Technical Report CHL-99-9
September 1999

US Army Corps of Engineers
Engineer Research and Development Center

Ashtubula River, Ohio, Sedimentation Study

Report 3
Erosion Experiments on Bed Sediments

by Allen M. Teeter, Doug Brister, Joe W. Parman, Clara J. Coleman

Approved For Public Release; Distribution Is Unlimited

20040505 055

Prepared for U.S. Army Engineer District, Buffalo

The contents of this report are not to be used for advertising, publication, or promotional purposes. Citation of trade names does not constitute an official endorsement or approval of the use of such commercial products.

The findings of this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

PRINTED ON RECYCLED PAPER

Technical Report CHL-99-9
September 1999

Ashtubula River, Ohio, Sedimentation Study

Report 3
Erosion Experiments on Bed Sediments

by Allen M. Teeter, Doug Brister, Joe W. Parman, Clara J. Coleman

U.S. Army Engineer Research and Development Center
Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Report 3 of a series

Approved for public release; distribution is unlimited

Prepared for U.S. Army Engineer District, Buffalo
Buffalo, NY 14207-3199

Army Engineer Research and Development Center Cataloging-in-Publication Data

Ashtubula River, Ohio, sedimentation study. Report 3, Erosion experiments on bed sediments / by Allen M. Teeter ... [et al.] ; prepared for U.S. Army Engineer District, Buffalo.
45 p. : ill. ; 28 cm. -- (Technical report ; CHL-99-9 rept.3)
Includes bibliographic references.
1. Ashtubula River (Ohio) 2. Marine sediments -- Ohio -- Ashtubula River -- Testing. 3. Erosion -- Ohio -- Ashtubula River -- Testing. 4. Sedimentation and deposition -- Ohio -- Ashtubula River -- Research. I. Teeter, Allen M. II. United States. Army. Corps of Engineers. Buffalo District. III. U.S. Army Engineer Research and Development Center. IV. Coastal and Hydraulics Laboratory (U.S.) V. Title: Erosion experiments on bed sediments. VI. Series: Technical report CHL ; 99-9 rept.3.
TA7 W34 no.CHL-99-9 rept.3

Contents

List of Figures

Preface

This report describes laboratory experiments performed at the U.S Army Engineer Research and Development Center (ERDC) Coastal and Hydraulics Laboratory (CHL) by the Sedimentation Engineering and Dredging Group (SEDG), Estuaries and Hydrosciences Division (EHSD). The work was performed between June 1994 and February 1996 as part of a sedimentation study sponsored by the U.S. Army Engineer District, Buffalo. The U.S. Environmental Protection Agency (USEPA), Region 5, is in charge of the overall project. Messrs. Ron Heath, Stephen Golyski, and Edward J. Hanlon are the project managers at ERDC, the Buffalo District, and USEPA, respectively.

Personnel of EHSD performed the work under the general supervision of Messrs. Frank A. Herrmann, Jr. (retired), Director, Hydraulics Laboratory (HL); Robert A. Sager (retired), Assistant Director, HL; and Dr. William H. McAnally, Jr., Chief, EHSD. The laboratory experiments were designed and this report written by Mr. Allen M. Teeter, SEDG. Messrs. Doug Brister and Joe W. Parman and Mrs. Clara J. Coleman, all of EHSD, performed the laboratory analyses. The CHL was formed in October 1996 with the merger of the Coastal Engineering Research Center and HL. Dr. James R. Houston is the Director of CHL.

At the time of publication of this report, Dr. Lewis E. Link was Acting Director of ERDC, and COL Robin R. Cababa, EN, was Commander.

The contents of this report are not to be used for advertising, publication, or promotional purposes. Citation of trade names does not constitute an official endorsement or approval of the use of such commercial products.

1 Introduction

Background

The Ashtabula River is located in northeastern Ohio and empties into Lake Erie. The lower 3.2 km of the river and a protected outer basin are used as harbor areas as shown in Figure 1. After World War II, the Ashtabula River and Ashtabula County were active shipyard and manufacturing centers. Contaminants were released over the decades, which became incorporated into riverbed sediments. After 1969, the upper 2,100 m of the navigation project was not maintained by dredging because of high levels of contaminants in the sediments. Between 1969 and 1990, bed elevations in the upper project increased from the authorized 168.4 m to between about 169.9 and 173.0 m by natural sedimentation. (The average lake level is 174.3 m.) Depths in the project channel decreased accordingly, and the upper project is no longer used for deep-draft waterborne commerce.

Today, surface-bed-sediment concentrations of contaminants are relatively low, but higher concentrations exist at depth in the sediments of the upper project. There is an ongoing Superfund remediation in the Fields Brook watershed that empties into the Ashtabula River. As part of the 1986 Record of Decision for that site, investigations were undertaken to address the nature and extent of contamination in the Ashtabula River.

A study to determine the potential mobility of contaminated sediments buried by natural sedimentation in the Ashtabula River was begun in 1994. Sediments might be mobilized by large riverflows, for example. During the initial phase of that study, field data were collected and a numerical hydrodynamic model was developed for the river. Presently, field data collection efforts are on standby, waiting to capture a large-flow event that would be of particular value for model verification.

As part of the ongoing sedimentation study, laboratory investigations were undertaken to gauge the erodibility of Ashtabula River bed sediments. Those experiments and results are described here. Fine-grained muddy and/or cohesive sediments' erodibility varies widely depending on mineral composition, clay content, organic content, density, and physicochemical makeup. Since a prediction of a particular fine-grained sediment's erodibility has considerable uncertainty, good estimates require experimental determinations.

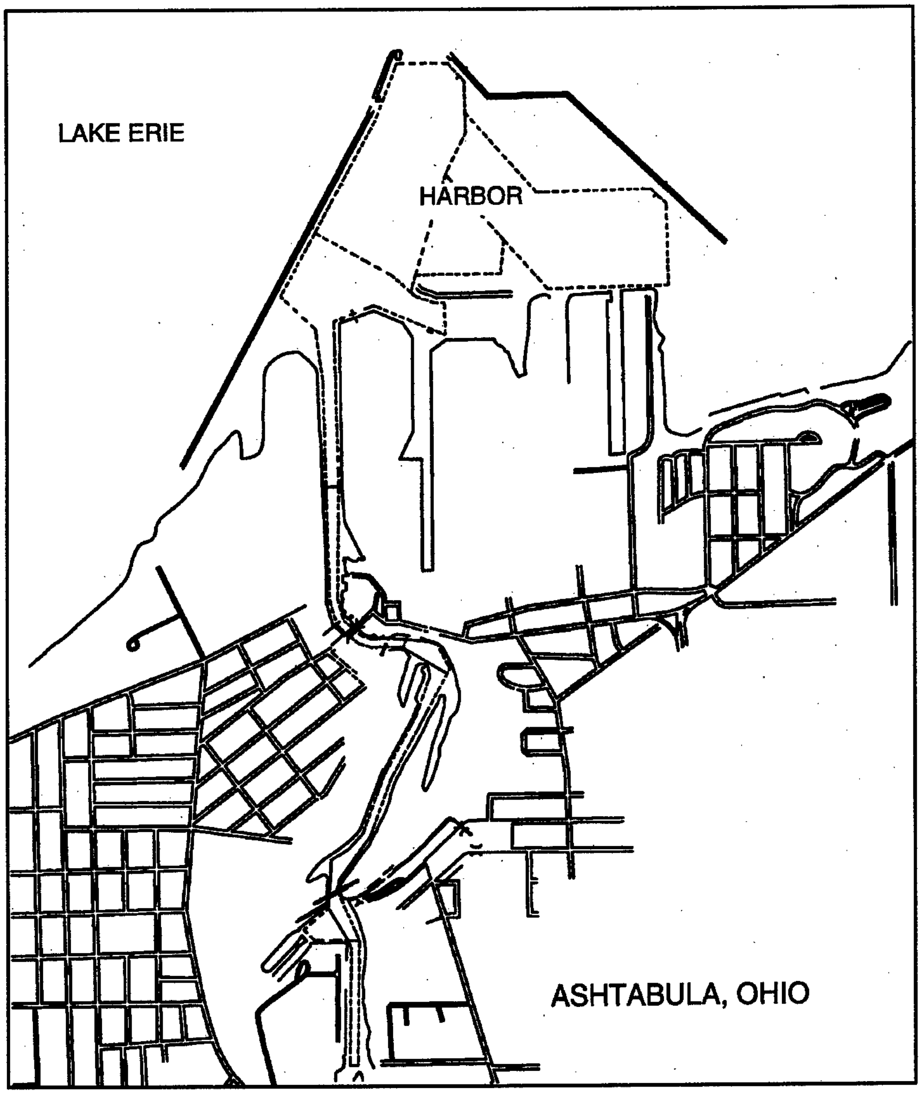


Figure 1. Project location

Objective

The objective of this work was to characterize the erodibility of Ashtabula River bed sediments and, thus, to aid in the estimation of the possible erosion of bed sediments by rare or low probability hydrologic/hydraulic events. Erosion of massive amounts of bed sediments could mobilize contaminants buried in Ashtabula River sediments. An assessment of this possibility requires estimation of sediment erodibility for use in numerical hydrodynamic/sedimentation models or other calculation procedures.

Scope

This is the third in a series of reports in a study to determine the potential magnitude and extent of erosion that might occur during rare or unlikely low probability events. The first report (Heath et al. 1999) presented interim results of field and model investigations. The second report (Fagerburg 1999) described field data collection in detail. This report describes laboratory investigations of bed-material erodibility on samples from Ashtabula River.

In general, sediments were collected by box corer, grab sampler, and vibracorer; characterized and undisturbed subsamples were used in erosion experiments. Samples were collected in 1994 at the sediment-bed surface and in 1995 as 1.22-m-long cores. Two erosion experimental devices were used to cover a wide range of hydraulic shear stresses. Ten experiments were performed in 1994, and five were performed in 1995. Each experiment had three to seven levels of applied hydraulic shear stress.

2 Experimental Methods

Erosion Experimental Devices

There are no standardized erosion test procedures, so experimental methods will be described in some detail. Two erosion test devices were employed. One device is a variation of the Particle Entrainment Simulator (PES) described by Tsai and Lick (1986). The other device was a Vertical-Loop Sediment Water Tunnel (VOST).

Particle Entrainment Simulator. The PES, fabricated at the U.S. Army Engineer Research and Development Center (ERDC), has an erosion chamber geometry identical to that used by several other investigators and is intended primarily as a field tool for erodibility assessment of undisturbed 11.75-cm-diam cohesive-sediment core sections. The PES is a portable device proposed by Tsai and Lick (1986) and used extensively for testing undisturbed core sections (Lavelle and Davis 1987; Davis 1993). An oscillating grid in the PES generates turbulence above sediment to simulate the erosive shear stress of a shear flow; therefore, mean bed shear stress, normally used to correlate erosion, is not available as a measurable parameter. The PES must be calibrated using another erosion device to obtain this parameter. The PES was originally calibrated by comparing test suspension concentrations with those from an annular flume. The original calibration was used to correlate oscillation rate to an equivalent shear stress. The range of equivalent shear stress created in the PES is about 0.2-0.6 Pa.

The PES erosion chamber is a vertical cylinder of 11.75 cm ID and is operated with 12.7 cm of water over the sediment bed. The oscillating disk is located at a minimum distance of 5.1 cm from the sediment bed and has an excursion of 2.54 cm. Details can be found in Tsai and Lick (1986), and a schematic of the PES used in these tests is shown in Figure 2. The mechanical aspects of the ERDC PES were slightly changed, but the dimensions of the erosion chamber and oscillating disk were true to the original.

Vertical-Loop Sediment Water Tunnel. The VOST is a smaller, higher flow version of a sediment water tunnel described by Teeter and Pankow (1989). It consists of two rectangular horizontal and two circular vertical sections arranged in a vertical plane. During operation, all sections are completely filled with water, and there are no free surfaces. Flow in the VOST is driven by a propeller pump in one of the two 15.24-cm-diam circular sections. The

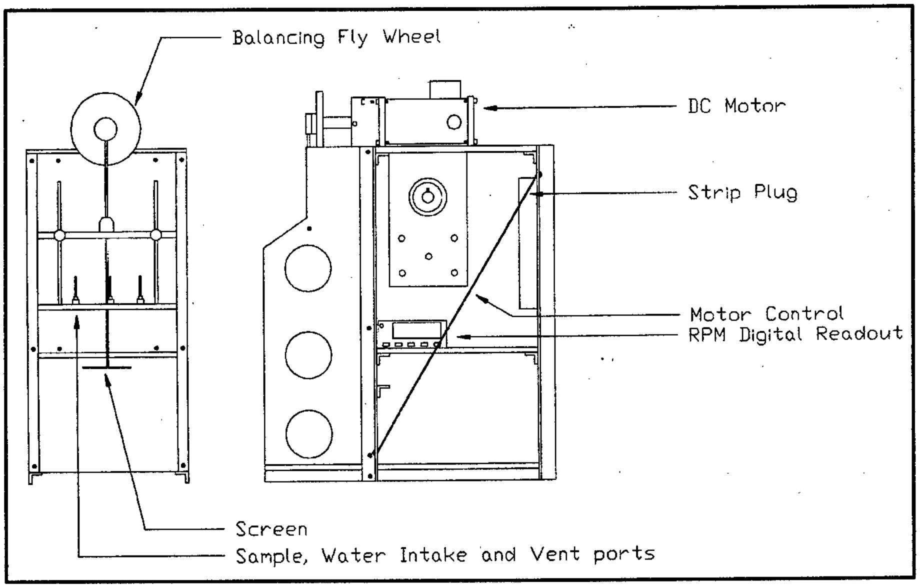


Figure 2. Schematic of the Particle Entrainment Simulator (PES)

horizontal tunnel sections are 7.6 cm high by 24.1 cm wide. The flow cross-sectional area averages 183 sq cm, and the flow length around the VOST is 3.5 m.

Flows in the VOST are up to 1.54 m/sec, generating a maximum average shear stress of almost 3 Pa. The volume of the system is 64 L. The test material is placed in a sample tray in the center of the lower horizontal section. The propeller pump is 2.6 m upstream from the bed-sediment sample tray. Figure 3 shows a schematic of the VOST.

The VOST shear stresses were calibrated by correlating propeller-pump motor voltage and flow speed to measured shear stress. Calibration shear stresses were measured using a hot-film sensor at nine locations over a clear acrylic plate positioned at the normal sediment-bed level. The shear stress sensor was calibrated in a laminar flow duct at known flow rates and pressure drops. The spatial variation of shear stress observed over the sediment bed was such that standard deviations divided by the mean shear stresses were 27 percent for shear stresses less than 1.1 Pa and decreased to 17 percent at maximum shear stress. The useful range of shear stresses produced in the VOST is about 0.35-2.5 Pa.

Erosion Test Procedures

In both experimental devices, shear stresses were stepped up and held for 30-40 min at each step. Suspension concentrations were monitored over time to estimate erosion and erosion rates from sediment-bed surfaces. Then from relationships between erosion rate and bed shear stress, the threshold or critical shear stress for erosion and the slope of the erosion curve can be determined.

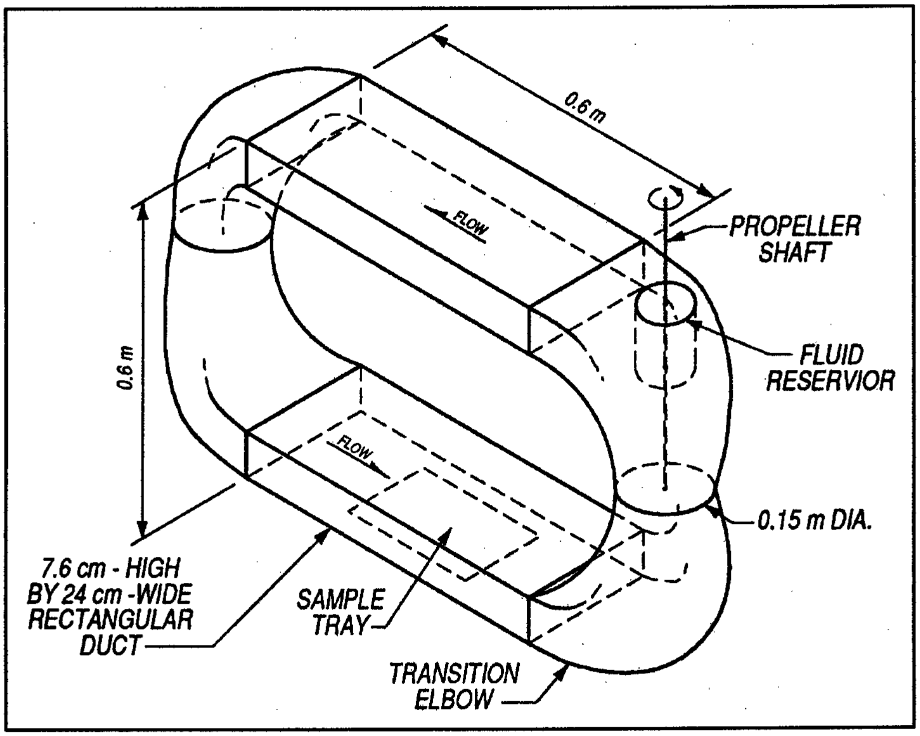


Figure 3. Schematic of the Vertical-Loop Sediment Water Tunnel (VOST)

PES. Equivalent shear stresses were increased stepwise during erosion tests and the suspension concentrations monitored with time. PES tests started with an initial 2-min period at 100 rpm to suspended very loose sediment that might result from the bed preparation. This initial step was equivalent to about 0.1 Pa but was meant only to prepare the sediment bed. The equivalent shear stresses were then stepped to 0.2, 0.3, 0.4, and 0.5 Pa when bed surface samples were tested or to 0.3, 0.5, and 0.6 Pa when samples from below the bed surface were tested. Experiments were conducted at 20.6-22.2 °C.

