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USE OF COAL COMBUSTION BY-PRODUCTS

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The disposal of waste products has become a big problem. This has generated interest in finding ways in which the waste products may be put to some constructive use. The by-products produced by burning coal in the power plants are among the waste products being considered for reuse. The volume of coal combustion by-products is increasing as the demand of power grows and more plants are established. According to the American Coal Ash Association, in 10 years (from 1976 to 1986), the annual production of power plant ash in the United States increased from 54 to 67 million tons. Ash production increased to 87 million tons in 1990. This has made coal ash one of the most important by-products being considered for reuse.

PROJECT BACKGROUND

The use of power plant ash in highway construction was limited until 1987 when the Surface Transportation and Uniform Relocation Act was introduced. The act strongly emphasized the use of coal ash in highway construction. The Federal Highway Administration (FHWA) began encouraging and aiding projects focusing on the use of coal ash as a potential highway construction material. The State of Indiana, being one of the largest producers of coal ash, was bound to join the program. Consequently, the Indiana Department of Transportation (INDOT) was directed by the General Assembly of the state to conduct a study to determine the feasibility of the use of coal combustion by-products by analyzing their cost, life and availability, and developing specifications to promote their use.

A research study was conducted and completed by Purdue University in 1990 under a Joint Highway Research Project to study the use of bottom ash in highway embankment and pavement construction. The study produced sufficiently encouraging results. Later, the University of Southern Indiana Forum for Coal Ash Utilization and GAI Consultants, Inc. (GAI) were selected to conduct a study financed by Indiana Electric Association to examine the potential uses of the coal combustion by-products in the state, including their availability, characteristics and marketability. The findings of that study were compiled in a report prepared in June 1993. The report contains details of locations, quantity and type of coal combustion by-products throughout the State of Indiana (see Figure 1). The report was reviewed and approved by INDOT. INDOT then selected three demonstration projects, one each in northern, central and southern Indiana. The U.S. 12 project in northern Indiana was the first project to be undertaken. I-80 at Burr Street was originally selected, however, construction was postponed. INDOT also prepared the "Special Provisions for Embankment Constructed of Coal Combustion By-Products" (Special Provisions) for the demonstration projects. However, the location of the source of the coal ash was yet to be finalized. A laboratory study funded by Northern Indiana Public Service Company (NIPSCO) was conducted by GAI to perform site specific tests on the ponded ash (including bottom ash, fly ash, and boiler slag materials) from three specific plants (Schahfer, Mitchell and Michigan City) to collect sufficient relevant data to select the source of bottom ash for the first demonstration project and to finalize the Special Provisions. Based on the results of the tests, INDOT selected bottom ash from the Schahfer Plant for use in the U.S. 12 demonstration project.

ENGINEERING AND CHEMICAL PROPERTIES

Laboratory testing was used to determine the engineering and chemical properties of the bottom ash. The typical engineering soil testing included moisture content, grain size distribution, specific gravity, permeability, direct shear, consolidation, California Bearing Ratio, unconfined compressive strength, and moisture-density relationships. The chemical testing included loss on ignition, sulfur content, corrosion potential, and leachate testing. Leachate tests were performed to determine the Indiana Administrative Code (IAC) waste type of the bottom ash as defined by the Indiana Department of Environmental Management.

The bottom ash samples were obtained from the ash storage area (pond) at the Schahfer Generating Station as shown on Figure 2. The samples were obtained from the surface since the materials are frequently mixed and pushed into stockpiles with a dozer, and therefore, no change in material properties was expected to occur with depth in the pond.

Test results of the Schahfer Station pond ash are presented on Tables 1 through 4 and Figures 3 and 4. The bottom ash consists of well-graded fine to coarse sand-sized particles with some hard gravel-sized particles. Particles are mostly black, with some glassy particles, and some dark brown particles.

Natural moisture contents and the grain size distribution of the Schahfer Station ash are presented in Table 1. A typical grain-size distribution curve is presented on Figure 3. Grain-size distribution analyses indicated that the material is predominantly sand-sized, with little fines (particles passing the No. 200 sieve).

Moisture-density relationships (AASHTO T99) for the Schahfer samples are presented by Figure 4. Associated maximum dry densities and optimum moisture contents are presented in Table 2 along with the other engineering properties of the bottom ash. Maximum dry densities range from 91.9 pcf to 115.6 pcf. Optimum moisture contents range from 15.0 percent to 23.6 percent.

Chemical analyses of Schahfer bottom ash are presented in Tables 3 and 4. Loss on ignition was less than 0.02 percent, indicating no detectable unburned carbon. Total and pyritic sulfur values are low, indicating an absence of pyritic material. Leachate testing on a samples indicate that the bottom ash is IAC Waste Type III. An IAC Waste Type III has concentrations that are less than 10 percent of the hazardous waste concentrations defined in the Resource Conservation and Recovery Act (RCRA).

CONSTRUCTION OF U.S. 12 DEMONSTRATION PROJECT

U.S. 12 was the first of four planned INDOT demonstration projects using coal ash in an INDOT highway embankment. GAI was present during a portion of U.S. 12 bottom ash placement and compaction to observe and document field procedures. GAI also performed an

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independent field study relative to determining in-place dry densities and moisture contents using the Troxler nuclear gage, conventional oven, microwave oven, and Speedy moisture methods.

Bridge approaches along U.S. Route 12 (Columbus Drive) were widened and raised in conjunction with INDOT bridge replacements over Kennedy Avenue (see Figure 5). Due to limited right-of-ways, raising the bridge approach embankments required steep 2H:1V slopes. Bottom ash placement was observed by GAI at the bridge approach west of the Kennedy Avenue Bridge. An embankment cross-section at this location is shown in Figure 6. The old road bed was left in place, and the old side slopes were stripped and benched. Bottom ash was placed and compacted in thin lifts, first to widen the embankment, then to raise the entire width of the embankment to the final subgrade elevation. Bottom ash was compacted with a BOMAG vibratory roller, Model 172, weighing 11,900 pounds with an impact force of 14 tons. The bottom ash was initially compacted using six passes of the roller, but was reduced to four passes based on field density test results. A cohesive soil cover was placed over the bottom ash as the bottom ash fill was raised.

GAI performed in-place wet density tests on the compacted bottom ash using the Troxler nuclear gage, and moisture content tests were performed using the Troxler nuclear gage, conventional oven method, microwave oven, and two Speedy moisture testers (calcium carbide gas pressure method). One-point AASHTO T99 (Standard Proctor) density tests were also performed.

Approximately 23,000 tons of bottom ash were delivered and placed at the U.S. 12 demonstration project. GAI observed, documented, and tested approximately 7,000 tons of the bottom ash, which was delivered and placed on the west side of the Kennedy Avenue Bridge. A total of 64 density tests, 234 moisture content tests, and 12 one-point AASHTO T99 tests were performed. Wet densities, dry densities and moisture contents are presented in Table 5. The dry densities on Table 5 were calculated using Troxler wet densities and conventional oven moisture contents. One-point AASHTO T99 test results are presented on Table 6.

Based on INDOT laboratory testing (AASHTO T99), the bottom ash had an optimum moisture content of 20.2 percent and a maximum dry density of 91.1 pounds per cubic foot (pcf) similar to the findings of the GAI study. The minimum acceptable compacted dry density of the bottom ash for the U.S. 12 project was 86.5 pcf (95 percent of maximum), with an allowable moisture content range of 11 percent to 17 percent.

As shown on Figure 7, the minimum allowable density of 86.5 was exceeded for all of the tested bottom ash. Only a few of the results were outside of the allowable moisture content range of 11 to 17 percent. Notice that at moisture contents outside of the allowable range, the required dry density was still achieved.

Based on previous GAI experience, Troxler nuclear density gages have been shown to give erroneous moisture readings due to the chemistry of coal combustion by-products. The conventional oven moisture method was considered the standard, with other methods calibrated against the conventional oven method. The conventional oven method is seldom used exclusively during field monitoring due to the time required for results, but is often used to calibrate other methods. Moisture content readings by the various methods typically require the following approximate time intervals: conventional oven - 24 hours; microwave oven - 15 minutes; Speedy moisture apparatus - 5 minutes; and nuclear gage - a few seconds (in addition to 5 minutes for the density test).

