8 feet. The monorail was attached to the vehicle by a mount which was fabricated specifically for this purpose. This mount supports the monorail during testing and incorporates provisions for aligning the monorail vertically. To stabilize the monorail-mount-vehicle system, two hydraulic jacks were employed beneath the frame of the vehicle on opposite sides of the monorail. The ANSI size "C" headform was used to impact the test surface.1/ The headform was equipped with a piezoelectric linear accelerometer to measure the acceleration imparted to the headform. The output of the accelerometer was channeled through a signal conditioner to a storage oscilloscope and a Severity Index (SI) analyzer. The peak acceleration produced by each impact was displayed on the SI analyzer and confirmed by the acceleration/time trace on the oscilloscope. Power to operate the instrumentation was obtained from a gasoline powered AC generator.

With the monorail test apparatus, the falling headform is not actually in free fall because of friction between the bearings of the headform carrier and monorail. Consequently, the equivalent free fall distance of the headform is less than the height of the headform at the time of its release. Determining the equivalent free fall distance of the headform is accomplished by measuring the velocity attained by the headform just prior to impact (using an optical velocity meter), and computing the equivalent free fall distance from the relation

$$h = \frac{v^2}{2g}$$

where

h = equivalent free fall distance,
v = velocity of the headform just prior to impact, and
g = gravitational constant (32.2 ft/sec^2).

In the sections that follow, it is the equivalent or computed drop height which is used.

Playground and Test Site Selection

The selection of playgrounds was guided by three criteria. The playgrounds would:

1. be within the Washington, D.C., metropolitan area,
2. have different soil characteristics, and
3. be accessible to the test equipment.

While there are hundreds of playgrounds in the metropolitan area, the limited resources of this project precluded an exhaustive search for soils having a broad range of characteristics. Furthermore, the urgency to initiate testing precluded coordinating and scheduling activities with several local park authorities. Because of these constraints and the fact that there is a sizeable acreage of park land in Montgomery County, the Montgomery County Parks Director's office of the Maryland-National Capitol Park and Planning Commission (M-NCPPC) was contacted. Subsequently, the M-NCPPC gave approval to conduct tests on county park land and provided assistance in selecting candidate test sites.*

Fourteen playgrounds were screened as likely candidates for this study. These sites were visited by the NBS project staff and representatives from AMBRIC Testing and Engineering Associates of Virginia, Inc. (AMBRIC),** the Consumer Product Safety Commission, and the M-NCPPC. This tour resulted in the final selection of five playgrounds--four playgrounds for impact performance testing of soil and one for testing asphalt. Hereafter, these test sites are referred to as playgrounds 1, 2, 3, 4, and the asphalt surface.

III. TEST PROCEDURES

Soil Impact Performance Tests

Two series of soil impact performance tests were conducted on each of the four playgrounds. This was specified in the study design to enable testing the same soils at different levels of moisture content. The first series was conducted on September 17th and 18th, following a relatively dry period of weather, and the second series was completed on October 4th, 1979, following a rainy period. Consequently, eight sets of tests were conducted (four playgrounds at two different times).

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*For this assistance the authors express their thanks to W. Colpitts, Deputy Director of Parks, and members of his staff.

**Because of the wide variation in soil characteristics and the expertise and equipment required to analyze and classify soils, AMBRIC Testing and Engineering Associates of Virginia, Inc. were contracted to ensure that the selection of sites satisfied the second criterion and to perform subsequent soil analyses.

The same test procedures were used for each of the eight sets of tests. Each set of tests consisted of six drops: two drops at a low height (approximately 3 feet); two drops at an intermediate height (approximately 5.5 feet), and two drops at a high height (approximately 8 feet).

The surface area impacted in each test was selected from within a narrow circular band between 6 and 12 inches beyond the perimeter of the merry-go-round located on each playground. This region was well suited for these tests because it offered a surface which receives uniform and relatively heavy use, it was easily accessible, and was large enough to provide 12 well spaced and distinct impact sites (6 sites for each series).

Generally, on almost all playgrounds in the Montgomery County Park system, the surface beneath and around play equipment is covered with a layer of finely crushed rock or organic material. With use, this material gradually is dispersed. The thickness of the material remaining in the four impact regions was usually between 0.5 and 1.5 inches. At each impact site, this layer of loose material was removed to expose the underlying surface prior to each drop. The exposed surface of the soil was then carefully leveled and examined for extraneous material (e.g., stones or tree roots) embedded in the surface. If such contamination was present, a different impact site was prepared. The vehicle/monorail test apparatus was then positioned so that the headform would impact the prepared surface. The hydraulic jacks were placed beneath the frame of the vehicle and adjusted, the monorail was plumbed, the velocity gauge was adjusted, and the release height of the headform was set. Finally, the headform was dropped onto the surface and the peak acceleration and velocity at impact were recorded. For the first series of tests, the specific location of each impact site was also recorded. This enabled these sites to be excluded from the second test series, thus avoiding impacting a previously tested site.

Density-Moisture Content

At the time the impact tests were performed, the in-place soil density and moisture content were measured with a nuclear test meter. Two measurements* of density and moisture content were obtained at each playground for each series of tests. These measurements were performed by AMBRIC Engineering in accordance with accepted ASTM practice.

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*Only one measurement was obtained for playgrounds 3 and 4 during the first series.

Soil Classification Test Procedures

A sample of soil from each of the four playgrounds was collected from the impact region and subsequently analyzed by AMBRIC Engineering at their laboratory facilities. The purpose of that analysis was to identify the soil type at each playground. Each sample was subjected to (1) a particle size analysis to determine the distribution of the particle size of each soil, (2) tests to determine the relationship between moisture content and density (standard Proctor test) of each soil, and (3) tests to determine the liquid and plastic limits of the soils. All of these tests were performed in accordance with accepted ASTM practices.

Asphalt Impact Performance Tests

The test procedures to determine the impact performance of asphalt were basically the same as those used for soils. Notable differences in the procedures were that asphalt was tested in only the first series and, because of the high peak accelerations obtained, the headform release height was limited to six inches. Tests were performed at three sites on the asphalt surface, which was part of a basketball court. This asphalt was estimated by park officials to be approximately 6 inches thick and composed of an ordinary "hot mix" material whose largest stone size was less than 3/8 inch in diameter.

IV. TEST RESULTS AND DISCUSSION

Before reviewing the data, it must be remembered that the scope of this study was extremely limited. The indefinite and complex character of soils, the inability to control important study variables, such as moisture, density, and composition, in conjunction with the limited number of test locations, confounds the picture that the data might imply. Consequently, while we have attempted to point out and explain differences and to generalize our observations, much of the following discussion is more descriptive than inferential.

Soil Analyses

Tables 1 and 2 and figure 3 show the results of the soil analysis performed by AMBRIC. The complete reports prepared by AMBRIC are included in Appendix A.

Soil deposits consist of solid soil particles, void spaces, and water that may exist in the void spaces surrounding the particles. The solid particles are basically disintegrated rock of varying size and shape. In this study soils were classified by the Unified Soil Classification System (ASTM D2487-69) in which soil classification is primarily related to particle-size distribution and plasticity.*

In the Unified Soil Classification System, there are four major divisions of soil types--gravel, sand, silt, and clay. These divisions are further subdivided into 14 categories. (See Appendix B.) Descriptions of the soil types tested in this study are shown in table 1.

The predominant soil type at the test sites was either a silt or a sand; however, the soils generally contained quantities of other soil types as indicated by their description. For example, a clayey, sandy silt indicates a mixture of clay and sand with the predominant soil type, silt.

Table 1. Classification of Soils

Playground	Soil Classification Designation	Description
1	ML	Silt
2	ML-CL	Gravelly Clayey Silt
3	SM-SC	Clayey Sandy Silt
4	SM	Micaceous Silty Clayey Sand

As shown by figure 3, the soils all contained a large percentage by weight of small or fine grained particles. At least 80 percent of the total weight of each soil sample consisted of particles less than .066 inch in diameter.

The differences in the particle-size distribution between the four test sites are difficult to characterize. For example, playground 4 had the lowest percentage of weight of particles less than .003 inch in diameter, but also less than 3 percent of its total weight was due to particles greater than .066 inch in diameter. Consequently, the difficulty in characterizing the

---

*Plasticity is a measure of the soil's ability to be remolded without raveling or breaking apart.

differences between the test sites, and the relatively large percentage of fine grained particles less than .003 inch in diameter, confounds any attempt to draw correlations between particle-size distribution and the impact attenuation performance of different soils.

The plasticity index of each soil sample was also determined for the purpose of classifying the soil. The plasticity of a soil is characterized by two measures--the plastic limit and the liquid limit. At a low water content a soil possesses the properties of a solid. As the moisture content of the soil increases, the soil acquires the properties of a semi-solid, then a plastic, and finally, a liquid. The plastic limit is the moisture content dividing the plastic and semi-solid state, and the liquid limit is the division between the plastic and liquid states. These limits are shown in table 2.

Table 2. Measures of Soil Plasticity

Playground	Plastic Limit	Liquid Limit	Plasticity Index
1	27	32	5
2	15	21	6
3	16	19	3
4	--	--	Non-plastic

The plasticity index is the numeric difference between the liquid and plastic limit. For three of the four soils tested, the plasticity index was very similar and very low, less than 6 (see also Appendix B). The soil of playground 4 was completely non-plastic.

In-place density and moisture content measurements were made at the time each of the eight sets of tests were performed. These measurements are shown in table 3.

