RECYCLED MATERIALS IN VERTICAL MOISTURE BARRIERS

PHASE II STUDY REPORT OF UTEP

Research Study No. "0-1354"

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September 1995

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INTRODUCTION

Various highway agencies have faced the problems of premature pavement deterioration due to shrinkage and swelling of subgrade soils. The shrinkage and swelling of the subgrade soil occurs due to the movement of water in and out of the soil. To prevent this movement of water, an impermeable layer (geomembrane) has been used by highway agencies on the sides of the road commonly known as a "Vertical Moisture Barrier". Vertical moisture barriers have been proven to be an effective means of reducing pavement deterioration's.

Most of the time the need for a vertical moisture barrier arises after the pavement has been in service for a while. The vertical moisture barriers are commonly constructed enclosing the existing pavements by digging a trench of 4 in. to 12 in. wide on both sides of the road and then placing the geomembrane inside the trench. Since the geomembranes are thin as compared to the width of the trench, the remaining area is filled commonly with granular material. The granular backfill material doesn't have much strength and eventually leads to the shear failures of the highways due to the traffic movement. Thus a stronger material that can support the pressure exerted on the trench backfill material can improve the performance of the barrier.

Another problem faced by the country is the safe disposal of toxic/hazardous waste produced by various industries throughout the country. These two needs justified the need of the present research project. The objective of this project was to identify waste products, evaluate the feasibility of its safe usage as a vertical moisture barrier and develop guidelines/specifications for usage by TxDOT. The project was divided in three phases: **Phase I,** Comprehensive literature review and identification of waste material, **Phase II,** Evaluation of identified waste material, and **Phase III,** Development of guidelines and specifications for the usage of recycled material as a vertical moisture barrier.

The first phase of the project was completed in February, 1995 and a meeting was held between the project director and the principal investigators. In this meeting, it was decided to

evaluate flyash, waste plastic, and recycled rubber as a backfill material in vertical moisture barrier. UTEP's task was to evaluate flyash as a filler for vertical moisture barriers.

The purpose of this report is to submit the findings of the second phase work performed at UTEP. The flyash was mixed with different proportions of cement, sand, and water to form a mortar and then this mortar was evaluated in terms of it's compressive strength, mobility of heavy metals, permeability, and shrinkage potential. Various proportions of flyash, cement, sand, and water were used in an attempt to select the best proportion that can be economically used in the field.

OBJECTIVE OF THE STUDY

The objective of the study (Phase II) was to evaluate the economical usage of flyash as a backfill material in the vertical moisture barrier. Mainly flyash was evaluated in terms of its strength, permeability, shrinkage potential, and mobility of heavy metals present in the flyash.

RESEARCH SCOPE

This study was limited to the following conditions:

1. Only one type of flyash i.e. "Flyash Type C", from a single source was evaluated in this study.
2. Mobility of only one heavy metal, Barium, was evaluated. No other heavy metals like arsenic, or lead were evaluated.
3. The study was limited to three levels of cement, three ratios of flyash sand, and two levels of water content.
4. All the specimens were tested after 28 days of curing. Due to time constraints, the curing was reduced from 28 days to 7 days by using hot water bath. However, the effect of using hot water bath on various properties of flyash-cement mortar was not evaluated as a part of this study.

EXPERIMENT DESIGN

The flyash was used as a replacement of cement as well as sand in a flyash-cement mortar system. Three levels of cement were used in this analysis 3, 5 and 7% (by weight). Three percent of the cement was used because the mortar was not workable below 3% cement. A maximum of 7% of cement was selected based on cost considerations. Three levels of flyash to sand ratios: 25/75, 50/50, and 75/25 were selected to cover the possible range of ratios with minimum number of laboratory tests. Two levels of water i.e. water-cement ratios 3 and 3.25 were selected because below 3, the mortar was not workable and above 3.25 the mortar was too fluid to prepare specimen. Only two water-cement ratios of 3 and 3.25 were used because of the time constraints imposed by the project. In total 18 specimens were required for each test.

The following tests were performed to evaluate the flyash cement sand mortar: 1) compressive strength test, 2) permeability test, 3) length change test, 4) acid digestion of sludge's and atomic absorption test, and 5) leaching tests. Description of the test methods is given in the following section.

LABORATORY TEST METHODS

The laboratory tests used in the evaluation of flyash-cement mortar are described in this section. All of the selected test methods were standard test procedures. Some steps of the test procedures were changed and these changes are described along with each test procedure.

COMPRESSIVE STRENGTH TEST

The compressive strength tests were performed as per the ASTM standard C-109-84. In total, 18 specimens were prepared for compressive strength test. All the standard test procedures were followed except for the two conditions. As per the ASTM standard, the specimen should be prepared in a 2 in. cube mold while the specimen for this test was prepared

in a cylindrical mold of size 3 in.(diameter) by 6 in.(height). The other difference was of the curing process. The specimen was cured in a water bath at 142 ° F for 7 days rather than being cured in humidity chamber for 28 days. This step was necessary to reduce the curing time.

PERMEABILITY TEST

The permeability test was performed on the specimen as per Corps of Engineers Standard CRD-C 163-92 (2). This test was performed to find the permeability as well as porosity of the mortar. The permeability test was performed following this standard with one exception. The deviation was the application of driving pressure, the driving pressure was applied directly to the water rather than using a gas water accumulator. The effect of applying the driving pressure directly to the water was also not evaluated.

LENGTH CHANGE TEST

The length change tests were performed as per ASTM standard C-157-89. This test was done to observe the change in length of the flyash-sand-cement mortar during the curing period. This test is not designed to find the coefficient of expansion or contraction of the mortar. The test results obtained from this test reflect the amount of expansion or contraction a mortar would have, after placing the mortar as a backfill material. This specimen was also placed in water bath for 7 days at 142 ° F for faster curing. Another deviation from standard test was that water bath consisted of regular tap water rather than lime saturated water. The effect of tap water was not evaluated as part of this research but may be evaluated as a part of the future research.

ACID DIGESTION OF SLUDGES AND ATOMIC ABSORPTION TEST

The literature review of flyash indicated that the flyash contains heavy metals. Gupta and Ray (2) indicated that the flyash contains heavy metal elements like Barium, Lead, Arsenic,

Mercury etc. in detectable quantities. Although the quantity of these of elements is quite small in flyash, still some of the elements are considered to be hazardous by EPA (3). The acid digestion of sludges procedure was performed on the flyash to prepare sludge samples that can be used by atomic absorption test. The atomic absorption test was performed to determine the concentration of barium in the flyash. The barium element was selected arbitrarily, since existing literature indicates that it is one of the most abundant. The acid digestion of sludges was performed as per EPA method 3050 (4) and the atomic absorption test was performed as per the EPA method 7080 (5). The test was performed exactly as per the EPA procedure.

EXTRACTION PROCEDURE TOXICITY TEST METHOD

This test was performed as per the EPA standard test method 1310A (6). This test was performed to find out the potential for leaching of the heavy metals from the mortar in the worst possible conditions. The test was performed exactly as outlined in the test procedure.

TEST RESULTS AND DISCUSSIONS

All the specimens were prepared using Type I cement, Type C flyash, and river sand. Laboratory moisture content and saturated surface dry specific gravity of sand was determined for calculating the actual amount of water required for water cement ratios. Table 1 shows different proportions of cement, sand, flyash, and water used for preparing all the specimens. In total 18 specimens were needed for each test to cover all the combinations of different proportions.

COMPRESSIVE STRENGTH TEST RESULTS

Results of the compressive strength tests are given in Table 2 and summarized in Figure 1. Minimum compressive strength was observed in specimens with 3% cement, 75/25 flyash to sand ratio for both water-cement ratios. All the specimens prepared using 3% cement

Table 1. Component Weigths of all Test Mixes

a.) Component Weights of Mixes Used In Shrinkage, Permability and Leaching Tests

Percent of Cement	Flyash Sand Ratio	Cement (lbs.)	Sand (lbs.)	Flyash (lbs.)	Water (3.00) (lbs.)	Water (3.25) (lbs.)
3	25/75	0.027	0.663	0.221	0.086	0.093
	50/50	0.027	0.442	0.442	0.085	0.091
	75/25	0.027	0.221	0.663	0.083	0.090
5	25/75	0.046	0.650	0.217	0.141	0.152
	50/50	0.046	0.433	0.433	0.139	0.151
	75/25	0.046	0.217	0.649	0.138	0.149
7	25/75	0.064	0.636	0.212	0.195	0.211
	50/50	0.064	0.424	0.424	0.194	0.210
	75/25	0.064	0.212	0.636	0.193	0.209

b.) Components Weights of Mixes Used In Compressive Strength Test

Percent of Cement	Flyash Sand Ratio	Cement (lbs.)	Sand (lbs.)	Flyash (lbs.)	Water (3.00) (lbs.)	Water (3.25) (lbs.)
3	25/75	0.2325	5.6378	1.8793	0.7311	0.7893
	50/50	0.2325	3.7585	3.7585	0.7199	0.7780
	75/25	0.2325	1.8793	5.6378	0.7087	0.7668
5	25/75	0.3875	5.5215	1.8405	1.1954	1.2923
	50/50	0.3875	3.681	3.681	1.1844	1.2813
	75/25	0.3875	1.8405	5.5215	1.1734	1.2703
7	25/75	0.5425	5.4056	1.8019	1.6598	1.7954
	50/50	0.5425	3.6038	3.6038	1.649	1.785
	75/25	0.5425	1.8019	5.4056	1.6383	1.7739

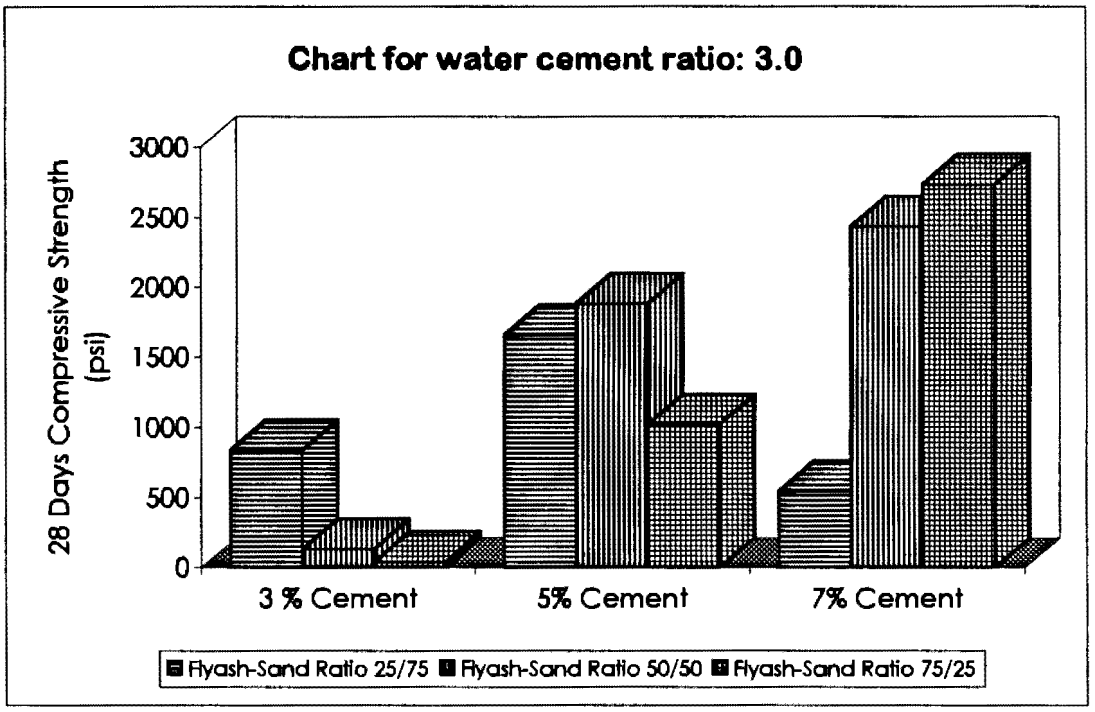
Table 2. Compressive Strength of Flyash-Sand-Cement Mortar

a. for Water-Cement Ratio of 3.00

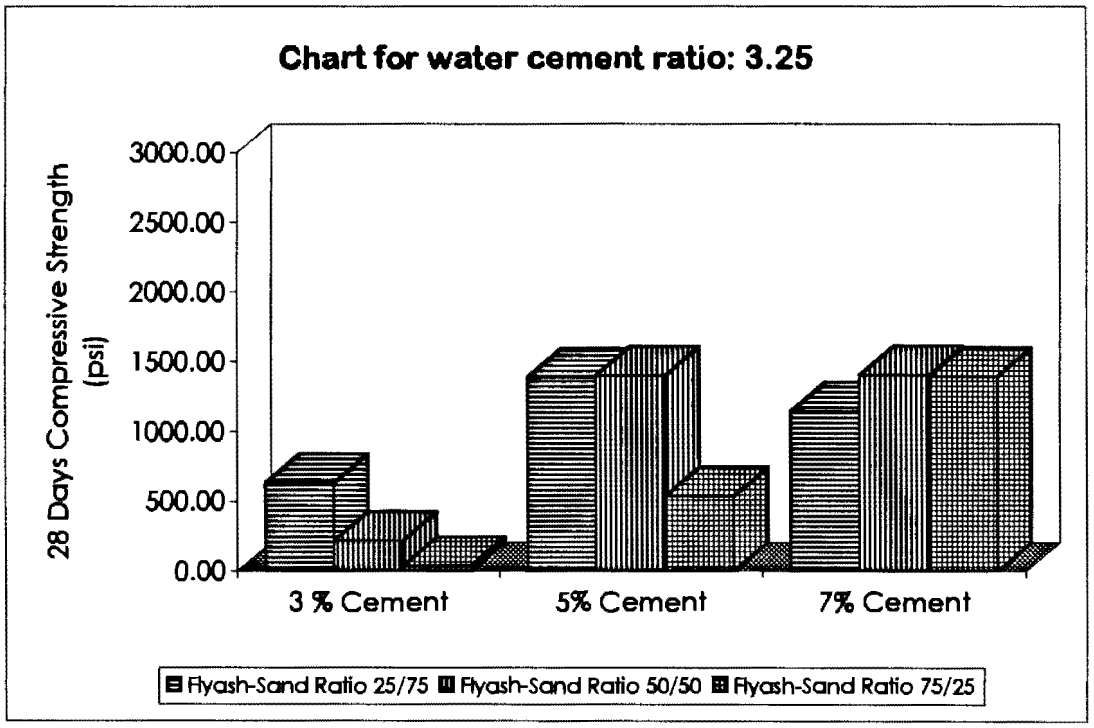
Flyash Sand Ratio	3 % Cement	5% Cement	7% Cement
25/75	838.53	1654.39	545.33
50/50	130.31	1881.02	2436.26
75/25	39.66	1019.83	2736.54

b. for Water-Cement Ratio of 3.25

Flyash Sand Ratio	3 % Cement	5% Cement	7% Cement
25/75	631.73	1388.10	1144.48
50/50	218.13	1399.43	1405.10
75/25	37.54	538.24	1396.60



a. For Water-Cement Ratio of 3.00



b. For Water-Cement Ratio of 3.25

Figure 1. Compressive Strength of Flyash-Sand-Cement Mortar

were difficult to work with and were breaking apart while taking out of the mold or while moving them to perform the compressive strength test. Most of the specimens prepared using 5 or 7 % cement showed good compressive strength capabilities except for two specimens; one specimen consisting of 5% cement, 75/25 flyash-sand ratio and water-cement ratio of 3.25 and the other specimen consisting of 7% cement, 25/75 flyash-sand ratio and water-cement ratio of 3. For both specimens to new replicates were prepared and tested again and the results were the same. The specimens that showed higher compressive strength were prepared with 7% cement, 50/50 flyash-sand ratios or higher and water-cement ratio of 3, as shown in Figure 1. If the proportions needed to be chosen solely on the basis of workability and compressive strength, the proportions would be 7% cement, 75/25 flyash-sand ratio and a water-cement ratio of 3. This proportion will also be good, from a recycling point of view, since maximum use of flyash can be accomplished.

PERMEABILITY TEST RESULTS

The complete set of permeability test results are given in Appendix A and a sample of the data obtained is shown in Table 3 and Figure 2. Table 3 shows the permeability test performed on a specimen prepared with 3% cement, 75/25 flyash-sand ratio, and water-cement ratio of 3.00. As per the test procedure the permeability test needs to be done until the ratio of incremental volume and incremental time becomes linear. This step is necessary to ensure steady state flow through the specimen. Figure 2 shows that at the beginning the ratio was nonlinear but after 8,000 sec. of testing the specimen achieved a steady state condition. The permeability of all the tests are summarized in Table 4 and Figure 3. The permeability varied from 1E-5 to 1E-9 cm/sec. The minimum permeability of 3.7E-9 cm/sec was observed in the specimens prepared with 5% cement, 75/25 flyash-sand ratio, and water-cement ratio of 3.00 while the maximum permeability of 1.47E-5 cm/sec was observed in the specimens prepared with 3% cement, 75/25 flyash-sand ratio, and water-cement ratio of 3.00. The specimens prepared with 5% or 7% cement showed lower permeability's especially with water-cement ratios of 3.00. The lower permeability mortar should be used as a backfill material because it

Table 3. Permeability of Specimen Consisting of 3% Cement, 75/25 Flyash-Sand Ratio with Water-Cement Ratio of 3.00

Specimen Id 18 Date of Experiment: 8/17/95 File Name: SPCMN18

Cement: 3% Flyash 72.78% Sand 24.25% Water/Cement: 3

Avg. Dia. of Spec.(cm):(7.2567 7.2644 7.2898)/3 7.27 cm

Avg. ht. of Spec.(cm): (7.2898 7.2898 7.2898)/3 7.29 cm

Crossectional Area of Specimen: 41.51 sqcm

Viscosity of Water : 9.33E-04 Pa-S Density of Water : 1.00 g/cm^3

Confining Pressure : 344.74 KPa Driving Pressure (P) : 275.79 KPa

Atm. Pressure (Pa) : 101.33 KPa Pressure Gradient (delta P): 174.47 KPa

Sat. Surface Dry Wt. of Specimen: 580.80 g. Dry Wt. of Specimen: 480.80 g

Submerged Unit Wt.of Specimen : 286.20 g.