Erosion experiments in the PES had 30-min steps at each of a series of increasing shear stresses. Samples of erosion chamber suspensions were collected starting 10 min after the start of the steps and was repeated every 5 min thereafter. Samples of 50 ml were withdrawn using a pump. Particle-free water was simultaneously introduced during sampling to keep the water level constant in the PES erosion chamber. Samples were filtered through 0.45-μm polycarbonate Nuclepore filters to determine total suspended material.

Because the suspension volume of the PES is relatively small, sample suspension concentrations were adjusted for the mass withdrawn during earlier sampling. During sampling, particle-free water was added to keep the water surface at a constant level, as previously described. A correction equal to the calculated decrease in concentration because of the sampling and chamber replenishment was added to the results of subsequent samples.

Samples were collected with a 15-cm-square box corer and subsampled with 11.75-cm-diam PES cylinders in the field. Sampling details are described by Fagerburg (1999). Sample cylinders were sealed with water standing on sediments and kept upright during shipping and storage. In the laboratory, water levels in the cylinders were adjusted according to PES procedures. The experimental sediments were allowed to stand 1-4 days before testing. After the sediment surface was tested, a piston was used to extrude samples partially from cylinders. Samples were then sliced to expose deeper sediment horizons, allowed to stand 1-4 days, and erosion was tested.

VOST. VOST experiments are performed on sediment cores. Sampling was performed in June 1995. Sample cores were about 1.22 m in length and 9.5 cm in diameter and were divided into 0.61-m sections in the field. In the laboratory, samples were subsampled with a 7.5-cm-ID by 4-cm-long cylinder for placement in the VOST. The sediment samples were then sprayed with water to cover their surfaces and allowed to stand overnight. Experiments were conducted at 18.3-20.6 °C.

Shear stress was increased incrementally, as with PES experiments. Seven 40-min steps were taken during each experiment. Shear stresses ranged from 0.35 to 2.33 Pa. Samples were collected 10 min after shear stress changes and every 10 min thereafter. Samples were filtered through 0.45-μm polycarbonate Nuclepore filters to determine total suspended material.

Sediment Characterization

Sediments were characterized by grain size, density (related to porosity and moisture), pH, moisture content, loss on ignition, and rheological behavior. Sediment grain size was determined by standard sieve and pipette analyses. Pipette analyses were performed on suspensions of about 5-g/L sediment concentration using a 5-g/L Calgon solution as a diluent. Sediment bulk wet density was determined with a pycnometer using standard procedures. Moisture content (m) was measured independently as the ratio of the water weight to the dry sediment weight of a sample.

Loss on ignition (LOI) was determined by first drying sediment at 105 °C until no further weight loss occurred or overnight, then firing the material at 550 °C for 1 hr. LOI is the fraction of dry weight lost during combustion.

Rheological characterizations were performed by creep test on select samples. A CarriMed model CLS 100 controlled stress rheometer was used with a 4-cm-diam parallel plate and 2-mm-gap geometry. Stresses of 2, 5, and 10 Pa were applied successively to 1994 samples. Stresses of 10, 20, and 30 Pa were applied successively to 1995 samples. Stress was applied for 3 min, removed, and the sample allowed to relax for 2 min. An additional equilibration time of 3 min was allowed between successive application of stresses. Creep tests were performed at 20 °C.

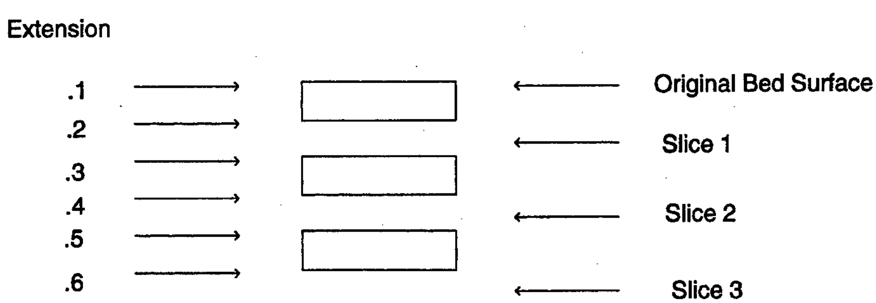
A special set of samples were collected for characterization with a Ponar grab sampler in June 1995. These surficial samples are different from the core samples used in erosion experiments.

3 Results

Erosion Experiments

Ten erosion experiments were performed with the PES on bed sediments collected from the Ashtabula River in June 1994. Five erosion experiments were performed in the VOST on bed sediments collected in June 1995. Sample locations are shown in Figure 4.

Tables 1 and 2 summarize results of the PES and VOST erosion experiments, respectively. The first three digits of the sample number correspond to the station number as shown in Figure 4. The letter A following the station number indicates that the sample was from near the right descending bank. The letter B following the station number indicates that the sample was from the channel centerline. Sample number extensions following the decimal indicate the surface exposed to the flow by horizontal slicing of the original core as follows:



Plots of suspension concentrations, adjusted for sampling depletion of suspended mass in the case of the PES, versus time are given in Plates 1-10 and 11-15 for the PES and VOST, respectively. Plates show regression lines for individual steps.

Erosion was time varying for most shear stress steps. Early portions of the steps had relatively rapid erosion rates that decreased with time and became constant during the later portions of the steps. This portion of the steps was not sampled. Much of the high erosion rate early in the steps was associated with the acceleration at the change in shear stress. Of greatest interest is the erosion rate at the ends of the steps, which was estimated by linear regression on the sampled suspended-sediment concentration (Plates 1-15). An F-statistic was

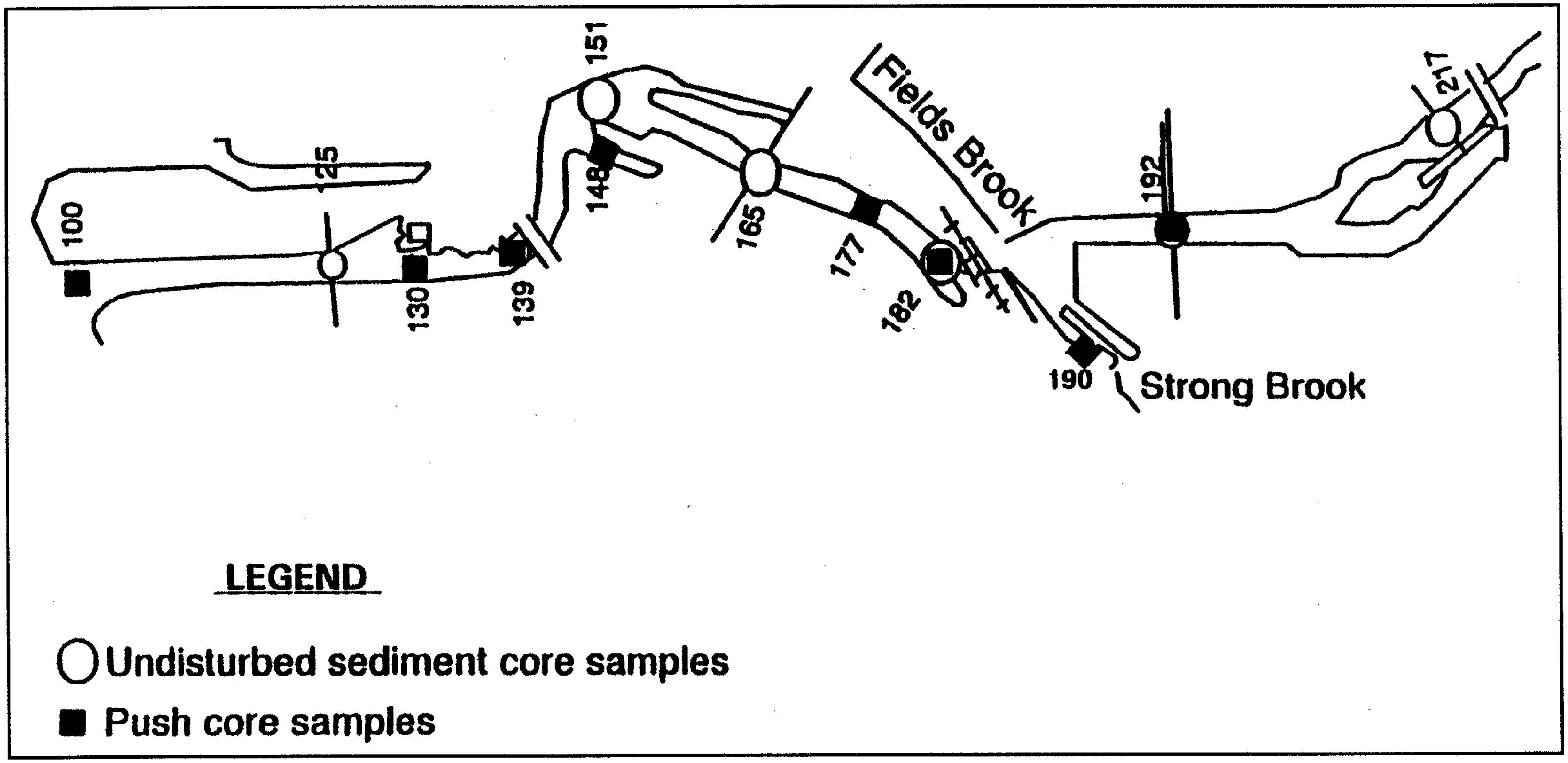


Figure 4. Bottom-sediment sampling locations

Table 1
Results of PES Erosion Tests on 1994 Samples

Sample	Density g/cu cm	Depth cm	Equiv. Shear Stress, Pa	Erosion Rate g/sq m/min
125B.1	1.469	0.0	0.4	1.0
			0.5	14.5
125B.3	1.459	8.9	0.5	25.4
			0.6	98.1
165B.1	1.498	0.0	0.3	2.0
			0.5	18.2
165B.5	1.543	14.0	0.5	8.3
			0.6	25.8
165B.4	1.538	14.0	0.5	4.1
			0.6	6.6
182B.1	1.473	0.0	0.4	1.8
			0.5	5.4
182B.3	1.465	8.9	0.5	5.5
			0.6	20.5
182B.2	1.521	8.9	0.6	2.2
217B.1	1.443	0.0	0.3	2.3
			0.5	5.4
217B.3	1.524	8.9	0.6	6.2

calculated for each regression to determine the probability (p-value) that the line was not significantly different from zero. Only results with p-values less than 0.1 and erosion rates greater than zero are reported in Tables 1 and 2.

Figures 5 and 6 summarize the results of the erosion experiments for the PES and VOST, respectively. The trend lines shown in these plots are standard least-squares regression fit to all points shown and which appear in Tables 1 and 2. The intercepts of the trend lines at the shear stress axis are indications of the threshold or critical shear stress for erosion.

Table 2
Results of VOST Erosion Tests on 1995 Samples

Sample	Density g/cu cm	Depth cm	Shear Stress Pa	Erosion Rate g/sq m/min
125A.1	1.823	0	0.98	3.4
			1.30	6.7
			1.62	64.2
			1.98	15.9
			2.33	30.0
125A.2	1.549	122	1.30	24.5
			1.62	67.9
			1.98	81.9
151A.1	1.545	0	1.30	7.6
			1.62	12.5
			1.98	58.1
			2.33	105.7
151A.2	1.653	122	1.62	2.8
			2.33	16.5
182A.1	1.554	0	1.62	17.1
			1.98	37.6

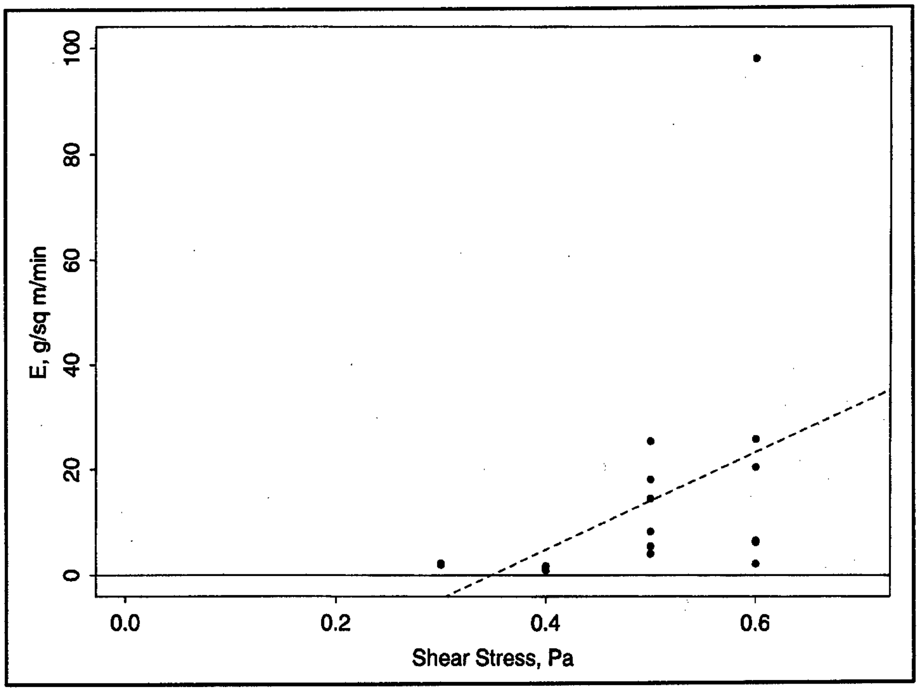


Figure 5. Summary of PES erosion experiment results with linear regression line

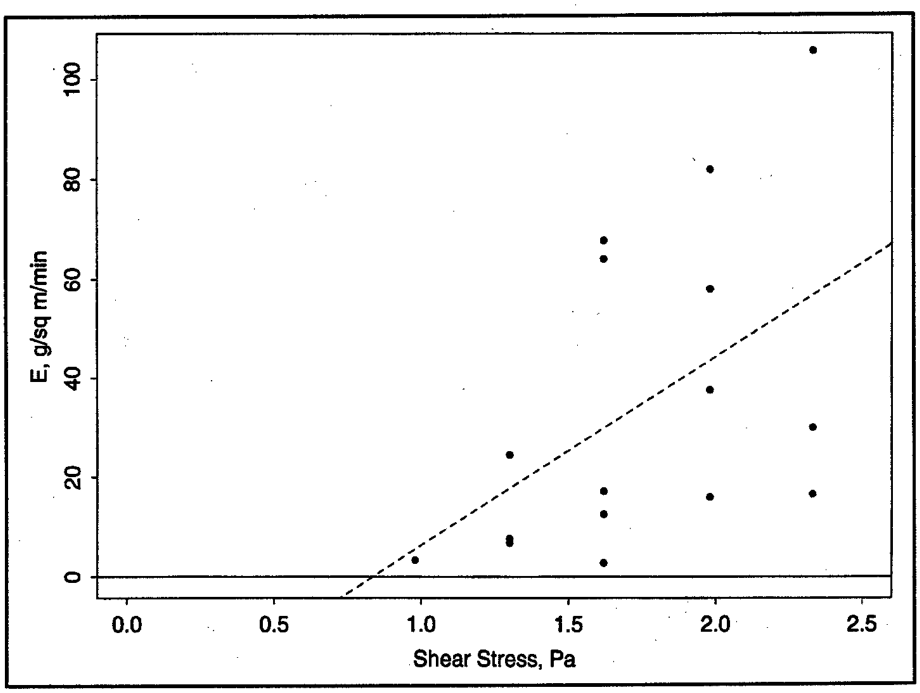


Figure 6. Summary of VOST erosion experiment results with linear regression line

Characterization

Rheologic characterizations consisted of creep tests to detect structural failure of the material. The method was described by James, Williams, and Williams (1987). This characterization was intended to supplement erosion experiments. Samples were subjected to shear stresses under appropriate conditions at stresses higher than those used in erosion tests. Erosion occurs when the cohesive bonds between individual particles and/or groups of particles are broken. The latter can be gauged by examining the mechanical response of a sediment, or more properly the sediment microstructure, to applied stress in a creep test.

The sediment property examined in a creep test is the yield stress above which thixotrophic breakdown of the sediment structure occurs, and massive erosion would be expected. Characteristic creep deformation curves for stresses below, at, and above the yield stress are given by James, Williams, and Williams (1987). Figure 7 shows a characteristic response for stresses below the yield stress displayed by sample 125B.1 at 10 Pa. When the stress was applied at time = 0.0, there was an instantaneous elastic strain in the sample of about 2.3E-3. The sample then underwent strain with both elastic and viscous components. After about 75 sec, the rate of strain (or shear) was constant—in this case about 9E-6 1/sec. The ratio of the stress to the shear gives a Newtonian viscosity of about 1E6 Pa*sec. After the stress was removed at time = 180 sec, the sample recovered the elastic component of the strain, while the viscous part was dissipated and not recovered.