Table 3. Density and Moisture Contents of the Four Soils at the Time of the Impact Performance Tests

Playground	Series 1				Series 2			
	Density		Moisture		Density		Moisture	
	(pcf)	Avg	(%)	Avg	(pcf)		(%)	
1	107.9 103.9	(105.9)	14.8 14.2	(14.5)	102.5 102.7	(102.6)	14.3 14.8	(14.6)
2	103.8 101.7	(102.8)	12.0 11.1	(11.6)	101.9 102.6	(102.3)	14.0 14.7	(14.4)
3	109.4	(109.4)	13.7	(13.7)	106.9 107.1	(107.0)	15.3 14.6	(15.0)
4	104.9	(104.9)	16.0	(16.0)	103.1 106.0	(104.6)	16.3 14.6	(15.5)
			Mean	(13.6)			Mean	(14.8)
			Std. Dev.	(1.7)			Std. Dev.	(0.7)

The in-place density (that is, the weight in pounds per cubic foot of the soil in its undisturbed condition) of playground 3 was the greatest, and perhaps playground 2 was the least dense. The greatest difference between any two density measurements, however, was less than 8 pounds per cubic foot.

The amounts of precipitation observed at the NBS prior to each test series was the major criterion for choosing the particular test dates. Indeed, the difference in accumulated precipitation just prior to each series was substantial, as indicated by the local climatological data collected by the National Weather Service. According to the Weather Service, no precipitation was recorded* during the ten days preceding the first test series. However, in the six days preceding the second test series, a total of 2.6 inches of precipitation fell in the area. Even though such a difference in precipitation was evident, only playground 2 and, to a lesser extent, playground 3 exhibited higher moisture contents for the second test series. In fact, the average of the two moisture content measurements obtained for playground 4 for the second test series was less than the moisture content measured in the first series and, yet, pools of water remained on the playground's surface at the time of the second test series.

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*These data are collected by the National Weather Service at Washington National Airport.

The increased precipitation prior to the second test series did raise the average moisture content for the four playgrounds (primarily due to the increases at playground 2 and playground 3) and also reduced moisture content differences between the four soils.

There are explanations for the unexpected low moisture level in the second test series. Basically, these involve characteristics of the soil that affect the drainage of water through the soil as well as across its surface. A discussion of this phenomenon, however, is beyond the scope of this study.

Impact Performance Data

The peak acceleration imparted to the test headform is the impact performance measure used in this study. These data are shown in figures 4 through 9. Figures 4 through 7 show the data for each playground and both test series. Data obtained from series 1 and 2 are depicted by the symbol 1 and 2, respectively. From an examination of the test data, it appears that the trend of the data can be approximated by the following equation:

$$\text{Peak Accel.} = C_1 \times \text{Drop Height} + C_2$$

where C_1 and C_2 are constants to be determined from the test data. This empirical relationship can be used to estimate the average peak acceleration for a particular drop height. Also, the earlier laboratory studies provide additional evidence to justify this linear relationship. Therefore, each of these figures includes the linear model obtained from a least squares fit of the data.

The data collected from playground 1 are shown in figure 4. Although the average peak accelerations differed for the two test series, this difference is probably not significant because the differential is only on the order of 15 g's. The average moisture contents and densities were also about the same for the two test series. None of the drop tests at this playground produced peak accelerations that exceeded the 200 g criterion. This level of acceleration has been proposed for use in evaluating the impact attenuation performance of playground surfacing materials.2/

Figure 5 shows the data collected from playground 2. The first test series produced significantly higher peak accelerations than obtained in the second series. The accelerations were consistently higher for corresponding drop heights and the average peak accelerations differed by 40 to 60 g's. While none of the accelerations from the second series exceeded the 200 g criterion, the soil conditions at the time of the first test produced peak accelerations of 200 g's at a drop height of approximately 5.5 feet. This difference may be explained, in part, by the soil's higher moisture content at the time of the second test series, which was 14.4 percent versus 11.6 percent for the first series. The effect that increased moisture in loose materials has on improving their ability to attenuate impacts was consistently demonstrated in the testing of sand and other loose materials in the laboratory.

Figure 6 shows the data collected from playground 3. As with playground 2, substantially higher peak accelerations were measured in the first test series. Although not as consistent, the differential exceeds 100 g's at the highest drop height. The average moisture content was also higher at the time of the second test series (15% versus 13.7%), but not to the extent that the moisture contents differed at playground 2. The 200 g criterion was exceeded at drop heights of approximately 4.5 feet and 8 feet for the first and second series data, respectively.

The soil conditions (moisture/density) of playground 4 were almost identical for both series of tests, as are the peak accelerations. Figure 7 shows these data. The differential in average peak accelerations does not exceed 10 g's. Drop heights above 6 feet produced average peak accelerations in excess of 200 g's.

Peak accelerations observed in each of the eight sets of tests (4 playgrounds, 2 series each) are shown collectively in figure 8. The data from each set of tests are uniquely numbered. The numbers 1, 2, 3, and 4 depict data from playground 1, 2, 3, and 4, respectively, for the first series, and the numbers 5, 6, 7, and 8 depict data from playgrounds 1, 2, 3, and 4, respectively, for the second series.

The peak accelerations obtained from playground 3 (first series) are clearly the highest. The density of that soil was also higher than that of any of the other soils. However, the soil density of playground 3 at the time of the second test series was also the highest for that series, yet peak accelerations obtained from that set (7) are lower than accelerations obtained from one of the less dense soils (2). Density alone, therefore, does not correlate well with peak acceleration.

Regarding moisture content, there is evidence to suggest that moisture has an effect on the impact attenuation performance of some soil types. It is worth noting again that the two soils having the least moisture, (2) and (3), produced relatively high peak accelerations. However, a relationship between moisture content and acceleration cannot be derived for these tests due to the absence of sufficient variability in the moisture contents of the four soils tested.

With regard to soil types, the absence of distinctive difference in the soils again masked possible differences in performance. For example, the soil of playground 3 was predominantly a silt, but also contained clay and sand components that were common to the other three soils.

Peak accelerations measured during tests on the asphalt surface are shown in table 4. Each of the three drops resulted in peak accelerations that exceeded 350 g's at a drop height of 0.43 foot.

Table 4. Impact Attenuation Performance of Asphalt

Peak Acceleration	Drop Height (ft)
1. 356	0.43
2. 394	0.43
3. 428	0.43

Comparison of Field and Laboratory Results

A comparison of field impact data to that obtained in the laboratory tests of surfacing materials is given in figure 9. In general, the soils impacted in this study produced peak accelerations which were greater than those produced by most loose materials, but considerably less than peak accelerations produced by asphalt, synthetic turf, and pea gravel. A perspective of test conditions must be maintained, however, when making these comparisons. The soils were tested in-situ, and, consequently, the test conditions (density, moisture, etc.) are those of a playground environment. The loose materials were tested in the laboratory and were not subjected to compaction, aging, or other conditions of playground exposure. Consequently, better performance should be expected from the materials tested in the laboratory. On the other hand, the soils were not tested over a full range of naturally occurring conditions. For example, the distinctive performance of playground 3 in the first test series appears to be related to its relatively low moisture content. For still lower levels of moisture, there is evidence that its ability to attenuate impacts would be further reduced. From the data collected in this study, it is not evident that the impact attenuation performance of a given soil would, under different conditions, approach the poor performance of pea gravel or asphalt.

V. SUMMARY

This study investigated the impact attenuation performance of playground soils and asphalt. These soils and asphalt were tested in-situ using a method of testing which was developed in an earlier laboratory study of playground surfacing materials. To facilitate mobility, the existing test apparatus was modified and mounted onto a vehicle. An engineering firm specializing in soil analyses was retained to assist in the selection of test locations, to conduct tests of the soils, and to classify the soils which were tested. Fourteen candidate sites were visited within the Montgomery County park system, and, subsequently, five playgrounds were selected--four for the purpose of testing soils and one for testing asphalt. The soils which were tested comprised four adjacent categories of the Unified Soil Classification System.

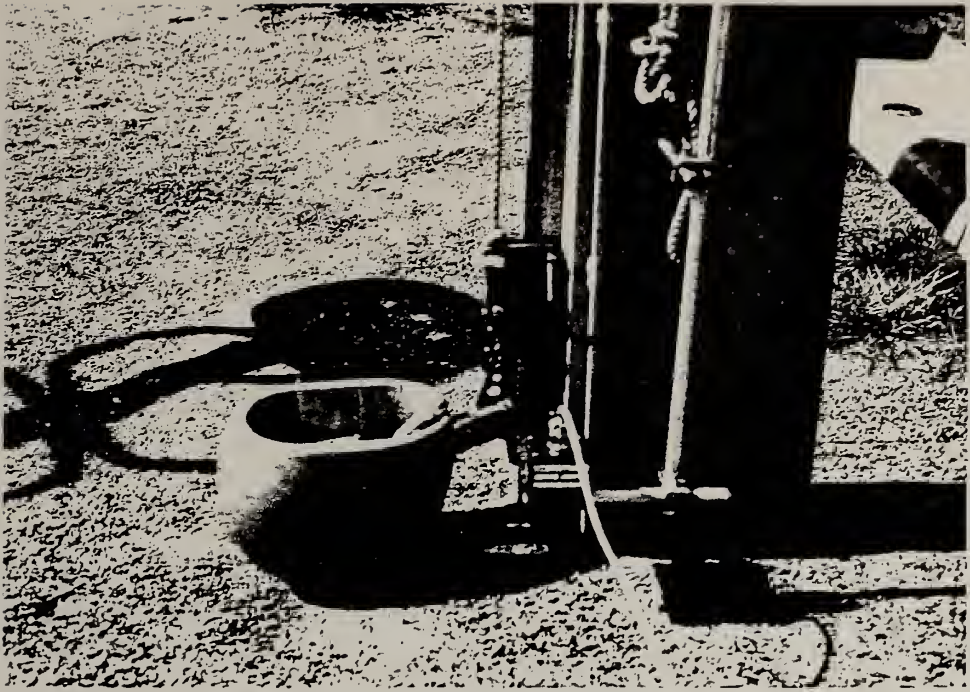
Two series of tests, the first series conducted in September and the second in October, provide the impact performance data. These data were analyzed to identify possible correlations between peak accelerations (the performance measure) and characteristics of the soil. Peak acceleration appears to be correlated with a soil's moisture content; other associations are not evidenced by the data. This is not surprising in view of the limited number of soils tested, the large number of variables that characterize a soil, and the confounding of these variables in the soils tested.