Reading No.	Time Elapsed (sec)	Incremental Time (sec)	Total Volume	Incremental Vol. Collected (ml)	Intrisic Permeability(sqcm	Hydraulic Conductivity (cm/sec)
1	0	0	0	0		
2	5	5	9.5	9.5	1.78326E-09	1.7476E-05
3	10	5	17.5	8	1.50169E-09	1.47166E-05
4	15	5	25.5	8	1.50169E-09	1.47166E-05
5	20	5	33.5	8	1.50169E-09	1.47166E-05
6	25	5	41.4	7.9	1.48292E-09	1.45326E-05
7	30	5	49.3	7.9	1.48292E-09	1.45326E-05
8	35	5	57.3	8	1.50169E-09	1.47166E-05
9	40	5	65.2	7.9	1.48292E-09	1.45326E-05
10	45	5	73.2	8	1.50169E-09	1.47166E-05

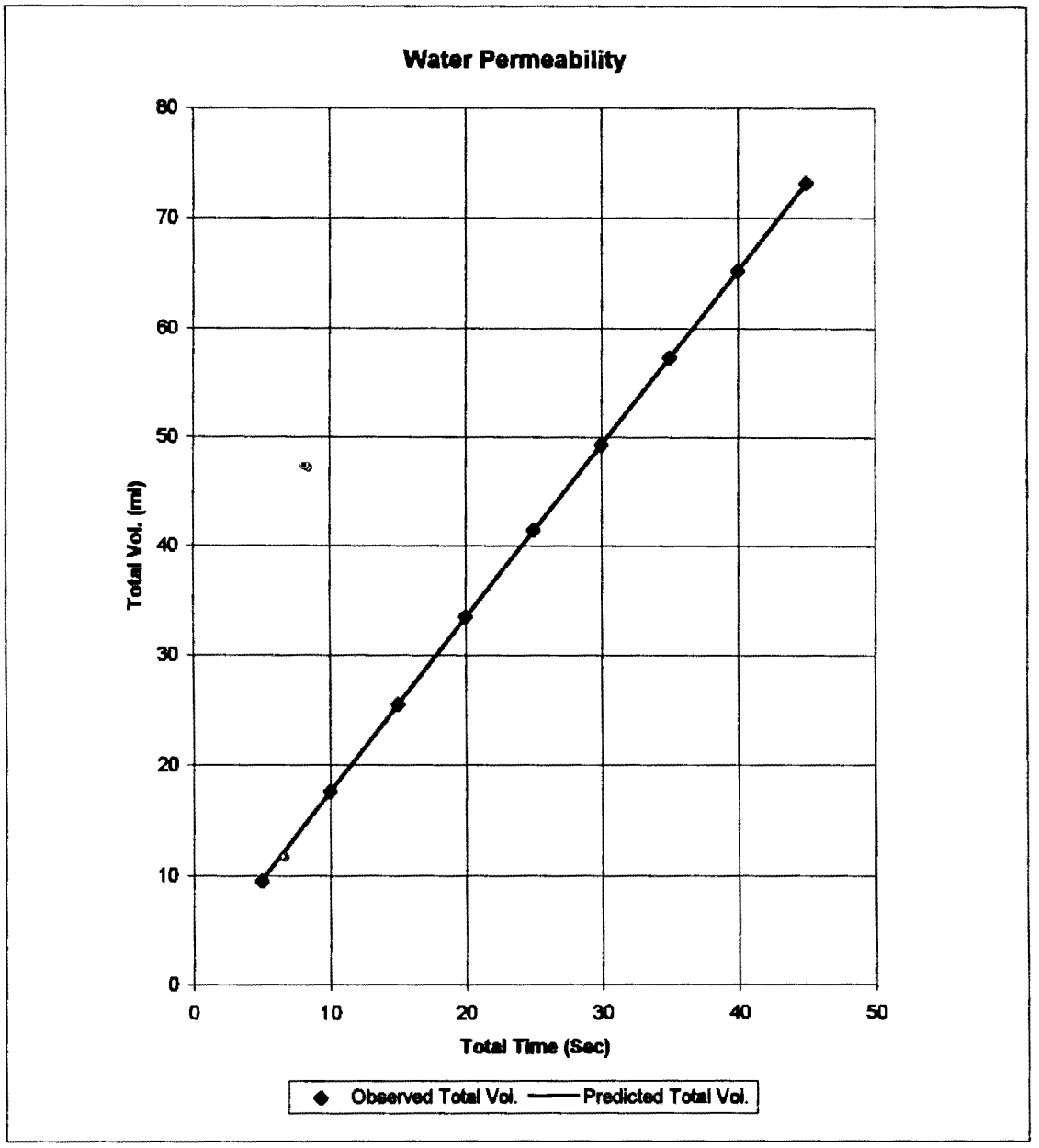


Figure 2. Permeability of Specimen Consisting of 3% Cement, 75/25 Flyash-Sand Ratio With Water-Cement Ratio of 3.00

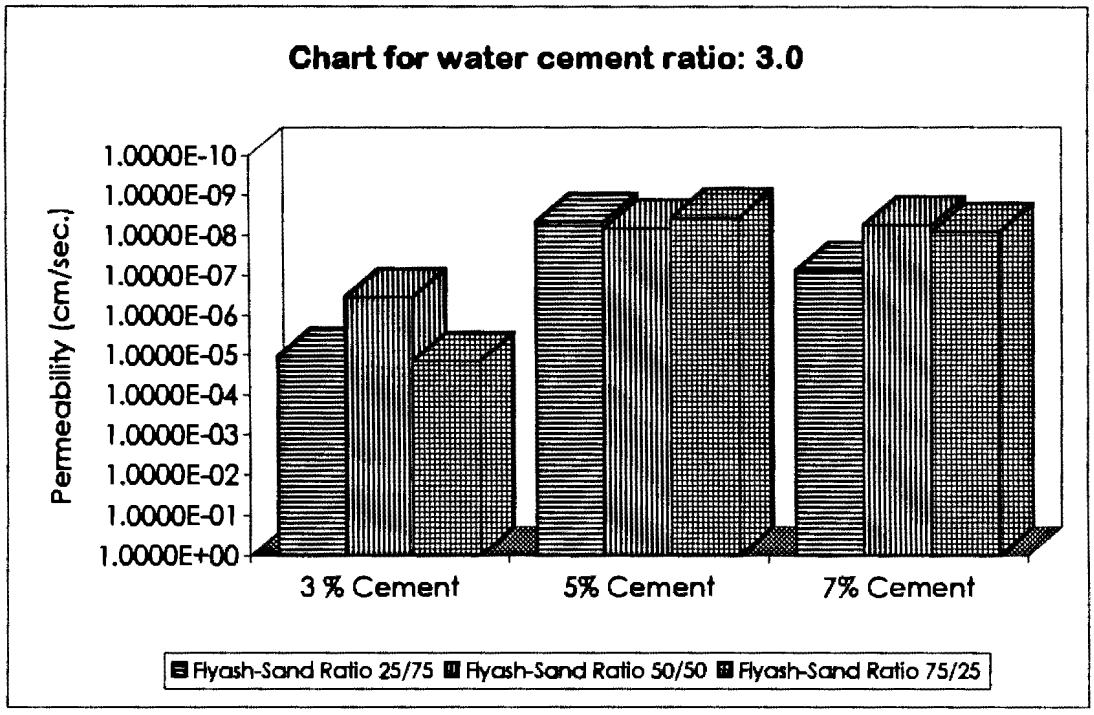
Table 4. Permeability of Flyash-Sand-Cement Mortar

a. for Water-Cement Ratio of 3.00

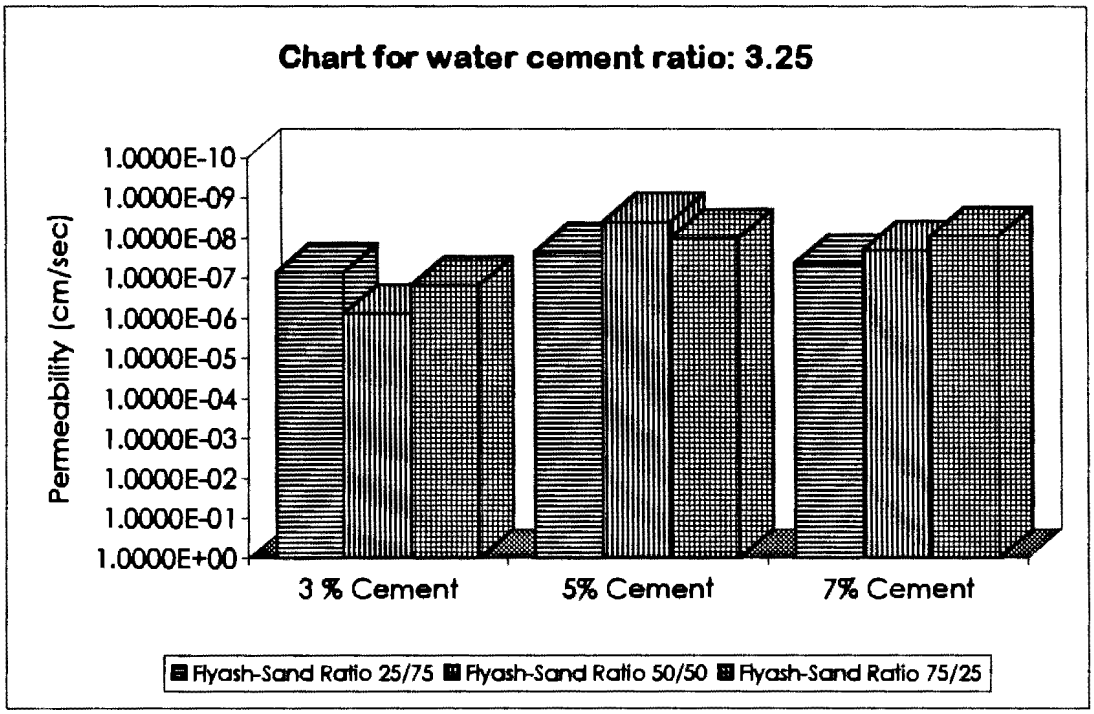
Flyash Sand Ratio	3 % Cement	5% Cement	7% Cement
25/75	1.1250E-05	4.7350E-09	8.0000E-08
50/50	3.6000E-07	7.0270E-09	5.7500E-09
75/25	1.4700E-05	3.7270E-09	8.4900E-09

b. for Water-Cement Ratio of 3.25

Flyash Sand Ratio	3 % Cement	5% Cement	7% Cement
25/75	7.2200E-08	2.2800E-08	4.3473E-08
50/50	7.8960E-07	4.0350E-09	2.0250E-08
75/25	1.5680E-07	1.0200E-08	8.7060E-09



a. For Water-Cement Ratio of 3.00



b. For Water-Cement Ratio of 3.25

Figure 3. Permeability of Flyash-Sand-Cement Mortar

will result in lower leaching of heavy metals from the backfill material i.e. specimens prepared with 5% or 7% cement.

The porosity of flyash-sand-cement mortar can also be obtained from the specimens prepared for permeability. After permeability test, specimens were taken out and the surface of the specimens was dried using towel paper to attain saturated surface dry conditions. Then the specimens were weighed to obtain saturated weight of the specimen. After measuring saturated weight, specimens were kept in oven for 24 hr. and then oven dry weight of the specimen was measured. The difference between the saturated and dry weight gives the weight of the water, when the specimen is fully saturated. The weight of water is equal to volume of water that in turn is equal to volume of voids. The ratio of volume of voids to the total volume (diameter and height of the specimen) multiplied by 100 will give porosity in %. This method was used in this test setup to measure the porosity of each specimen. The porosity obtained from the tests are given in Table 5. The porosity of all the proportions varied from 16.78% to 38.14%. The specimens prepared with 3% cement, 25/75 flyash-sand ratio and water-cement ratio of 3.25 showed less porosity as compared to the other proportions. Also, the specimens prepared with 75/25 flyash-sand ratios and 5% and higher cement showed higher porosity fro both water-cement ratios.

LENGTH CHANGE TEST RESULTS

The length change test was also performed on 18 specimens and the results obtained from the tests are shown in Table 6. The results obtained from the tests indicate change in length of specimens after 28 days of curing. The positive sign indicates that the specimen expanded (%) and the negative sign indicates that the specimen shrank (%). The minimum expansion of 0.005 % was observed in specimens prepared with 3% cement, 75/25 flyash-sand ratio, and water-cement ratio of 3.25. The maximum expansion of 0.12% was observed in the specimen prepared with 3% cement, 75/25 flyash-sand ratio, and a water-cement ratio of 3. The minimum contraction of -0.012 % was observed in the specimen prepared with 7% cement, 25/75 flyash-sand ratio, and water-cement ratio of 3.25 while the maximum

Table 5. Porosity of Flyash-Sand-Cement Mortar

a. for Water-Cement Ratio of 3.00

Flyash Sand Ratio	3 % Cement	5% Cement	7% Cement
25/75	27.46	30.13	22.87
50/50	38.41	32.60	21.87
75/25	34.89	30.34	23.59

b. for Water-Cement Ratio of 3.25

Flyash Sand Ratio	3 % Cement	5% Cement	7% Cement
25/75	18.89	16.78	18.00
50/50	23.92	21.17	19.07
75/25	25.18	31.33	33.05

Table 6. Length Change of Flyash-Sand-Cement Mortar

a. Water-cement ratio of 3.00

% of cement	Flyash-Sand Ratio	Li (in.)*	Lx (in.)+	Delta L (%)++
3	25/75	0.0100	0.0067	-0.0333
	50/50	-0.0040	-0.0060	-0.0200
	75/25	-0.0160	-0.0040	0.1200
5	25/75	-0.0020	0.0070	0.0900
	50/50	0.0109	0.0193	0.0840
	75/25	0.0078	0.0094	0.0160
7	25/75	-0.0180	-0.0070	0.1100
	50/50	-0.0020	-0.0010	0.0100
	75/25	-0.0025	0.0000	0.0250

b. Water-cement ratio of 3.25

% of cement	Flyash-Sand Ratio	Li (in.)*	Lx (in.)+	Delta L (%)++
3	25/75	0.0061	0.0037	-0.0240
	50/50	0.0060	0.0043	-0.0170
	75/25	-0.0040	-0.0035	0.0050
5	25/75	-0.0200	-0.0260	-0.0600
	50/50	0.0002	0.0030	0.0280
	75/25	0.0107	0.0197	0.0900
7	25/75	0.0060	0.0048	-0.0120
	50/50	-0.0030	-0.0048	-0.0180
	75/25	-0.0030	-0.0005	0.0250

*Li=Difference between the length of specimen and reference bar before 28 days curing or no curing

+Lx=Difference between the length of specimen and reference bar after 28 days of curing.

++Delta L (%) =(Lx-Li)*100/G
G= Gage Length 10 in. (Length of the refrence bar)

contraction of 0.06 % was observed in the specimen prepared with 5% cement, 25/75 flyash-sand ratio, and water-cement ratio of 3.25. All the specimens showed that the length change is not very significant because only .1% of maximum expansion was observed. However, more testing may be needed to clarify the effect that the water bath had on the curing of specimens in term of the length change. It can be concluded from the above tests that the proportions do not have any significant effect on the length change.

ATOMIC ABSORPTION TEST RESULTS

The atomic absorption test was performed on the eight samples, prepared using acid digestion of sludges method, of flyash "Type C",. All the samples were collected and tested randomly. The purpose of this test was to find the actual quantity of Barium present in the flyash before the extraction procedure was performed on the flyash-sand-cement mortar. All the samples were digested for a fixed period of time and then the concentration of barium in the fluid was found through the atomic absorption test. The test results are given in Table 7. The amount of Barium varied from 3300 mg/Kg to 1465 mg/Kg with an average of 2313 mg/Kg. For the purpose of calculating the amount of barium leached out of the specimens, the average value of 2313 mg/Kg. was used.

EXTRACTION PROCEDURE TEST RESULTS

The leaching test was performed on replicate specimens i.e. 36 specimens. The results obtained from the testing are shown in Table 8 and 9. Both the tables show how much of barium flyash was in the extracted solution and the percentage of barium leached out of the specimens. The amount of barium leaching out was higher in all the specimens prepared with 25/75 flyash-sand ratios. As the flyash-sand ratio increases the amount of flyash leaching out decreases. As per EPA recommendations (7), the amount of heavy metal, in this case Ba, in the extract should be below 100 mg/Liter and all the specimens are

Table 7. Atomic Absorption Test Results of Flyash Samples

Sample Number	Absorbance		Average Absorbance	Concentration (ppm)	Ba(mg)/kg of Flyash
	Reading1	Reading2			
1	.023	0.023	0.0225	47.50	2375.00
2	.027	0.027	0.0270	66.00	3300.00
3	.018	0.019	0.0185	35.66	1783.00
4	.024	0.021	0.0225	45.80	2290.00
5	.019	0.019	0.0190	37.00	1850.00
6	.022	0.023	0.0225	45.80	2290.00
7	.026	0.027	0.0265	63.00	3150.00
8	.016	0.016	0.0160	29.30	1465.00

Average Concentration of Ba (mg)/Kg of Flyash = 2313

Table 8. Leaching of Barium From Flyash-Sand-Cement Mortar (for Water Cement ratio of 3.00)

Cement (%)	Flyash Sand Ratio	Absorbance Reading		Ba Conc. in Extract (mg/L)		Average Amount of Ba Leached out (mg)	Amount of Barium in the Specimen (mg)	Amount of Barium Leached out (%)
		Specimen 1	Specimen 2	Specimen 1	Specimen 2			
3	25/75	0.013	0.011	9.12	7.75	16.5326	56.13	29.45
	50/50	0.009	0.010	6.37	7.12	13.2202	122.27	10.81
	75/25	0.013	0.007	9.12	4.75	13.5926	168.40	8.07
5	25/75	0.013	0.013	9.12	9.12	17.8752	55.07	32.46
	50/50	0.009	0.008	6.37	5.62	11.7502	110.14	10.67
	75/25	0.021	0.007	14.12	4.75	18.4926	165.20	11.19
7	25/75	0.020	0.008	13.5	5.62	18.7376	54.04	34.67
	50/50	0.008	0.007	5.62	4.75	10.1626	108.08	9.40
	75/25	0.013	0.005	9.12	2.88	11.76	162.12	7.25

Table 9. Leaching of Barium From Flyash-Sand-Cement Mortar (for Water Cement ratio of 3.25)

Cement (%)	Flyash Sand Ratio	Absorbance Reading		Ba Conc. in Extract (mg/L)		Average Amount of Ba Leached out (mg)	Amount of Barium in the Specimen (mg)	Amount of Barium Leached out (%)
		Specimen 1	Specimen 2	Specimen 1	Specimen 2			
3	25/75	0.014	0.012	9.75	8.4	17.787	56.13	31.69
	50/50	0.012	0.007	8.4	4.75	12.887	122.27	10.54
	75/25	0.006	0.011	3.87	7.75	11.3876	168.40	6.76
5	25/75	0.014	0.010	9.75	7.12	16.5326	55.07	30.02
	50/50	0.010	0.006	7.12	3.87	10.7702	110.14	9.78
	75/25	0.009	0.006	6.37	3.87	10.0352	165.20	6.07
7	25/75	0.011	0.009	7.75	6.37	13.8376	54.04	25.61
	50/50	0.008	0.006	5.62	3.87	9.3002	108.08	8.60
	75/25	0.009	0.005	6.37	2.88	9.065	162.12	5.59

well below the limit; minimum of 2.88 mg/L and a maximum of 9.12 mg/L, specified by the EPA. However, the amount of Ba leaching out from the specimens is lower in the specimens with 5% or 7% cement as compared to 3% cement. On the basis of results obtained from extraction test specimens prepared with 75/25 flyash-sand ratio, water-cement ratio of 3.00 for both 5% and 7% cement can be used safely. However, these tests were performed to evaluate the mobility of one heavy metal Ba and it's quite possible that the other heavy metals may show different leaching potential. Therefore, a more comprehensive testing program should be implemented before the stabilized flyash can be safely used as a trench backfill material. Also, Mr. Jon Prusinski of Houston Lighting & Power Company was contacted for information regarding leaching tests performed by their organization. The information provided by Mr. Prusinski showed that the leaching of barium was less than 2 mg/L for the flyash produced by his company.