Microwave and conventional oven moisture content readings demonstrated a near 1:1 relationship in the range of 11 to 17 percent, as illustrated on Figure 8. A linear regression analysis derived the following relationship, in which W equals moisture content:

W (oven dry, percent) = 0.8 W (microwave, percent) + 3.6 percent

This close correlation is similar to previous GAI experience using microwave ovens with coal combustion by-products. Calibration equations for the Troxler and the two Speedy moisture test apparatus used are as follows:

W (oven dry, percent) = 1.5 W (Troxler, percent) + 4.9 percent

W (oven dry, percent) = 1.6 W (Speedy 1, percent) + 1.5 percent

W (oven dry, percent) = 1.2 W (Speedy 2, percent) + 0.1 percent

These relationships are illustrated on Figures 9, 10, and 11, respectively. These correlations are applicable only within the tested moisture range and for the Schahfer bottom ash used during this work. Note that when the Speedy method is used, a calibration curve is needed for each apparatus.

One-point AASHTO T99 density (moisture-density relationship) tests were performed to monitor material variability. All one-point AASHTO T99 test material samples were taken from stockpiles rather than recompacting field compacted material. This procedure eliminates the effects of excessive particle breakdown. The one-point AASHTO T99 field density test results are plotted with previously determined GAI laboratory compaction curves on Figure 4. These one-point AASHTO T99 field density tests indicate the bottom ash used at the U.S. 12 project was similar to the bottom ash used in the laboratory testing (samples S-3 and S-4). A comparison of the Table 5 field dry densities with the Table 6 minimum acceptable dry densities for each date indicates that all of the tested compacted bottom ash exceeded 95 percent of the required maximum dry density.

In addition to a compaction monitoring study, the following field observations were made:

1. Bottom ash was delivered in 20-ton dump trucks and stockpiled on site. No construction delays were caused by the use of bottom ash.

2. The bottom ash was spread and compacted in approximate 8" lifts. Required densities were achieved with four passes of the 11,900 pound BOMAG vibratory roller.

3. The cover soil was clayey and was placed as specified by INDOT. The method of placing the cover as the embankment fill is raised is preferred to placing a soil veneer over the completed bottom ash fill, as it provides better bonding of the layers and reduces the tendency of the cover soil to slough off. The method of first placing a soil berm, then compacting ash within that berm, more effectively compacts the outermost zone of bottom ash.

4. The side slopes of the existing embankment were benched to notch the new and old fills together and to prevent reflective cracking due to abrupt changes in materials.

5. Personnel from FHWA, INDOT, NIPSCO, GAI, and U.S. Ash observed bottom ash placement.

CONCLUSIONS

The conclusions that can be made from the observations, documentation, and field study are:

1. The microwave oven method resulted in a near 1:1 correspondence with the conventional oven moisture content test results.

2. Moisture contents based on the nuclear gage and Speedy moisture testers did not directly match the conventional oven readings, but these devices can be calibrated to monitor moisture. The calibration curves presented in this report are applicable only with the S-3 and S-4 Schahfer bottom ash within the tested water content range.

3. The one-point AASHTO T99 method can be used to monitor compaction of variable materials, including ponded coal combustion by-products.

4. Schahfer S-3 and S-4 ponded bottom ash was compacted to the required minimum dry density without difficulty using a vibratory roller with a static weight of 11,900 pounds and an impact force of 14 tons.

5. Watering the bottom ash was performed during compaction to achieve moisture contents within the required allowable range. This procedure was not necessary, added expense to the contractor, and caused portions of the cohesive soil encasement to become saturated. INDOT changed the specified moisture content range in the Special Provisions from 13 to 17 percent to 11 to 17 percent.

The laboratory test results and the U.S. 12 demonstration project indicate that Schahfer Station pond ash is suitable for use in an engineered compacted structural fill. No pyritic material was detected in the materials tested. Leachate levels indicate IAC Waste Type III which would be accepted by the Indiana Department of Environmental Management for use in an INDOT embankment. Engineering and chemical data can be used in site-specific determinations of Schahfer pond ash compaction criteria, slope stability, time rate and amount of consolidation, suitability as drainage aggregate or subbase, and corrosion potential when used as backfill material. The engineering properties of the bottom ash are similar to those of other bottom ashes which have been successfully used as drainage aggregate and/or bulk fill material.

RECOMMENDATIONS

The following recommendations were made to provide additional information and experience as a basis for INDOT's Special Provisions:

1. A test program to determine the minimum water content at which dusting is not a problem, but the required density is achieved using vibratory compaction operated at resonant frequency, would be useful to minimize or eliminate field watering.

2. For future embankments, it is recommended that watering of the bottom ash should be eliminated, or minimized and drainage be provided at the toe of the slope (e.g., bleeder pipes) to prevent saturation of the base or cover of the embankment. Laboratory testing by GAI (Figure 3) shows that adequate densities can be achieved at low moisture contents. This recommendation may apply to natural granular soils, as well as bottom ash.

   Note that with cohesive soils, the optimum moisture content is specified not only to achieve the required density, but also to achieve the required shear strength, permeability and shrink-swell characteristics. These effects are less applicable to cohesionless granular materials.

3. GAI experience in the field has shown that bottom ash can be compacted to 95 percent of AASHTO T99 over a wide range of moisture contents. Compaction by vibratory roller is most effective (and efficient) at the resonant frequency. On equipment with variable frequencies, this can be determined by operating the equipment on the bottom ash and gradually increasing the frequency until a person standing about 20 feet away feels the maximum ground movement. The resonant frequency is specific to the bottom ash, lift thickness and weight and area of the compactor. Effectiveness of the compactor is also affected by the speed of travel and number of passes.

4. For granular materials which do not develop peaked moisture-density relationships using AASHTO T99 compaction tests, the use of relative density criteria may be a better indicator of adequate compaction.

Table 1

MOISTURE CONTENT AND GRAIN SIZE

Sample	Material	Sample Can	Natural Moisture Content (%)	Grain Size Distribution		
				Gravel (%)	Sand (%)	< No. 200 Sieve (%)
S-1	Bottom Ash	Composite		1.0	98.6	0.4
		A	2.0			
		B	1.9	1.8	97.8	0.4
		C	1.5			
S-2	Bottom Ash	Composite		5.5	93.8	0.7
		A	2.4			
		B	2.0	3.8	95.5	0.7
		C	2.4			
S-3	Bottom Ash	Composite		22.2	75.1	2.7
		A	7.3			
		B	15.2	18.8	79.0	2.2
		C	7.7			
S-4	Bottom Ash	Composite		25.9	71.2	2.9
		A	7.8			
		B	6.8	31.6	65.6	2.8
		C	8.0			
S-5	Bottom Ash	Composite		34.1	62.2	3.7
		A	12.3			
		B	7.3	26.7	69.3	4.0
		C	12.4			

Table 2

ENGINEERING PROPERTIES

Sample	Material	Specific Gravity	Permeability (cm/sec)	Maximum Dry Density (pcf)	Optimum Moisture Content (%)	ϕ (°)	C_c	C_v (sq in/min)	CBR
S-1	Bottom Ash	2.87	2.5×10^{-1}	115.6	15.7	37	0.04	0.08	25.7
S-2	Bottom Ash	2.80	NT[1]	111.9	15.0	NT	NT	NT	NT
S-3	Bottom Ash	2.47	1.5×10^{-1}	95.8	20.8	33	0.13	0.20	18.9
S-4	Bottom Ash	2.46	NT	97.7	19.5	NT	NT	NT	NT
S-5	Bottom Ash	2.43	9×10^{-2}	91.9	23.6	33	0.10	0.20	18.6

(1) NT - not tested.

Table 3

CHEMICAL ANALYSES

Sample	pH[1]	Loss on Ignition (%)	Total Sulfur (%)	Pyritic Sulfur (%)	Redox[1] (mV)	Resistivity (ohm-cm)
S-1	8.8	< 0.02	0.09	< 0.01	- 902	17,521
S-2	8.9	< 0.02	0.08	< 0.01	- 908	19,817
S-3	8.1	< 0.02	0.12	< 0.01	- 605	2,017
S-4	8.1	< 0.02	0.95	< 0.01	- 475	2,094
S-5	8.2	< 0.02	0.10	< 0.01	- 570	2,809

[1] 1:1 As-received sample and distilled water by volume.