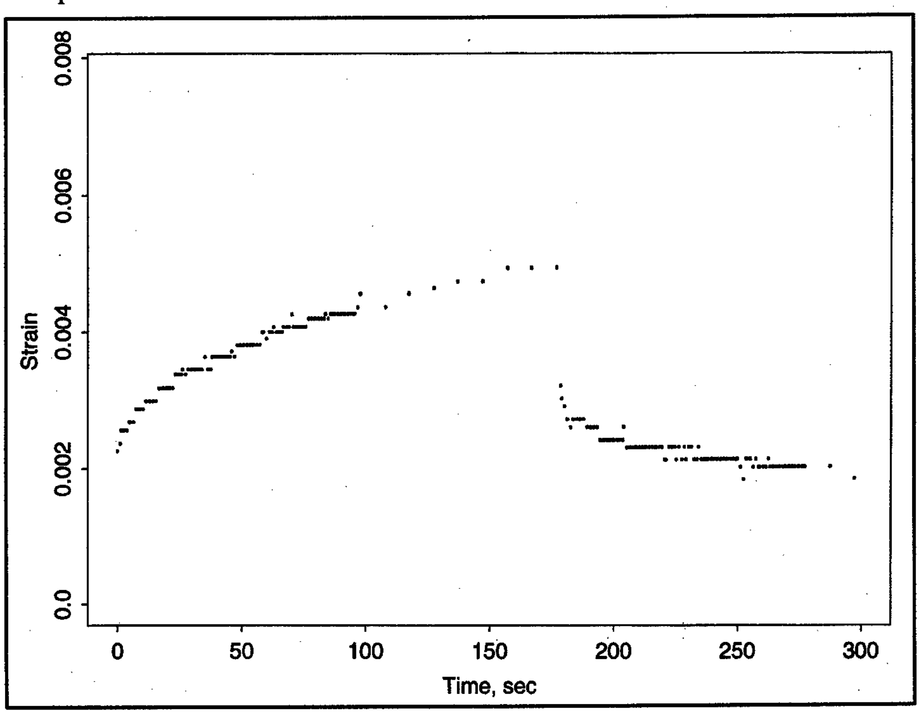


Figure 7. Example creep deformation curve for sample 125B.1 at 10 Pa

Creep tests were performed on all 1994 samples (125B.1, 125B.3, 182B.1, 182B.2, 182B.3, 165B.1, 165B.4, 165B.5, 217B.1, and 217B.3) used in erosion experiments. Samples were tested at 2, 5, and 10 Pa as previously described. Of the 1995 samples, four of the characterization grab samples (125B, 151B, 165B, and 177B) and two of the core samples (125A.2 and 182A.2) were creep tested. These samples were tested at 10, 20, and 30 Pa. Sample densities are given in Tables 1-3. None of the samples displayed structural failure as would occur if the applied stress was greater than the yield stress.

Table 3
Characterization of 1995 Grab Samples

Sample	Density g/cu cm	% Clay	% Silt	% Sand	pH	% Moisture	% LOI
125B	1.369	22	66	12	6.6	100.5	5.8
130B	1.474	31	68	1	6.8	77.9	5.3
139B	1.411	26	70	4	6.5	118.1	5.4
151A	1.398	22	72	6	6.4	127.1	5.7
151B	1.376	28	58	14	6.4	123.7	6.1
165B	1.499	15	61	24	6.3	83.2	5.9
177B	1.400	23	42	35	6.4	117.4	6.7

Table 3 shows sample density, grain-size parameters, pH, percent moisture, and LOI of seven of the 1995 characterization grab samples. Complete grain-size distributions are presented in Plates 16-22. Densities of sediments used in erosion tests can be found in Tables 1 and 2.

4 Discussion

Erosion experiment results from both devices had a lot of scatter that is characteristic of erosion data generally. Much of the data scatter probably came from heterogeneities in the sediment material. Samples from near the sediment-bed surface had leaf and twig plant matter that hindered or accelerated erosion in some specific cases. Naturally deposited sediments such as those used in erosion experiments also have subtle spatial variations in grain-size distribution and density that affect erosion rates.

Some moisture was lost from the 1995 cores prior to the erosion experiments. When sample 125A was prepared in the laboratory, leakage from the core was evident. Comparison of densities between erosion experimental material and characterization samples (Tables 2 and 3) indicates that the core material had appreciably higher densities consistent with fluid leaks from cores. In particular, sample 125A.1 had appreciably higher density than 125A.2 or other core samples. Other core density measurements were higher than grab samples, but not appreciably higher than the 1994 core samples. Normally, higher densities greatly reduce sediment erodibility. However, erosion results from sample 125A.1 were not the lowest of the 1995 samples. It is not known exactly how sample dewatering may have affected erodibility.

The most appropriate data analysis procedure was to consider each erosion measurement as a sample from a variable process. It follows that the central tendency of the data is the best measure of the process. On the other hand, a conservative or worst-case erosion curve used along with the mean curve in a numerical model will give a measure of the sensitivity of erosion estimates to the assumed erosion curve and bind the maximum expected erosion. Therefore, both mean-trend and worst-case erosion curves were produced.

The erosion results from the PES and the VOST should be considered together. Figure 8 presents the combined erosion data and several trend lines. The short-dashed line is a linear regression on all the points. This line has a negative shear stress axis intercept that is inconsistent with the individual regressions presented in Figures 5 and 6 and physically unreasonable.

Critical shear stress for erosion varied between samples. Linear regression indicated critical shear stresses of 0.34 Pa for PES and 0.8 Pa for the VOST experiments, as indicated by shear stress axis intercepts in Figures 5 and 6. Note that because of the relatively large water volume of the VOST, small erosion rates occurring just above the critical shear stress might not have been detected. Therefore, the critical shear stress indicated by the VOST experiments may be

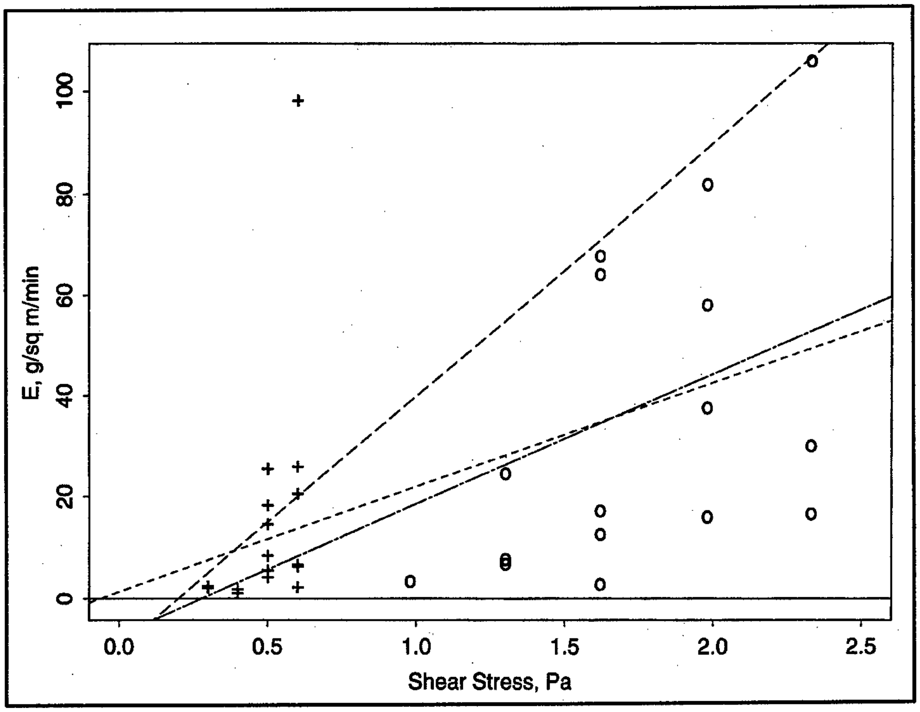


Figure 8. Combined PES and VOST results (see text for explanation of trend lines)

too high. The PES experiments are believed to be better indicators of critical shear stress.

The short-long dashed linear-regression line in Figure 8 was forced to have a shear stress axis intercept of 0.28 Pa. That intercept was chosen to be slightly lower than the PES regression, but consistent with the overall trend in the data and the lowest erosion rate values measured. The multiple R-square of this regression was 0.54, with a standard error of 4.1 on the computed slope of 25.77. The standard error of the residuals was 25.3 g/sq m/min. The third line indicated by long dashes has a shear stress axis intercept of 0.2 Pa and a slope of 50 and is a conservative line that describes the upper envelope of most of the erosion data.

There were no obvious trends in erodibility either vertically within cores or along the channel length. The erosion rates are comparable with those previously measured at similar shear stresses and material density from other locations.

5 Summary and Conclusions

In the reaches of interest, Ashtabula River bed sediments are fine grained, mostly silt (42-72 percent), and described as a sandy-clayey or clayey-sandy silt. Clay content was 15-30 percent. Bed material was well settled and partially consolidated, and 1994 erosion experimental sediments had densities of 1.44-1.54 g/cu cm. The density of the sediment varied by less than 0.08 g/cu cm over the top 9 cm and by 0.09 g/cu cm over a 1.22-m core.

Bed-material samples were subjected to 0.2-0.6 Pa shear stresses in the PES and 0.35-2.33 Pa in the VOST erosion devices. Erosion thresholds and rates varied because of sample heterogeneities unrelated to sample position. Erosion experiment results allowed estimation of mean and worst-case erosion curves.

Erodibility parameters are model dependent. For the erosion process descriptor used in the two-dimensional numerical sedimentation model applied in other parts of this study (described by Teeter and Pankow (1989)), the mean erosion curve can be characterized by a critical shear stress of 0.28 Pa and an erosion rate constant M of 7.22 g/sq m/min. The conservative line has a critical shear stress of 0.2 Pa and an erosion rate constant M of 10 g/sq m/min.

No sediment structural failure or massive erosion is expected for shear stresses less than 10 Pa. The 1995 samples indicated that structural failure would not occur at less than 30 Pa.

References

Davis, W. R. (1993). "The role of bioturbation in sediment resuspension and its interaction with physical shearing," *J. Exp. Mar. Bio;. Ecol.* 171, Elseveir, 187-200.

Fagerburg, T. L. (1999). "Ashtabula River, Ohio, sedimentation study; Report 2, Field data collection," Technical Report CHL-99-9, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

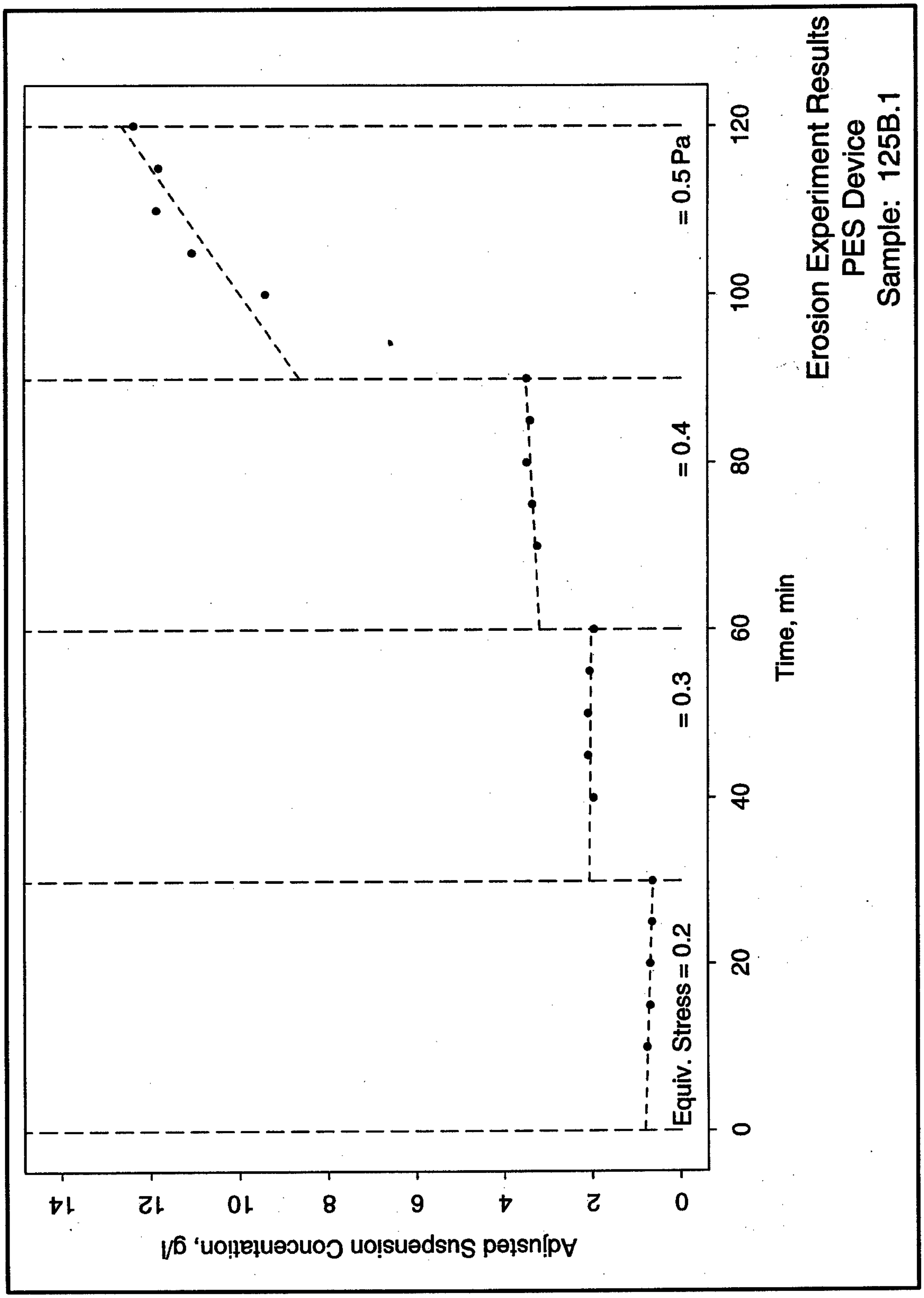
Heath, R. E., Fagerburg, T. L., Parchure, T., Teeter, A. M., and Boyt, B. (1999). "Ashtabula River, Ohio, sedimentation study; Report 1, Field and numerical model investigations of channel scour, 1994 interim results," Technical Report CHL-99-9, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

James, A. E, Williams, D. J. A., and Williams, P. R. (1987). "Direct measurement of static yield properties of cohesive suspensions," *Rheologic Acta* 26, 437-446.

Lavelle, J. W., and Davis, W. R. (1987). "Measurements of benthic sediment erodibility in Puget Sound, Washington," NOAA Techn. Memorandum ERL PMEL-72, Pacific Marine Environ. Lab., Seattle, WA.

Teeter, A. M., and Pankow, W. (1989). "Deposition and erosion testing on the composite dredged material sediment sample from New Bedford Harbor, Massachusetts," Technical Report HL-89-11, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Tsai, C.-H., and Lick, W. (1986). "A portable device for measuring sediment resuspension," *J. Great Lakes Res.* 12(4), 314-321.



Erosion Experiment Results
PES Device
Sample: 125B.1
Time, min
Adjusted Suspension Concentration, g/l
Equiv. Stress = 0.2
= 0.3
= 0.4
= 0.5 Pa
0
20
40
60
80
100
120
0
2
4
6
8
10
12
14

Plate 1

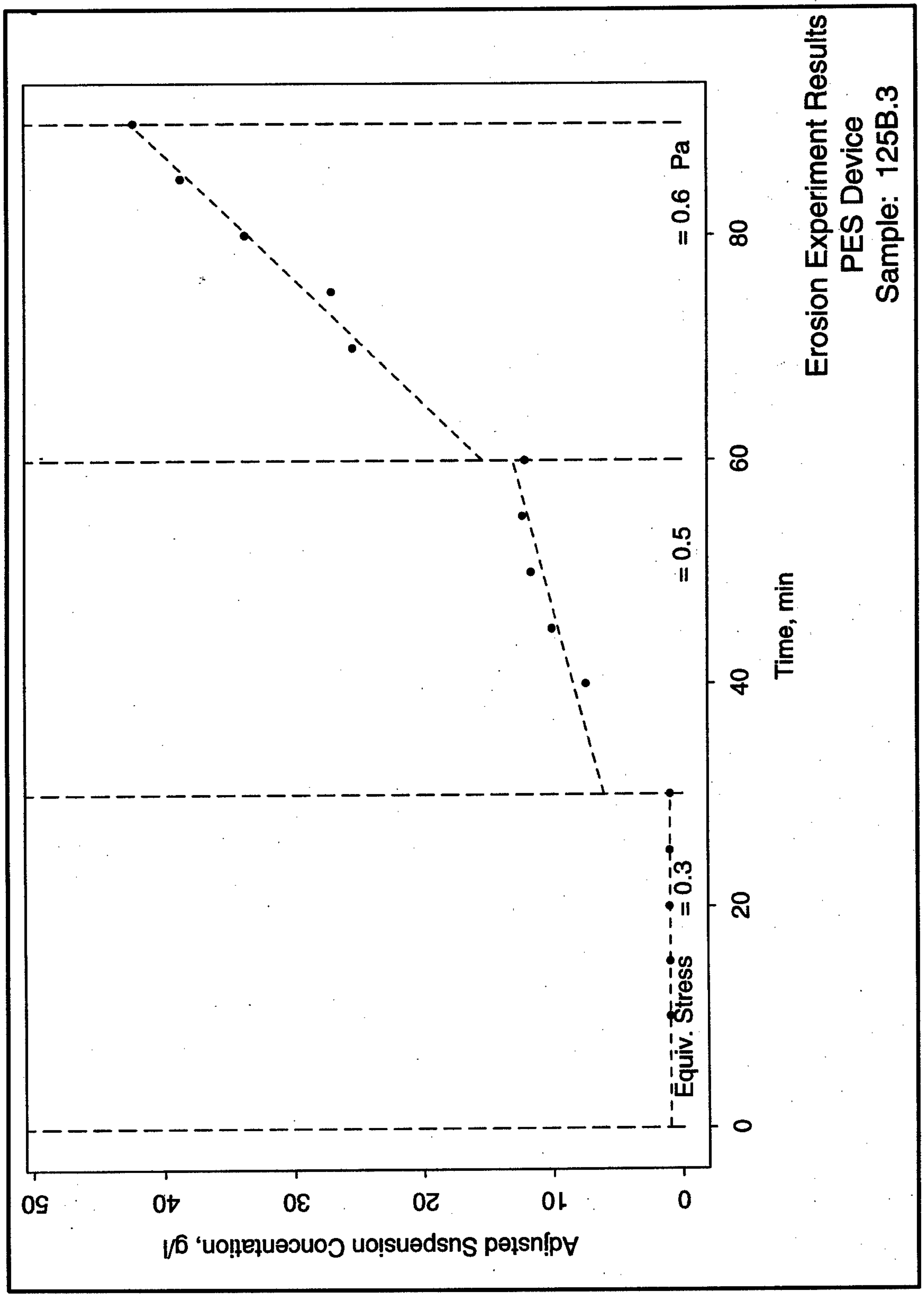

Erosion Experiment Results
PES Device
Sample: 125B.3
Time, min
0
20
40
60
80
Adjusted Suspension Concentration, g/l
0
10
20
30
40
50
Equiv. Stress = 0.3
= 0.5
= 0.6 Pa