CONCLUSIONS

Based on the test results of the limited test program described, it can be concluded that it's feasible to use flyash-sand-cement mortar as a backfill material. However, more testing is required to ensure safe environmental usage of flyash-sand-cement mortar. The test program described showed that 7% cement, 75/25 flyash-sand ratio, with water-cement ratio of 3.00 is probably the best compromise. This mix showed maximum compressive strength (unconfined) of 2736 psi, this will help in reducing the shear failures of the highways. Also, this will allow quite a large amount of flyash to be disposed. The permeability test results indicated that the specimens have a permeability of 8.49E-09 cm/sec (or 3.34E-09 in./sec). The minimum permeability of 3.7E-09 was observed in the specimen prepared with 5% cement, 75/25 flyash-sand ratio and water-cement ratio of 3.00. However, the compressive strength is

approximately one third of the proposed proportion of 7% cement, 75/25 flyash-sand ratio. Also, the magnitude of the permeability is same i.e. E-09. The permeability test results also favor usage of same proportions as compressive strength test results. The leaching tests indicate that the minimum amount of leaching i.e. 5.59% (or 4.625 mg/L) can be achieved if the specimens consisted of 7% cement, 75/25 flyash-sand ratio with a water-cement-ratio of 3.25. However, the specimens prepared with suggested proportions showed leaching of 7.25% (or 6 mg/L). Even though the difference is of approximately of 1.375 mg/L, still its well below the EPA limit. Therefore, the leaching test results also indicate usage of the selected proportion as a trench filler material in vertical moisture barrier.

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3. Stabilization/Solidification of CERCLA and RCRA Wastes, *United States Environmental Protection Agency*, EPA/625/6-89/022, May 1989.
4. EPA Test Method 3050, Test Methods For Evaluating Solid Waste, *United States Environmental Protection Agency*, Volume 1, Section A, pages 3050/1-3050/3, September, 1986.
5. EPA Test Method 7080, Test Methods For Evaluating Solid Waste, *United States Environmental Protection Agency*, Volume 1, Section A, pages 7080/1-7080/3, September, 1986.
6. EPA Test Method 1310A, Test Methods For Evaluating Solid Waste, *United States Environmental Protection Agency*, Volume 1, Section C, pages 1310A/1 1310A/18, September, 1986.

7. EPA, Federal Register 55, 11862 (3/29/90), RCRA Toxicity Characteristic Final Rule.

APPENDIX A

Specimen Id 1 Date of Experiment: 8/9/95 File Name: SPCMN1

Cement: 7% Flyash 23.25% Sand 69.75% Water/Cement: 3.25

Avg. Dia. of Spec.(cm):(7.1755 7.1755 7.239)/3 7.20 cm

Avg. ht. of Spec.(cm): (7.112 6.858 6.985)/3 6.99 cm

Crossectional Area of Specimen: 40.68 sqcm

Viscosity of Water : 9.33E-04 Pa-S Density of Water : 1 g/cm^3

Confining Pressure : 344.74 KPa Driving Pressure (P) : 275.79 KPa

Atm. Pressure (Pa) : 101.33 KPa Pressure Gradient (delta P): 174.47 KPa

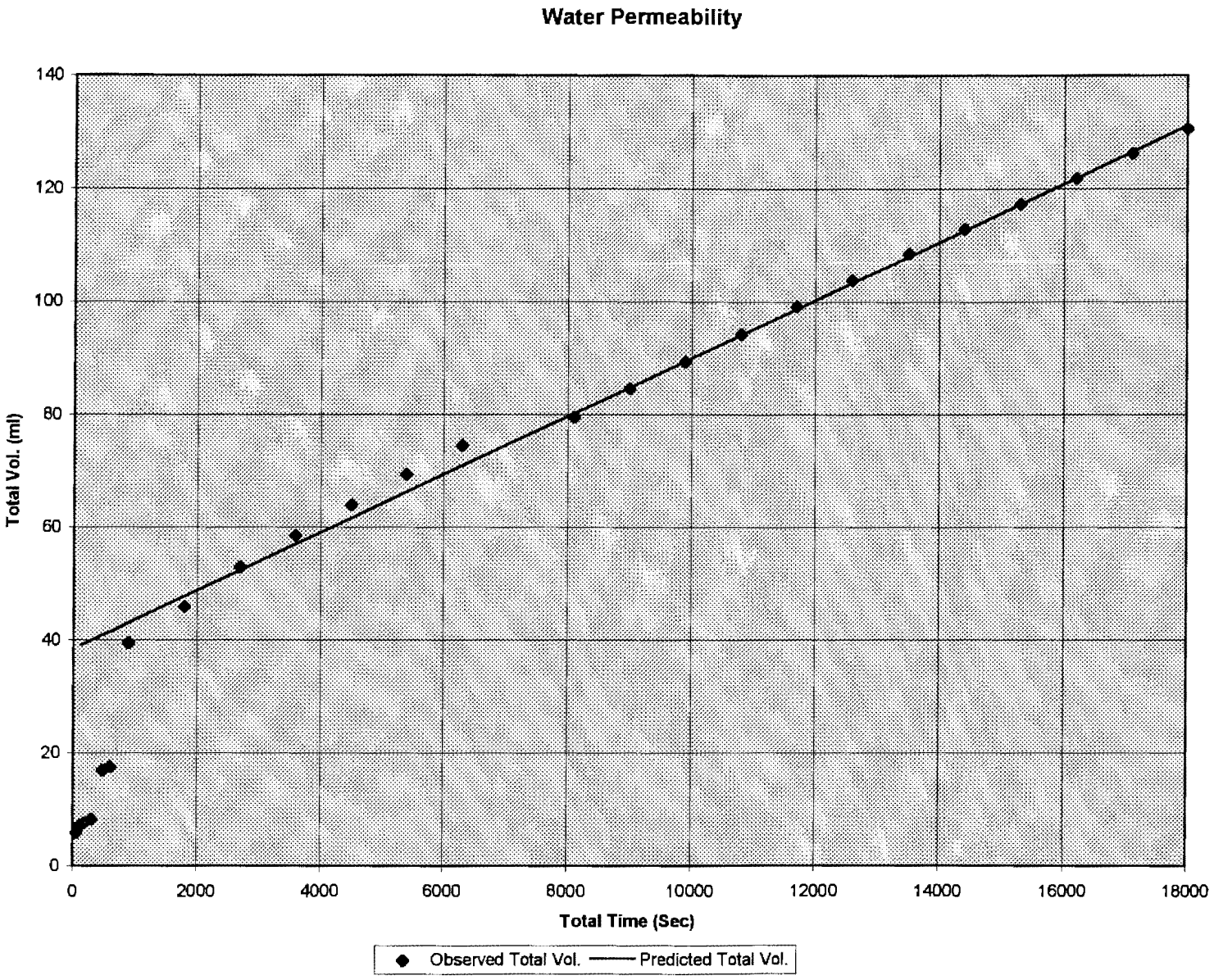
Sat. Surface Dry Wt. of Specimen: 587.87 g. Dry Wt. of Specimen: 509.8 g

Submerged Unit Wt.of Specimen : 287.8 g.

Reading No.	Time Elapsed (sec)	Incremental Time (sec)	Total Volume Collected (ml)	Incremental Vol. Collected (ml)	Intrisic Permeability(sqcm	Hydraulic Conductivity (cm/sec)
1	0	0	0	0		
2	60	60	5.9	5.9		
3	120	60	7.2	1.3	1.9886E-11	1.94882E-07
4	180	60	7.6	0.4	6.11875E-12	5.99638E-08
5	300	120	8.2	0.6	4.58907E-12	4.49728E-08
6	480	180	16.9	8.7	4.4361E-11	4.34737E-07
7	600	120	17.6	0.7	5.35391E-12	5.24683E-08
8	900	300	39.4	21.8	6.66944E-11	6.53605E-07
9	1800	900	45.9	6.5	6.62865E-12	6.49608E-08
10	2700	900	52.9	7	7.13855E-12	6.99578E-08
11	3600	900	58.5	5.6	5.71084E-12	5.59662E-08
12	4500	900	63.9	5.4	5.50688E-12	5.39674E-08
13	5400	900	69.35	5.45	5.55787E-12	5.44671E-08
14	6300	900	74.5	5.15	5.25193E-12	5.14689E-08
15	8100	900	79.5	5	5.09896E-12	4.99698E-08
16	9000	900	84.55	5.05	5.14995E-12	5.04695E-08
17	9900	900	89.3	4.75	4.84401E-12	4.74713E-08
18	10800	900	94.2	4.9	4.99698E-12	4.89704E-08
19	11700	900	99.2	5	5.09896E-12	4.99698E-08

20	12600	900	103.85	4.65	4.74203E-12	4.64719E-08
21	13500	900	108.55	4.7	4.79302E-12	4.69716E-08
22	14400	900	112.9	4.35	4.4361E-12	4.34737E-08
23	15300	900	117.25	4.35	4.4361E-12	4.34737E-08
24	16200	900	121.85	4.6	4.69105E-12	4.59722E-08
25	17100	900	126.25	4.4	4.48709E-12	4.39734E-08
26	18000	900	130.55	4.3	4.38511E-12	4.29741E-08

Water Permeability of Specimen No. 1



Specimen Id 2 Date of Experiment: 8/9/95 File Name: SPCMN2

Cement: 7% Flyash 46.49% Sand 46.49% Water/Cement: 3.25

Avg. Dia. of Spec.(cm):(7.1755 7.1882 7.1755)/3 7.18 cm

Avg. ht. of Spec.(cm): (7.0612 7.0612 7.0612)/3 7.06 cm

Crossectional Area of Specimen: 40.58 sqcm

Viscosity of Water : 9.33E-04 Pa-S Density of Water : 1.00 g/cm^3

Confining Pressure : 344.74 KPa Driving Pressure (P) : 275.79 KPa

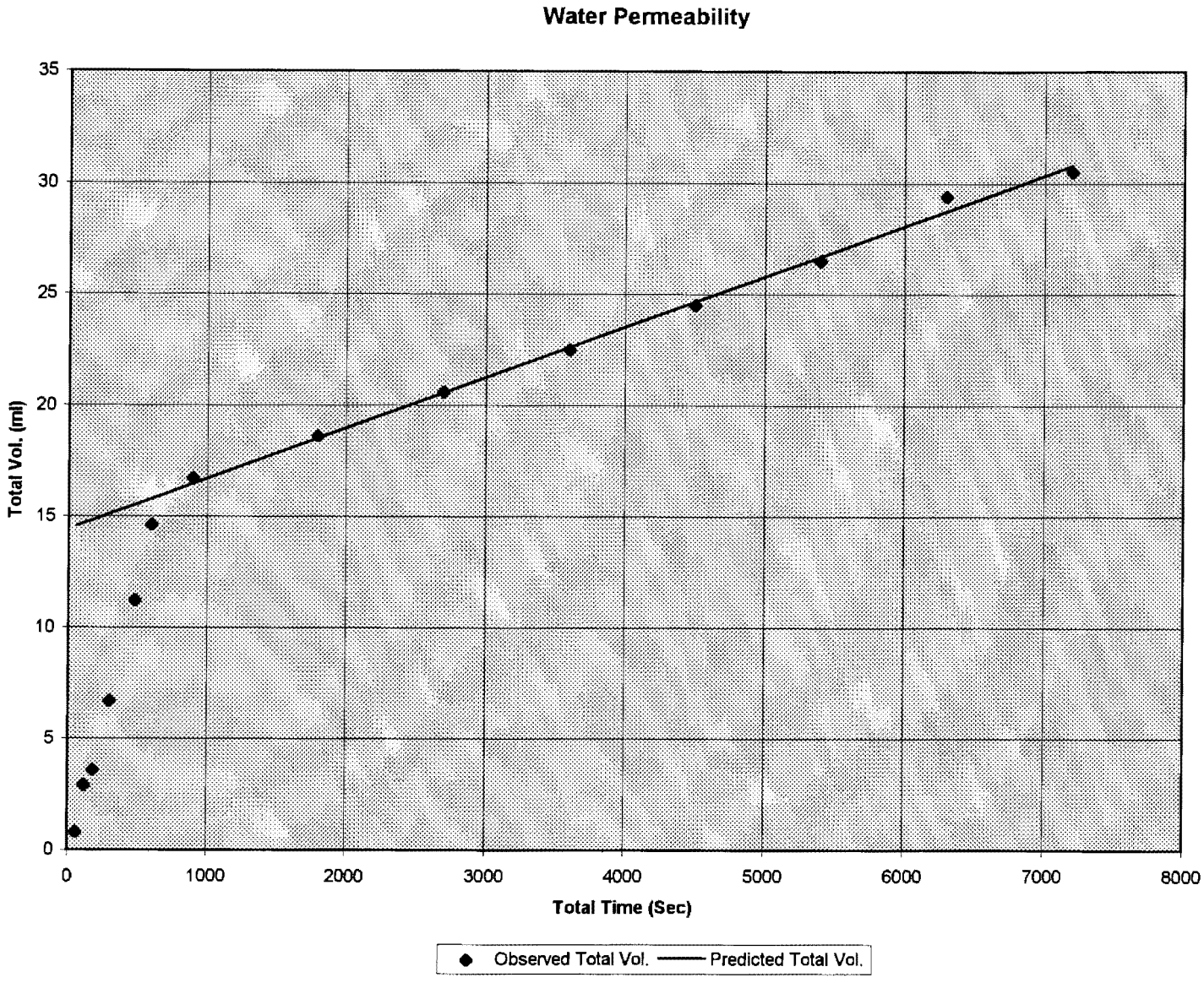
Atm. Pressure (Pa) : 101.33 KPa Pressure Gradient (delta P): 174.47 KPa

Sat. Surface Dry Wt. of Specimen: 579.14 g. Dry Wt. of Specimen: 469.10 g

Submerged Unit Wt.of Specimen : 287.8 g.