Table 4

INDIANA ADMINISTRATIVE CODE (IAC)
RESTRICTED WASTE SITE TYPE CRITERIA
AND SCHAHFER POND ASH LEACHATE

Parameter	Concentrations (milligrams per liter)			
	IAC		Schahfer	
	Type IV	Type III	S-1	S-4
(1) For Parameters Using the EP Toxicity Test:[1]				
Arsenic	≤ 0.05	≤ 0.5	< 0.002	< 0.002
Barium	≤ 1	≤ 10	< 0.10	< 0.10
Cadmium	≤ 0.01	≤ 0.1	0.029	0.049
Chromium	≤ 0.05	≤ 0.5	< 0.05	< 0.05
Lead	≤ 0.05	≤ 0.5	< 0.10	0.21
Mercury	≤ 0.002	≤ 0.02	< 0.0002	< 0.0002
Selenium	≤ 0.01	≤ 0.1	< 0.002	< 0.002
Silver	≤ 0.05	≤ 0.5	< 0.001	< 0.001
(2) For Parameters Using the Leaching Method Test:				
Barium	≤ 1	≤ 10	< 0.10	< 0.10
Boron	≤ 2	≤ 20	1.00	1.00
Chlorides	≤ 250	≤ 2,500	1.04	1.23
Copper	≤ 0.25	≤ 2.5	< 0.02	< 0.02
Cyanide, Total	≤ 0.2	≤ 2	< 0.005	< 0.005
Fluoride	≤ 1.4	≤ 14	< 0.10	< 0.10
Iron	≤ 1.5	≤ 15	0.09	0.06
Manganese	≤ 0.05	≤ 0.5	< 0.01	< 0.01
Nickel	≤ 0.2	≤ 2	< 0.04	< 0.04
Phenols	≤ 0.3	≤ 3	< 0.005	< 0.005
Sodium	≤ 250	≤ 2,500	1.12	1.27
Sulfate	≤ 250	≤ 2,500	2.17	15.3
Sulfide, Total	≤ 1[2]	≤ 5	1.00	1.00
Total Dissolved Solids	≤ 500	≤ 5,000	304	260
Zinc	≤ 2.5	≤ 25	0.009	0.011
pH (Standard Units)	6 - 9	5 - 10	8.8	8.0

(1) IDEM allows EP toxicity test or TCLP test - TCLP test performed on Schahfer pond ash.

(2) If detection limit problems exist, please consult the Office of Solid and Hazardous Waste for guidance.

Source: Indiana Administrative Code, 329 IAC 2-9-3 and personal communication with the IDEM Solid Waste Management Branch, September 1992 and GAI laboratory data.

Table 5

MOISTURE CONTENT AND DENSITY TEST RESULTS
U.S. ROUTE 12

Lift[1]	Station	Offset (ft)	Troxler Wet Density (pcf)	Dry[2] Density (pcf)	Moisture Content (%)					Speedy Apparatus Number
					Troxler Six-Inch	Troxler Back-Scatter	Conventional Oven	Microwave Oven	Speedy Reading	
1	55+50	52R	115.8	101.2	5.7	6.5	14.4	13.3	-	-
2	56+00	52R	116.1	100.7	6.4	5.7	15.3	15.0	9.0	1
3	55+10	40R	107.1	95.6	5.4	4.8	12.0	9.2	6.9	1
4	56+90	50R	123.3	107.9	6.7	7.0	14.3	16.7	-	-
9	55+55	40R	109.2	98.0	3.7	-	11.4	10.9	9.0	2
9	56+20	40R	108.5	97.4	4.3	-	11.4	11.4	11.2	2
11	56+70	40R	115.6	102.2	5.1	4.9	13.1	12.1	11.1	2
13	56+00	50R	117.4	103.3	5.4	5.4	13.7	12.2	11.5	2
14	56+50	45R	108.5	97.5	4.2	4.2	11.3	10.6	8.2	2
16	55+50	50R	120.7	105.2	6.8	6.3	14.7	13.5	10.3	2
17	55+50	55R	112.7	100.5	5.0	4.9	12.1	11.3	-	-
19	55+75	50R	113.1	105.8	2.2	2.5	6.9	7.1	6.6	2
19	56+40	50R	116.0	103.3	4.4	4.1	12.3	11.0	11.0	2
	54+90	15R	126.5	109.7	5.8	6.2	15.3	14.1	12.5	2
24	56+60	10R	119.4	96.1	10.7	10.7	24.3	21.3	18.2	2

(1) Lift 17 was the first lift over the old roadbed.

(2) Dry density = Troxler wet density ÷ (1 + conventional oven moisture content [percent]/100)

Table 6

ONE-POINT AASHTO T99 DENSITY TEST RESULTS
U.S. ROUTE 12

Date	Troxler Wet Density (pcf)	Conventional Oven Moisture Content (%)	One-Point AASHTO T99 Dry Density (pcf)	Compaction Curve (see Figure 3)	Maximum Dry Density (pcf)	Minimum Acceptable Dry Density (95% of Maximum Dry Density) (pcf)
07/21/94	103.2	13.9	90.6	S-3	95.8	91.0
	103.8	13.3	91.6	S-3	95.8	91.0
	108.9	14.0	95.5	S-4	97.7	92.8
	106.5	15.7	92.0	S-3	95.8	91.0
07/25/94	107.1	14.9	93.2	S-3	95.8	91.0
07/27/94	105.9	16.9	90.6	S-5	92.0	87.4
07/28/94	108.6	15.7	93.9	S-3	95.8	91.0
07/29/94	106.8	12.2	95.2	S-4	97.7	92.8
	100.8	7.1	94.1	S-4	97.7	92.8
08/01/94	109.8	12.2	97.9	S-12	100.0	95.0
08/02/94	112.8	14.8	98.3	S-12	100.0	95.0
09/09/94	110.4	15.3	95.8	S-4	97.7	92.8