Plate 2

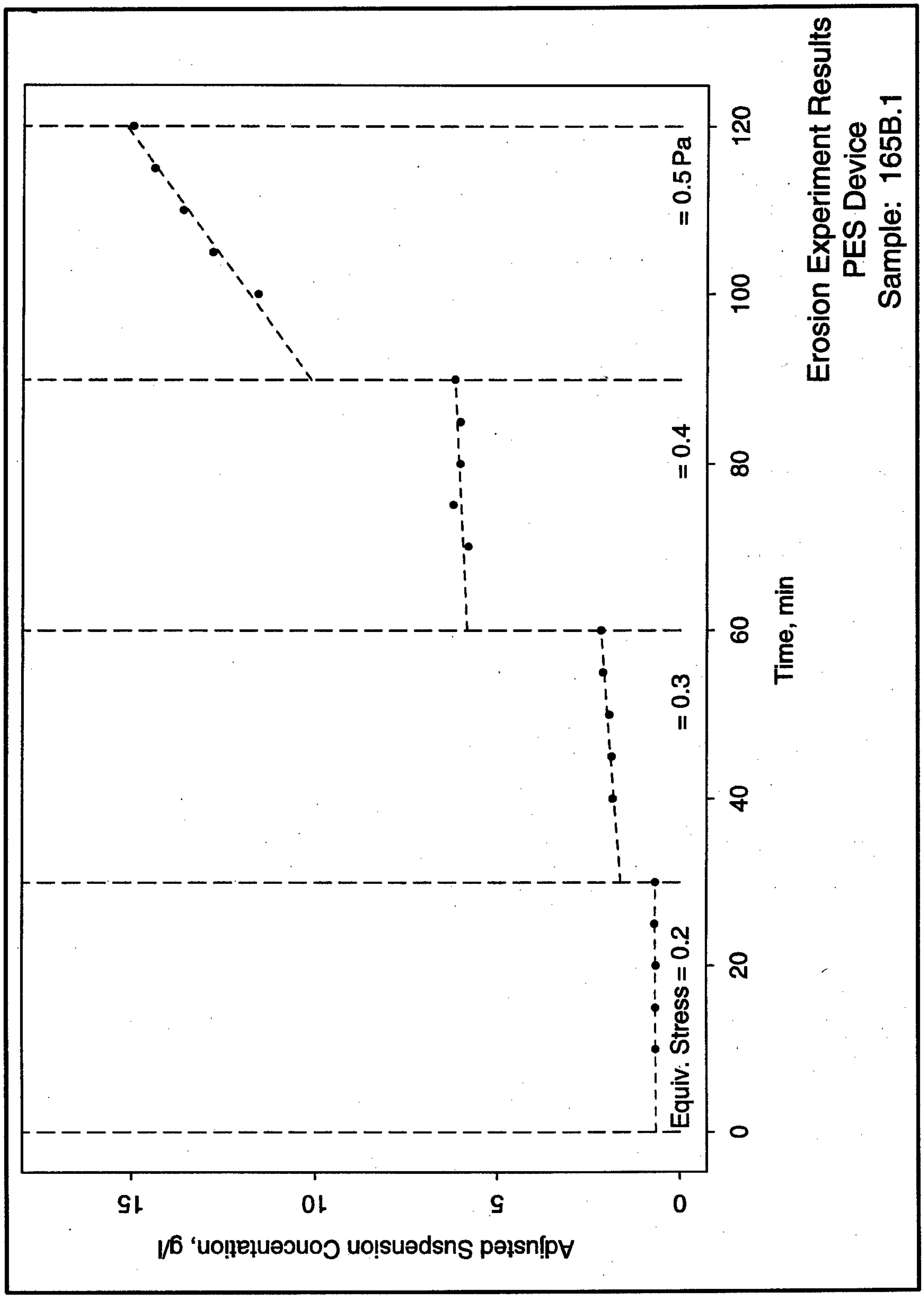

Erosion Experiment Results
PES Device
Sample: 165B.1
Time, min
Adjusted Suspension Concentration, g/l
Equiv. Stress = 0.2
= 0.3
= 0.4
= 0.5 Pa
0
20
40
60
80
100
120
0
5
10
15

Plate 3

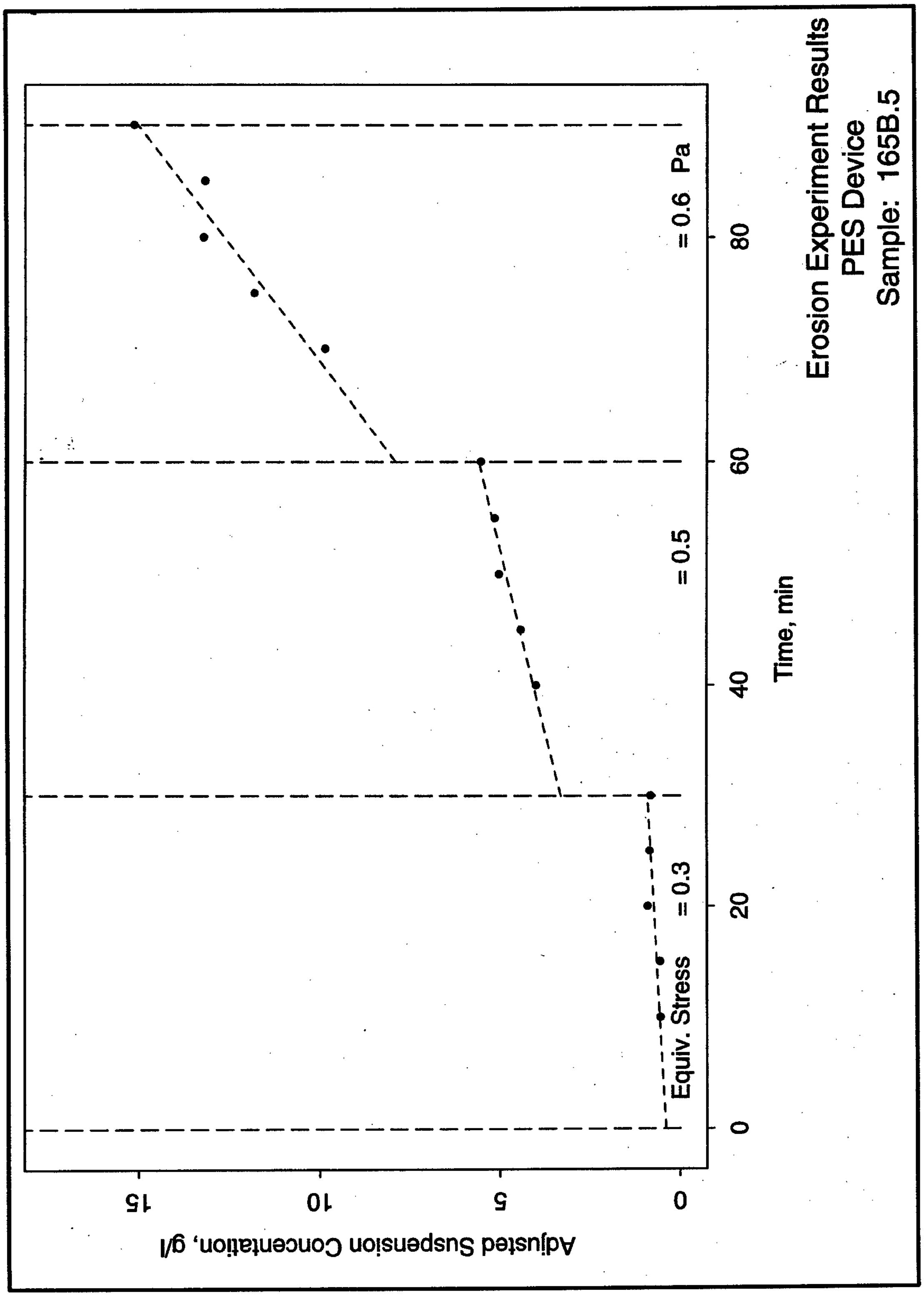
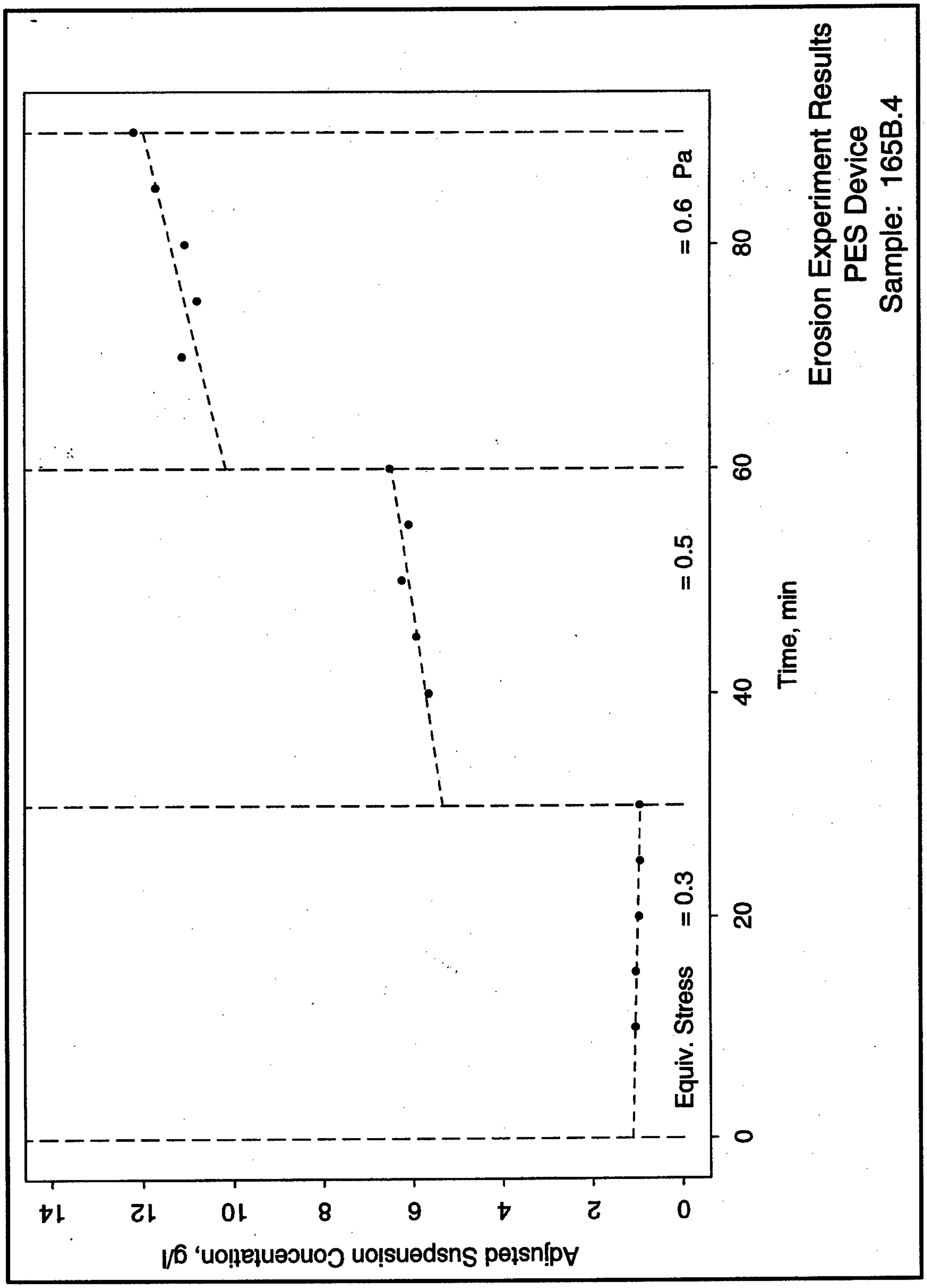
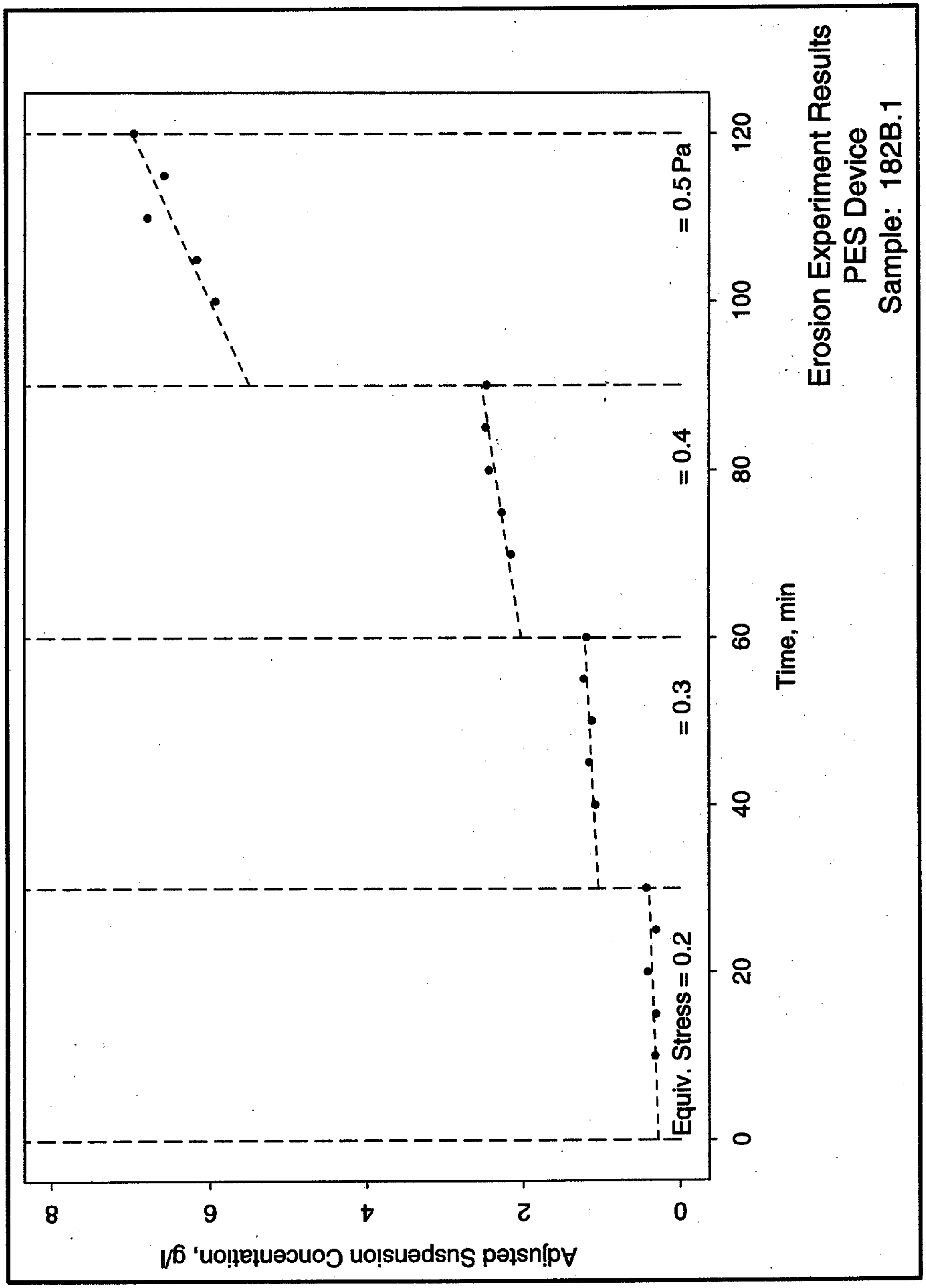

Erosion Experiment Results
PES Device
Sample: 165B.5
Time, min
Adjusted Suspension Concentation, g/l
Equiv. Stress = 0.3
= 0.5
= 0.6 Pa
0
20
40
60
80
0
5
10
15