Reading No.	Time Elapsed (sec)	Incremental Time (sec)	Total Volume Collected (ml)	Incremental Vol. Collected (ml)	Intrisic Permeability(sqcm	Hydraulic Conductivity (cm/sec)
1	0	0	0	0		
2	60	60	0.8	0.8		
3	120	60	2.9	2.1	3.25504E-11	3.18994E-07
4	180	60	3.6	0.7	1.08501E-11	1.06331E-07
5	300	120	6.7	3.1	2.40253E-11	2.35448E-07
6	480	180	11.2	4.5	2.32503E-11	2.27853E-07
7	600	120	14.6	3.4	2.63504E-11	2.58234E-07
8	900	300	16.7	2.1	6.51009E-12	6.37989E-08
9	1800	900	18.6	1.9	1.96336E-12	1.92409E-08
10	2700	900	20.6	2	2.06669E-12	2.02536E-08
11	3600	900	22.5	1.9	1.96336E-12	1.92409E-08
12	4500	900	24.5	2	2.06669E-12	2.02536E-08
13	5400	900	26.5	2	2.06669E-12	2.02536E-08
14	6300	900	29.4	2.9	2.99671E-12	2.93677E-08
15	7200	900	30.5	1.1	1.13668E-12	1.11395E-08

Water Permeability of Specimen No. 2



Specimen Id 3 Date of Experiment: 8/30/95 File Name: SPCMN3

Cement: 7% Flyash 69.75% Sand 23.25% Water/Cement: 3.25

Avg. Dia. of Spec.(cm):(7.163 6.568 7.275)/3 7.00 cm

Avg. ht. of Spec.(cm): (7.170 7.244 7.310)/3 7.24 cm

Crossectional Area of Specimen: 33.89 sqcm

Viscosity of Water : 9.33E-04 Pa-S Density of Water : 1.00 g/cm^3

Confining Pressure : 344.74 KPa Driving Pressure (P) : 275.79 KPa

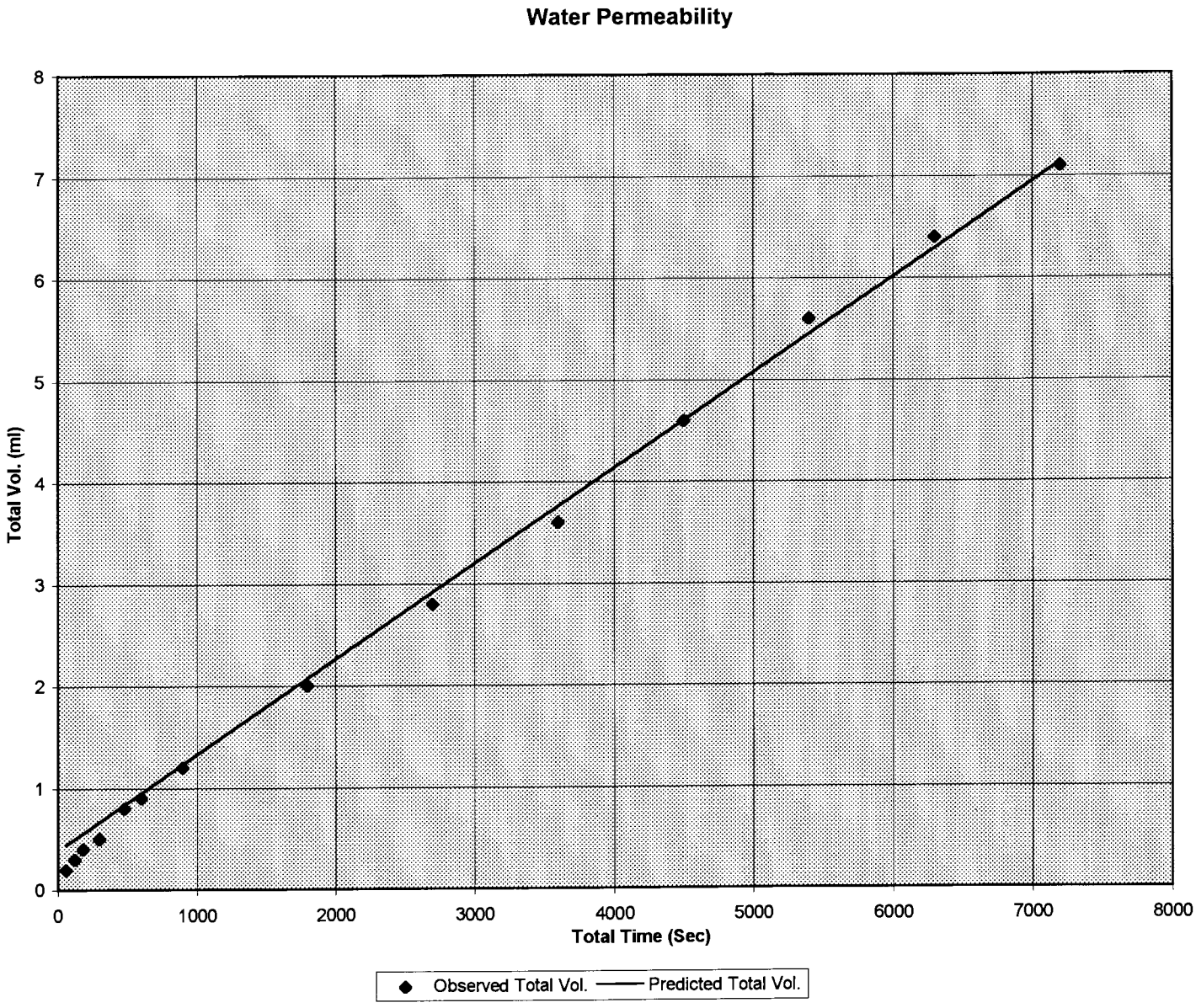
Atm. Pressure (Pa) : 101.33 KPa Pressure Gradient (delta P): 174.47 KPa

Sat. Surface Dry Wt. of Specimen: 598.80 g. Dry Wt. of Specimen: 513.20 g

Submerged Unit Wt.of Specimen : 310.80 g.

Reading No.	Time Elapsed (sec)	Incremental Time (sec)	Total Volume Collected (ml)	Incremental Vol. Collected (ml)	Intrisic Permeability(sqcm	Hydraulic Conductivity (cm/sec)
1	0	0	0.1	0.1		
2	60	60	0.2	0.1		
3	120	60	0.3	0.1	1.90373E-12	1.86566E-08
4	180	60	0.4	0.1	1.90373E-12	1.86566E-08
5	300	120	0.5	0.1	9.51866E-13	9.32829E-09
6	480	180	0.8	0.3	1.90373E-12	1.86566E-08
7	600	120	0.9	0.1	9.51866E-13	9.32829E-09
8	900	300	1.2	0.3	1.14224E-12	1.11939E-08
9	1800	900	2	0.8	1.01532E-12	9.95017E-09
10	2700	900	2.8	0.8	1.01532E-12	9.95017E-09
11	3600	900	3.6	0.8	1.01532E-12	9.95017E-09
12	4500	900	4.6	1	1.26915E-12	1.24377E-08
13	5400	900	5.6	1	1.26915E-12	1.24377E-08
14	6300	900	6.4	0.8	1.01532E-12	9.95017E-09
15	7200	900	7.1	0.7	8.88408E-13	8.7064E-09
16	8100	900	7.8	0.7	8.88408E-13	8.7064E-09
17	9000	900	8.5	0.7	8.88408E-13	8.7064E-09
18	9900	900	9.2	0.7	8.88408E-13	8.7064E-09

Water Permeability of Specimen No. 3



Specimen Id 4 Date of Experiment: 8/9/95 File Name: SPCMN4

Cement: 7% Flyash 23.25% Sand 69.75% Water/Cement: 3

Avg. Dia. of Spec.(cm):(7.188 7.188 7.188)/3 7.19 cm

Avg. ht. of Spec.(cm): (6.477 6.502 6.553)/3 6.51 cm

Crossectional Area of Specimen: 40.58 sqcm

Viscosity of Water : 9.33E-04 Pa-S Density of Water : 1.00 g/cm^3

Confining Pressure : 344.74 KPa Driving Pressure (P) : 275.79 KPa

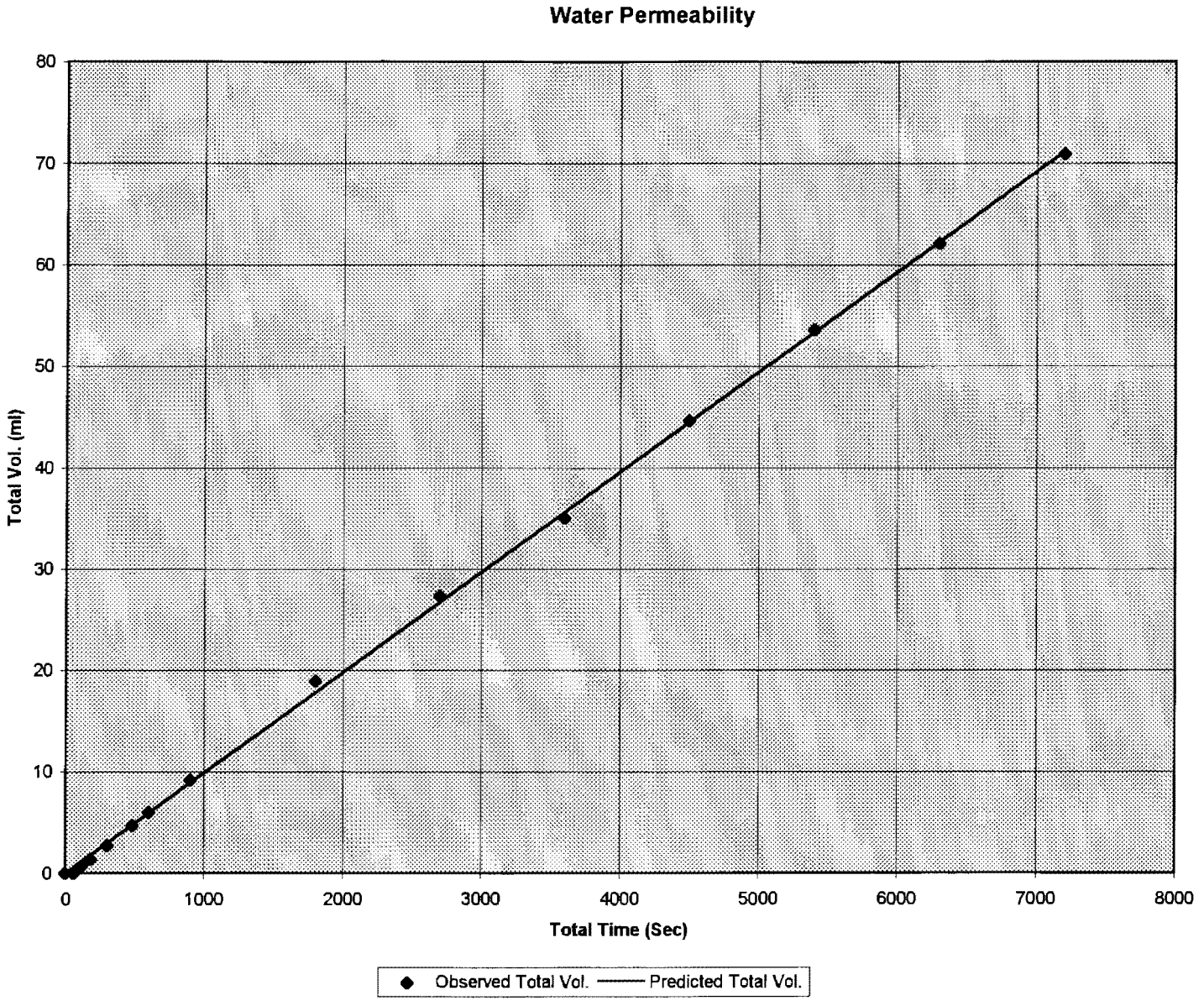
Atm. Pressure (Pa) : 101.33 KPa Pressure Gradient (delta P): 174.47 KPa

Sat. Surface Dry Wt. of Specimen: 542.10 g. Dry Wt. of Specimen: 462.50 g

Submerged Unit Wt.of Specimen : 281.50 g.

Reading No.	Time Elapsed (sec)	Incremental Time (sec)	Total Volume Collected (ml)	Incremental Vol. Collected (ml)	Intrisic Permeability(sqcm	Hydraulic Conductivity (cm/sec)
1	0	0	0	0		
2	60	60	0	0		
3	120	60	0.7	0.7	1.00048E-11	9.80467E-08
4	180	60	1.4	0.7	1.00048E-11	9.80467E-08
5	300	120	2.7	1.3	9.29014E-12	9.10433E-08
6	480	180	4.7	2	9.52834E-12	9.33778E-08
7	600	120	6	1.3	9.29014E-12	9.10433E-08
8	900	300	9.2	3.2	9.14721E-12	8.96427E-08
9	1800	900	18.9	9.7	9.24249E-12	9.05764E-08
10	2700	900	27.3	8.4	8.00381E-12	7.84373E-08
11	3600	900	35	7.7	7.33683E-12	7.19009E-08
12	4500	900	44.6	9.6	9.14721E-12	8.96427E-08
13	5400	900	53.6	9	8.57551E-12	8.404E-08
14	6300	900	62.1	8.5	8.09909E-12	7.93711E-08
15	7200	900	70.9	8.8	8.38494E-12	8.21724E-08

Water Permeability of Specimen No. 4



Specimen Id 5 Date of Experiment: 8/10/95 File Name: SPCMN5

Cement: 7% Flyash 46.49% Sand 46.49% Water/Cement: 3

Avg. Dia. of Spec.(cm):(7.1628 7.1628 7.1628)/3 7.16 cm

Avg. ht. of Spec.(cm): (7.239 7.239 7.239)/3 7.24 cm

Crossectional Area of Specimen: 40.30 sqcm

Viscosity of Water : 9.33E-04 Pa-S Density of Water : 1.00 g/cm^3

Confining Pressure : 344.74 KPa Driving Pressure (P) : 275.79 KPa

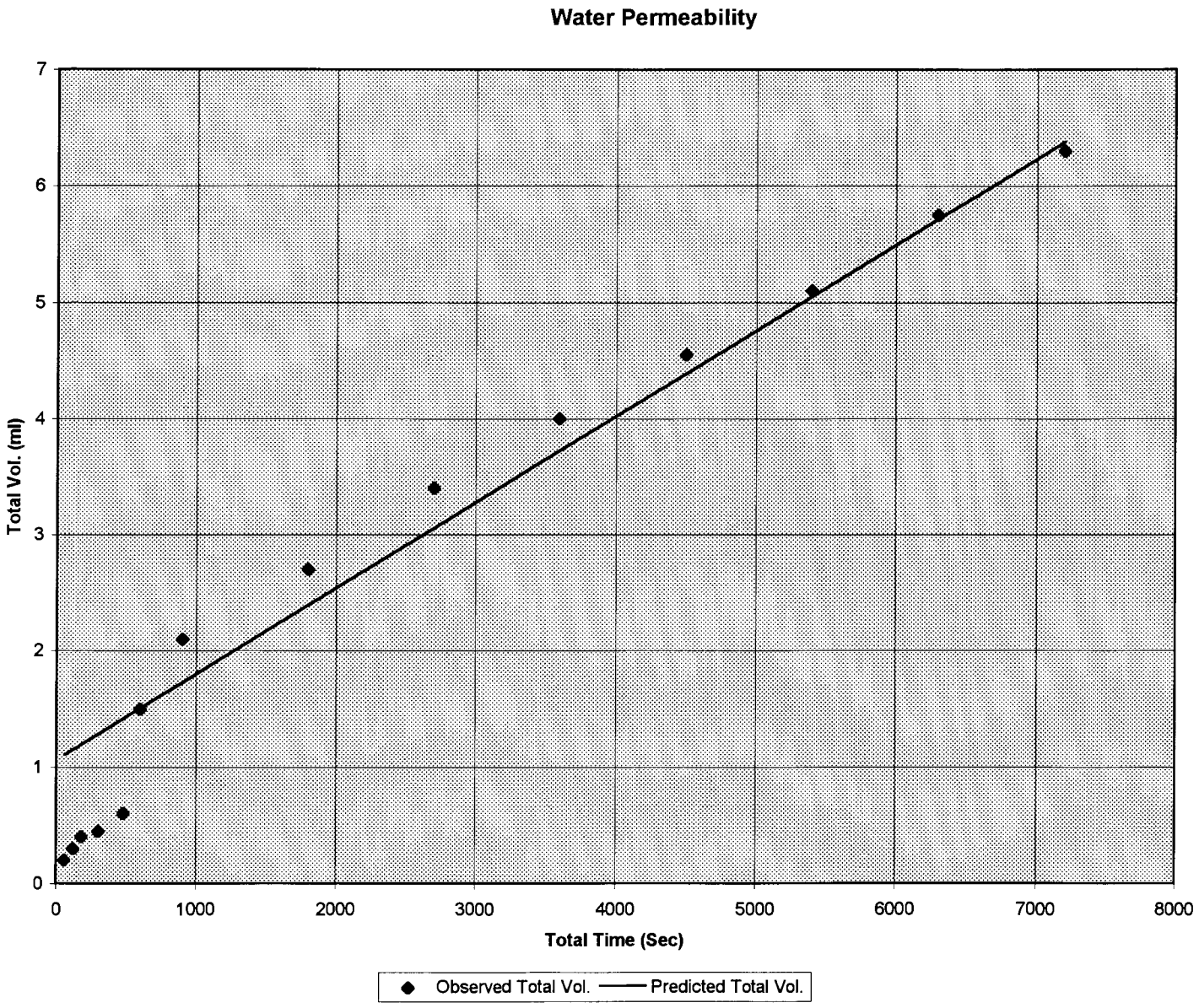
Atm. Pressure (Pa) : 101.33 KPa Pressure Gradient (delta P): 174.47 KPa

Sat. Surface Dry Wt. of Specimen: 611.71 g. Dry Wt. of Specimen: 516.60 g

Submerged Unit Wt.of Specimen : 314.50 g.