A comparison of the impact performances of soil and other surfacing materials was made. This comparison showed that the impact performances of these materials form three distinct groups. Asphalt, synthetic turf, and pea gravel are materials that do not attenuate an impact very well. Asphalt, which was tested in this study, was the worst performer, producing an average peak acceleration of 400 g's at a drop height of approximately 0.4 foot. In general, the soils tested produced lower peak accelerations, but not as low as most of the loose surfacing materials (6 inches in depth) which were tested in the laboratory. However, a perspective of test conditions must be maintained when making these comparisons. The soils were tested in-situ, but none of the loose materials were tested under conditions of a playground environment.

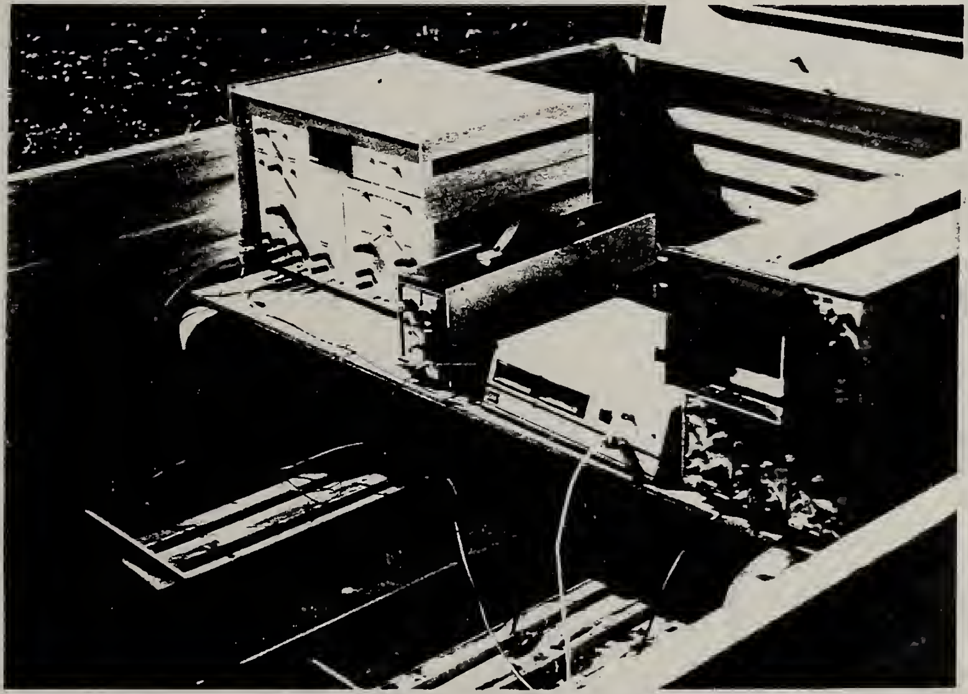
A. Monorail Support System

B. Typical Test Set-Up

FIGURE 1.



A. Headform and Carriage Assembly



B. Signal Processing Equipment

FIGURE 2.