Plate 4



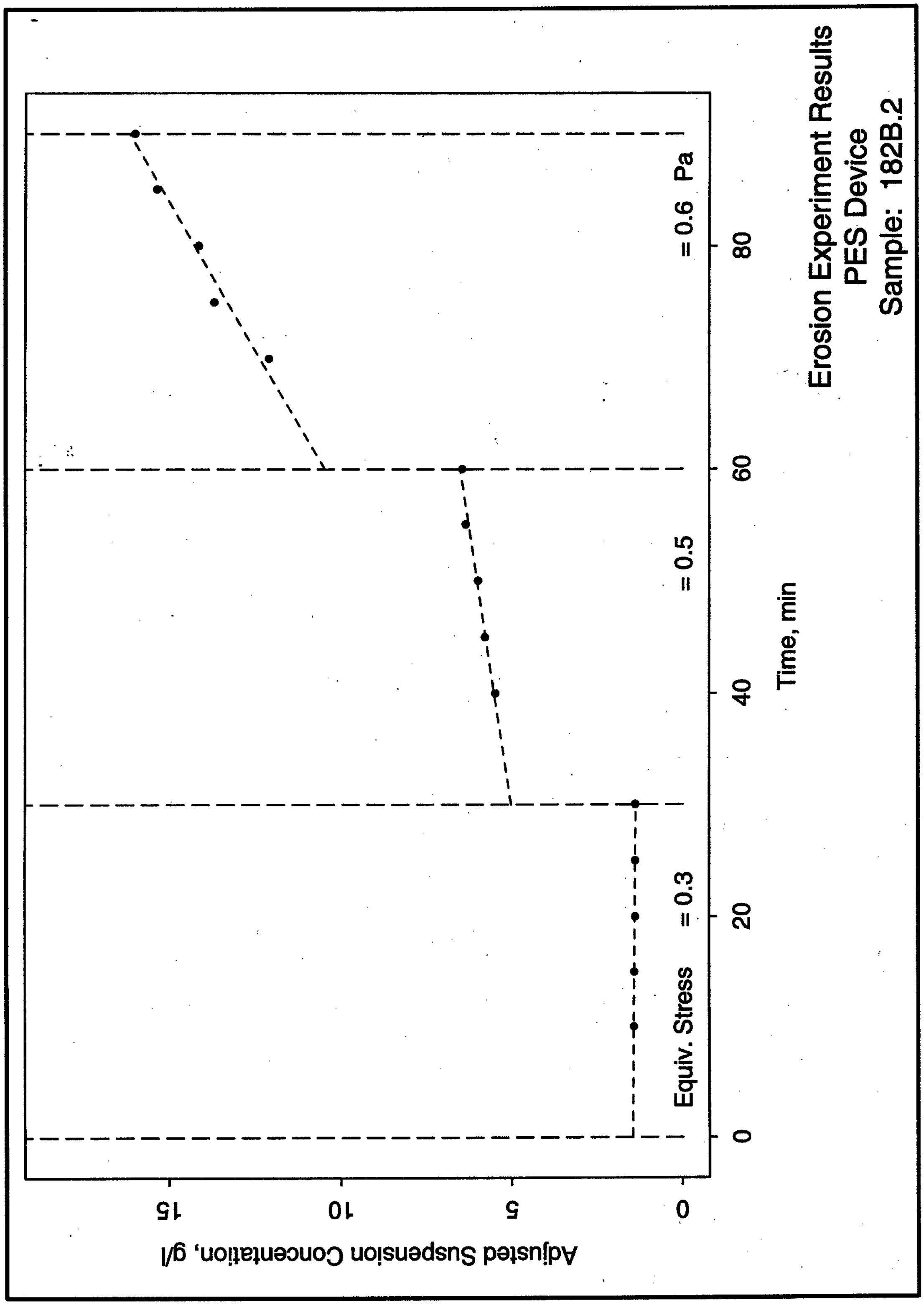
Erosion Experiment Results
PES Device
Sample: 165B.4
Adjusted Suspension Concentration, g/l
Time, min
Equiv. Stress = 0.3
= 0.5
= 0.6 Pa
0
2
4
6
8
10
12
14
0
20
40
60
80

Plate 5



Erosion Experiment Results
PES Device
Sample: 182B.1
Adjusted Suspension Concentration, g/l
Time, min
Equiv. Stress = 0.2
= 0.3
= 0.4
= 0.5 Pa
0
2
4
6
8
0
20
40
60
80
100
120

Plate 6



Erosion Experiment Results
PES Device
Sample: 182B.2
Adjusted Suspension Concentration, g/l
Time, min
Equiv. Stress = 0.3
= 0.5
= 0.6 Pa
0
5
10
15
0
20
40
60
80

Plate 7

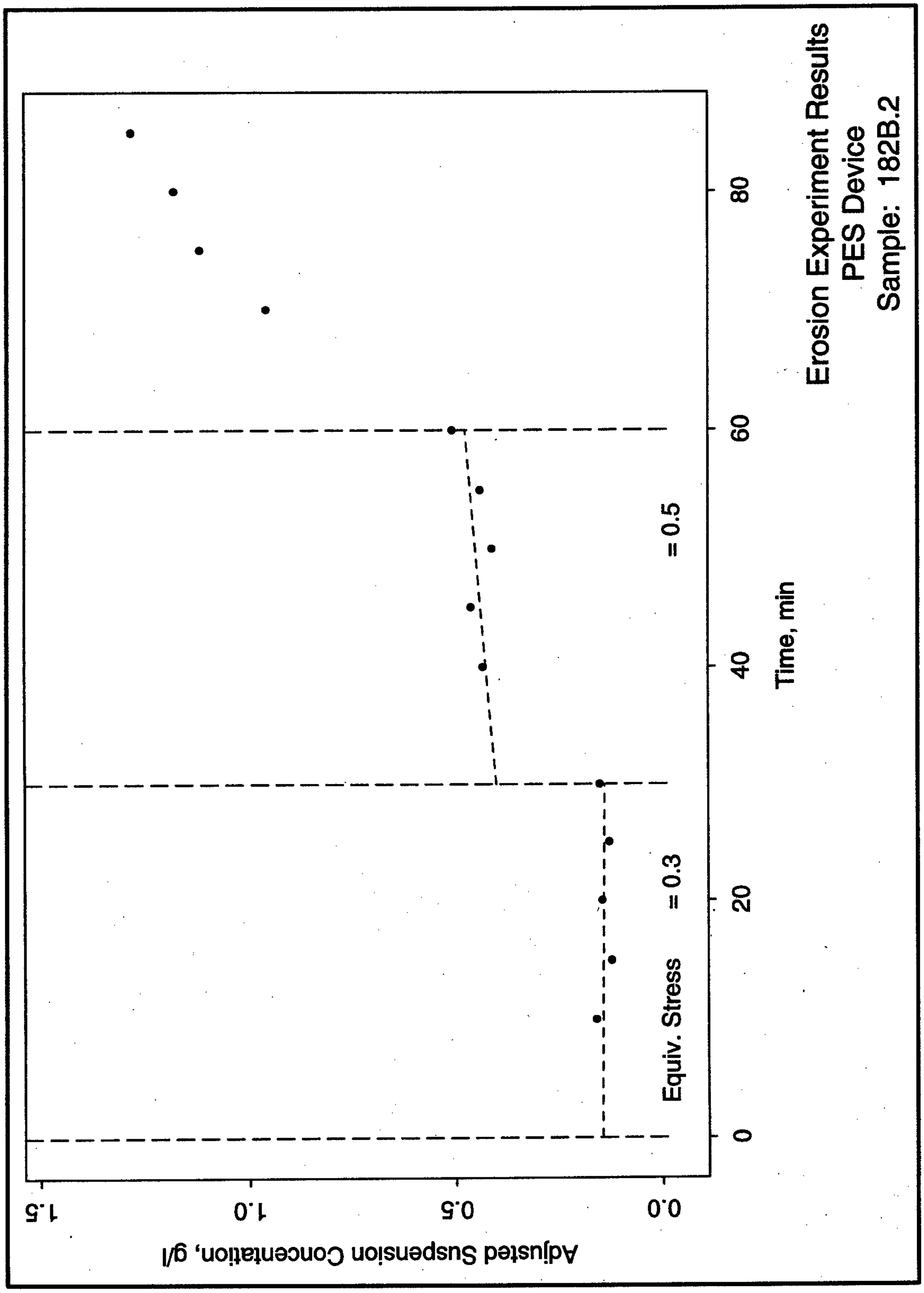
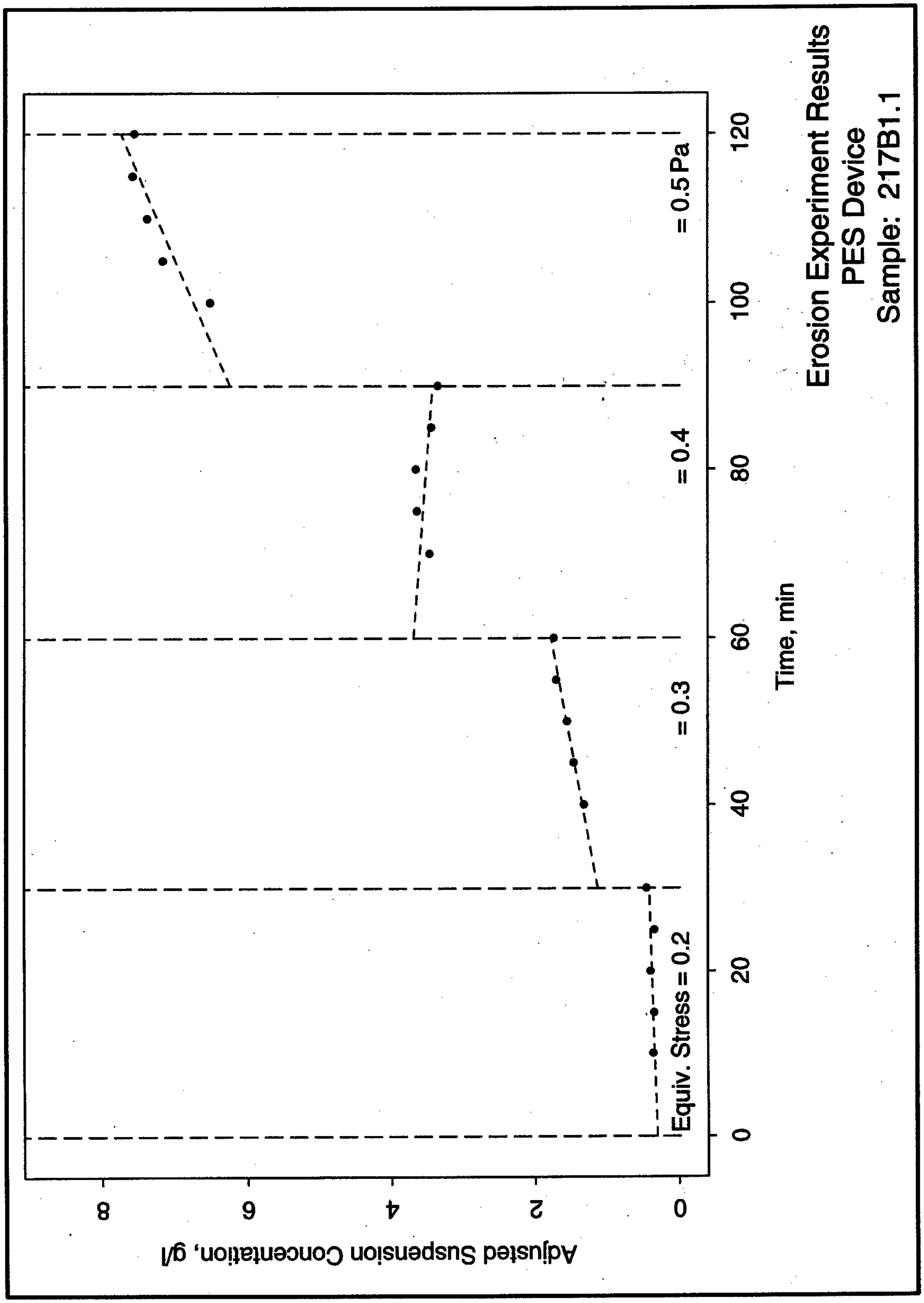

Erosion Experiment Results
PES Device
Sample: 182B.2
Adjusted Suspension Concentration, g/l
0.0
0.5
1.0
1.5
Time, min
0
20
40
60
80
Equiv. Stress = 0.3
= 0.5

Plate 8



Erosion Experiment Results
PES Device
Sample: 217B1.1
Adjusted Suspension Concentation, g/l
Time, min
Equiv. Stress = 0.2
= 0.3
= 0.4
= 0.5 Pa
0
2
4
6
8
0
20
40
60
80
100
120

Plate 9

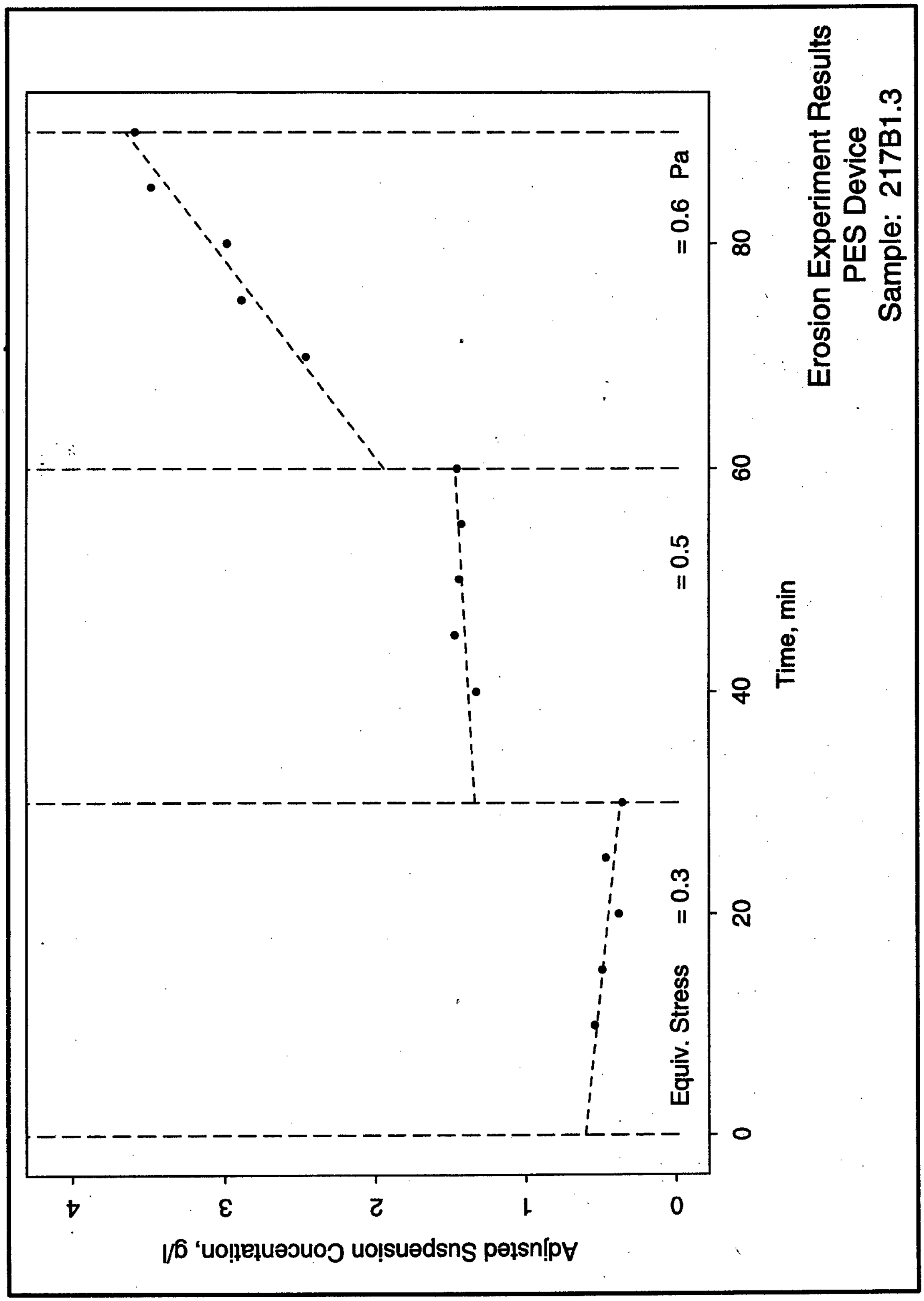
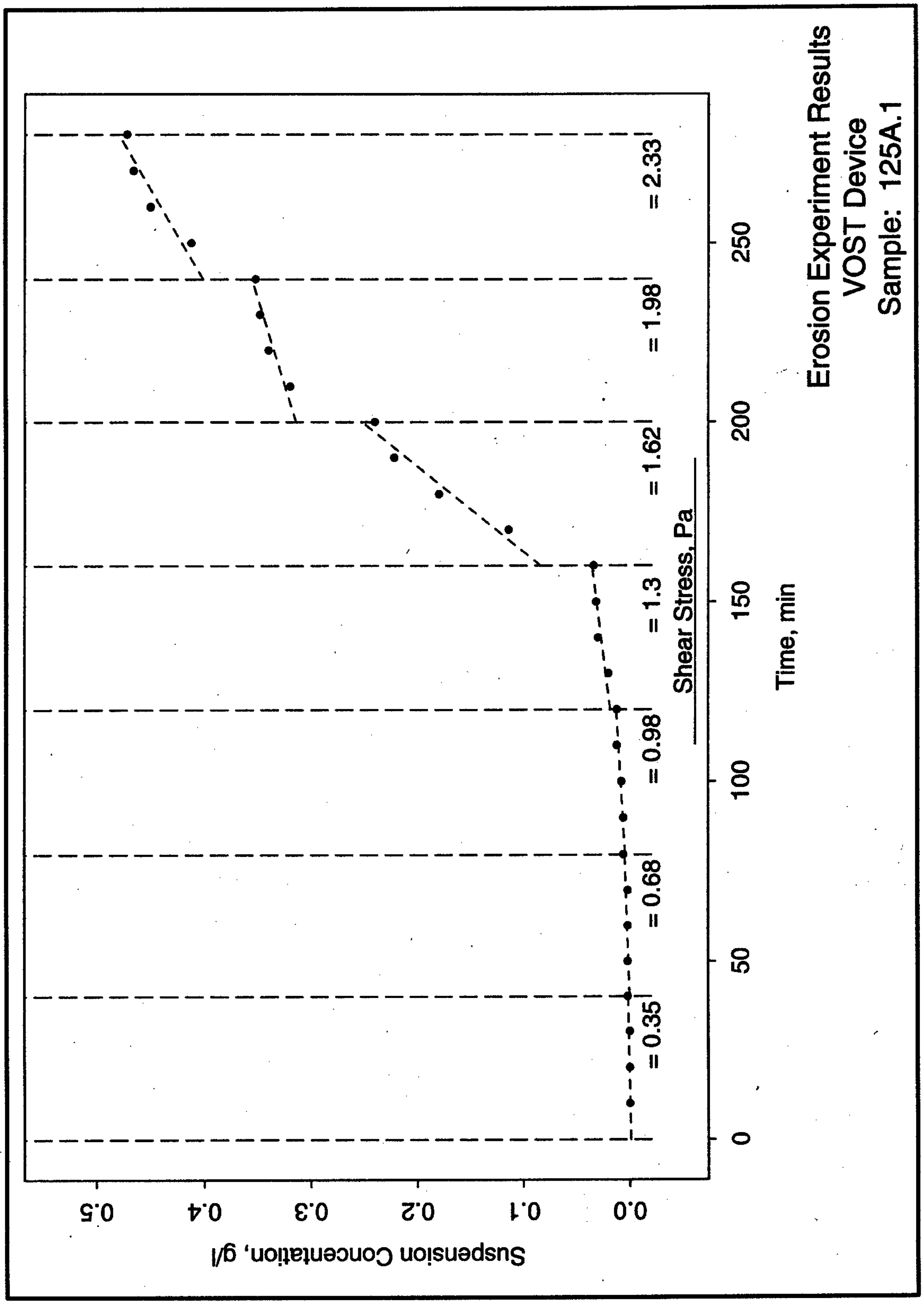