Reading No.	Time Elapsed (sec)	Incremental Time (sec)	Total Volume Collected (ml)	Incremental Vol. Collected (ml)	Intrisic Permeability(sqcm	Hydraulic Conductivity (cm/sec)
1	0	0	0	0		
2	60	60	0.2	0.2		
3	120	60	0.3	0.1	1.60034E-12	1.56833E-08
4	180	60	0.4	0.1	1.60034E-12	1.56833E-08
5	300	120	0.45	0.05	4.00085E-13	3.92083E-09
6	480	180	0.6	0.15	8.0017E-13	7.84167E-09
7	600	120	1.5	0.9	7.20153E-12	7.0575E-08
8	900	300	2.1	0.6	1.92041E-12	1.882E-08
9	1800	900	2.7	0.6	6.40136E-13	6.27333E-09
10	2700	900	3.4	0.7	7.46825E-13	7.31889E-09
11	3600	900	4	0.6	6.40136E-13	6.27333E-09
12	4500	900	4.55	0.55	5.86791E-13	5.75056E-09
13	5400	900	5.1	0.55	5.86791E-13	5.75056E-09
14	6300	900	5.75	0.65	6.93481E-13	6.79611E-09
15	7200	900	6.3	0.55	5.86791E-13	5.75056E-09
16	8100	900	6.85	0.55	5.86791E-13	5.75056E-09
17	9000	900	7.5	0.65	6.93481E-13	6.79611E-09

Water Permeability of Specimen No. 5



Specimen Id 6 Date of Experiment: 8/10/95 File Name: SPCMN6

Cement: 7% Flyash 69.75% Sand 23.25% Water/Cement: 3

Avg. Dia. of Spec.(cm):(7.2644 7.112 7.1628)/3 7.18 cm

Avg. ht. of Spec.(cm): (7.2453 7.2453 7.2453)/3 7.25 cm

Crossectional Area of Specimen: 39.73 sqcm

Viscosity of Water : 9.33E-04 Pa-S Density of Water : 1.00 g/cm^3

Confining Pressure : 344.74 KPa Driving Pressure (P) : 275.79 KPa

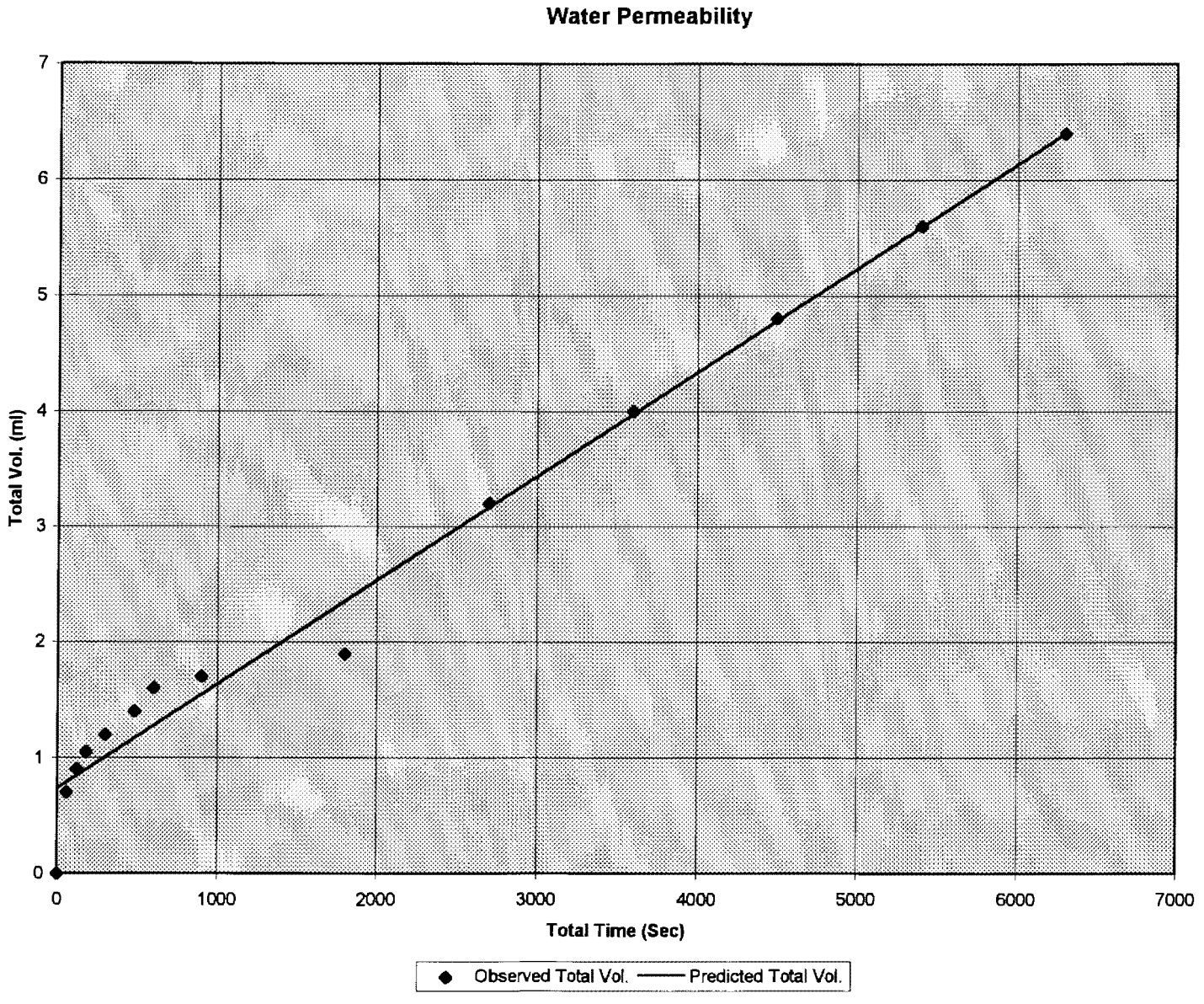
Atm. Pressure (Pa) : 101.33 KPa Pressure Gradient (delta P): 174.47 KPa

Sat. Surface Dry Wt. of Specimen: 591.50 g. Dry Wt. of Specimen: 504.10 g

Submerged Unit Wt.of Specimen : 317.70 g.

Reading No.	Time Elapsed (sec)	Incremental Time (sec)	Total Volume Collected (ml)	Incremental Vol. Collected (ml)	Intrisic Permeability(sqcm	Hydraulic Conductivity (cm/sec)
1	0	0	0.6	0.6		
2	60	60	0.7	0.1		
3	120	60	0.9	0.2	3.24939E-12	3.18441E-08
4	180	60	1.05	0.15	2.43704E-12	2.3883E-08
5	300	120	1.2	0.15	1.21852E-12	1.19415E-08
6	480	180	1.4	0.2	1.08313E-12	1.06147E-08
7	600	120	1.6	0.2	1.6247E-12	1.5922E-08
8	900	300	1.7	0.1	3.24939E-13	3.18441E-09
9	1800	900	1.9	0.2	2.16626E-13	2.12294E-09
10	2700	900	3.2	1.3	1.40807E-12	1.37991E-08
11	3600	900	4	0.8	8.66505E-13	8.49175E-09
12	4500	900	4.8	0.8	8.66505E-13	8.49175E-09
13	5400	900	5.6	0.8	8.66505E-13	8.49175E-09
14	6300	900	6.4	0.8	8.66505E-13	8.49175E-09

Water Permeability of Specimen No. 6



Specimen Id 7 Date of Experiment: 8/11/95 File Name: SPCMN7

Cement: 5% Flyash 23.75% Sand 71.25% Water/Cement: 3.25

Avg. Dia. of Spec.(cm):(7.1628 7.1755 7.1882)/3 7.18 cm

Avg. ht. of Spec.(cm): (7.2136 7.2136 7.2136)/3 7.21 cm

Crossectional Area of Specimen: 40.44 sqcm

Viscosity of Water : 9.33E-04 Pa-S Density of Water : 1.00 g/cm^3

Confining Pressure : 344.74 KPa Driving Pressure (P) : 275.79 KPa

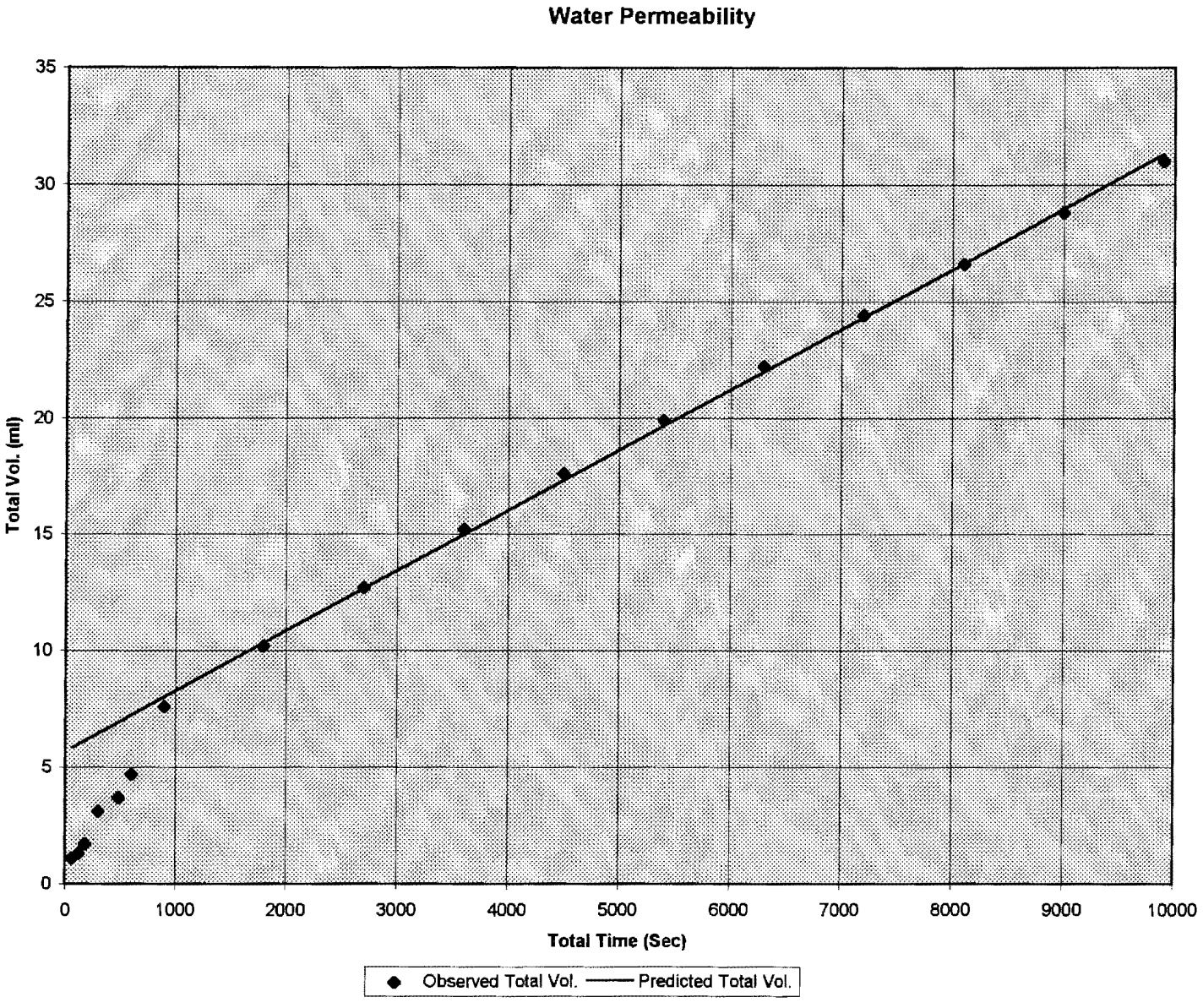
Atm. Pressure (Pa) : 101.33 KPa Pressure Gradient (delta P): 174.47 KPa

Sat. Surface Dry Wt. of Specimen: 629.38 g. Dry Wt. of Specimen: 562.70 g

Submerged Unit Wt.of Specimen : 338.50 g.

Reading No.	Time Elapsed (sec)	Incremental Time (sec)	Total Volume Collected (ml)	Incremental Vol. Collected (ml)	Intrisic Permeability(sqcm	Hydraulic Conductivity (cm/sec)
1	0	0	0.6	0.6		
2	60	60	1.1	0.5		
3	120	60	1.3	0.2	3.17817E-12	3.11461E-08
4	180	60	1.7	0.4	6.35634E-12	6.22921E-08
5	300	120	3.1	1.4	1.11236E-11	1.09011E-07
6	480	180	3.7	0.6	3.17817E-12	3.11461E-08
7	600	120	4.7	1	7.94542E-12	7.78652E-08
8	900	300	7.6	2.9	9.21669E-12	9.03236E-08
9	1800	900	10.2	2.6	2.75441E-12	2.69933E-08
10	2700	900	12.7	2.5	2.64847E-12	2.59551E-08
11	3600	900	15.2	2.5	2.64847E-12	2.59551E-08
12	4500	900	17.6	2.4	2.54254E-12	2.49169E-08
13	5400	900	19.9	2.3	2.4366E-12	2.38786E-08
14	6300	900	22.2	2.3	2.4366E-12	2.38786E-08
15	7200	900	24.4	2.2	2.33066E-12	2.28404E-08
16	8100	900	26.6	2.2	2.33066E-12	2.28404E-08
17	9000	900	28.8	2.2	2.33066E-12	2.28404E-08
18	9900	900	31	2.2	2.33066E-12	2.28404E-08

Water Permeability of Specimen No. 7



Specimen Id 8 Date of Experiment: 8/11/95 File Name: SPCMN8

Cement: 5% Flyash 47.50% Sand 47.50% Water/Cement: 3.25

Avg. Dia. of Spec.(cm):(7.239 7.3025 7.1882)/3 7.24 cm

Avg. ht. of Spec.(cm): (7.3025 7.2644 7.2136)/3 7.26 cm

Crossectional Area of Specimen: 41.88 sqcm

Viscosity of Water : 9.33E-04 Pa-S Density of Water : 1.00 g/cm^3

Confining Pressure : 344.74 KPa Driving Pressure (P) : 275.79 KPa

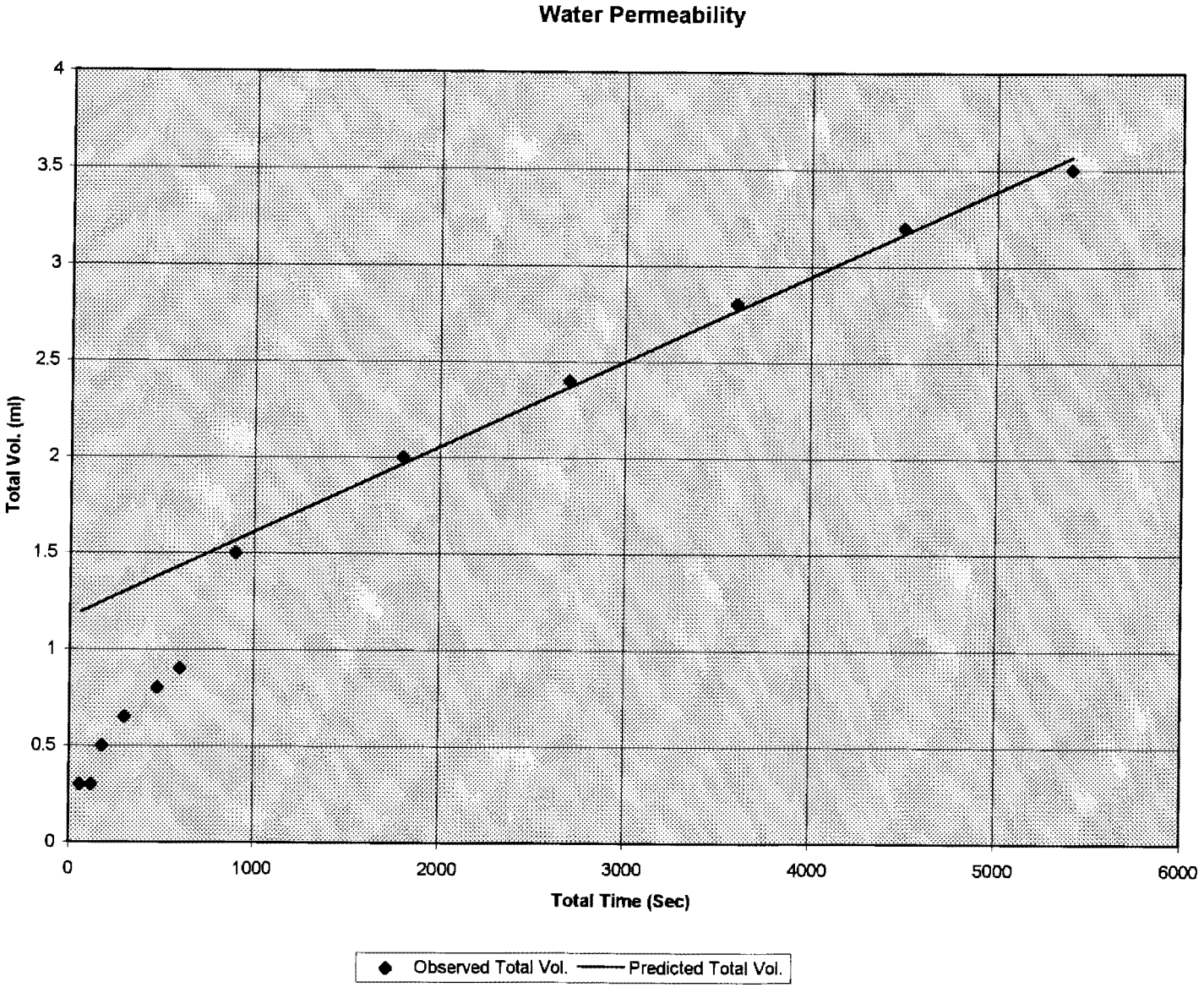
Atm. Pressure (Pa) : 101.33 KPa Pressure Gradient (delta P): 174.47 KPa

Sat. Surface Dry Wt. of Specimen: 639.50 g. Dry Wt. of Specimen: 573.00 g

Submerged Unit Wt.of Specimen : 374.40 g.

Reading No.	Time Elapsed (sec)	Incremental Time (sec)	Total Volume Collected (ml)	Incremental Vol. Collected (ml)	Intrisic Permeability(sqcm	Hydraulic Conductivity (cm/sec)
1	0	0	0.1	0.1		
2	60	60	0.3	0.2		
3	120	60	0.3	0	0	0
4	180	60	0.5	0.2	3.0884E-12	3.02663E-08
5	300	120	0.65	0.15	1.15815E-12	1.13499E-08
6	480	180	0.8	0.15	7.72099E-13	7.56657E-09
7	600	120	0.9	0.1	7.72099E-13	7.56657E-09
8	900	300	1.5	0.6	1.85304E-12	1.81598E-08
9	1800	900	2	0.5	5.14733E-13	5.04438E-09
10	2700	900	2.4	0.4	4.11786E-13	4.0355E-09
11	3600	900	2.8	0.4	4.11786E-13	4.0355E-09
12	4500	900	3.2	0.4	4.11786E-13	4.0355E-09
13	5400	900	3.5	0.3	3.0884E-13	3.02663E-09