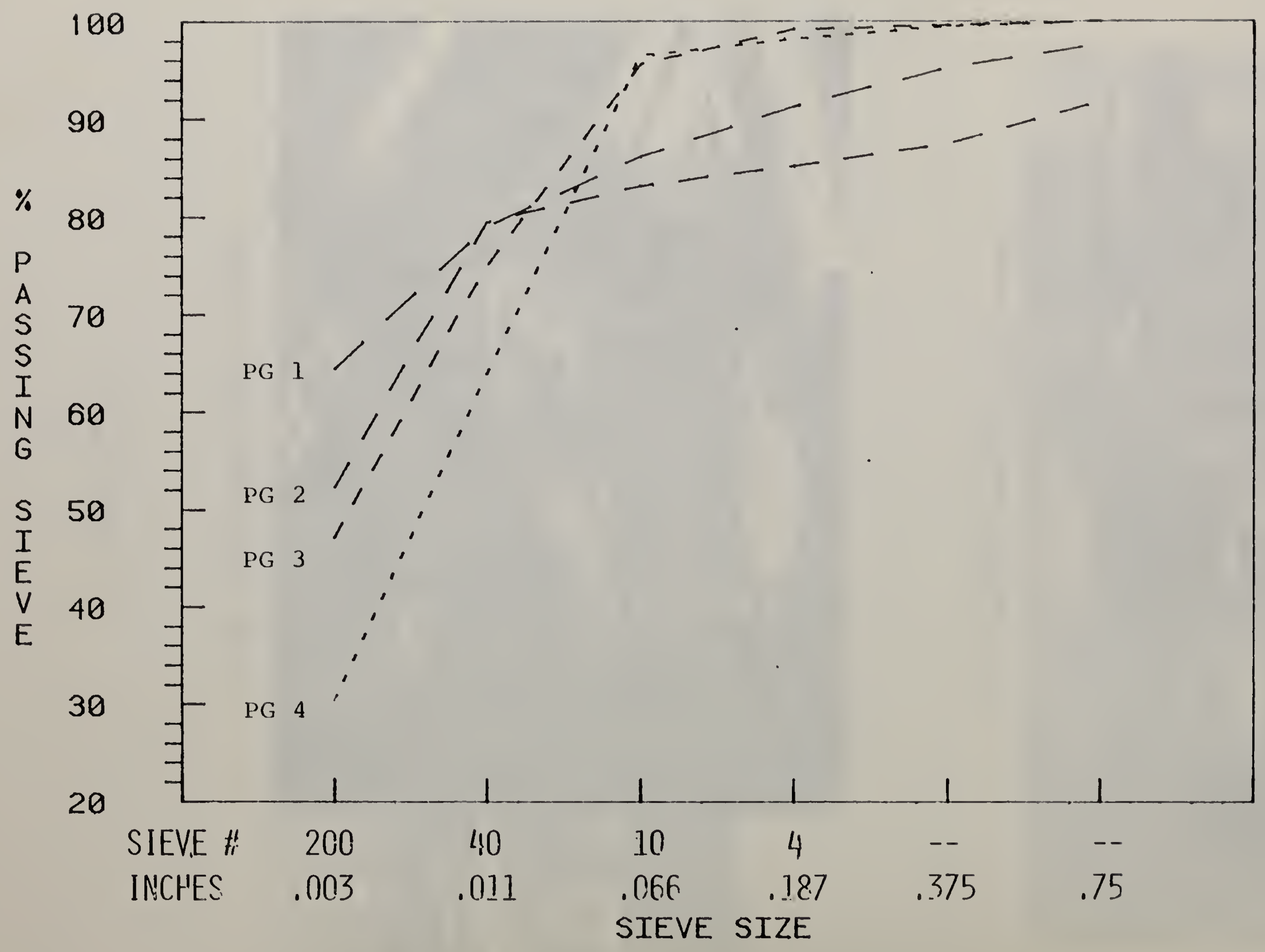


FIG. 3: PARTICLE SIZE OF THE FOUR PLAYGROUND SOILS

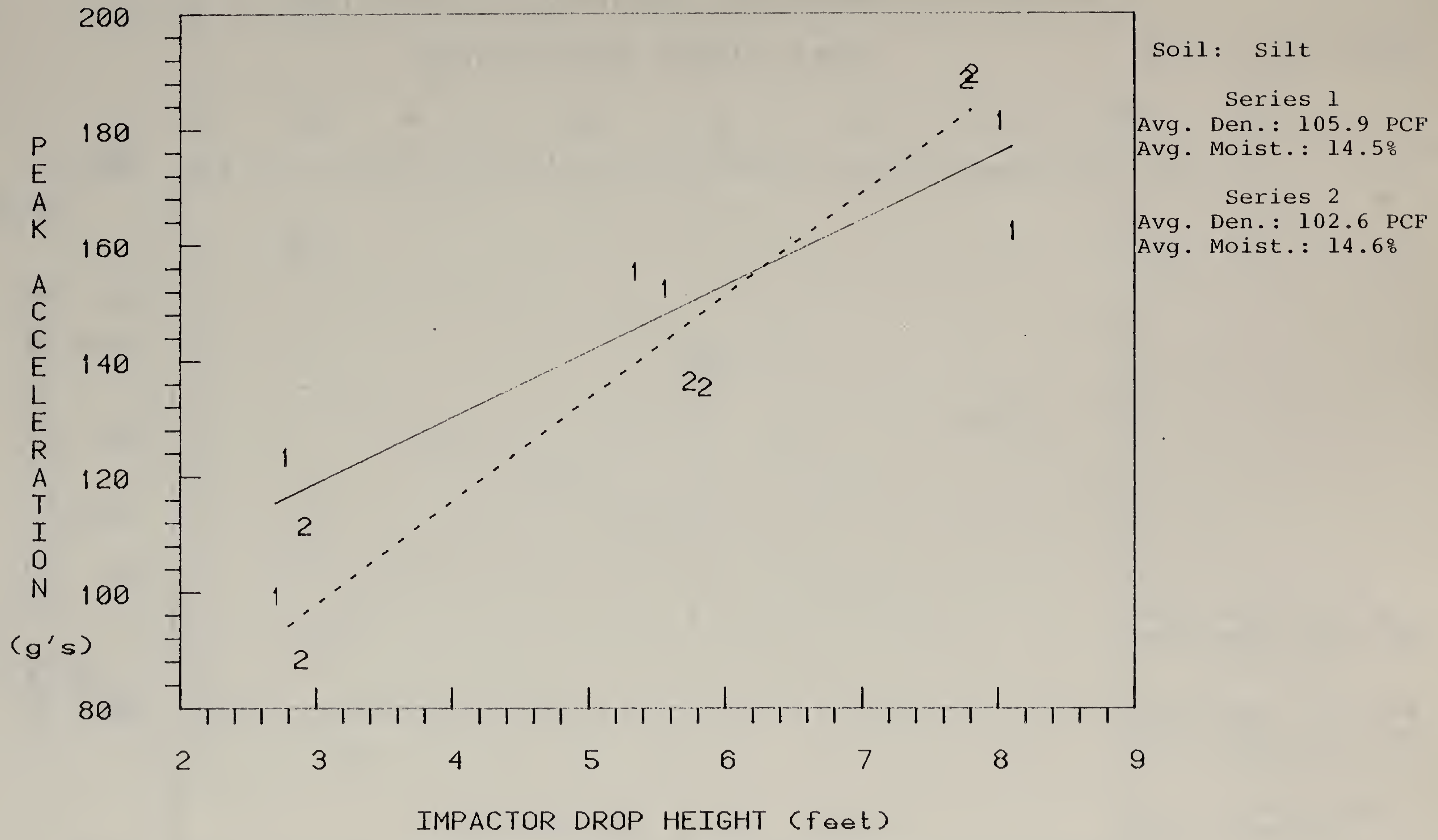


FIG. 4: SOIL IMPACT ATTENUATION PERFORMANCE-PLAYGROUND 1

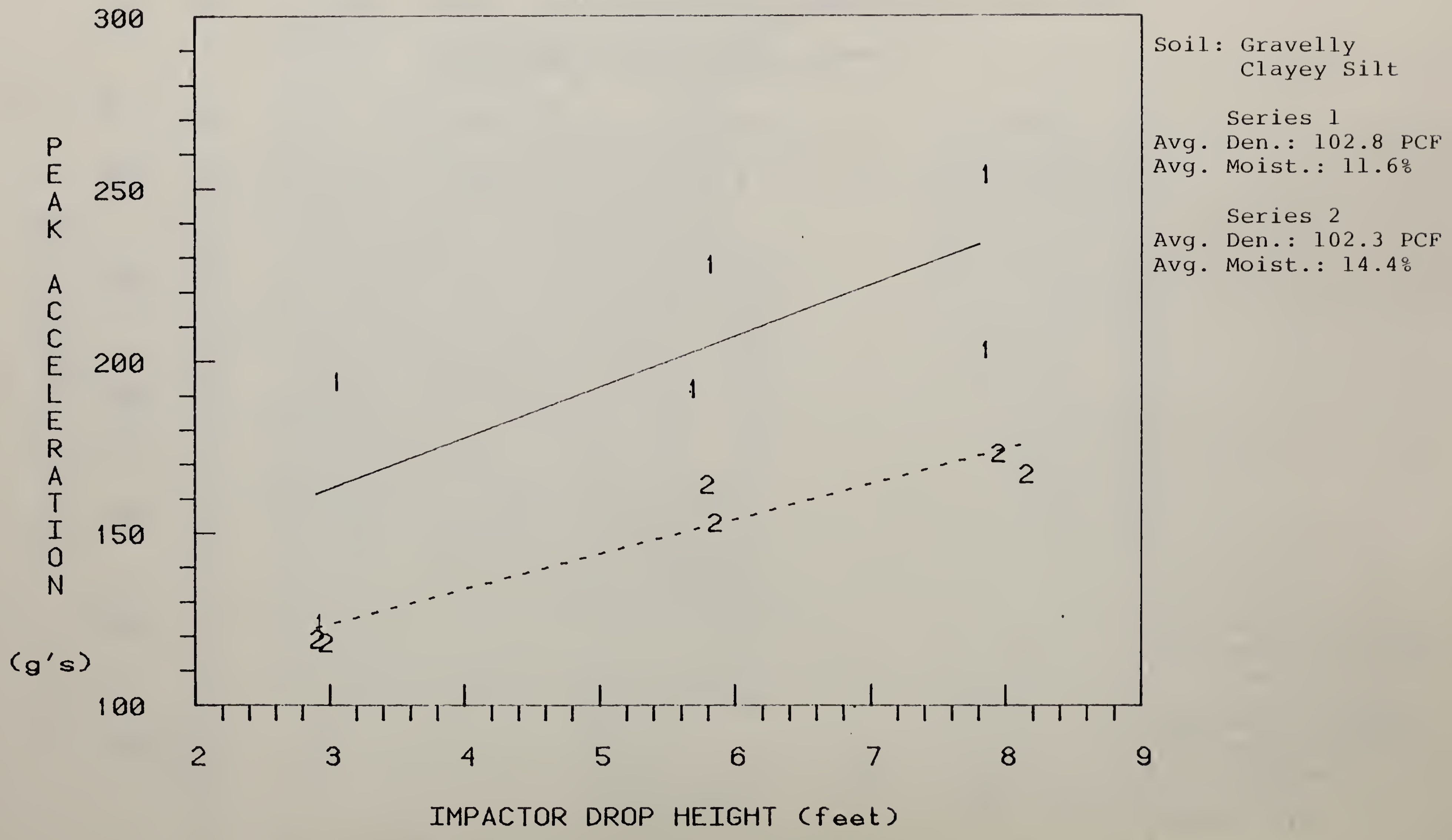


FIG. 5: SOIL IMPACT ATTENUATION PERFORMANCE-PLAYGROUND 2

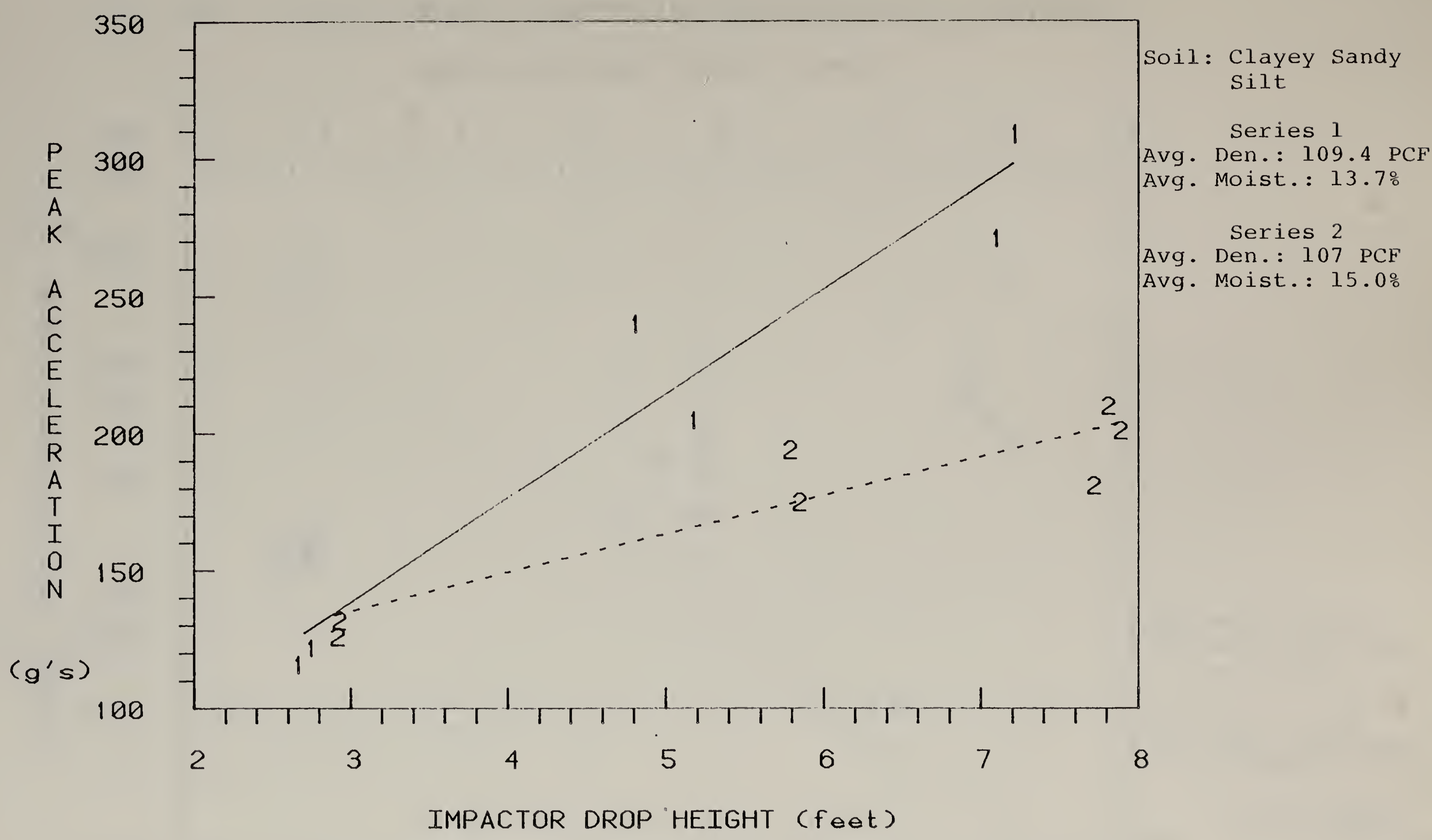


FIG. 6: SOIL IMPACT ATTENUATION PERFORMANCE-PLAYGROUND 3

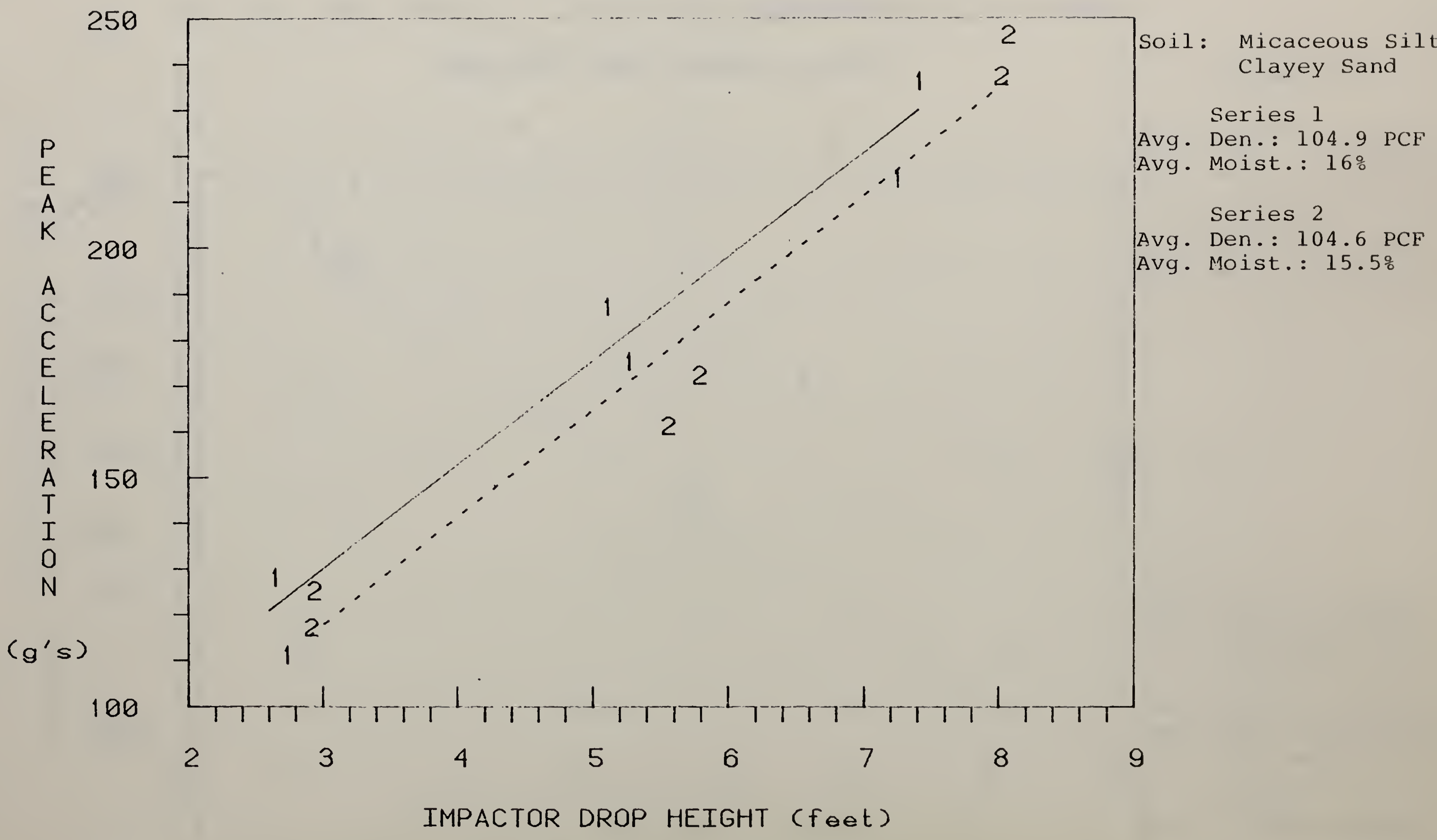


FIG. 7: SOIL IMPACT ATTENUATION PERFORMANCE-PLAYGROUND 4

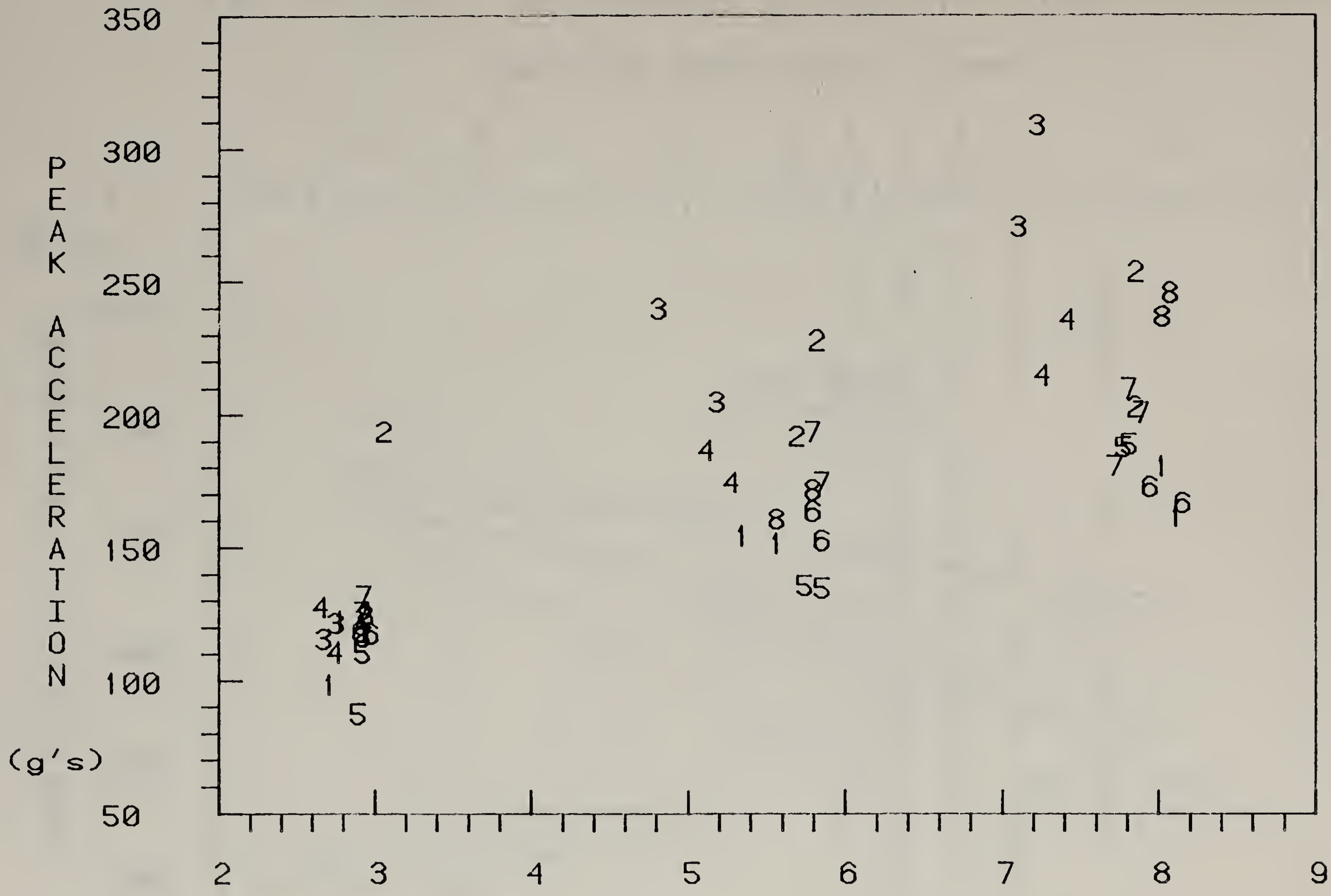


FIG. 8: SOIL IMPACT ATTENUATION PERFORMANCE-ALL PLAYGROUNDS

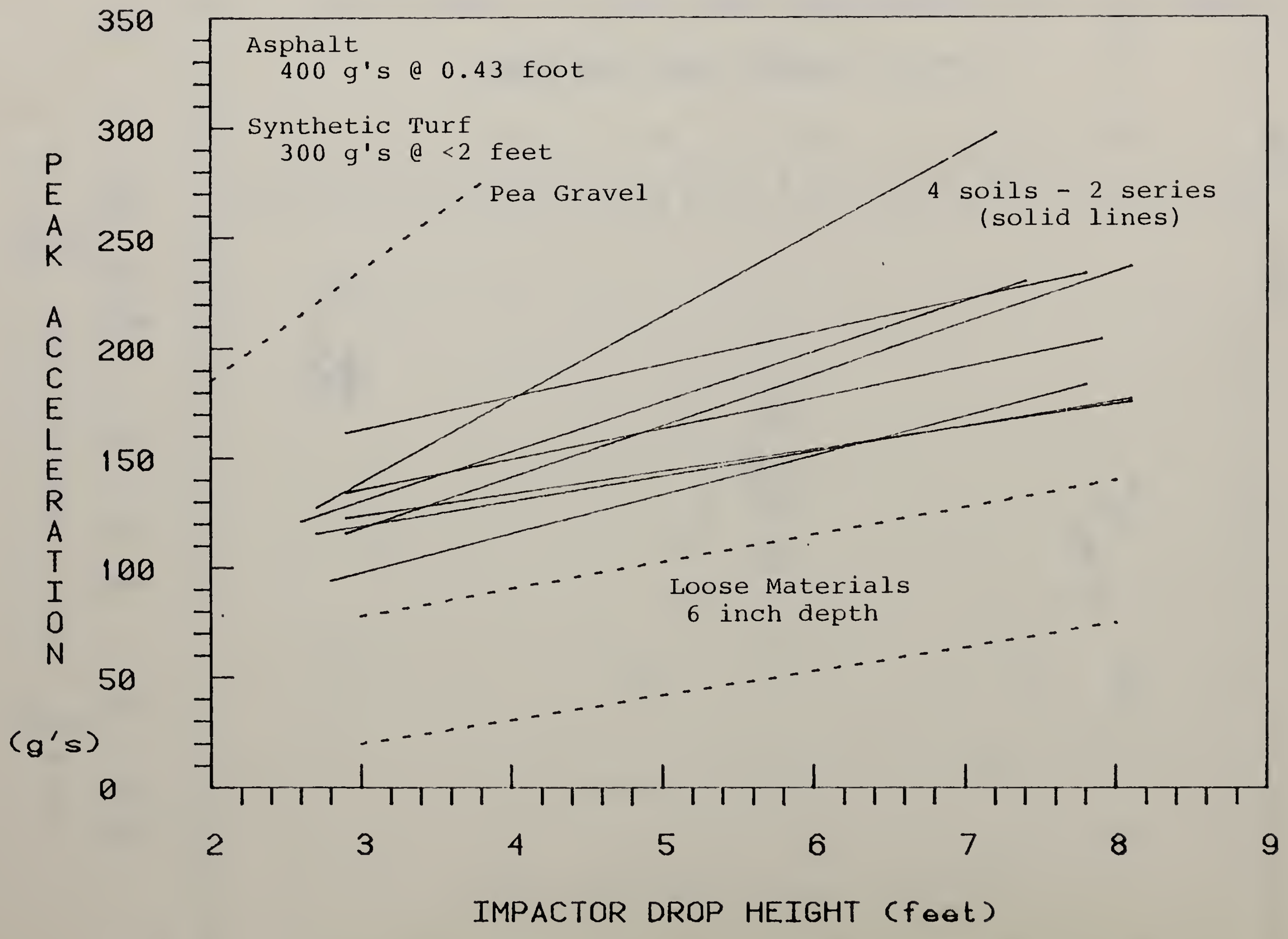


FIG. 9: IMPACT PERFORMANCE OF SOILS AND OTHER MATERIALS

APPENDIX A. SOIL ANALYSIS REPORTS

The results of the soil analyses reported by AMBRIC Testing and Engineering Associates of Va., Inc., are included in this appendix. Specific identification of the four playgrounds has been deleted from these reports.

AMBRIC TESTING & ENGINEERING ASSOCIATES OF VA., INC.

REGISTERED ENGINEERS
• INSPECTORS •

TESTING LABORATORIES
• CHEMISTS •

4110 Wheeler Avenue
Alexandria, Va. 22304
(703) 370-3100

Report No. NBS-1

2 October 1979

National Bureau of Standards
Building 220, Room A359
Washington, D. C. 20234

Re: Impact Study
Soil Sample Analysis
Purchase Order No. AB-9621

Attn: Mr. Wm. Beine

Gentlemen:

We report results of our laboratory and field testing of soil sampled on 17 and 18 September 1979. A preliminary visual site investigation was conducted on 11 September 1979 to isolate recreational areas having distinct differences in soil classifications.

Dry density-moisture content tests were taken at the above sites at the time of sampling with results as follows:

Playground 1	107.9 pcf @ 14.8% & 103.9 @ 14.2%
Playground 2	103.8 pcf @ 12.0% & 101.7 @ 11.1%
Playground 3	109.4 pcf @ 13.7%
Playground 4	104.9 pcf @ 16.0%

Laboratory analyses of the procured samples were performed in accordance with applicable ASTM standards, and are enclosed.

Respectfully Submitted

D. D. Meisel, P.E.

Field Representative: David F. Williams
S-4909
DFW/ano

AMBRIC TESTING & ENGINEERING ASSOCIATES OF VA., INC.

REGISTERED ENGINEERS
• INSPECTORS •

TESTING LABORATORIES
• CHEMISTS •

4110 Wheeler Avenue
Alexandria, Va. 22304
(703) 370-3100

Report No. NBS-2

5 October 1979

National Bureau of Standards
Building 220, Room A359
Washington, D. C. 20234

Re: Impact Study - Field
Testing - Series II

Attn: Mr. Wm. Beine

Gentlemen:

We report results of our field testing of soil at the four subject sites on 4 October 1979.

	Test 1	Test 2
Playground 1	102.5 pcf @ 14.3%	102.7 pcf @ 14.8
Playground 2	101.9 pcf @ 14.0%	102.6 pcf @ 14.7
Playground 3	106.9 pcf @ 15.3%	107.1 pcf @ 14.6
Playground 4	103.1 pcf @ 16.3%	105.0 pcf @ 14.5

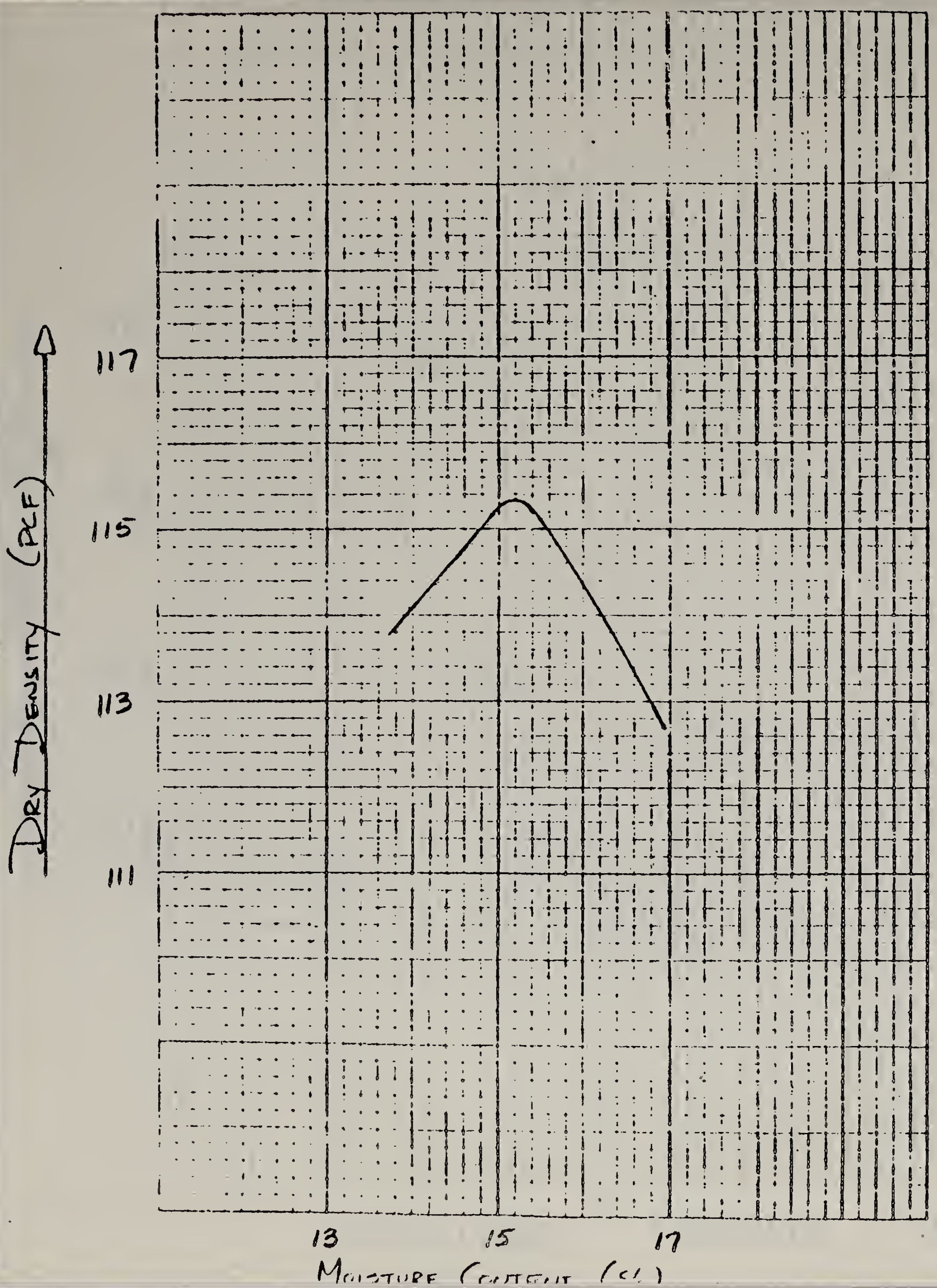
Respectfully submitted,

B. E. Peebles, P.E.

Field Representative: David F. Williams
S-4930
RMB/ano

National Bureau of Standards

		Playground 1	Playground 2	Playground 3	Playground 4
Visual Description		Reddish Brown Silt	Light Brown Gravelley Clayey Silt	Light Brown Clayey Sandy Silt	Multi-color Micaceous Si Clayey Sand
Classification		ML	ML-CL	SM-SC	SM
Sieve Analysis					
% passing	3/4"	97.7%	91.8	100	100 %
	3/8'	95.3%	87.5	99.6	99.5%
	#4	91.3	85.2	99.2	98.2
	#10	86.2	83.2	94.6	96.5
	#40	79.0	79.5	75.1	63.9
	#80	75.3	70.5	59.6	43.2
	#200	64.4	52.3	47.1	30.4
Atterberg Limits					
Liquid Limit		32	21	19	--
Plastic Limit		27	15	16	--
Plasticity Index		5	6	3	NP
Maximum Density (pcf)		115.3	117.3	121.8	104.8
Optimum Moisture		15.2	14.0	11.9	19.0



JOB NAME : NATIONAL BUREAU OF STANDARDS

REPORT No. : NBS-1

CLIENT : PO # AB-9621

DATE SAMPLED : 17 SEPTEMBER 1979

SOURCE OF MATERIAL : Playground 1

NATURAL MOISTURE CONTENT (%) : 14.5

TEST METHOD : ASTM D698 "A"

MAXIMUM DRY DENSITY (PCF) : 115.3

OPTIMUM MOISTURE CONTENT (%) : 15.2

VISUAL CLASSIFICATION : REDDISH BROWN SILT (ML)

LL : 32

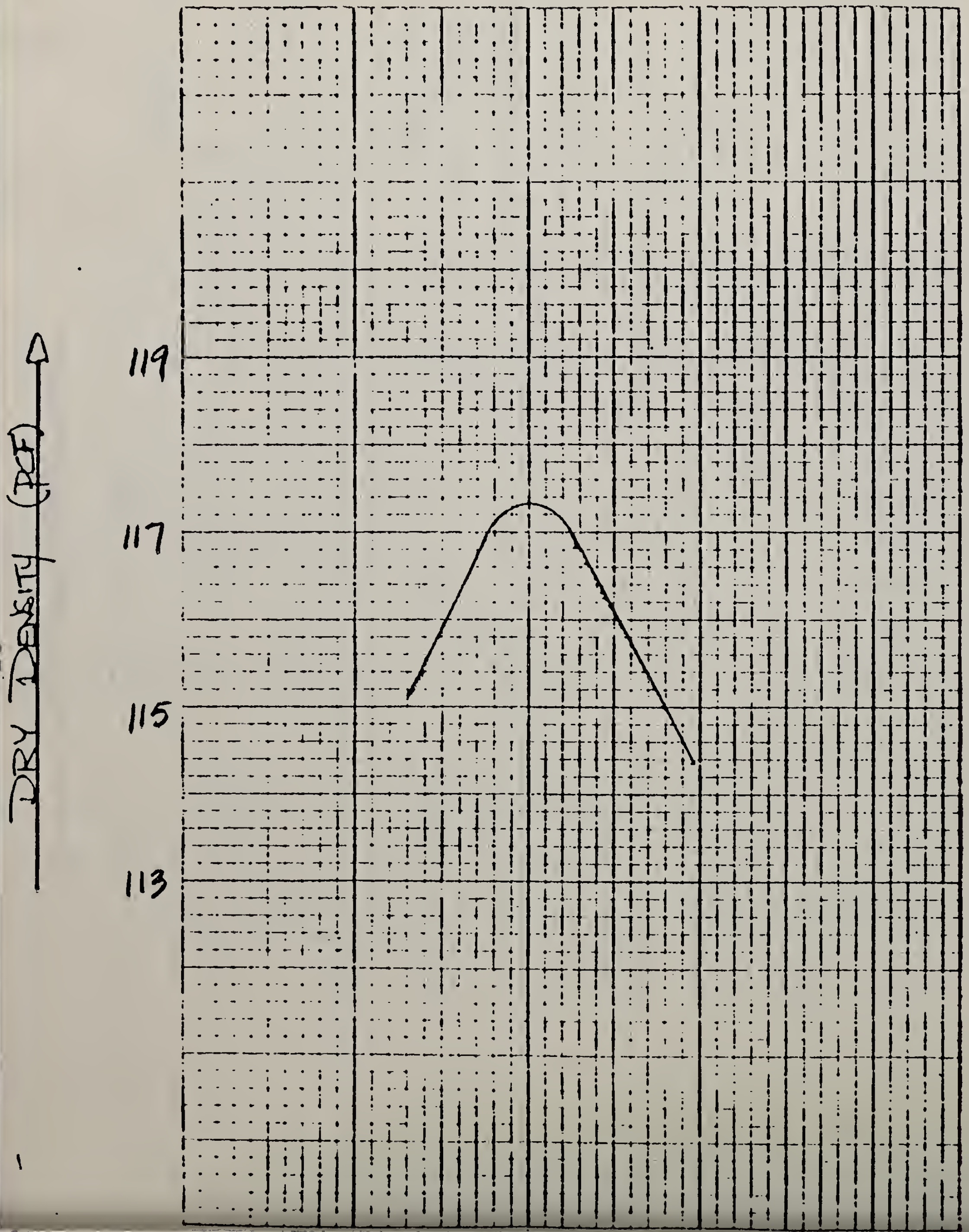
PL : 27

PI : 5

GRADATION

SIEVE SIZE	% PASSING
1	100
3/4	97.7
3/8	95.3
#4	91.3
#10	86.2
#40	79.0
#80	75.3
#200	64.4

MOISTURE - DENSITY RELATIONS



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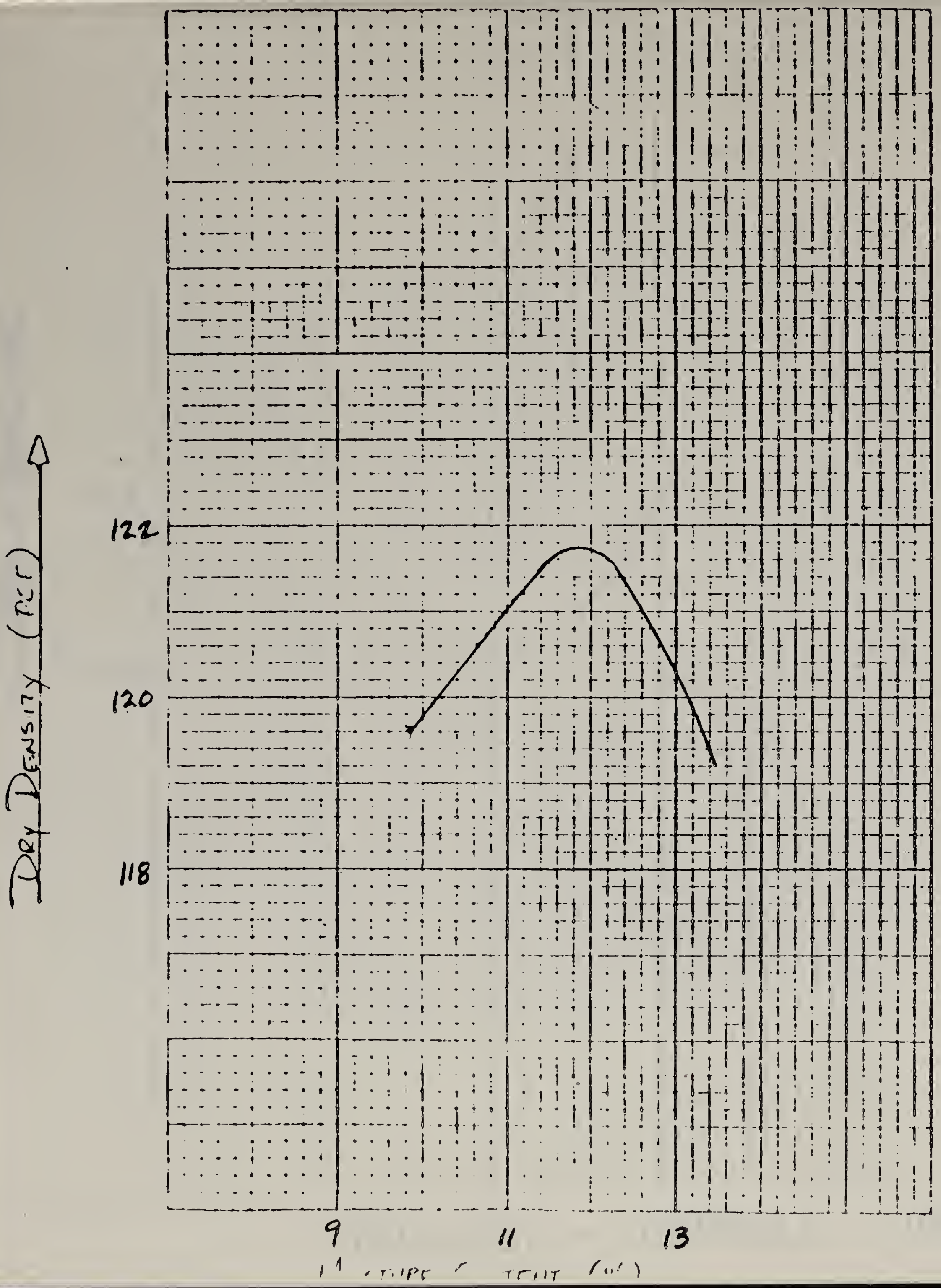
DATE SAMPLED : 17 SEPTEMBER 1979
SOURCE OF MATERIAL : Playground 2

NATURAL MOISTURE CONTENT (%) : 11.6
TEST METHOD : ASTM D 698 "A"
MAXIMUM DRY DENSITY (PCF) : 117.3
OPTIMUM MOISTURE CONTENT (%) : 14.0
VISUAL CLASSIFICATION : LIGHT BROWN GRAVELLY CLAYEY SILT (ML-CL)

LL : 21
PL : 15
PI : 6

GRADATION

SIEVE SIZE	% PASSING
1"	100
3/4"	91.8
3/8	87.5
#4	85.2
#10	83.5
#40	79.5
#80	70.5
#200	52.3



JOB NAME : NATIONAL BUREAU OF STANDAR

REPORT No. : NBS-1

CLIENT : PO # A3-9621

DATE SAMPLED : 18 SEPTEMBER 1979

SOURCE OF MATERIAL Playground 3

NATURAL MOISTURE CONTENT (%): 13.7

TEST METHOD : ASTM D 698 "A"

MAXIMUM DRY DENSITY (PCF) : 121.8

OPTIMUM MOISTURE CONTENT (%): 11.9

VISUAL CLASSIFICATION : LIGHT BROWN CLAYEY SANDY SILT (SM-SC)

LL : 19

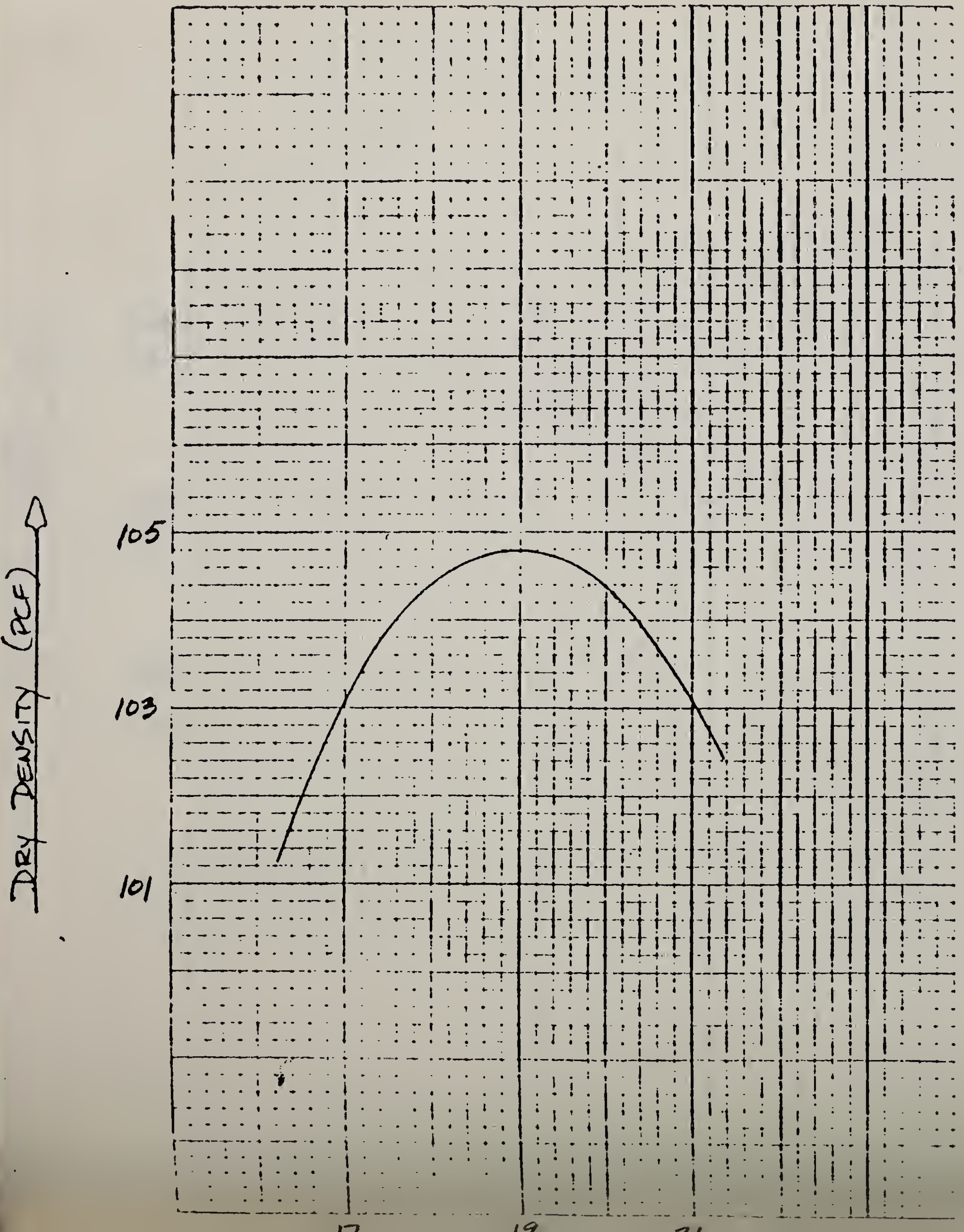
PL : 16

PI : 3

GRADATION

SIEVE SIZE	% PASSING
3/4	100
3/8	99.6
#4	99.2
#10	94.6
#40	75.1
#80	59.6
#200	47.1

MOISTURE - DENSITY RELATIONS



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REPORT No. : NBS-1

CLIENT : PO # AB-9621

DATE SAMPLED : 18 SEPTEMBER 1979

SOURCE OF MATERIAL : Playground 4

NATURAL MOISTURE CONTENT (%): 16.0

TEST METHOD : ASTM D698 "A"

MAXIMUM DRY DENSITY (PCF) : 104.8

OPTIMUM MOISTURE CONTENT (%) : 19.0

VISUAL CLASSIFICATION : MULTI-COLOR MICACEOUS SILTY CLAYEY SAND (SM)

LL : —

PL : —

PI : NP

GRADATION

SIEVE SIZE	% PASSING
3/4"	100
3/8"	99.5
#4	98.2
#10	96.5
#40	63.9
#80	43.2
#200	30.4

APPENDIX B. SOIL CLASSIFICATION CHART

MAJOR DIVISIONS			GROUP SYMBOLS	TYPICAL NAMES
COARSE-GRAINED SOILS More than 50% retained on No. 200 sieve*	GRAVELS 50% or more of coarse fraction retained on No. 4 sieve	CLEAN GRAVELS	GW	Well-graded gravels and gravel-sand mixtures, little or no fines
			GP	Poorly graded gravels and gravel-sand mixtures, little or no fines
		GRAVELS WITH FINES	GM	Silty gravels, gravel-sand-silt mixtures
			GC	Clayey gravels, gravel-sand-clay mixtures
	SANDS More than 50% of coarse fraction passes No. 4 sieve	CLEAN SANDS	SW	Well-graded sands and gravelly sands, little or no fines
			SP	Poorly graded sands and gravelly sands, little or no fines
		SANDS WITH FINES	SM	Silty sands, sand-silt mixtures
			SC	Clayey sands, sand-clay mixtures
FINE-GRAINED SOILS 50% or more passes No. 200 sieve*	SILTS AND CLAYS Liquid limit 50% or less		ML	Inorganic silts, very fine sands, rock flour, silty or clayey fine sands
			CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays
			OL	Organic silts and organic silty clays of low plasticity
	SILTS AND CLAYS Liquid limit greater than 50%		MH	Inorganic silts, micaceous or diatomaceous fine sands or silts, elastic silts
			CH	Inorganic clays of high plasticity, fat clays
			OH	Organic clays of medium to high plasticity
Highly Organic Soils			PT	Peat, muck and other highly organic soils

* Based on the material passing the 3-in. (75-mm) sieve.

Fig. 1—Soil Classification Chart.

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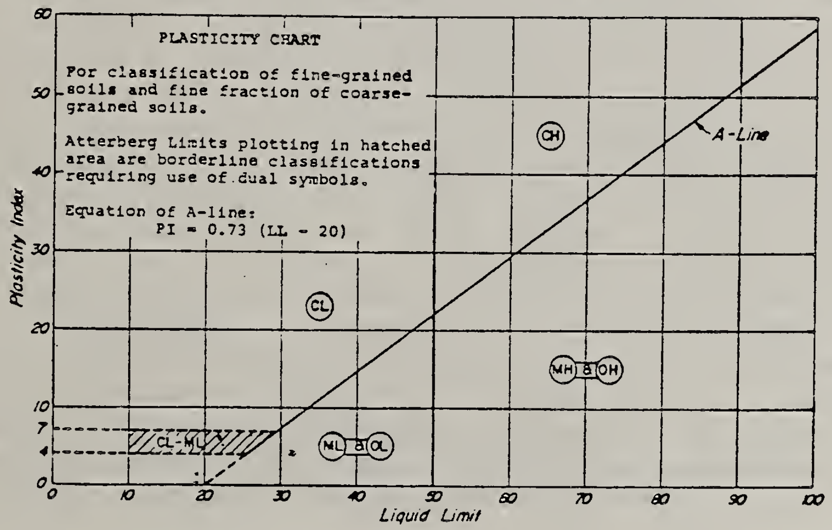
	CLASSIFICATION CRITERIA	
Classification on basis of percentage of fines Less than 5% Pass No. 200 sieve GW, GP, SW, SP More than 12% Pass No. 200 sieve GM, GC, SM, SC 5% to 12% Pass No. 200 sieve Borderline Classification requiring use of dual symbols	$C_u = D_{60}/D_{10}$ Greater than 4 $C_z = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3	
	Not meeting both criteria for GW	
	Atterberg limits plot below "A" line or plasticity index less than 4	Atterberg limits plotting in hatched area are borderline classifications requiring use of dual symbols
	Atterberg limits plot above "A" line and plasticity index greater than 7	
	$C_u = D_{60}/D_{10}$ Greater than 6 $C_z = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3	
	Not meeting both criteria for SW	
	Atterberg limits plot below "A" line or plasticity index less than 4	Atterberg limits plotting in hatched area are borderline classifications requiring use of dual symbols
	Atterberg limits plot above "A" line and plasticity index greater than 7	



Visual-Manual Identification, See ASTM Designation D 2488.

FIG. 1—*Continued.*

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1. Standard for Protective Headgear for Vehicular Users, ANSI Z90.1, 1973, American National Standards Institute, Inc., 1430 Boradway, New York, New York.

2. Mahajan, B. M., and Beine, W. B., "Impact Attenuation Performance of Surfaces Installed Under Playground Equipment," NBSIR 79-1707 February 1979.

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5. Publication Date

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7. AUTHOR(S)

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DEPARTMENT OF COMMERCE
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Final

14. Sponsoring Agency Code

15. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

Impact attenuation performance tests were conducted on the playing surface of selected public playgrounds in Montgomery County, Maryland, using a test method developed in an earlier laboratory investigation of surfacing materials. Controlled impacts were obtained by dropping an instrumented headform in guided free-fall onto the test surfaces from various heights. The peak acceleration imparted to the headform during impact was recorded as the performance parameter.

At four playgrounds, the tests were performed on the undisturbed soil underlying existing play equipment. At a fifth location, the asphalt surface of an outdoor basketball court was tested. Soil samples from each playground were collected, analyzed and classified in accordance with standard methods prescribed by the ASTM. Separate tests were conducted following periods of dry and wet weather and on-site measurements of soil density and moisture content were recorded at the time of tests.

Analysis of results indicated an apparent correlation between a soil's performance and its moisture content; correlation with other soil characteristics were not evident. The peak accelerations produced by the playground soils were much lower than those produced by the asphalt surface but higher than those produced by most loose materials previously tested in the laboratory.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Asphalt; impact attenuation; peak acceleration; playground safety; playground surfaces; soil; surfacing materials; test method

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