Erosion Experiment Results
PES Device
Sample: 217B1.3
Adjusted Suspension Concentration, g/l
Time, min
Equiv. Stress = 0.3
= 0.5
= 0.6 Pa
0
1
2
3
4
0
20
40
60
80

Plate 10


Erosion Experiment Results
VOST Device
Sample: 125A.1
Suspension Concentation, g/l
Time, min
Shear Stress, Pa
= 0.35
= 0.68
= 0.98
= 1.3
= 1.62
= 1.98
= 2.33
0.0
0.1
0.2
0.3
0.4
0.5
0
50
100
150
200
250

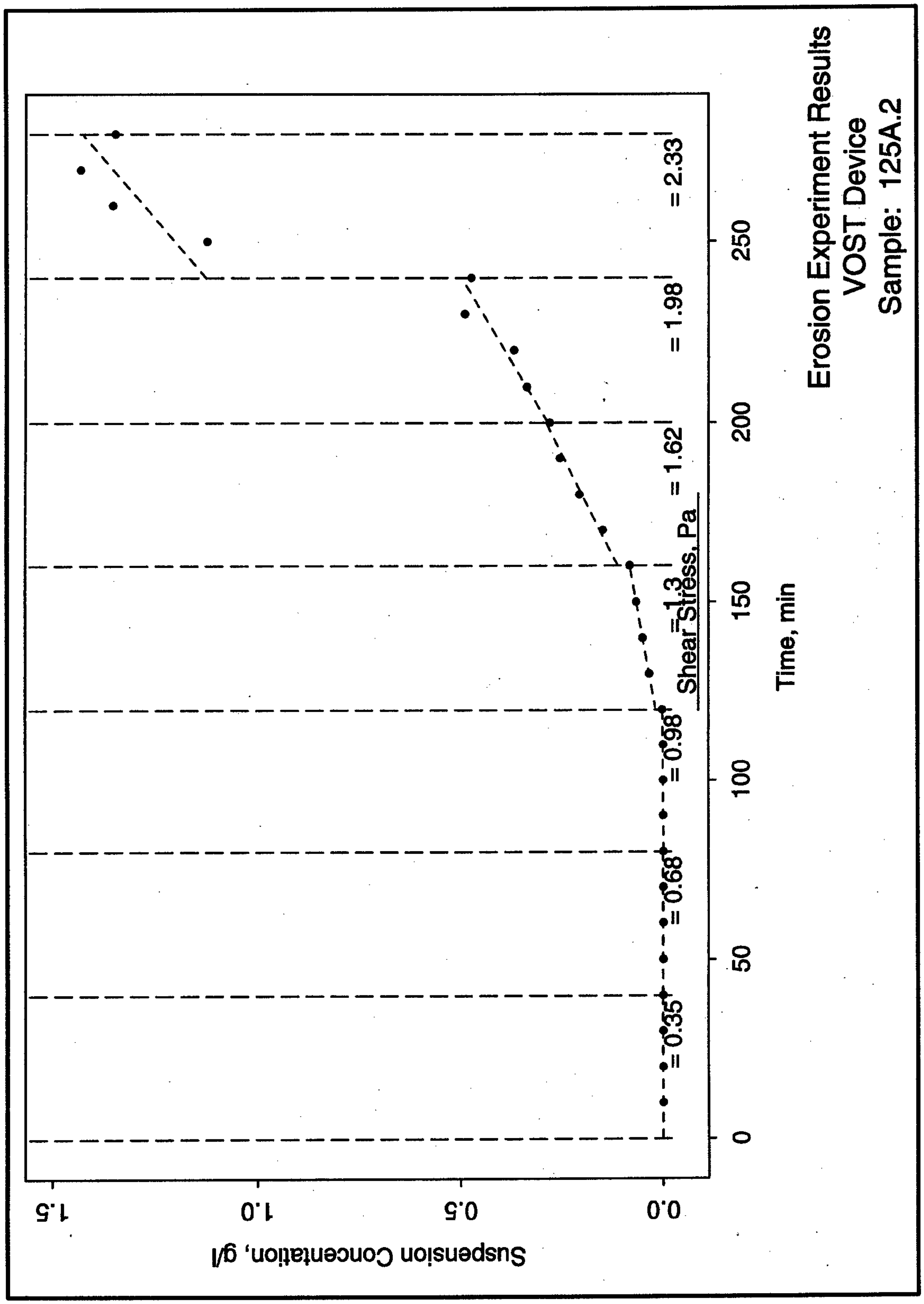

Erosion Experiment Results
VOST Device
Sample: 125A.2
Shear Stress, Pa
= 0.35
= 0.68
= 0.98
= 1.3
= 1.62
= 1.98
= 2.33
Time, min
0
50
100
150
200
250
Suspension Concentation, g/l
0.0
0.5
1.0
1.5

Plate 12

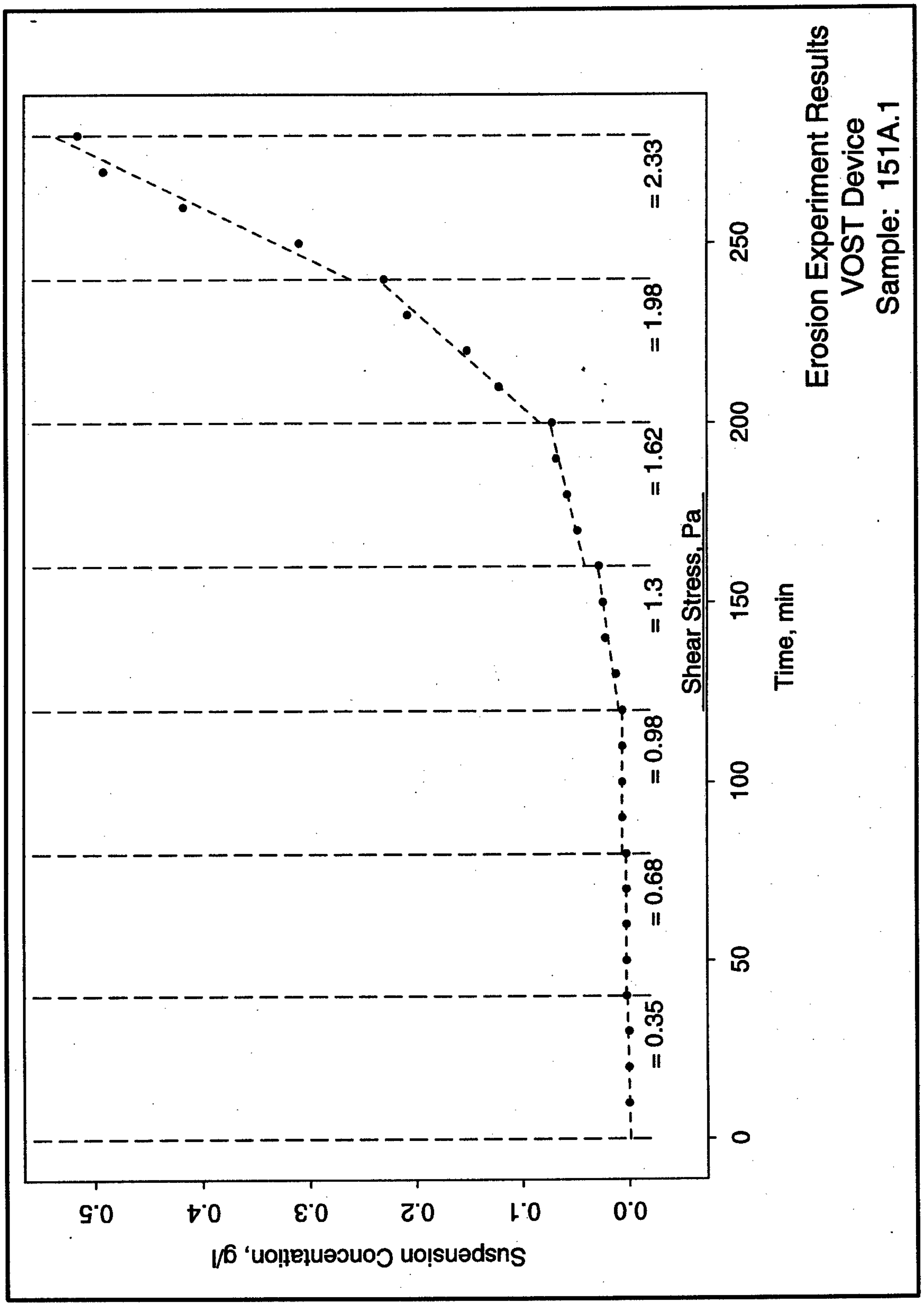

Erosion Experiment Results
VOST Device
Sample: 151A.1
Suspension Concentration, g/l
0.0
0.1
0.2
0.3
0.4
0.5
Time, min
0
50
100
150
200
250
Shear Stress, Pa
= 0.35
= 0.68
= 0.98
= 1.3
= 1.62
= 1.98
= 2.33

Plate 13

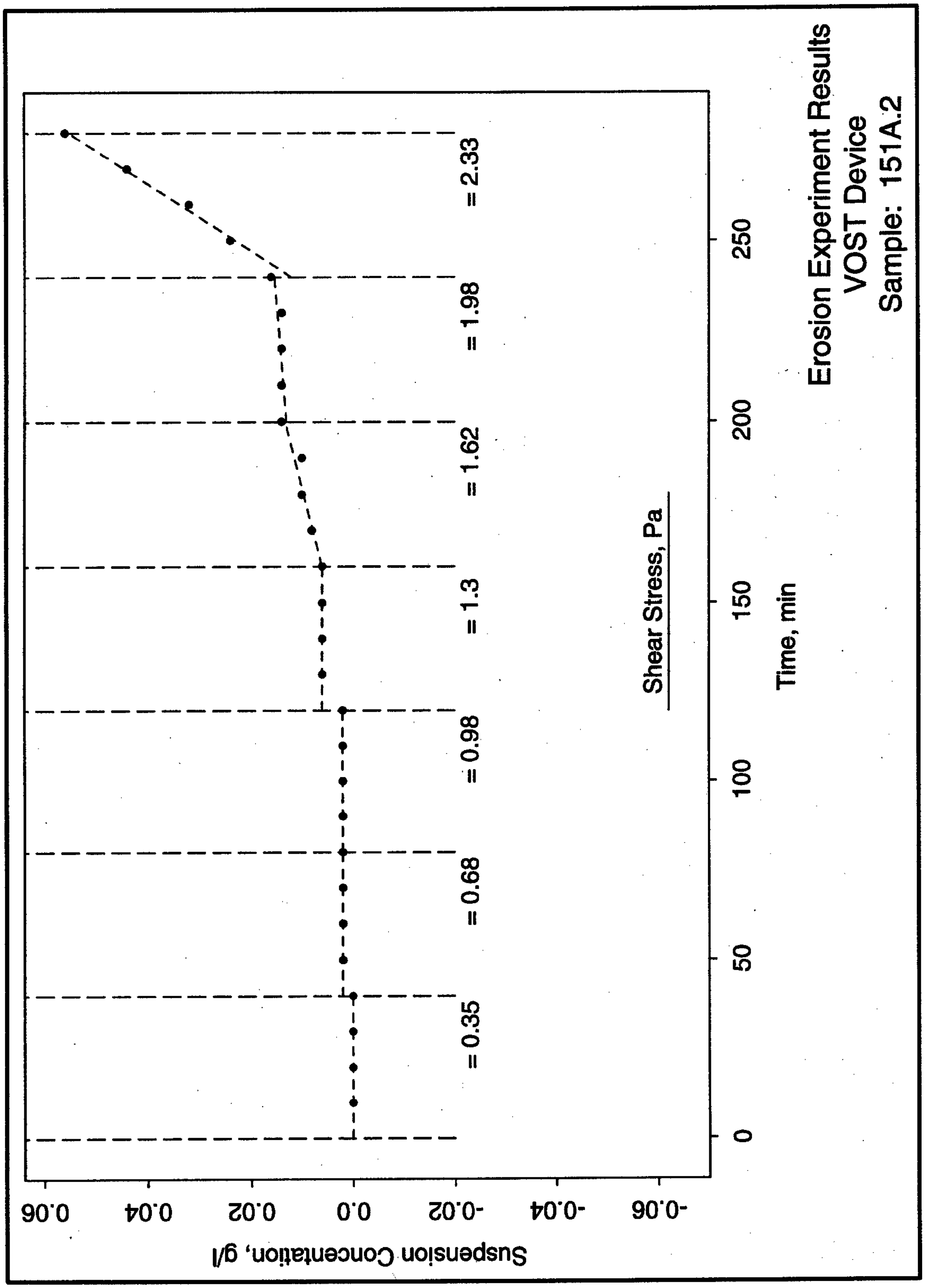

Erosion Experiment Results
VOST Device
Sample: 151A.2
Shear Stress, Pa
= 0.35
= 0.68
= 0.98
= 1.3
= 1.62
= 1.98
= 2.33
Time, min
0
50
100
150
200
250
Suspension Concentation, g/l
0.06
0.04
0.02
0.0
-0.02
-0.04
-0.06