Water Permeability of Specimen No. 8



Specimen Id 9 Date of Experiment: 8/11/95 File Name: SPCMN9

Cement: 5% Flyash 71.25% Sand 23.75% Water/Cement: 3.25

Avg. Dia. of Spec.(cm):(7.0485 7.239 7.1882)/3 7.16 cm

Avg. ht. of Spec.(cm): (7.1882 7.3152 7.1374)/3 7.21 cm

Crossectional Area of Specimen: 41.16 sqcm

Viscosity of Water : 9.33E-04 Pa-S Density of Water : 1.00 g/cm^3

Confining Pressure : 344.74 KPa Driving Pressure (P) : 275.79 KPa

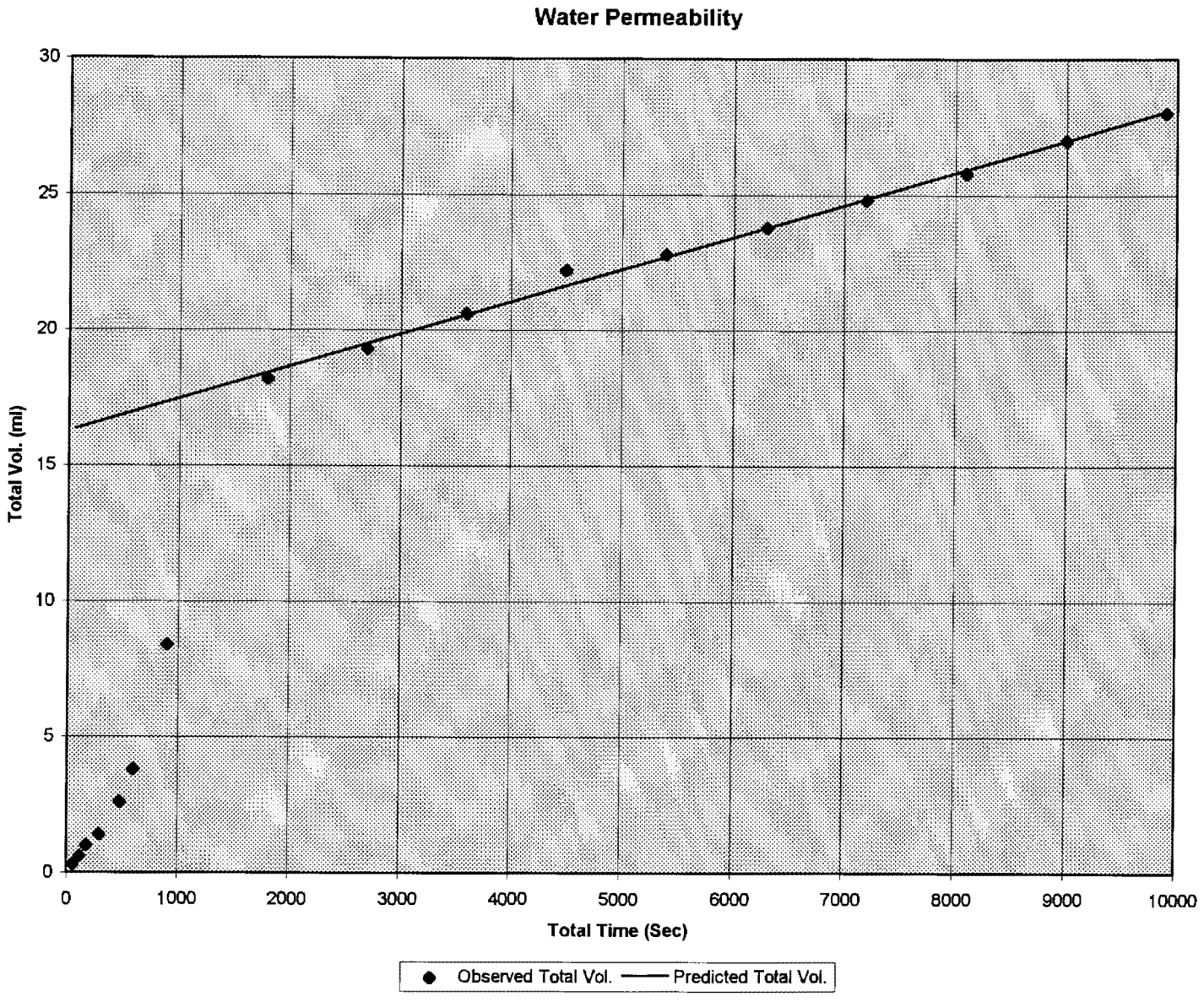
Atm. Pressure (Pa) : 101.33 KPa Pressure Gradient (delta P): 174.47 KPa

Sat. Surface Dry Wt. of Specimen: 612.70 g. Dry Wt. of Specimen: 542.70 g

Submerged Unit Wt.of Specimen : 318.00 g.

Reading No.	Time Elapsed (sec)	Incremental Time (sec)	Total Volume Collected (ml)	Incremental Vol. Collected (ml)	Intrisic Permeability(sqcm	Hydraulic Conductivity (cm/sec)
1	0	0	0	0		
2	60	60	0.3	0.3		
3	120	60	0.6	0.3	4.68399E-12	4.59031E-08
4	180	60	1	0.4	6.24531E-12	6.12041E-08
5	300	120	1.4	0.4	3.12266E-12	3.0602E-08
6	480	180	2.6	1.2	6.24531E-12	6.12041E-08
7	600	120	3.8	1.2	9.36797E-12	9.18061E-08
8	900	300	8.4	4.6	1.43642E-11	1.40769E-07
9	1800	900	18.2	9.8	1.02007E-11	9.99667E-08
10	2700	900	19.3	1.1	1.14497E-12	1.12207E-08
11	3600	900	20.6	1.3	1.35315E-12	1.32609E-08
12	4500	900	22.2	1.6	1.66542E-12	1.63211E-08
13	5400	900	22.8	0.6	6.24531E-13	6.12041E-09
14	6300	900	23.8	1	1.04089E-12	1.02007E-08
15	7200	900	24.8	1	1.04089E-12	1.02007E-08
16	8100	900	25.8	1	1.04089E-12	1.02007E-08
17	9000	900	27	1.2	1.24906E-12	1.22408E-08
18	9900	900	28	1	1.04089E-12	1.02007E-08

Water Permeability of Specimen No. 9



Specimen Id 10 Date of Experiment: 8/14/95 File Name: SPCMN10

Cement: 5% Flyash 23.75% Sand 71.25% Water/Cement: 3

Avg. Dia. of Spec.(cm):(7.239 7.239 6.985)/3 7.15 cm

Avg. ht. of Spec.(cm): (6.477 6.8834 6.731)/3 6.70 cm

Crossectional Area of Specimen: 41.16 sqcm

Viscosity of Water : 9.33E-04 Pa-S Density of Water : 1.00 g/cm^3

Confining Pressure : 344.74 KPa Driving Pressure (P) : 275.79 KPa

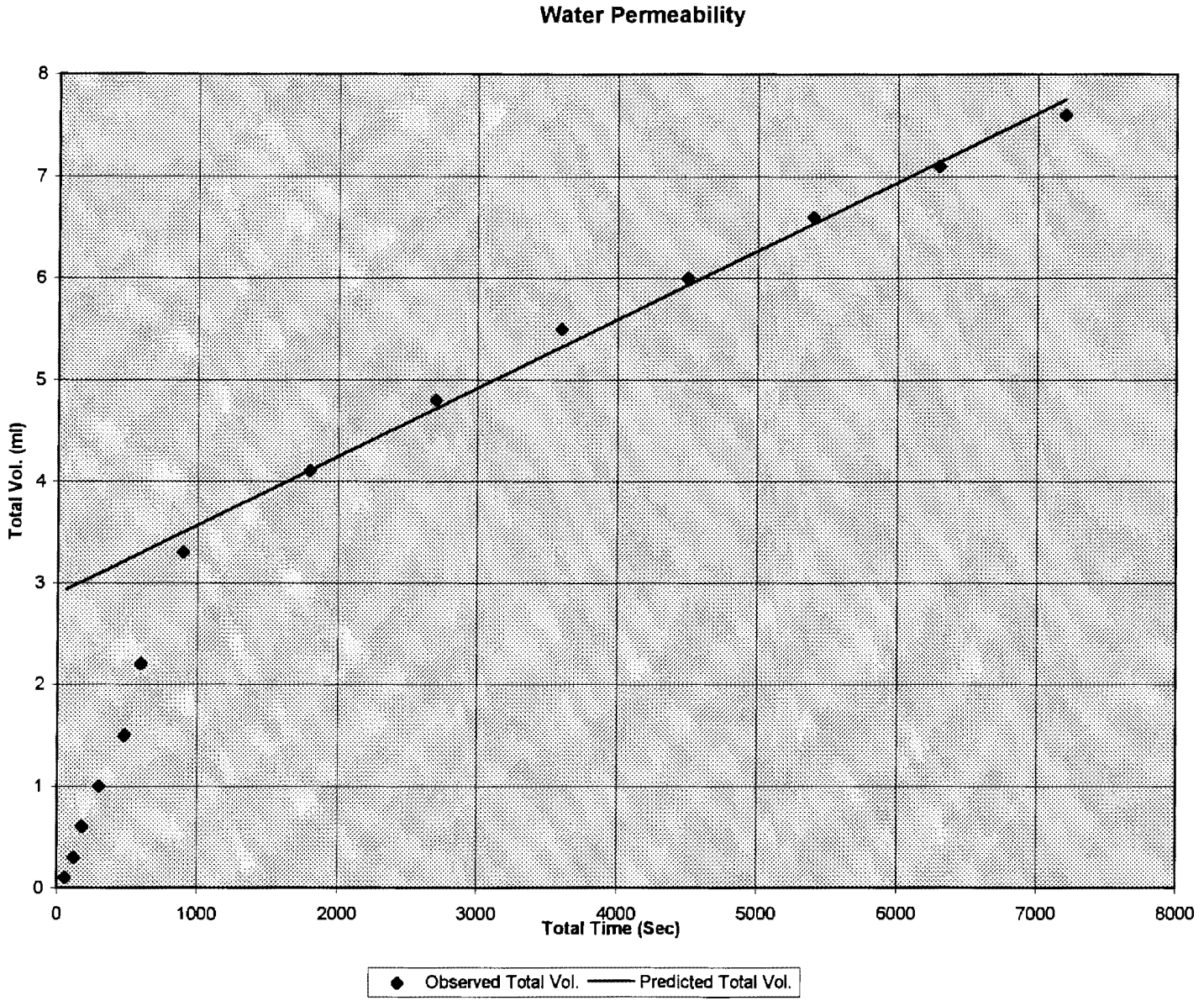
Atm. Pressure (Pa) : 101.33 KPa Pressure Gradient (delta P): 174.47 KPa

Sat. Surface Dry Wt. of Specimen: 594.80 g. Dry Wt. of Specimen: 542.70 g

Submerged Unit Wt.of Specimen : 328.10 g.

Reading No.	Time Elapsed (sec)	Incremental Time (sec)	Total Volume Collected (ml)	Incremental Vol. Collected (ml)	Intrisic Permeability(sqcm	Hydraulic Conductivity (cm/sec)
1	0	0	0	0		
2	60	60	0.1	0.1		
3	120	60	0.3	0.2	2.89909E-12	2.8411E-08
4	180	60	0.6	0.3	4.34863E-12	4.26166E-08
5	300	120	1	0.4	2.89909E-12	2.8411E-08
6	480	180	1.5	0.5	2.41591E-12	2.36759E-08
7	600	120	2.2	0.7	5.0734E-12	4.97193E-08
8	900	300	3.3	1.1	3.189E-12	3.12522E-08
9	1800	900	4.1	0.8	7.7309E-13	7.57628E-09
10	2700	900	4.8	0.7	6.76454E-13	6.62924E-09
11	3600	900	5.5	0.7	6.76454E-13	6.62924E-09
12	4500	900	6	0.5	4.83181E-13	4.73517E-09
13	5400	900	6.6	0.6	5.79817E-13	5.68221E-09
14	6300	900	7.1	0.5	4.83181E-13	4.73517E-09
15	7200	900	7.6	0.5	4.83181E-13	4.73517E-09

Water Permeability of Specimen No. 10



Specimen Id 11 Date of Experiment: 8/15/95 File Name: SPCMN11

Cement: 5% Flyash 47.50% Sand 47.50% Water/Cement: 3

Avg. Dia. of Spec.(cm):(7.1247 7.2644 7.2263)/3 7.21 cm

Avg. ht. of Spec.(cm): (7.17296 7.1628 7.112)/3 7.15 cm

Crossectional Area of Specimen: 41.45 sqcm

Viscosity of Water : 9.33E-04 Pa-S Density of Water : 1.00 g/cm^3

Confining Pressure : 344.74 KPa Driving Pressure (P) : 275.79 KPa

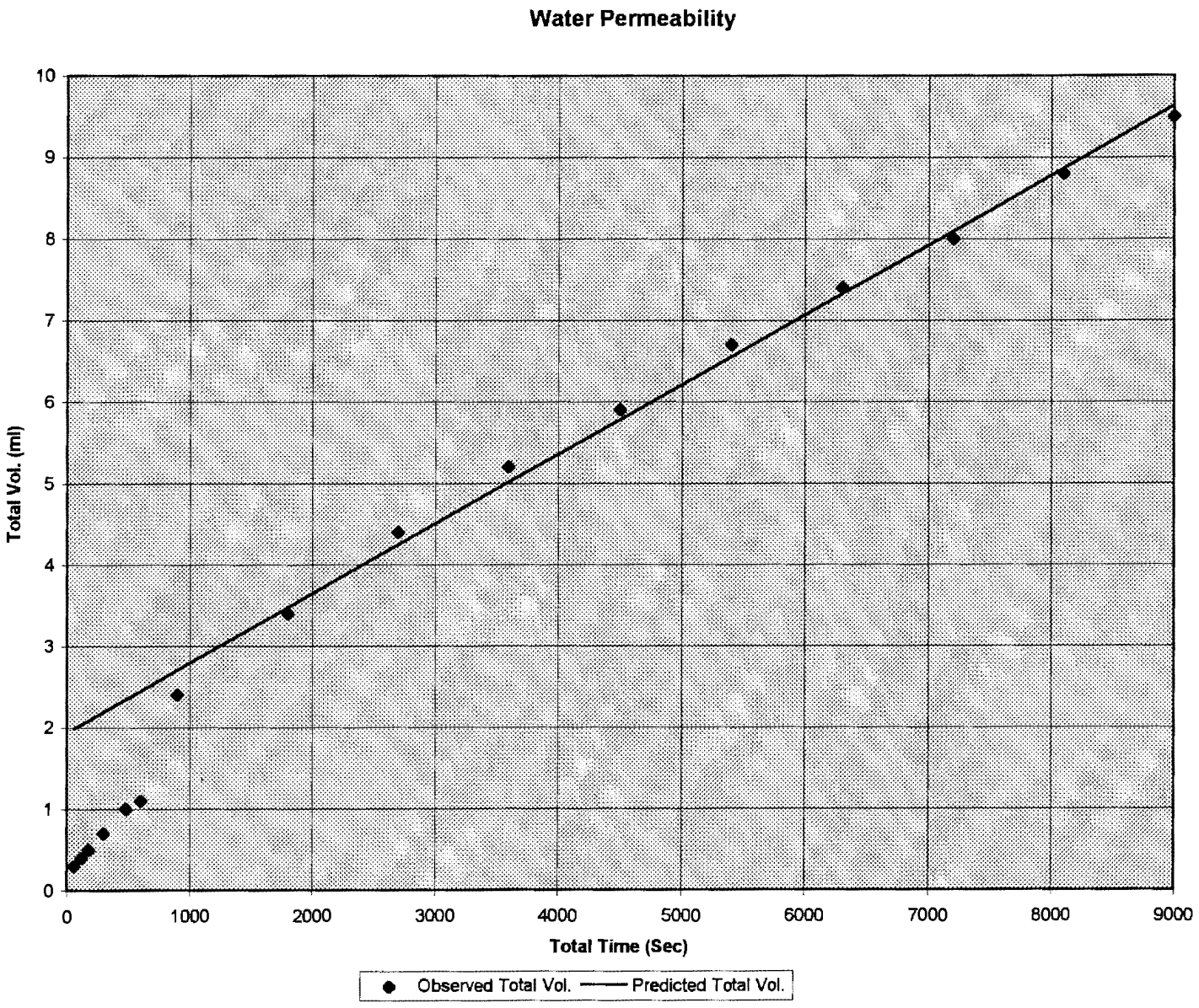
Atm. Pressure (Pa) : 101.33 KPa Pressure Gradient (delta P): 174.47 KPa

Sat. Surface Dry Wt. of Specimen: 614.10 g. Dry Wt. of Specimen: 543.20 g

Submerged Unit Wt.of Specimen : 325.60 g.

Reading No.	Time Elapsed (sec)	Incremental Time (sec)	Total Volume Collected (ml)	Incremental Vol. Collected (ml)	Intrisic Permeability(sqcm	Hydraulic Conductivity (cm/sec)
1	0	0	0.2	0.2		
2	60	60	0.3	0.1		
3	120	60	0.4	0.1	1.5366E-12	1.50587E-08
4	180	60	0.5	0.1	1.5366E-12	1.50587E-08
5	300	120	0.7	0.2	1.5366E-12	1.50587E-08
6	480	180	1	0.3	1.5366E-12	1.50587E-08
7	600	120	1.1	0.1	7.683E-13	7.52934E-09
8	900	300	2.4	1.3	3.99516E-12	3.91525E-08
9	1800	900	3.4	1	1.0244E-12	1.00391E-08
10	2700	900	4.4	1	1.0244E-12	1.00391E-08
11	3600	900	5.2	0.8	8.1952E-13	8.03129E-09
12	4500	900	5.9	0.7	7.1708E-13	7.02738E-09
13	5400	900	6.7	0.8	8.1952E-13	8.03129E-09
14	6300	900	7.4	0.7	7.1708E-13	7.02738E-09
15	7200	900	8	0.6	6.1464E-13	6.02347E-09
16	8100	900	8.8	0.8	8.1952E-13	8.03129E-09
17	9000	900	9.5	0.7	7.1708E-13	7.02738E-09

Water Permeability of Specimen No. 11



Specimen Id 12 Date of Experiment: 8/15/95 File Name: SPCMN12

Cement: 5% Flyash 71.25% Sand 23.75% Water/Cement: 3

Avg. Dia. of Spec.(cm):(7.1755 6.56844 7.1755)/3 6.97 cm

Avg. ht. of Spec.(cm): (7.3025 7.239 7.1628)/3 7.23 cm

Crossectional Area of Specimen: 33.89 sqcm

Viscosity of Water : 9.33E-04 Pa-S Density of Water : 1.00 g/cm^3

Confining Pressure : 344.74 KPa Driving Pressure (P) : 275.79 KPa

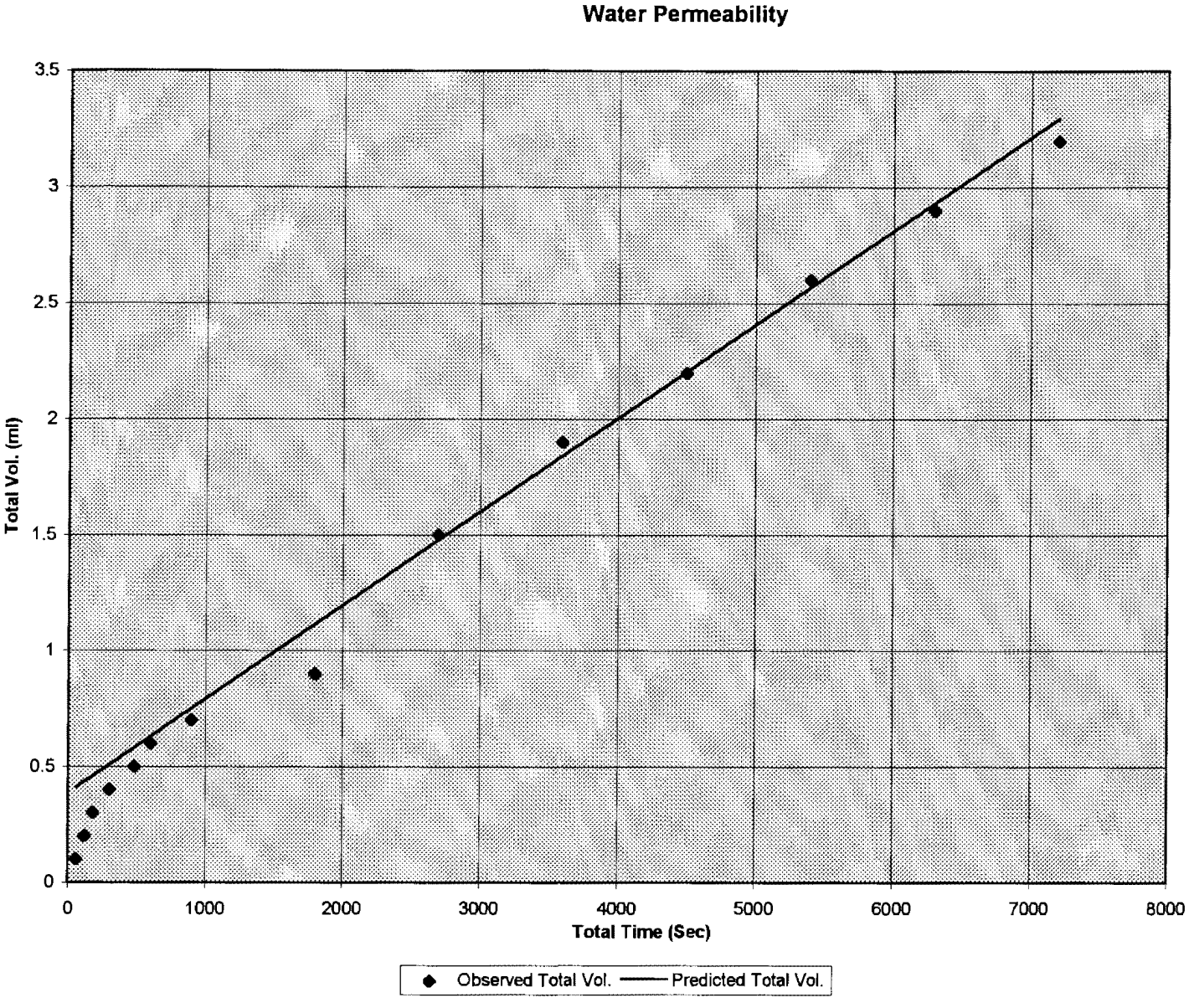
Atm. Pressure (Pa) : 101.33 KPa Pressure Gradient (delta P): 174.47 KPa

Sat. Surface Dry Wt. of Specimen: 610.10 g. Dry Wt. of Specimen: 548.40 g

Submerged Unit Wt.of Specimen : 320.20 g.

Reading No.	Time Elapsed (sec)	Incremental Time (sec)	Total Volume Collected (ml)	Incremental Vol. Collected (ml)	Intrisic Permeability(sqcm	Hydraulic Conductivity (cm/sec)
1	0	0	0	0		
2	60	60	0.1	0.1		
3	120	60	0.2	0.1	1.90195E-12	1.86391E-08
4	180	60	0.3	0.1	1.90195E-12	1.86391E-08
5	300	120	0.4	0.1	9.50976E-13	9.31956E-09
6	480	180	0.5	0.1	6.33984E-13	6.21304E-09
7	600	120	0.6	0.1	9.50976E-13	9.31956E-09
8	900	300	0.7	0.1	3.8039E-13	3.72783E-09
9	1800	900	0.9	0.2	2.53594E-13	2.48522E-09
10	2700	900	1.5	0.6	7.60781E-13	7.45565E-09
11	3600	900	1.9	0.4	5.07187E-13	4.97043E-09
12	4500	900	2.2	0.3	3.8039E-13	3.72783E-09
13	5400	900	2.6	0.4	5.07187E-13	4.97043E-09
14	6300	900	2.9	0.3	3.8039E-13	3.72783E-09
15	7200	900	3.2	0.3	3.8039E-13	3.72783E-09
16	8100	900	3.5	0.3	3.8039E-13	3.72783E-09
17	9000	900	3.8	0.3	3.8039E-13	3.72783E-09

Water Permeability of Specimen No. 12



Specimen Id 13 Date of Experiment: 8/16/95 File Name: SPCMN13

Cement: 3% Flyash 24.25% Sand 72.75% Water/Cement: 3.25

Avg. Dia. of Spec.(cm):(7.1628 7.1628 7.1628)/3 7.16 cm

Avg. ht. of Spec.(cm): (7.2898 7.2898 7.2898)/3 7.29 cm

Crossectional Area of Specimen: 40.30 sqcm

Viscosity of Water : 9.33E-04 Pa-S Density of Water : 1.00 g/cm^3

Confining Pressure : 344.74 KPa Driving Pressure (P) : 275.79 KPa

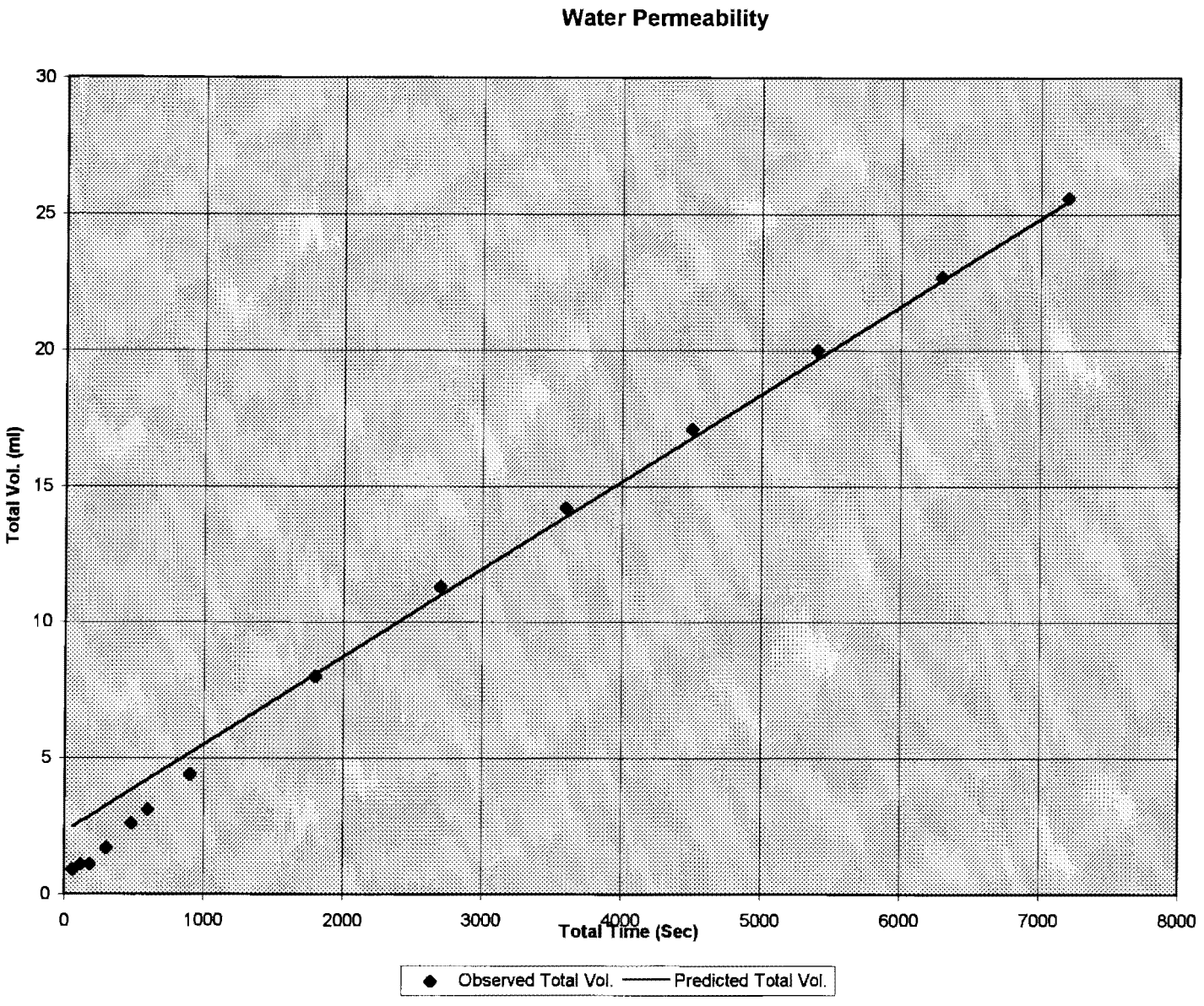
Atm. Pressure (Pa) : 101.33 KPa Pressure Gradient (delta P): 174.47 KPa

Sat. Surface Dry Wt. of Specimen: 623.70 g. Dry Wt. of Specimen: 574.40 g

Submerged Unit Wt.of Specimen : _____ g.

Reading No.	Time Elapsed (sec)	Incremental Time (sec)	Total Volume Collected (ml)	Incremental Vol. Collected (ml)	Intrisic Permeability(sqcm	Hydraulic Conductivity (cm/sec)
1	0	0	0.6	0.6		
2	60	60	0.9	0.3		
3	120	60	1.1	0.2	3.22314E-12	3.15868E-08
4	180	60	1.1	0	0	0
5	300	120	1.7	0.6	4.83471E-12	4.73802E-08
6	480	180	2.6	0.9	4.83471E-12	4.73802E-08
7	600	120	3.1	0.5	4.02893E-12	3.94835E-08
8	900	300	4.4	1.3	4.19008E-12	4.10628E-08
9	1800	900	8	3.6	3.86777E-12	3.79041E-08
10	2700	900	11.3	3.3	3.54546E-12	3.47455E-08
11	3600	900	14.2	2.9	3.1157E-12	3.05339E-08
12	4500	900	17.1	2.9	3.1157E-12	3.05339E-08
13	5400	900	20	2.9	3.1157E-12	3.05339E-08
14	6300	900	22.7	2.7	2.90083E-12	2.84281E-08
15	7200	900	25.6	2.9	3.1157E-12	3.05339E-08
16	8100	900	28.3	2.7	2.90083E-12	2.84281E-08
17	9000	900	31	2.7	2.90083E-12	2.84281E-08
18	9900	900	33.9	2.9	3.1157E-12	3.05339E-08

Water Permeability of Specimen No. 13



Specimen Id 14 Date of Experiment: 8/16/95 File Name: SPCMN14

Cement: 3% Flyash 48.50% Sand 48.50% Water/Cement: 3.25

Avg. Dia. of Spec.(cm):(7.1628 7.1628 7.239)/3 7.19 cm

Avg. ht. of Spec.(cm): (7.2898 7.2898 7.2898)/3 7.29 cm

Crossectional Area of Specimen: 40.30 sqcm

Viscosity of Water : 9.33E-04 Pa-S Density of Water : 1.00 g/cm^3

Confining Pressure : 344.74 KPa Driving Pressure (P) : 275.79 KPa

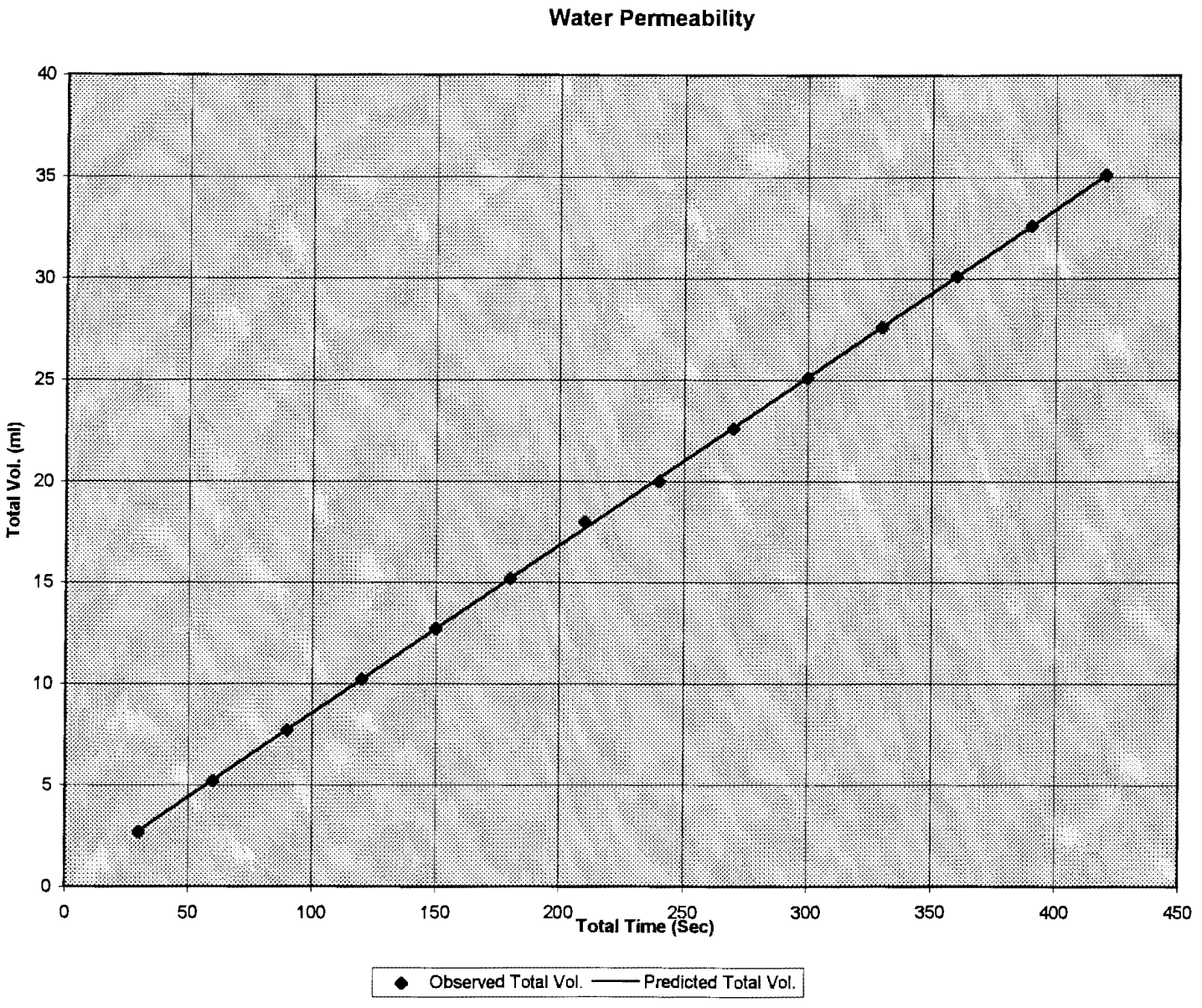
Atm. Pressure (Pa) : 101.33 KPa Pressure Gradient (delta P): 174.47 KPa

Sat. Surface Dry Wt. of Specimen: 629.40 g. Dry Wt. of Specimen: 567.20 g

Submerged Unit Wt.of Specimen : 334.20 g.

Reading No.	Time Elapsed (sec)	Incremental Time (sec)	Total Volume Collected (ml)	Incremental Vol. Collected (ml)	Intrisic Permeability(sqcm	Hydraulic Conductivity (cm/sec)
1	0	0	0	0		
2	30	30	2.7	2.7		
3	60	30	5.2	2.5	8.05785E-11	7.8967E-07
4	90	30	7.7	2.5	8.05785E-11	7.8967E-07
5	120	30	10.2	2.5	8.05785E-11	7.8967E-07
6	150	30	12.7	2.5	8.05785E-11	7.8967E-07
7	180	30	15.2	2.5	8.05785E-11	7.8967E-07
8	210	30	18	2.8	9.0248E-11	8.8443E-07
9	240	30	20	2	6.44628E-11	6.31736E-07
10	270	30	22.6	2.6	8.38017E-11	8.21256E-07
11	300	30	25.1	2.5	8.05785E-11	7.8967E-07
12	330	30	27.6	2.5	8.05785E-11	7.8967E-07
13	360	30	30.1	2.5	8.05785E-11	7.8967E-07
14	390	30	32.6	2.5	8.05785E-11	7.8967E-07
15	420	30	35.1	2.5	8.05785E-11	7.8967E-07
16	450	30	37.6	2.5	8.05785E-11	7.8967E-07

Water Permeability of Specimen No. 14



Specimen Id 15 Date of Experiment: 8/16/95 File Name: SPCMN15

Cement: 3% Flyash 72.75% Sand 24.25% Water/Cement: 3.25

Avg. Dia. of Spec.(cm):(7.239 6.985 7.17804)/3 7.13 cm

Avg. ht. of Spec.(cm): (7.1882 7.112 7.239)/3 7.18 cm

Crossectional Area of Specimen: 39.97 sqcm

Viscosity of Water : 9.33E-04 Pa-S Density of Water : 1.00 g/cm^3

Confining Pressure : 344.74 KPa Driving Pressure (P) : 275.79 KPa

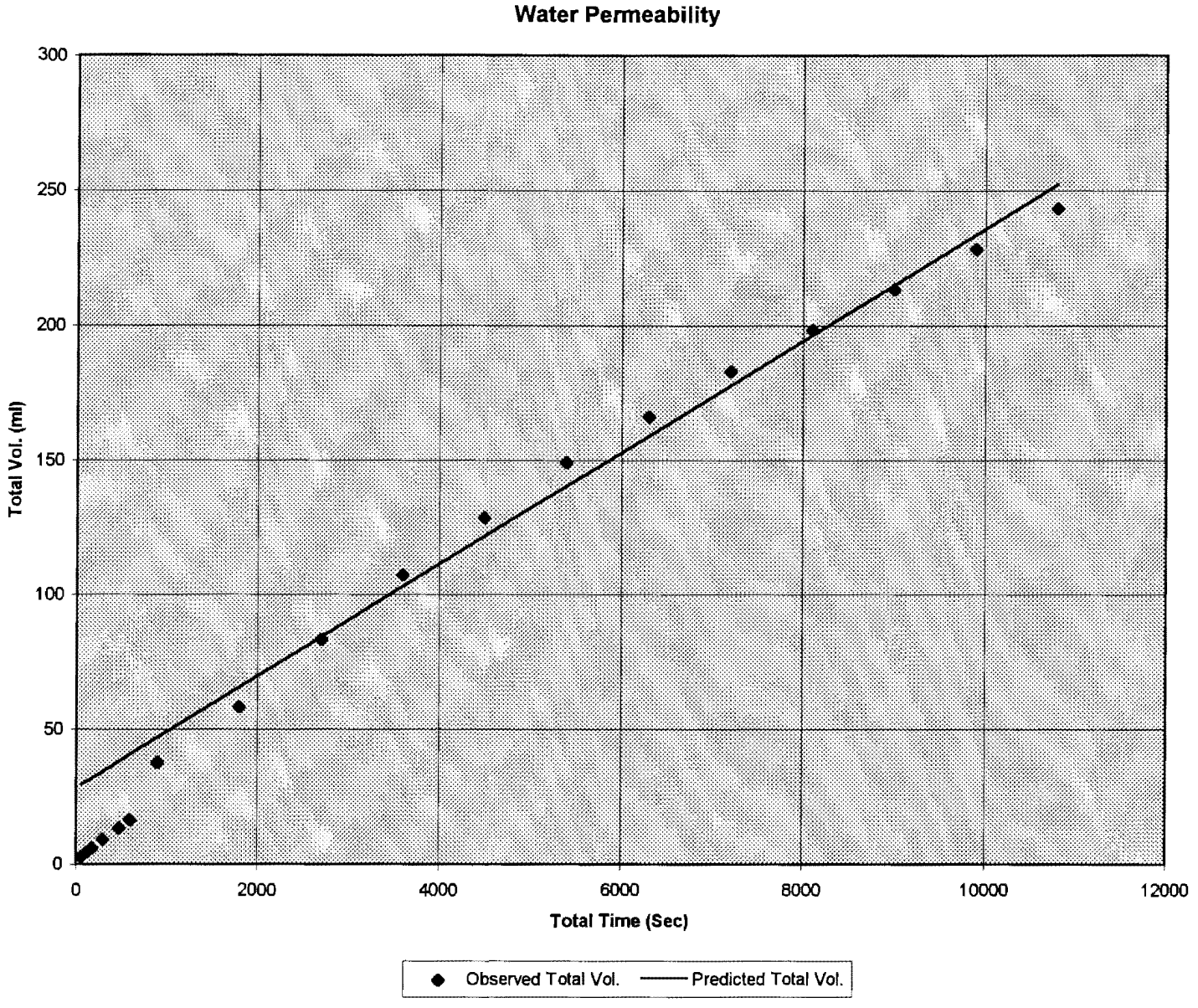
Atm. Pressure (Pa) : 101.33 KPa Pressure Gradient (delta P): 174.47 KPa

Sat. Surface Dry Wt. of Specimen: 569.20 g. Dry Wt. of Specimen: 479.30 g

Submerged Unit Wt.of Specimen : 279.80 g.

Reading No.	Time Elapsed (sec)	Incremental Time (sec)	Total Volume Collected (ml)	Incremental Vol. Collected (ml)	Intrisic Permeability(sqcm	Hydraulic Conductivity (cm/sec)
1	0	0	2	2		
2	60	60	2.8	0.8	1.28006E-11	1.25446E-07
3	120	60	4.5	1.7	2.72012E-11	2.66572E-07
4	180	60	6.1	1.6	2.56012E-11	2.50891E-07
5	300	120	9.2	3.1	2.48011E-11	2.43051E-07
6	480	180	13.5	4.3	2.29344E-11	2.24757E-07
7	600	120	16.4	2.9	2.32011E-11	2.2737E-07
8	900	300	37.6	21.2	6.78431E-11	6.64862E-07
9	1800	900	58.2	20.6	2.19743E-11	2.15349E-07
10	2700	900	83.2	25	2.66679E-11	2.61345E-07
11	3600	900	107.2	24	2.56012E-11	2.50891E-07
12	4500	900	128.5	21.3	2.2721E-11	2.22666E-07
13	5400	900	149	20.5	2.18677E-11	2.14303E-07
14	6300	900	166.1	17.1	1.82408E-11	1.7876E-07
15	7200	900	182.9	16.8	1.79208E-11	1.75624E-07
16	8100	900	198.3	15.4	1.64274E-11	1.60989E-07
17	9000	900	213.3	15	1.60007E-11	1.56807E-07
18	9900	900	228.3	15	1.60007E-11	1.56807E-07
19	10800	900	243.3	15	1.60007E-11	1.56807E-07

Water Permeability of Specimen No. 15



Specimen Id 16 Date of Experiment: 8/17/95 File Name: SPCMN16

Cement: 3% Flyash 24.25% Sand 72.75% Water/Cement: 3

Avg. Dia. of Spec.(cm):(7.2644 7.1882 7.2898)/3 7.25 cm

Avg. ht. of Spec.(cm): (7.2644 7.2644 7.2644)/3 7.26 cm

Crossectional Area of Specimen: 41.25 sqcm

Viscosity of Water : 9.33E-04 Pa-S Density of Water : 1.00 g/cm^3

Confining Pressure : 344.74 KPa Driving Pressure (P) : 275.79 KPa

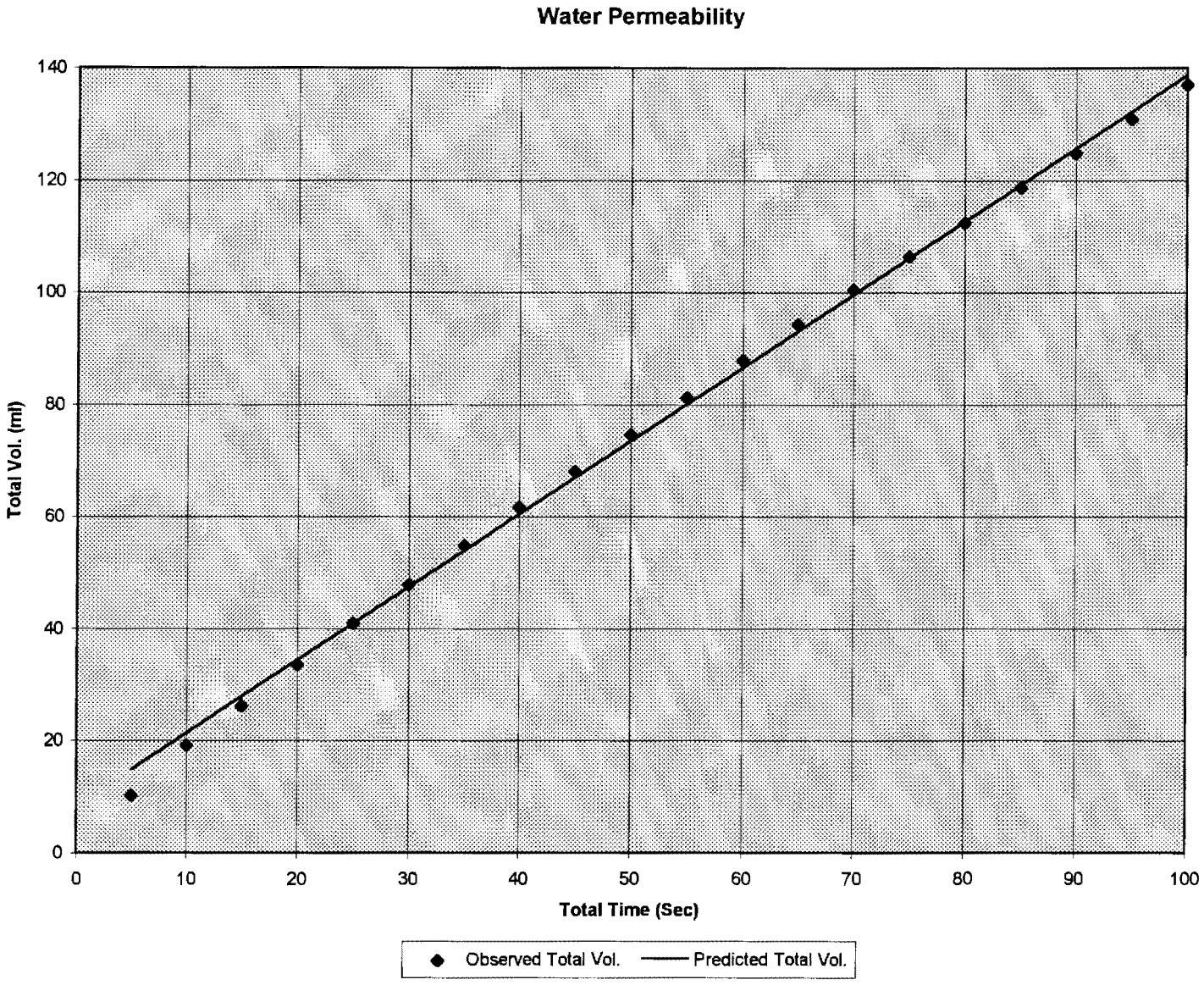
Atm. Pressure (Pa) : 101.33 KPa Pressure Gradient (delta P): 174.47 KPa

Sat. Surface Dry Wt. of Specimen: 640.70 g. Dry Wt. of Specimen: 586.80 g

Submerged Unit Wt.of Specimen : 347.70 g.

Reading No.	Time Elapsed (sec)	Incremental Time (sec)	Total Volume Collected (ml)	Incremental Vol. Collected (ml)	Intrisic Permeability(sqcm	Hydraulic Conductivity (cm/sec)
1	0	0	1	0		
2	5	5	10.2	9.2	1.73179E-09	1.69716E-05
3	10	5	19.2	9	1.69414E-09	1.66026E-05
4	15	5	26.2	7	1.31767E-09	1.29131E-05
5	20	5	33.5	7.3	1.37414E-09	1.34666E-05
6	25	5	40.9	7.4	1.39296E-09	1.3651E-05
7	30	5	47.8	6.9	1.29884E-09	1.27287E-05
8	35	5	54.8	7	1.31767E-09	1.29131E-05
9	40	5	61.6	6.8	1.28002E-09	1.25442E-05
10	45	5	68.1	6.5	1.22355E-09	1.19908E-05
11	50	5	74.7	6.6	1.24237E-09	1.21753E-05
12	55	5	81.3	6.6	1.24237E-09	1.21753E-05
13	60	5	87.9	6.6	1.24237E-09	1.21753E-05
14	65	5	94.3	6.4	1.20472E-09	1.18063E-05
15	70	5	100.5	6.2	1.16708E-09	1.14374E-05
16	75	5	106.5	6	1.12943E-09	1.10684E-05
17	80	5	112.5	6	1.12943E-09	1.10684E-05
18	85	5	118.7	6.2	1.16708E-09	1.14374E-05
19	90	5	124.8	6.1	1.14825E-09	1.12529E-05
20	95	5	130.9	6.1	1.14825E-09	1.12529E-05
21	100	5	137	6.1	1.14825E-09	1.12529E-05

Water Permeability of Specimen No. 16



Specimen Id 17 Date of Experiment: 8/17/95 File Name: SPCMN17

Cement: 3% Flyash 48.50% Sand 48.50% Water/Cement: 3

Avg. Dia. of Spec.(cm):(7.2644 7.3152 7.2898)/3 7.29 cm

Avg. ht. of Spec.(cm): (7.2644 7.1628 7.1628)/3 7.20 cm

Crossectional Area of Specimen: 41.74 sqcm

Viscosity of Water : 9.33E-04 Pa-S Density of Water : 1.00 g/cm^3

Confining Pressure : 344.74 KPa Driving Pressure (P) : 275.79 KPa

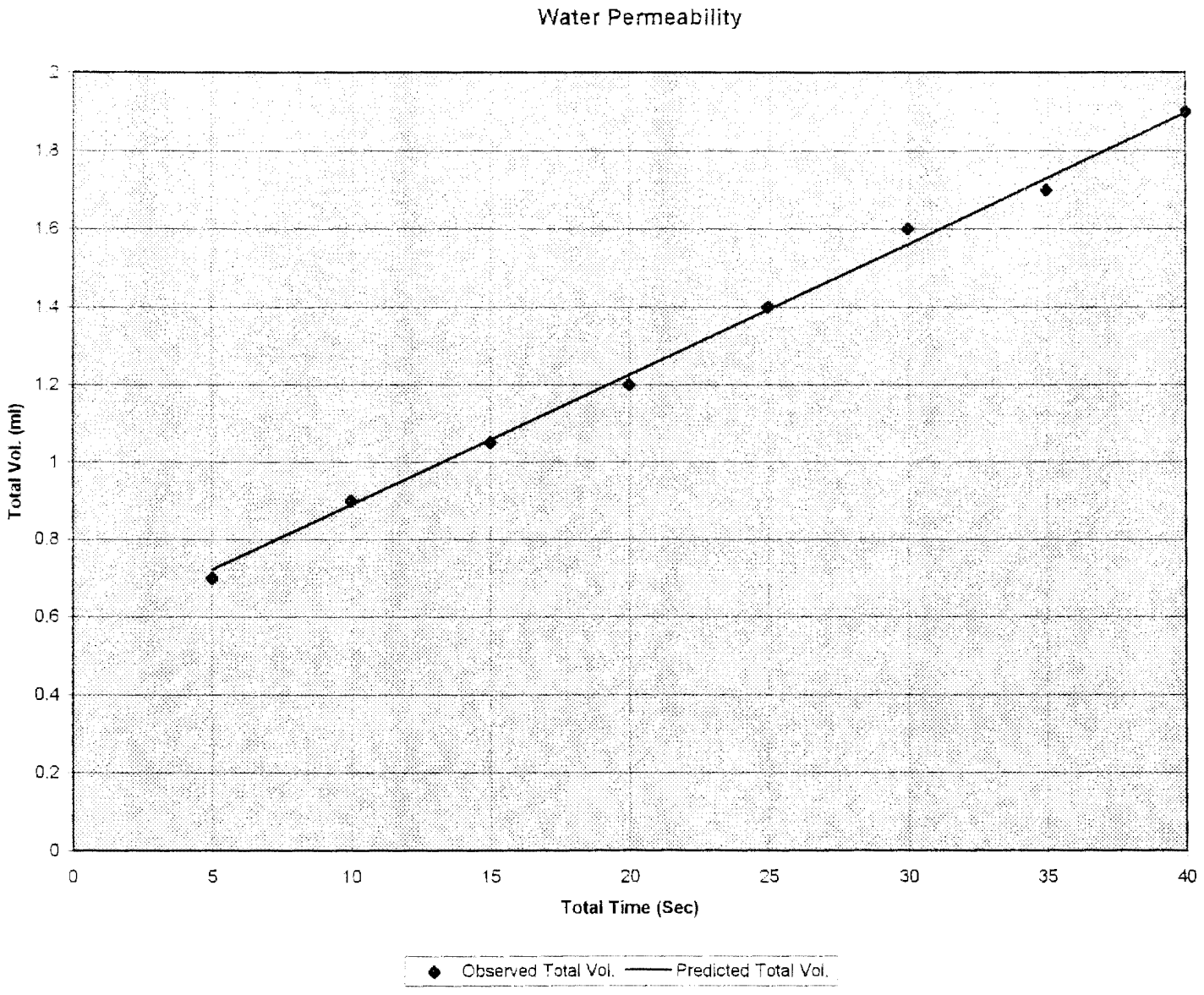
Atm. Pressure (Pa) : 101.33 KPa Pressure Gradient (delta P): 174.47 KPa

Sat. Surface Dry Wt. of Specimen: 647.70 g. Dry Wt. of Specimen: 590.40 g

Submerged Unit Wt.of Specimen : 351.50 g.

Reading No.	Time Elapsed (sec)	Incremental Time (sec)	Total Volume Collected (ml)	Incremental Vol. Collected (ml)	Intrisic Permeability(sqcm	Hydraulic Conductivity (cm/sec)
1	0	0	0.6	0.6		
2	5	5	0.7	0.1	1.84324E-11	1.80637E-07
3	10	5	0.9	0.2	3.68647E-11	3.61274E-07
4	15	5	1.05	0.15	2.76485E-11	2.70956E-07
5	20	5	1.2	0.15	2.76485E-11	2.70956E-07
6	25	5	1.4	0.2	3.68647E-11	3.61274E-07
7	30	5	1.6	0.2	3.68647E-11	3.61274E-07
8	35	5	1.7	0.1	1.84324E-11	1.80637E-07
9	40	5	1.9	0.2	3.68647E-11	3.61274E-07

Water Permeability of Specimen No. 17



Specimen Id 18 Date of Experiment: 8/17/95 File Name: SPCMN18

Cement: 3% Flyash 72.75% Sand 24.25% Water/Cement: 3

Avg. Dia. of Spec.(cm):(7.2567 7.2644 7.2898)/3 7.27 cm

Avg. ht. of Spec.(cm): (7.2898 7.2898 7.2898)/3 7.29 cm

Crossectional Area of Specimen: 41.51 sqcm

Viscosity of Water : 9.33E-04 Pa-S Density of Water : 1.00 g/cm^3

Confining Pressure : 344.74 KPa Driving Pressure (P) : 275.79 KPa

Atm. Pressure (Pa) : 101.33 KPa Pressure Gradient (delta P): 174.47 KPa

Sat. Surface Dry Wt. of Specimen: 580.80 g. Dry Wt. of Specimen: 480.80 g

Submerged Unit Wt.of Specimen : 286.20 g.

Reading No.	Time Elapsed (sec)	Incremental Time (sec)	Total Volume	Incremental Vol. Collected (ml)	Intrisic Permeability(sqcm	Hydraulic Conductivity (cm/sec)
1	0	0	0	0		
2	5	5	9.5	9.5	1.78326E-09	1.7476E-05
3	10	5	17.5	8	1.50169E-09	1.47166E-05
4	15	5	25.5	8	1.50169E-09	1.47166E-05
5	20	5	33.5	8	1.50169E-09	1.47166E-05
6	25	5	41.4	7.9	1.48292E-09	1.45326E-05
7	30	5	49.3	7.9	1.48292E-09	1.45326E-05
8	35	5	57.3	8	1.50169E-09	1.47166E-05
9	40	5	65.2	7.9	1.48292E-09	1.45326E-05
10	45	5	73.2	8	1.50169E-09	1.47166E-05

Water Permeability of Specimen No. 18