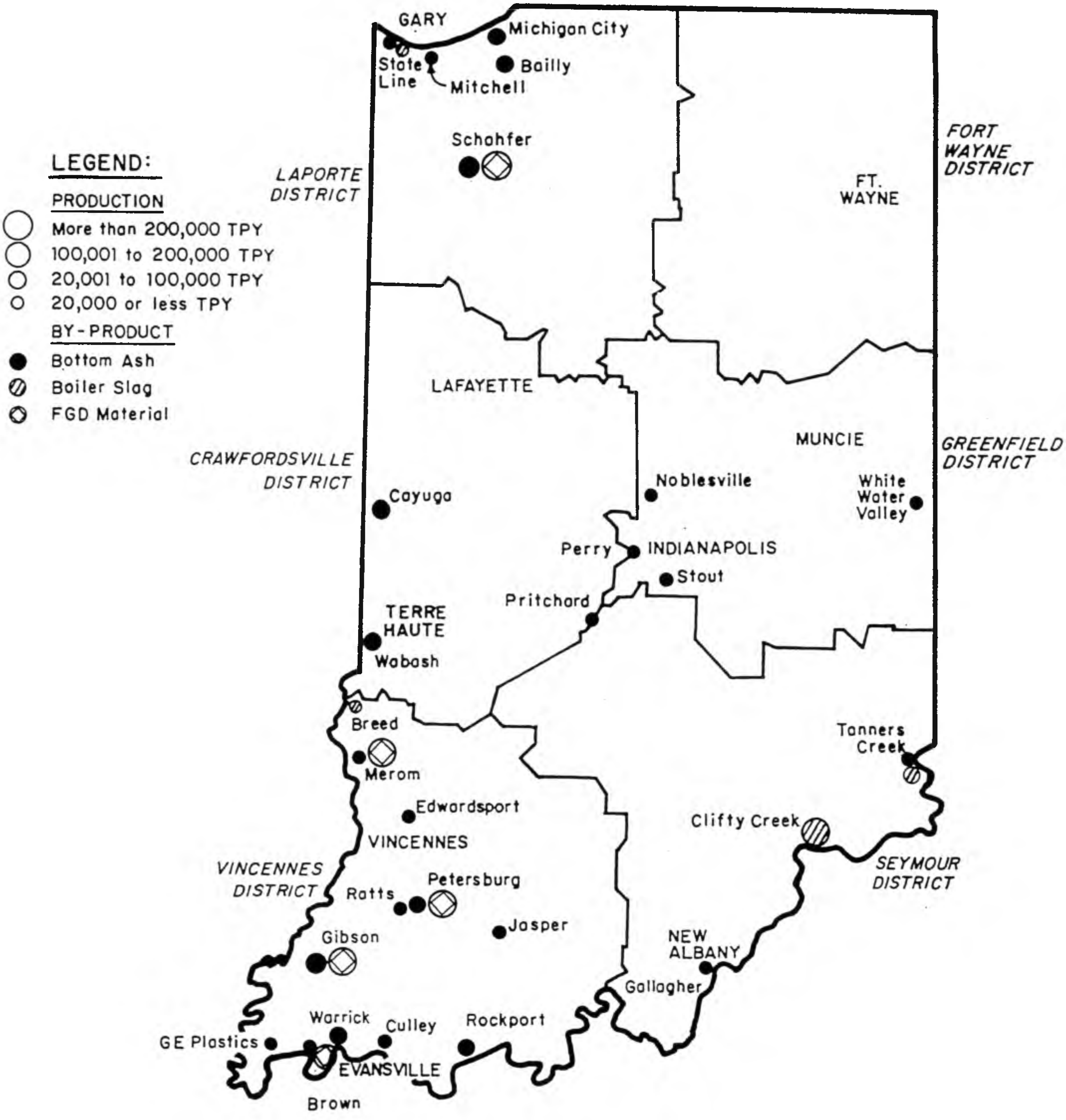

FIGURE 1

INDIANA

BOTTOM ASH, BOILER SLAG AND FGD MATERIAL PRODUCTION

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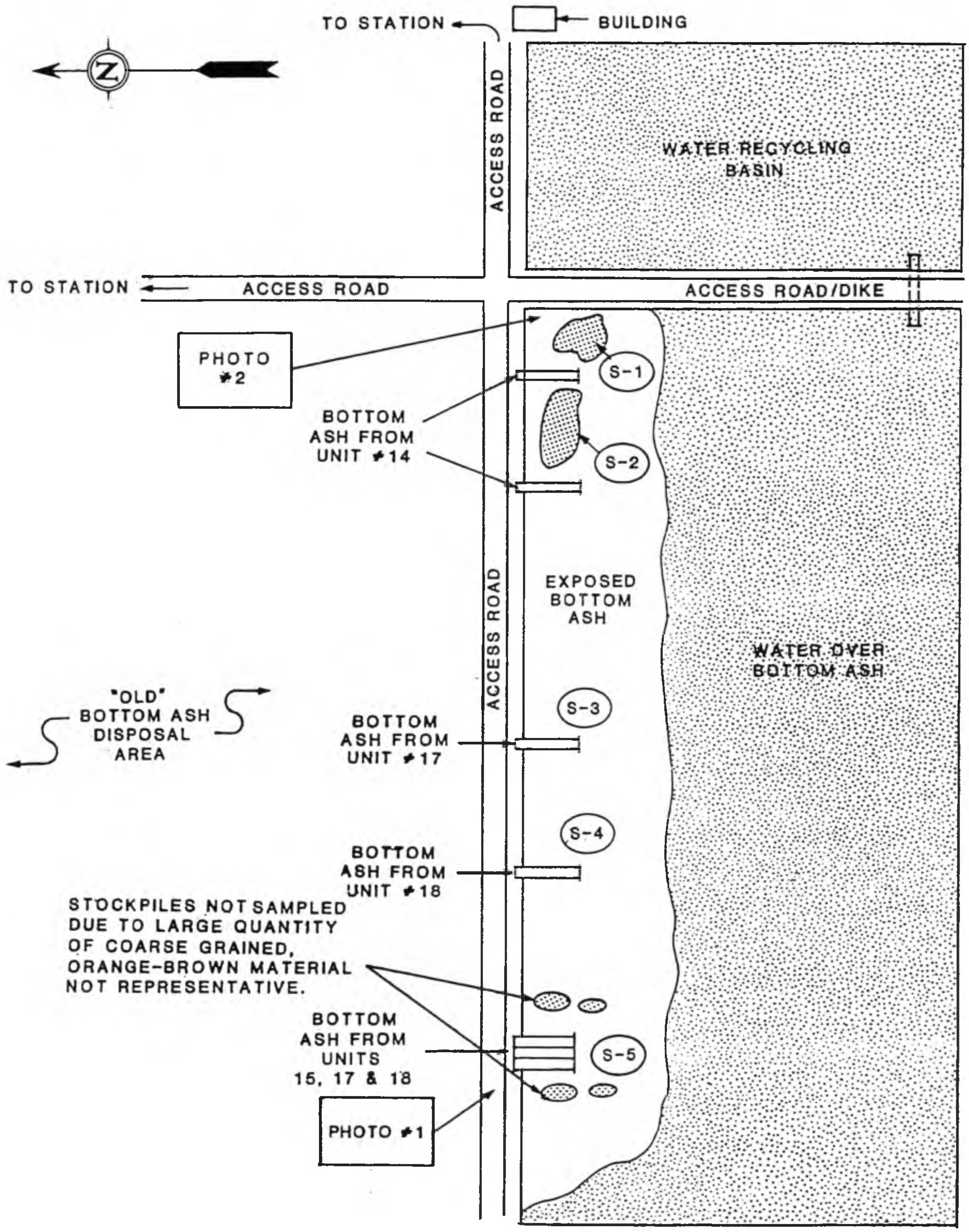

FIGURE 2

SKETCH OF ASH STORAGE AREA (POND)
WITH SAMPLING LOCATIONS
AT SHAHFER GENERATING STATION

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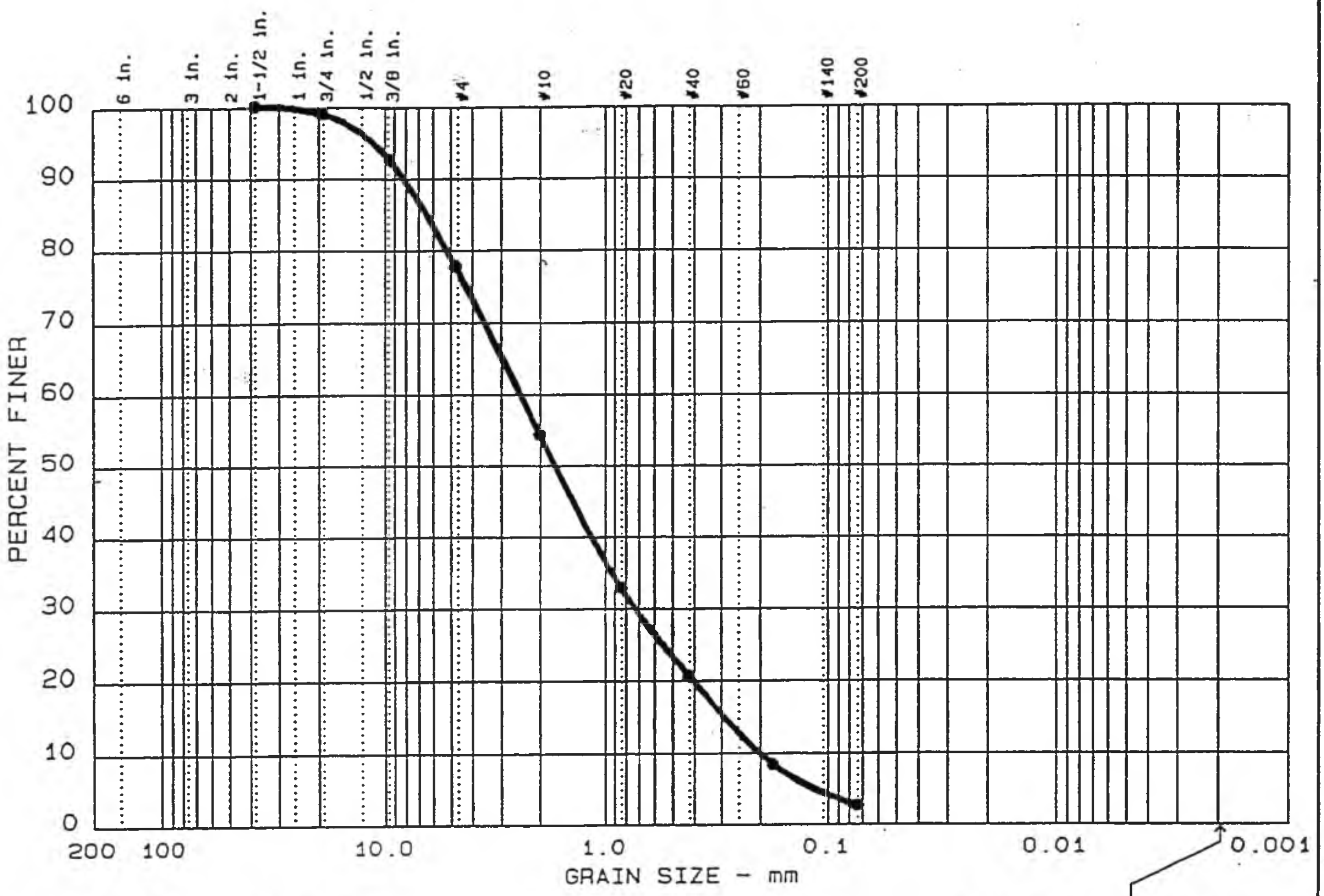

	Test	% +3"	% GRAVEL	% SAND	% SILT	% CLAY
●	15	0.0	22.2	75.1	2.7	

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
●			6.38	2.45	1.70	0.724	0.2884	0.2018	1.06	12.2

FIGURE 3

GRAIN SIZE DISTRIBUTION OF BOTTOM ASH

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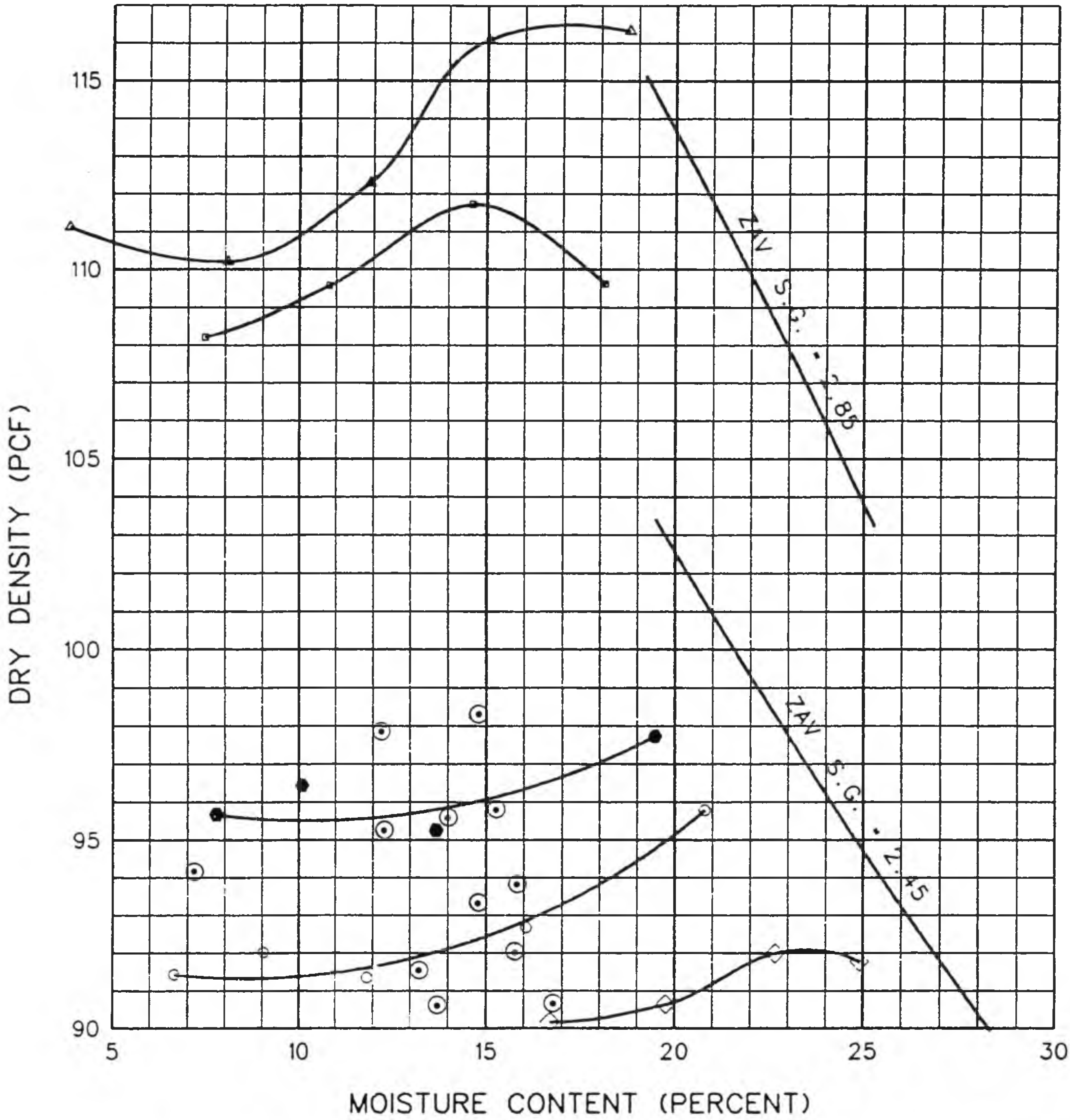

△ S-1 - BOTTOM ASH S.G. = 2.87
▫ S-2 - BOTTOM ASH S.G. = 2.80
○ S-3 - BOTTOM ASH S.G. = 2.47
● S-4 - BOTTOM ASH S.G. = 2.46
◇ S-5 - BOTTOM ASH S.G. = 2.43
⊙ ONE-POINT AASHTO T99

FIGURE 4

MOISTURE-DENSITY RELATIONSHIP OF BOTTOM ASH

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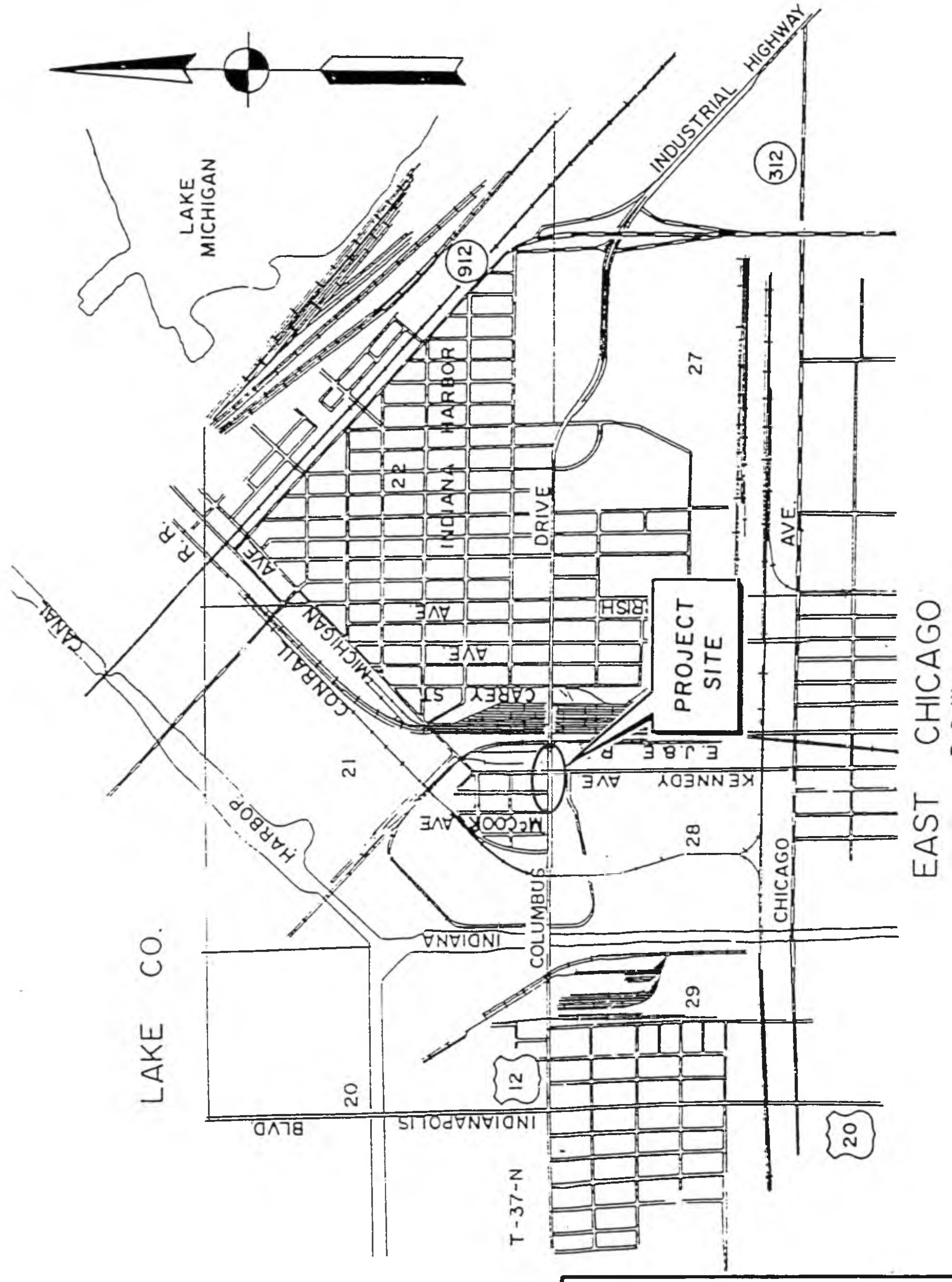

FIGURE 5

SITE LOCATION
U.S. 12 (COLUMBUS DRIVE)

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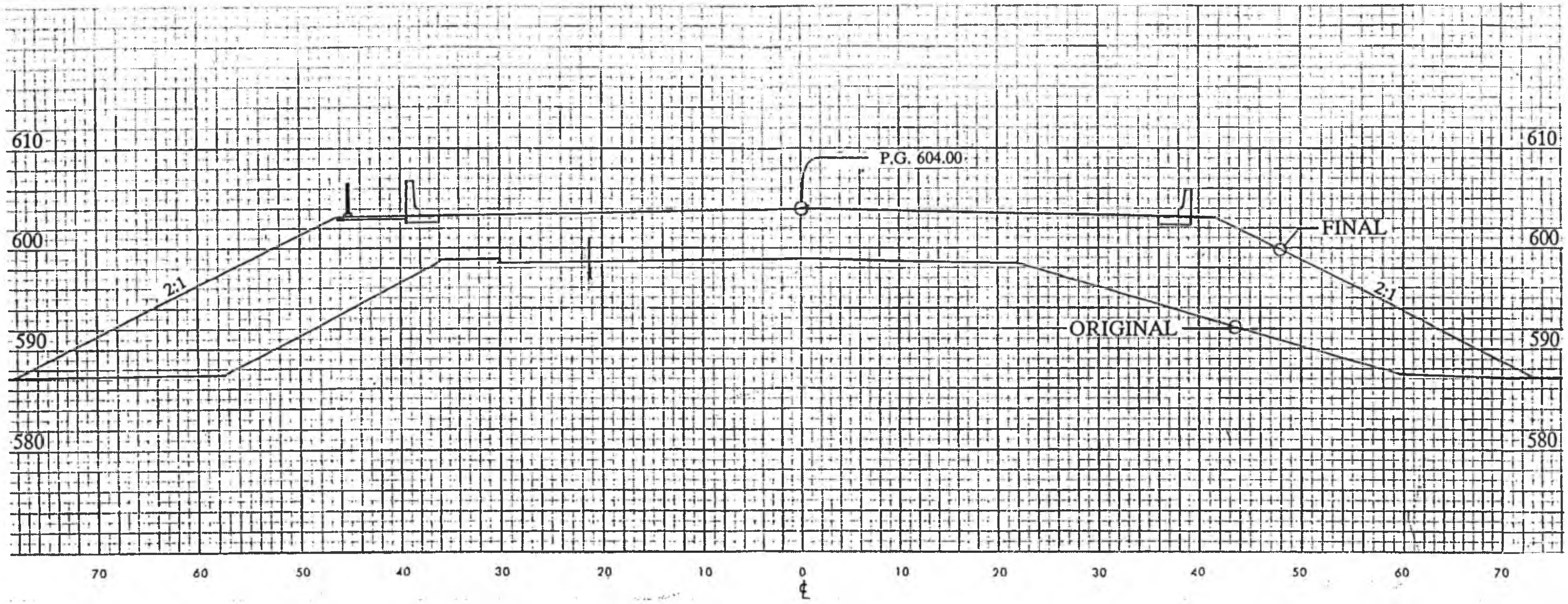

FIGURE 6

TYPICAL CROSS-SECTION,
EMBANKMENT WIDENING/RAISING U.S. 12

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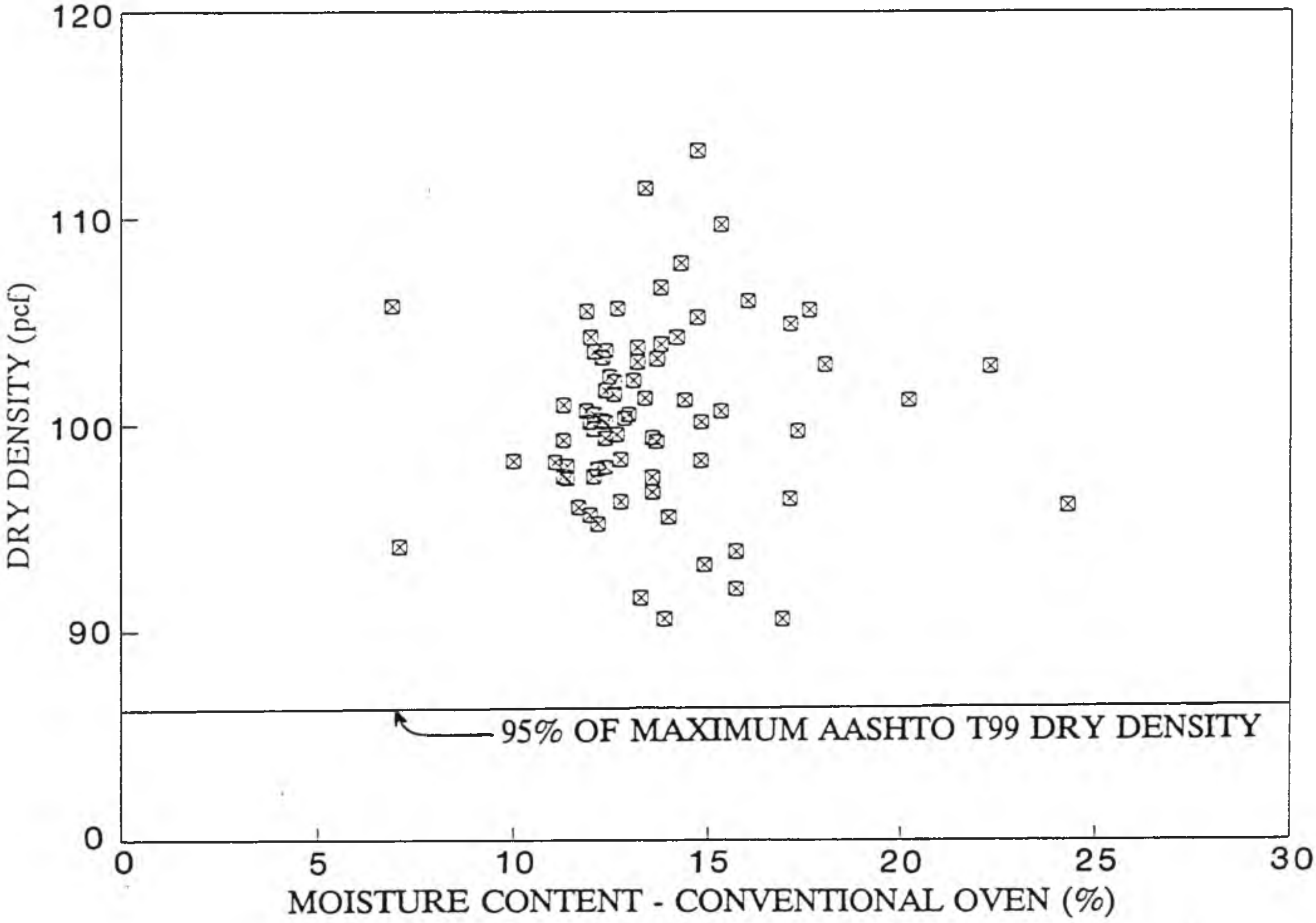

FIGURE 7

DRY DENSITY VS. MOISTURE CONTENT
(CONVENTIONAL OVEN)
FOR FIELD TESTING

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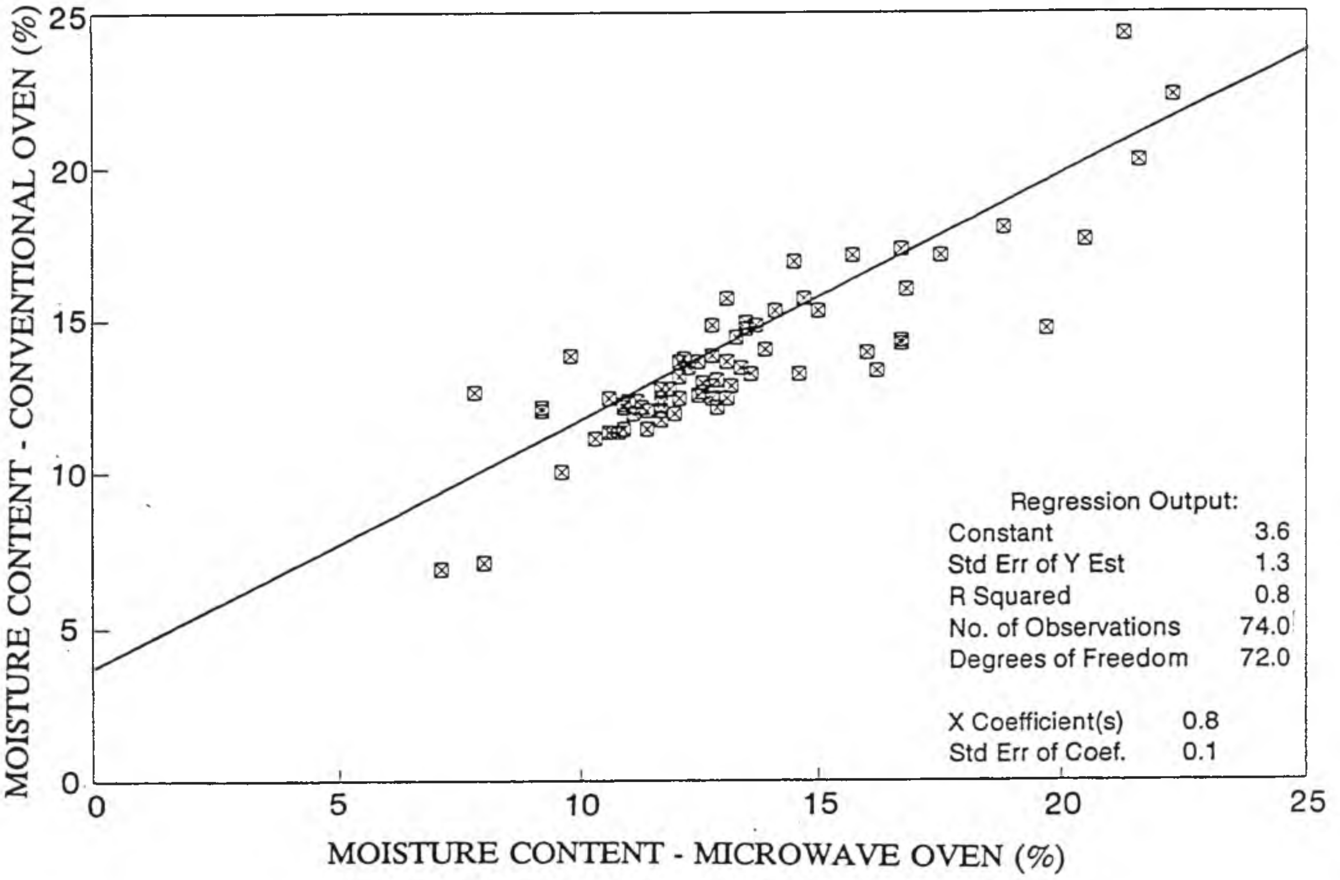

FIGURE 8

MOISTURE CONTENTS,

CONVENTIONAL OVEN
VS.
MICROWAVE OVEN

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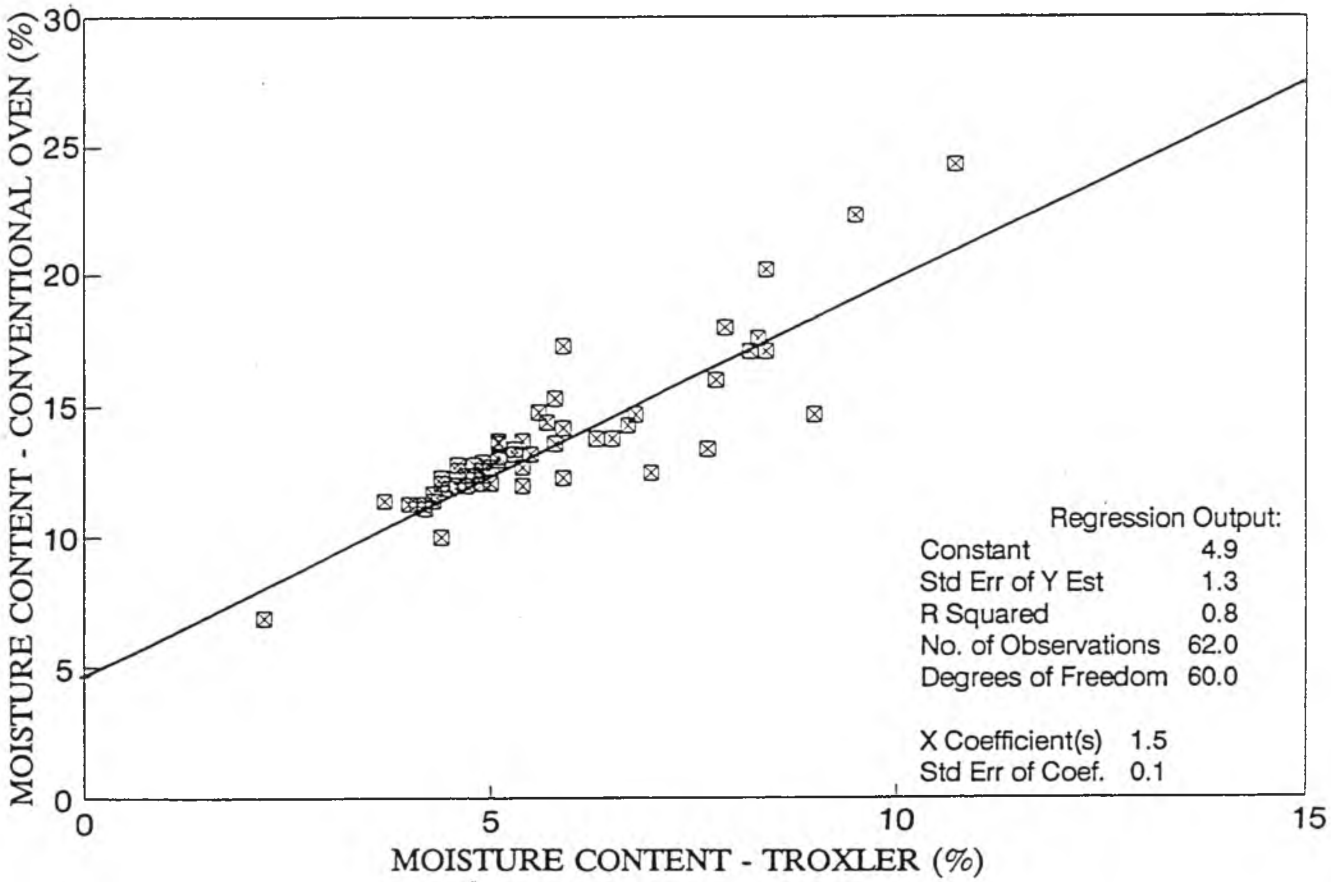

FIGURE 9

MOISTURE CONTENTS,

CONVENTIONAL OVEN
VS.
TROXLER NUCLEAR GAGE

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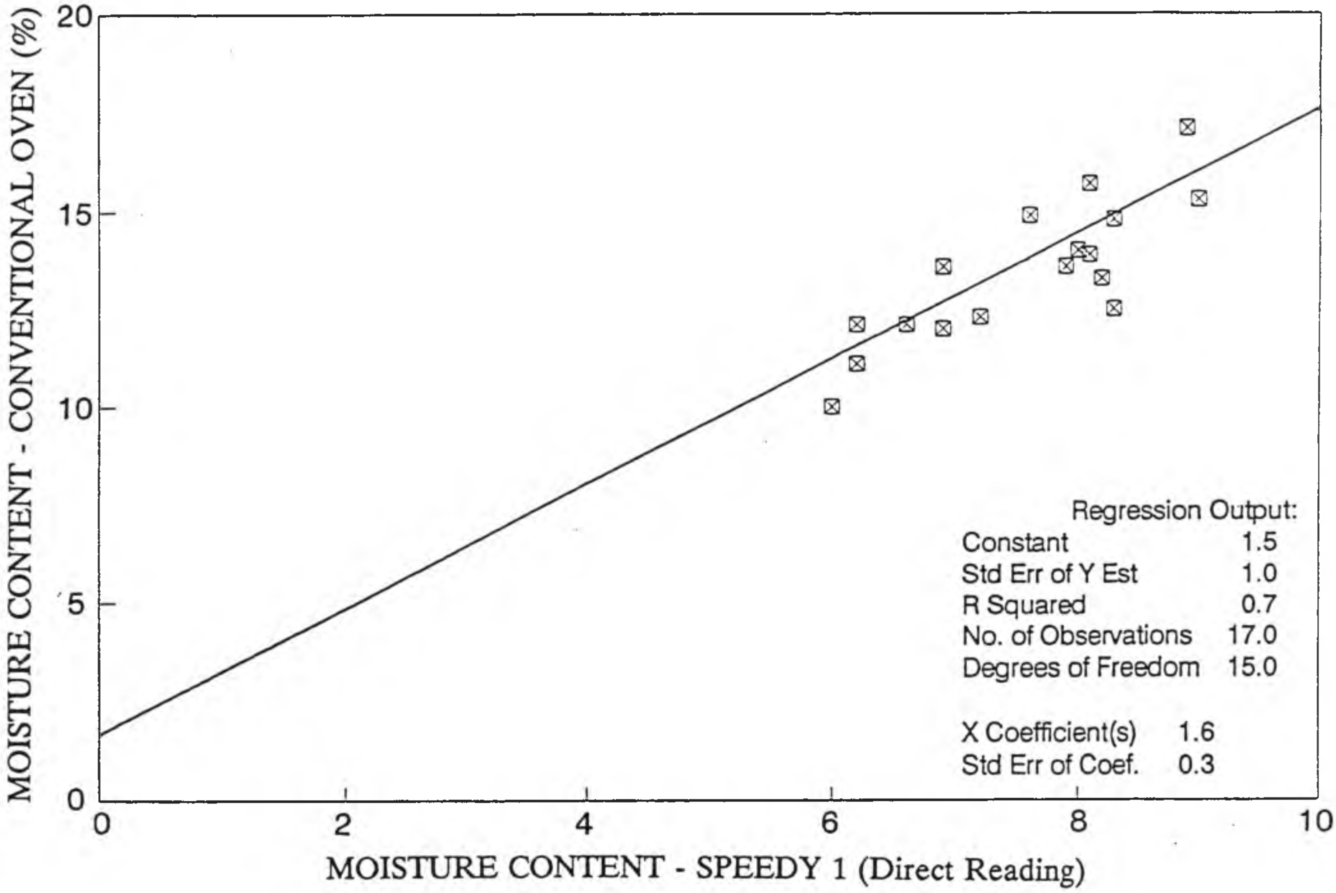

FIGURE 10

MOISTURE CONTENTS,

CONVENTIONAL OVEN
VS.
SPEEDY 1 (DIRECT READING)

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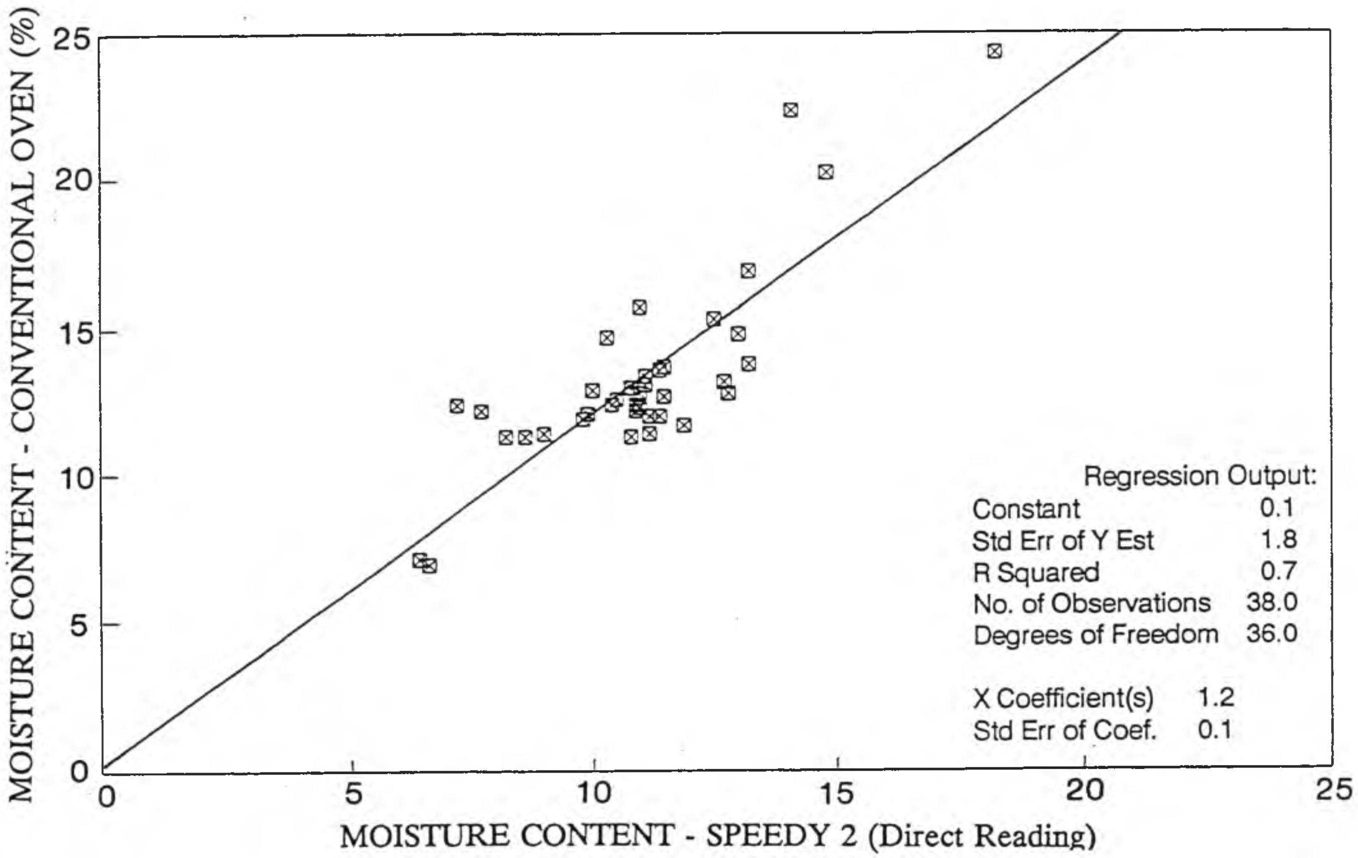

FIGURE 11

MOISTURE CONTENTS,

CONVENTIONAL OVEN
VS.
SPEEDY 2 (DIRECT READING)

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