Plate 14

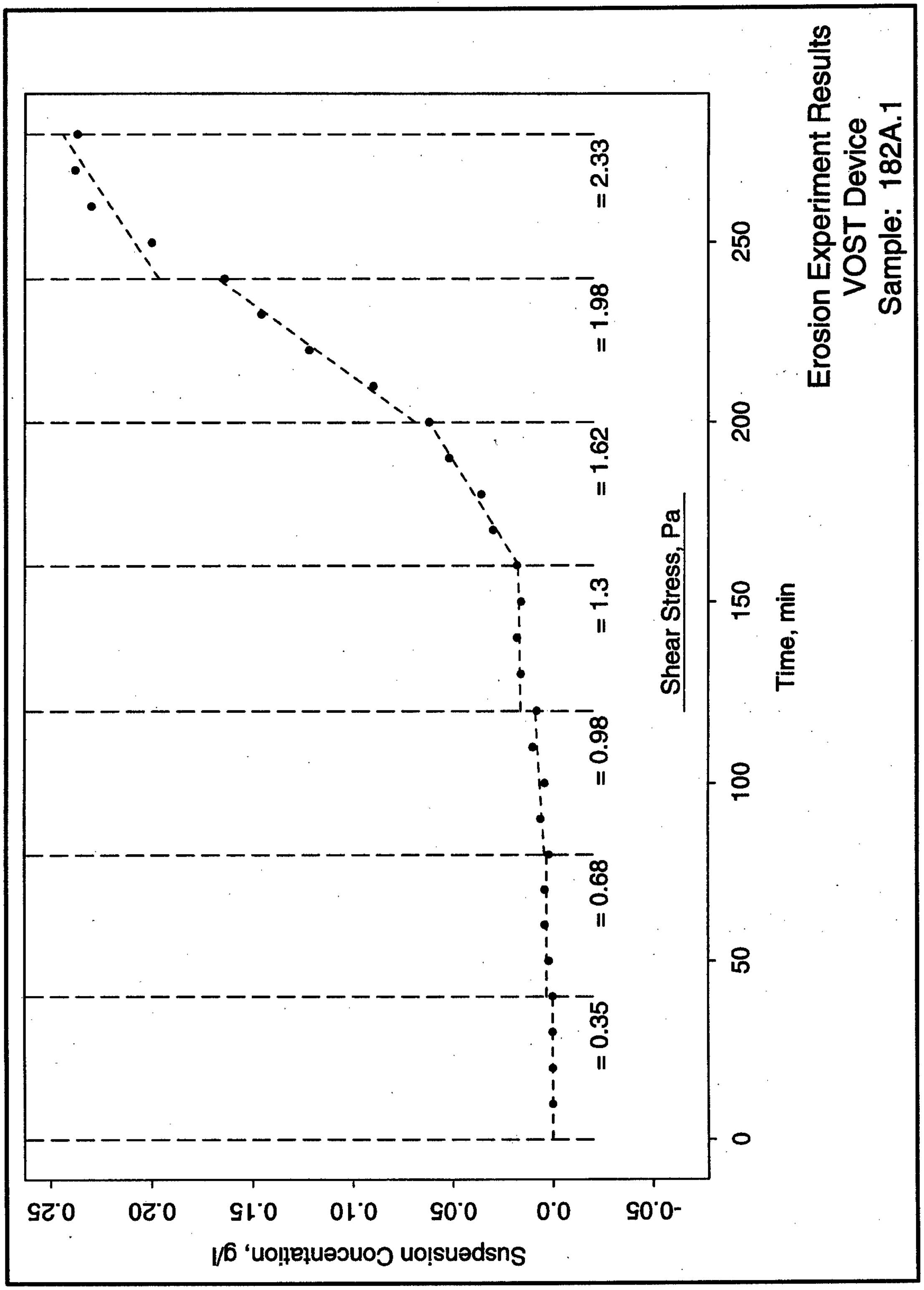

Erosion Experiment Results
VOST Device
Sample: 182A.1
Suspension Concentation, g/l
Time, min
Shear Stress, Pa
= 0.35
= 0.68
= 0.98
= 1.3
= 1.62
= 1.98
= 2.33
0
50
100
150
200
250
-0.05
0.0
0.05
0.10
0.15
0.20
0.25

Plate 15

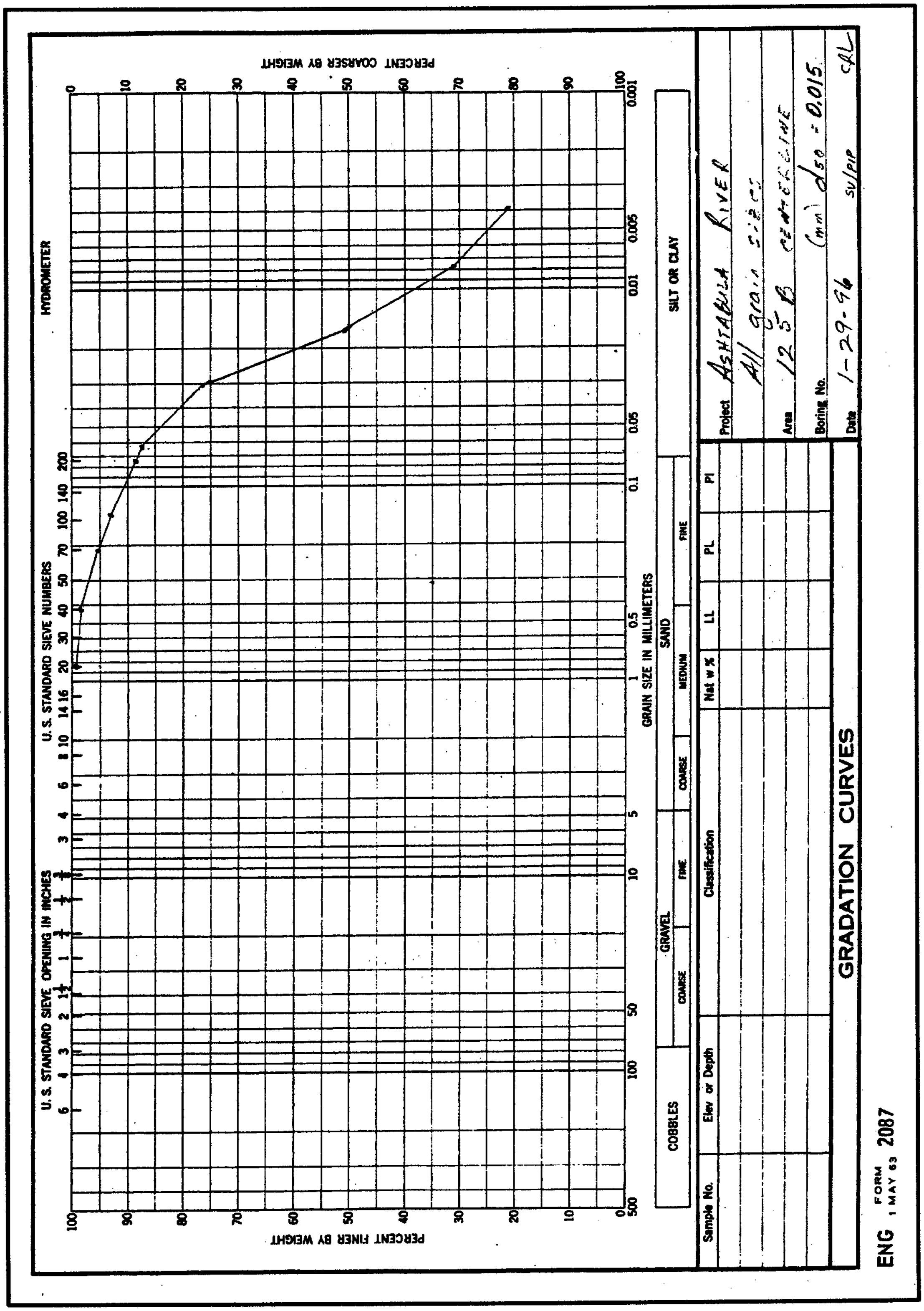
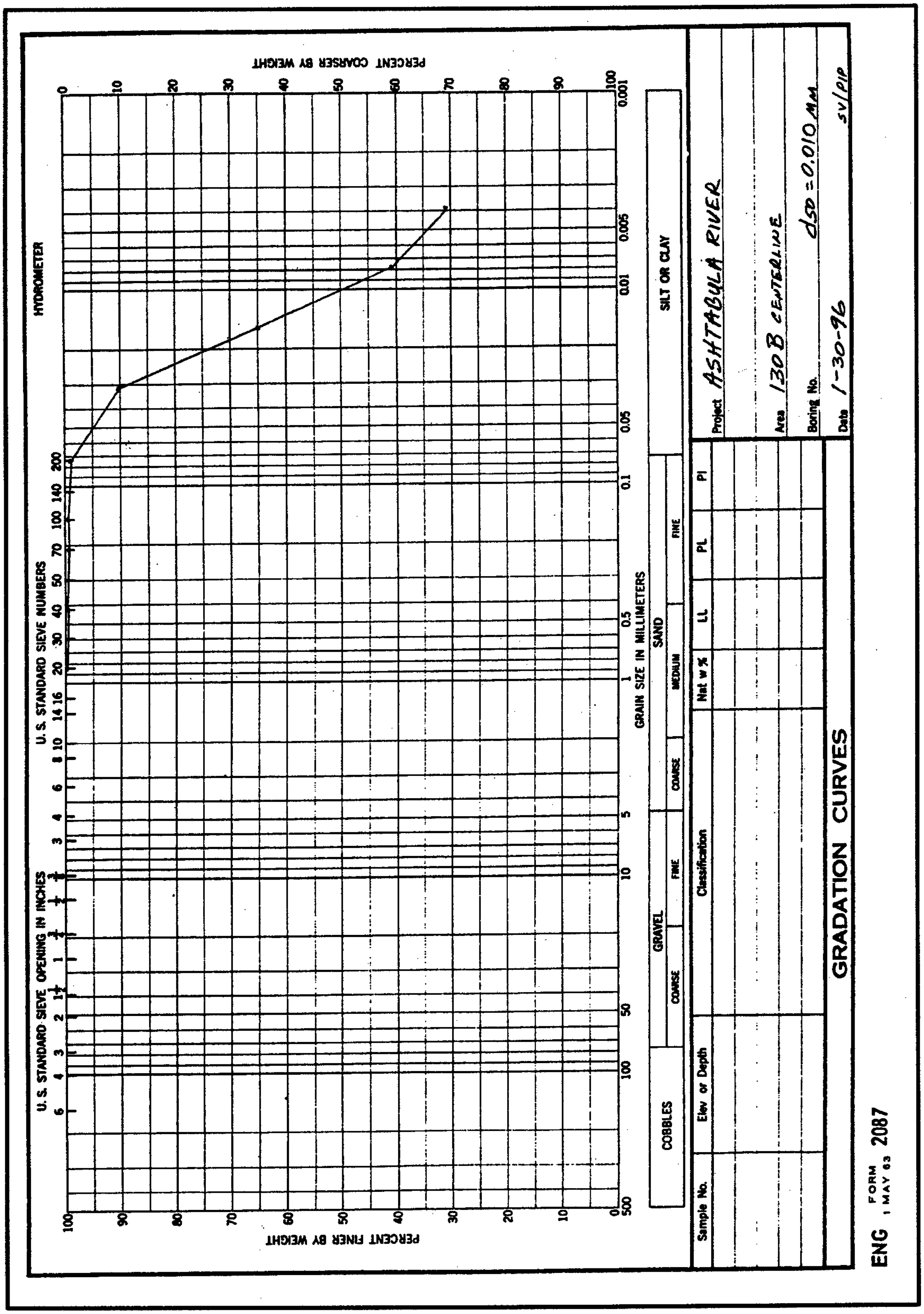
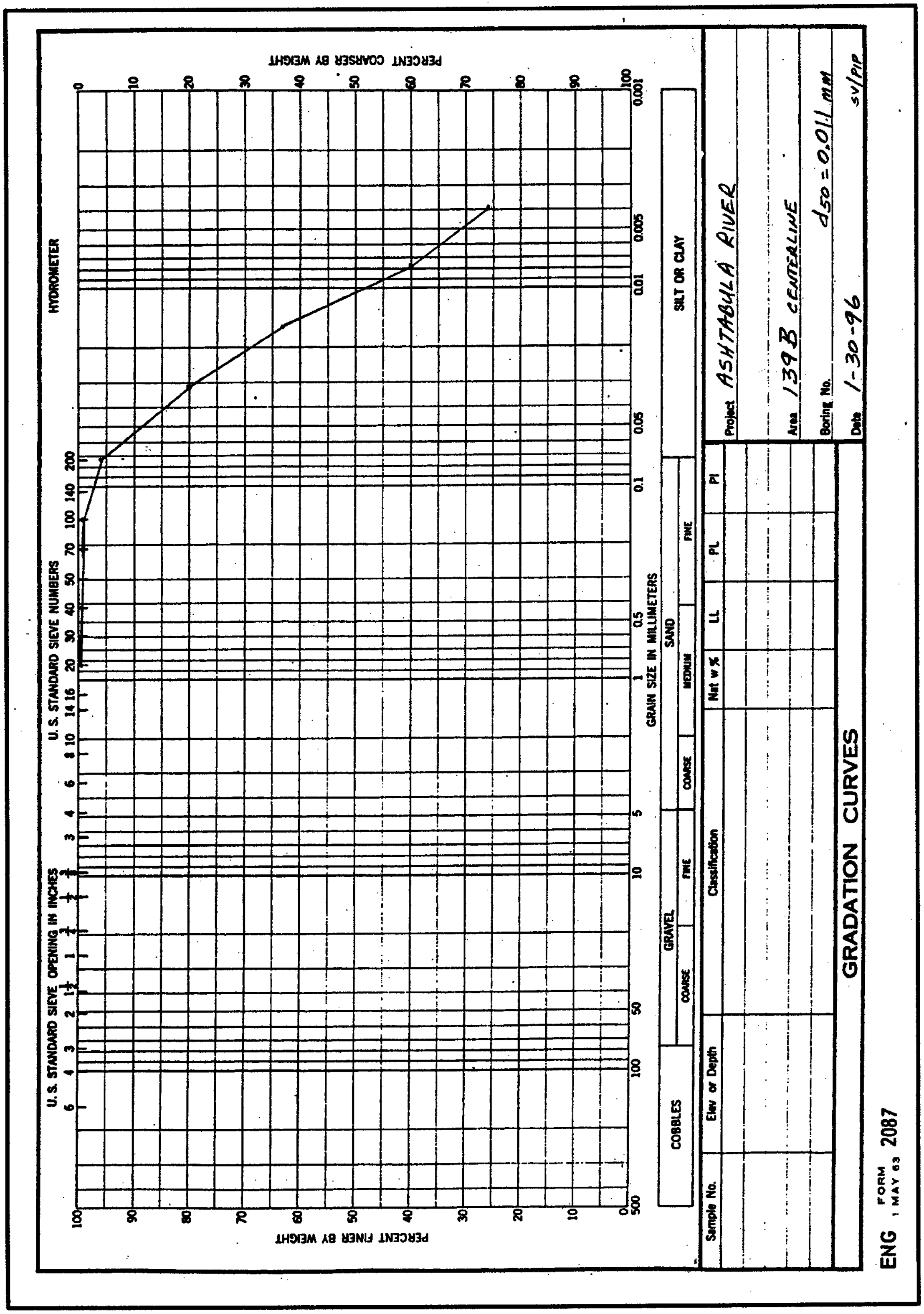

U. S. STANDARD SIEVE OPENING IN INCHES
U. S. STANDARD SIEVE NUMBERS
HYDROMETER
PERCENT FINER BY WEIGHT
PERCENT COARSER BY WEIGHT
GRAIN SIZE IN MILLIMETERS
COBBLES
GRAVEL
COARSE
FINE
SAND
COARSE
MEDIUM
FINE
SILT OR CLAY
Sample No.
Elev or Depth
Classification
Nat w %
LL
PL
PI
Project Ashtabula River
All grain sizes
Area 12 5 B
Boring No.
(mm) d50 = 0.015
Date 1-29-96
SU/PIP
CAL
GRADATION CURVES
ENG FORM 1 MAY 63 2087

Plate 16

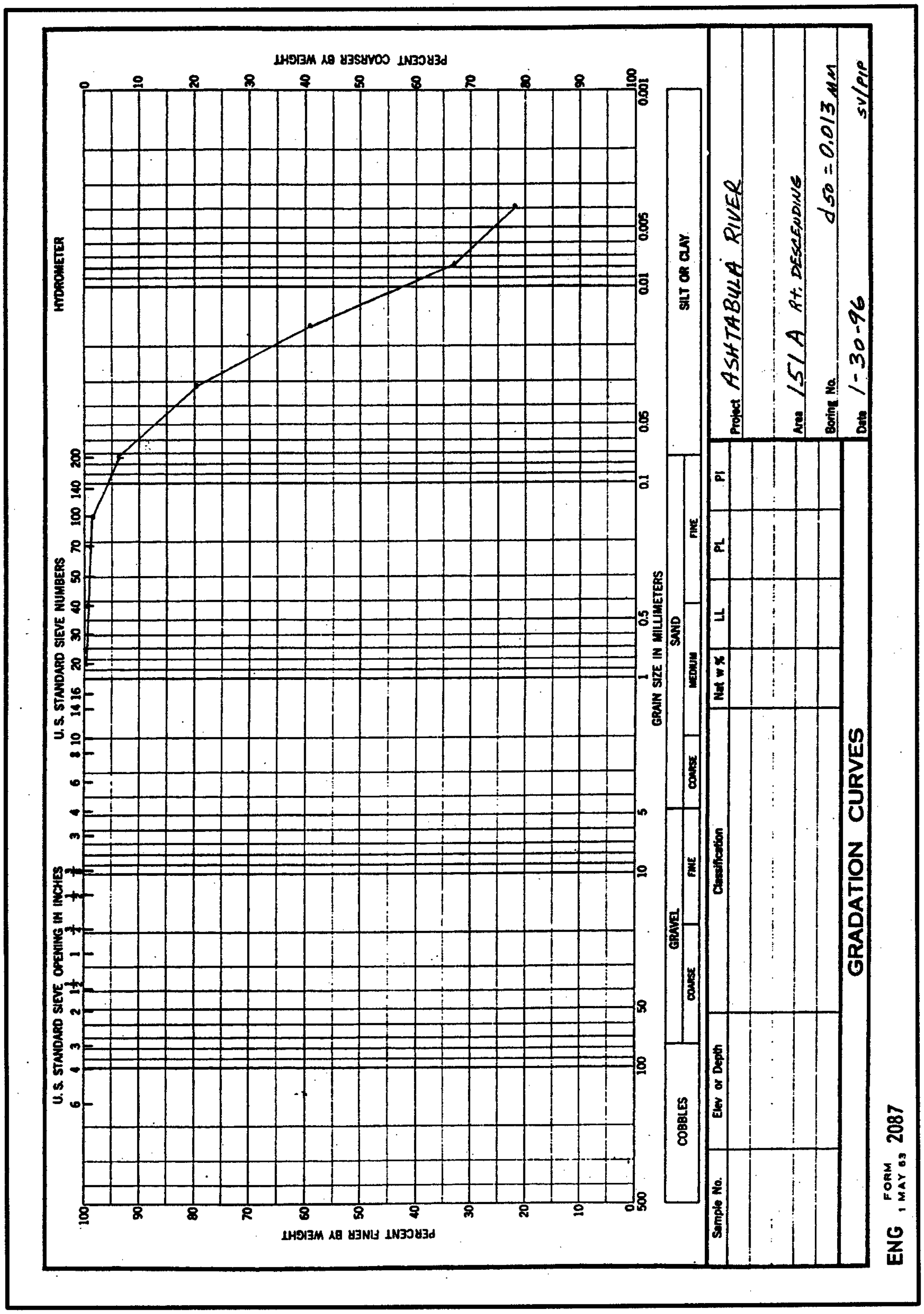


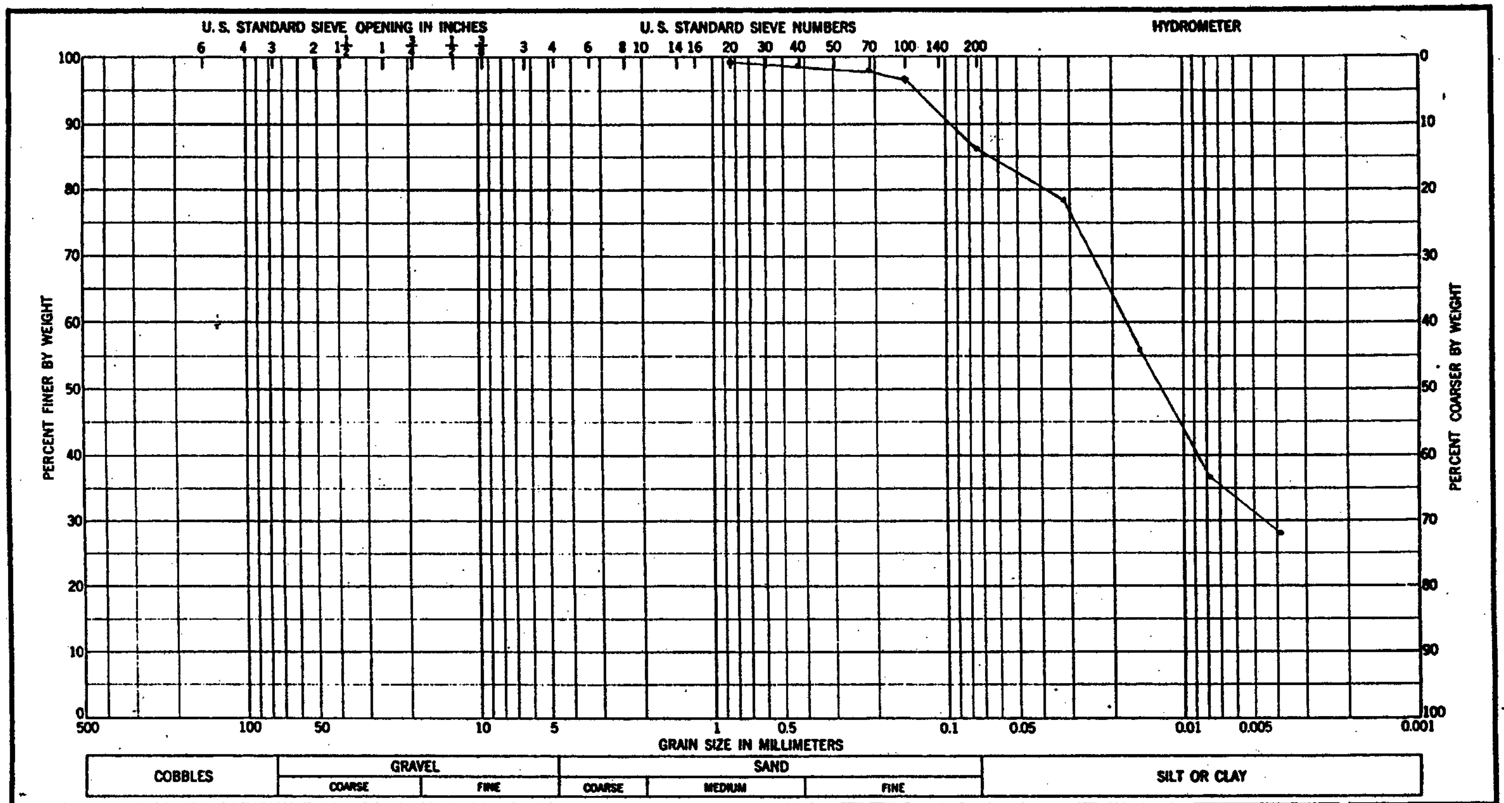
U. S. STANDARD SIEVE OPENING IN INCHES
U. S. STANDARD SIEVE NUMBERS
HYDROMETER
PERCENT FINER BY WEIGHT
PERCENT COARSER BY WEIGHT
GRAIN SIZE IN MILLIMETERS
COBBLES
GRAVEL
COARSE
FINE
SAND
COARSE
MEDIUM
FINE
SILT OR CLAY
Sample No.
Elev or Depth
Classification
Nat w %
LL
PL
PI
Project ASHTABULA RIVER
Area 130 B CENTERLINE
d50 = 0.010 MM
Boring No.
Date 1-30-96
SV/PIP
GRADATION CURVES
ENG FORM 1 MAY 63 2087



U. S. STANDARD SIEVE OPENING IN INCHES
U. S. STANDARD SIEVE NUMBERS
HYDROMETER
PERCENT FINER BY WEIGHT
PERCENT COARSER BY WEIGHT
GRAIN SIZE IN MILLIMETERS
COBBLES
GRAVEL
SAND
SILT OR CLAY
Sample No.
Elev or Depth
Classification
Nat w %
LL
PL
PI
Project ASHTABULA RIVER
Area 139B CENTERLINE
$d_{50} = 0.011$ mm
Boring No.
Date 1-30-96
GRADATION CURVES
ENG FORM 1 MAY 63 2087

Plate 18


U. S. STANDARD SIEVE OPENING IN INCHES
U. S. STANDARD SIEVE NUMBERS
HYDROMETER
PERCENT COARSER BY WEIGHT
PERCENT FINER BY WEIGHT
GRAIN SIZE IN MILLIMETERS
COBBLES
GRAVEL
COARSE
FINE
SAND
COARSE
MEDIUM
FINE
SILT OR CLAY
Sample No.
Elev or Depth
Classification
Nat w %
LL
PL
PI
Project ASHTABULA RIVER
Area 151A Rt. DESCENDING
d50 = 0.013 MM
Boring No.
Date 1-30-96
SV/PIP
GRADATION CURVES
ENG FORM 1 MAY 63 2087



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project ASHTABULA RIVER

Area 151 B CENTERLINE

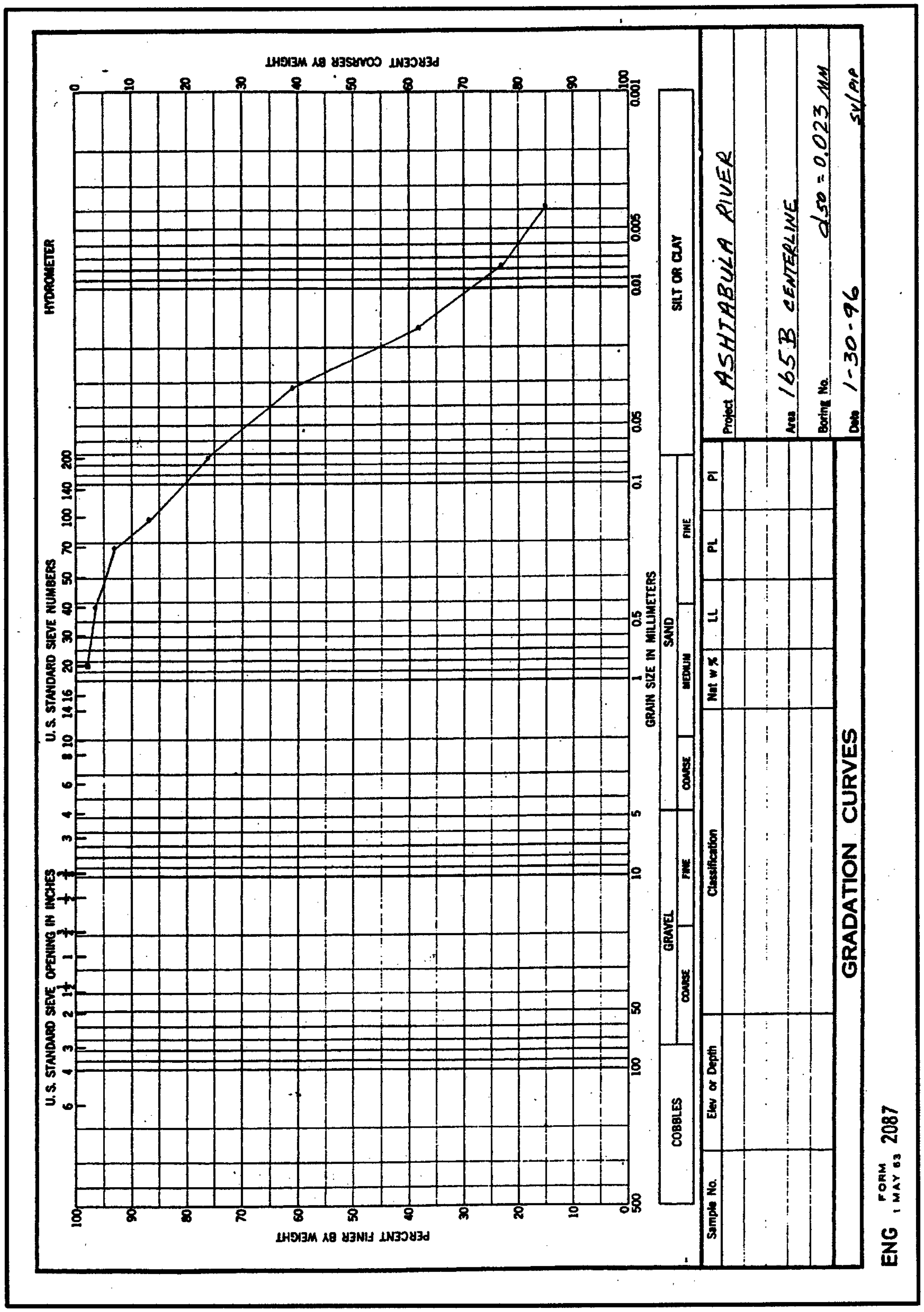
Boring No. d50 = 0.013 mm

Date 1-30-96 sv/pip

GRADATION CURVES

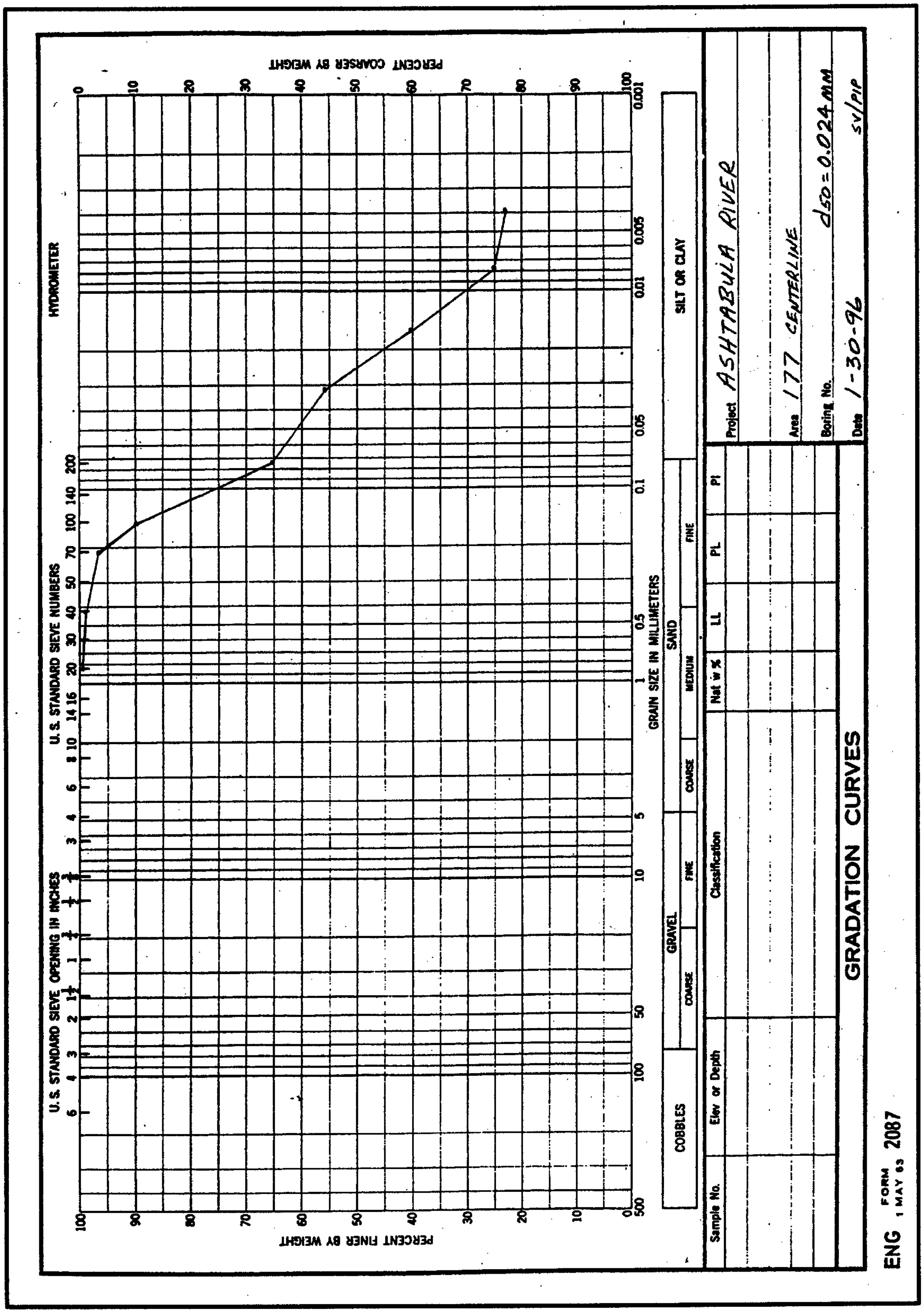
ENG FORM 1 MAY 63 2087

Plate 20



U.S. STANDARD SIEVE OPENING IN INCHES
U.S. STANDARD SIEVE NUMBERS
HYDROMETER
PERCENT FINER BY WEIGHT
PERCENT COARSER BY WEIGHT
GRAIN SIZE IN MILLIMETERS
COBBLES
GRAVEL
COARSE
FINE
SAND
COARSE
MEDIUM
FINE
SILT OR CLAY
Sample No.
Elev or Depth
Classification
Nat w %
LL
PL
PI
Project ASHTABULA RIVER
Area 165B CENTERLINE
Boring No. d50 = 0.023 MM
Date 1-30-96
SV/PIP
GRADATION CURVES
ENG FORM 1 MAY 63 2087

Plate 21



GRADATION CURVES
U.S. STANDARD SIEVE OPENING IN INCHES
U.S. STANDARD SIEVE NUMBERS
HYDROMETER
GRAIN SIZE IN MILLIMETERS
PERCENT FINER BY WEIGHT
PERCENT COARSER BY WEIGHT
COBBLES
GRAVEL
SAND
SILT OR CLAY
Sample No.
Elev or Depth
Classification
Nat w %
LL
PL
PI
Project ASHTABULA RIVER
Area 177 CENTERLINE
Boring No.
d50=0.024 MM
Date 1-30-96
sv/PIP
ENG FORM 1 MAY 63 2087

Plate 22

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
September 1999

3. REPORT TYPE AND DATES COVERED
Report 3 of a series

4. TITLE AND SUBTITLE
Ashtubula River, Ohio, Sedimentation Study; Report 3, Erosion Experiments on Bed Sediments

5. FUNDING NUMBERS

6. AUTHOR(S)
Allen M. Teeter, Doug Brister, Joe W. Parman, Clara J. Coleman

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Engineer Research and Development Center
Waterways Experiment Station
3909 Halls Ferry Road, Vicksburg, MS 39180-6199

8. PERFORMING ORGANIZATION REPORT NUMBER
Technical Report CHL-99-9

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Engineer District, Buffalo
1776 Niagara Street
Buffalo, NY 14207-3199

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Bed-sediment samples from the Ashtabula River in Ohio were subjected to stepwise increasing shear stresses to assess erodibility. Ten erosion experiments were performed in an oscillating-screen erosion chamber, and five experiments were performed in a water tunnel. Imposed shear stress ranged from 0.2 to 2.33 Pa. Sediments were characterized by grain size, density, pH, moisture content, loss on ignition, and rheological behavior. Sediments wre mostly silt (42-72 percent) with clay content ranging from 15 to 30 percent. Scatter in the experimental erosion results did not appear to be related to sample location or other factors. Taken by device, the indicated threshold for erosion was 0.34 Pa for the oscillating-screen erosion chamber and 0.8 Pa for the water tunnel. Taking all tests together, a reasonable threshold for erosion was 0.28 Pa. Mean erosion rate constant, or erosion rate at twice the threshold shear stress, was 7.2 g/sq m/min.

14. SUBJECT TERMS

Cohesive sediment	Erosion
Erodibility	Erosion threshold

15. NUMBER OF PAGES
45

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED		