US ARMY CORPS
OF ENGINEERS
NEW YORK DISTRICT

CRANFORD, NEW JERSEY

CRANFORD LEVEE RELIABILITY REPORT FOR FLOOD RISK MANAGEMENT RAHWAY, NJ

October 2011
U.S. Army Corps of Engineers
New York District

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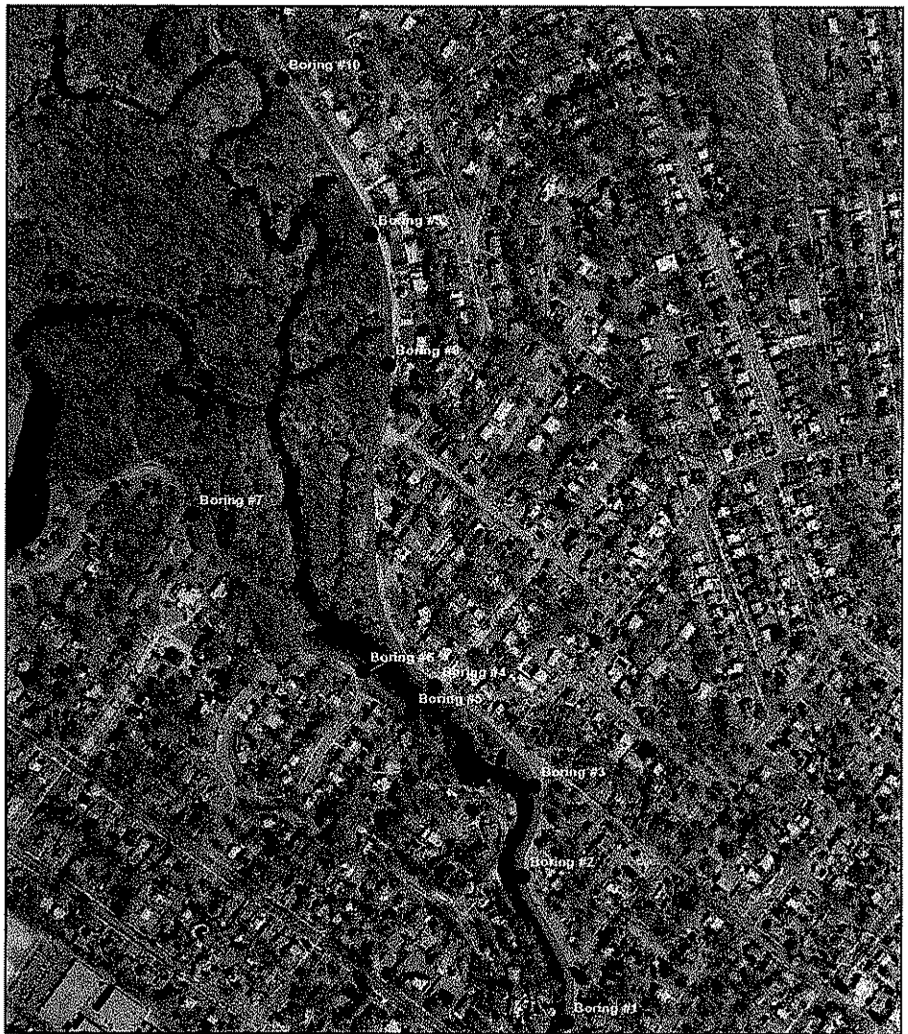
INTRODUCTION

The Cranford levee system has two levees on either side of the Rahway River. The levee on the right overbank is approximately 1,000 feet long. The levee on the left overbank is approximately 3,700 feet long. The heights of the levees vary from 4' to 6.0 feet. Borings were taken along various sections of the levee to determine the soil type, density, and permeability of the levee material as well as to determine the foundation under the levee. The additional subsurface data is needed to determine if the Cranford levee meets US Army Corps of Engineers standards for levee design with respect to determining if piping (erosion of the soil from excessive seepage) would occur at the toe of the levee at the land side and to determine the possibility of seepage and piping under the levee. The data would also be used for the land side slope stability analysis.

REFERENCES

1. EM 1110-2-1913, Design and Construction of Levees, http://140.194.76.129/publications/eng-manuals/em1110-2-1913/toc.htm

2. ETL 1110-2-556, Risk-Based Analysis in Geotechnical Engineering for Support of Planning Studies, http://140.194.76.129/publications/eng-tech-ltrs/etl1110-2-556/toc.html



Boring Locations

FINDINGS

The reliability of the Rahway River Levees in Cranford, NJ was determined from the seepage and stability analyses. Around 2009, the levees were in fairly good condition with little or no land side slope erosion or toe erosion. The top or crowns of the levees are paved with an asphalt surface walkway. The levees are narrow and at their highest point, they are 6 feet above the street level.

SEEPAGE ANALYSIS

Seepage analysis was performed using the Corps LEVSEP95 program. Information from subsurface explorations and lab testing such as soil types, permeability, submerged unit weight of the soils, and levee cross sections were input into the program. This program is based on the methods and mathematical formulas found in EM 1110-2-1913, DESIGN AND CONSTRUCTION OF LEVEES. LEVSEP95 computed the seepage volume underneath the levee and the exit gradient (I) at the toe of the levee on the land side. The exit gradient demonstrates whether or not a soil has become liquefied or "quick" and it presents a structural instability in the levee. The exit gradient is an indicator of levee erosion or piping at the levee toe on the landside. A potentially dangerous condition is present when the exit gradient is *greater* than 0.5.

The typical levee section at each boring where the seepage analysis was performed is shown in Figures 5 thru 8. In this analysis the Gray Silt and sand layer is assumed to be the impervious blanket. This impervious blanket is interpolated to extend to the river on the riverside of the levee and from 20 to 36 feet from the landside toe underneath the asphalt road pavement. The thickness of the Gray Silt blanket was determined from the borings which is about 3 feet. The Gray Silt blanket was encountered in all four levee sections and could be the previous riverbed. The asphalt road pavement was not included as the impervious blanket due to cracks in the pavement and relatively thin layers of the top asphalt surface. The Red Silty Sand stratum is assumed to be the pervious layer underneath the Gray Silt blanket. The Red Silty Sand layer ranges approximately in thickness from 1 to 10 feet.

The four seepage analyses were performed at sections along the levee that correspond to the location of the borings shown in the table below. In-hole permeability or falling head tests were performed at these borings to calculate the permeability constant for the seepage analysis. The seepage results indicate that the seepage volume (amount of water flowing underneath the levee) was relatively low and the exit gradient high. Most of the exit gradient (I) values were above 0.5, which is the approximate critical point where erosion or piping may occur at the levee toe. Therefore, there is the potential risk of failure of the levee before the flood waters overtop the levee. The results of the exit gradient for the levee sections are as follows:

Boring Location	***Exit Gradient (I)***
2	1.0
3	.71
4&5	.29
6	1.13

The above exit gradients indicate that the only section that is not above the critical gradient is at the section between Borings 4 & 5. All other sections have exit gradients greater than 0.5.

STABILITY ANALYSIS

The stability analysis of the levees was performed at the most critical section of the levee. It was done at the highest crown elevation from both the land and river side (boring location 6). Two stability analyses were performed: one with the levee intact; another with some erosion along the levee slope and toe. There were a total of 12 runs for both analyses.

The stability analysis runs were done using the UTEXAS4 program. UTEXAS4 is a US Army Corps soil stability analysis program that uses the subsurface exploration data obtained to determine a safety factor for sliding failures of soils. Some of the runs used a levee section with the slope and toe in place (no erosion) and another set of runs with erosion.

The UTEXAS4 program determined that the section, without any erosion, had a safety factor against sliding failure of the slope equal to 28.31. Another set of runs used a levee section with the toe and slope eroded at a steep angle. For these runs, the lowest safety factor equal to 2.74. All of the stability analysis runs used the piezometric line of rapid drawdown with erosion through the Gray Silt layer underneath the levee. It is assumed in the stability analysis that overtopping would occur causing the erosion of the landside levee toe and part of the side slopes.

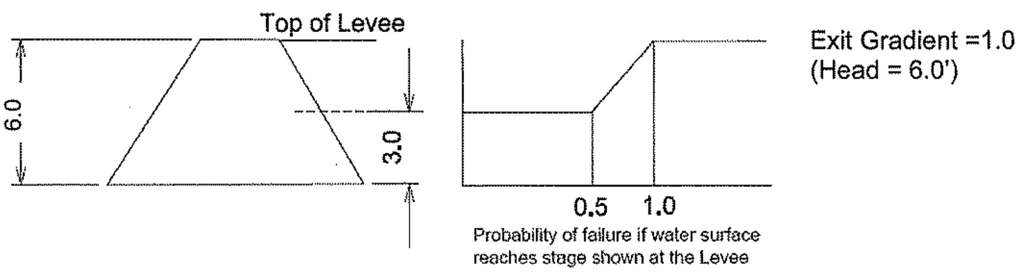
This indicates that as the toe and slope begin to erode the safety factor against sliding failure begins to drop rapidly. This can be seen according to the runs (on the UTEXAS4 graphs). Although safety factors are very high, the stability results indicate that as erosion begins the safety factor will drop rapidly into critical failure conditions.

RELIABILITY AND RISK

Reliability of a levee can also be shown in graph form in accordance with ETL 1110-2-556 "Risk-Based Analysis in Geotechnical Engineering for Support of Planning Studies" as a probability of failure vs. water surface on a typical levee. The probabilities of failure on selected boring locations are shown in the figures below. The Y-axis is the stage (height of water on the levee) and the X-axis presents the probability of failure. The lower limit of each curve is known as the probable non-failure point and the upper limit represents the probable failure point. The non-failure point represents the lowest chance of failure for the levee up to the stage that corresponds to that probability. The failure point represents the stage in which failure of the levee is imminent. The curve between the lower limit and upper limit represented will give a probability for failure at any given stage in between the upper and lower limits. The probability curves were determined by using the Underseepage Analysis presented in ETL 1110-2-556.

FIGURES

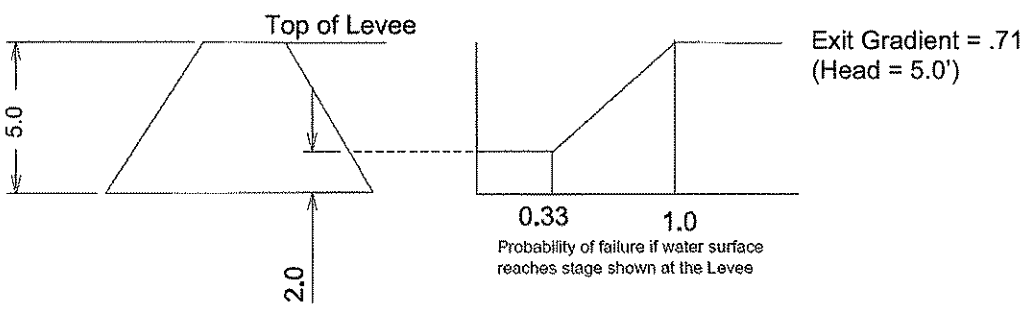
LEVEE CROSS SECTION
(Near Boring # 2)



Note: As the water height or stage goes up, the exit gradient increases which makes the toe of the Levee more susceptible to piping and erosion.

FIGURE 1

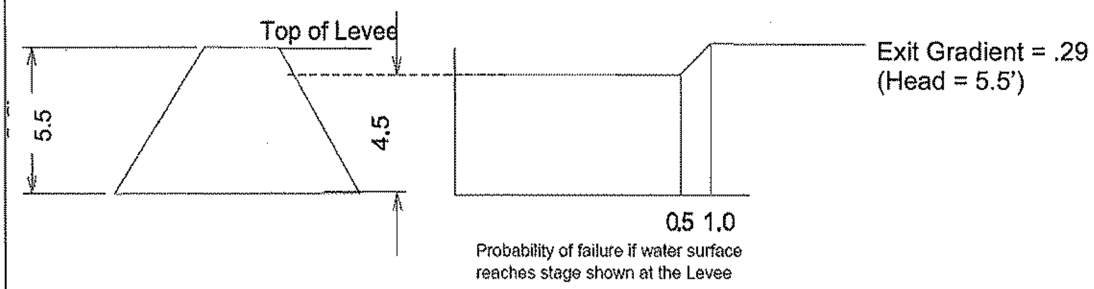
LEVEE CROSS SECTION
(Near Boring # 3)



Note: As the water height or stage goes up, the exit gradient increases which makes the toe of the Levee more susceptible to piping and erosion.

FIGURE 2

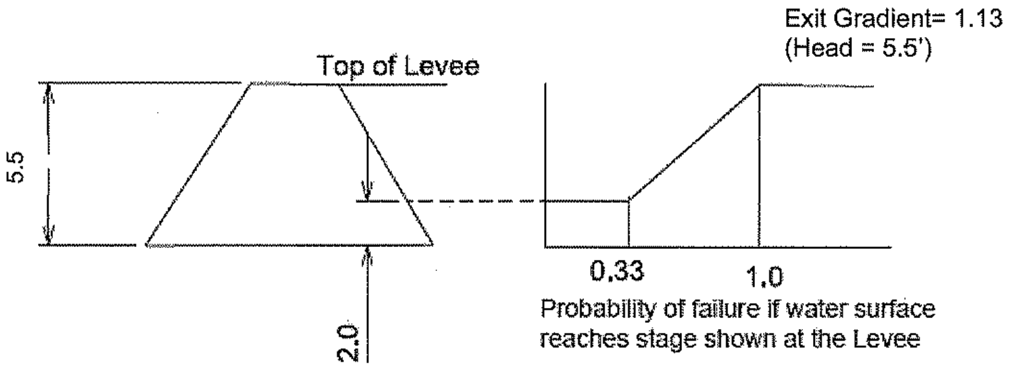
LEVEE CROSS SECTION
(Near Boring 4&5)



Note: As the water height or stage goes up, the exit gradient is below .5 at the top of levee.

FIGURE 3

LEVEE CROSS SECTION
(Near Boring # 6)



Note: As the water height or stage goes up, the exit gradient increases which makes the toe of the Levee more susceptible to piping and erosion.

FIGURE 4

CONCLUSION - ARMY CORPS LEVEE STANDARDS

Based on the findings, the levees at Cranford would need to be modified because they do not meet Army Corps standards present in EM 1110-2-1913. The levees' foundation either lacks seepage cutoffs or impervious cores. The subsurface exploration did not find any impervious cores under the levees which is a clear indication that these levees do not meet Corps standards.

According to EM 1110-2-1913 Section 1 Paragraph 5.2, Corps standards recommend levees to be built with either an impervious core or a seepage cutoff to prevent piping, which could possibly reduce the exit gradients below a critical condition.

RECOMMENDATIONS

In order for the Cranford levees to meet Army Corps standards, the following remedial options are provided:

1. Levee modification: Construct a seepage berm to lengthen the seepage path, which would result in a decreased exit gradient. This would have to be constructed on the river side where more land is available for the berm.

2. Levee modification: Install an impervious core, which could be constructed of a clay core into the current levee system.

3. Levee modification: Widen the levee and increase the levee height to prevent piping and toe erosion. Widening the levee would increase the distance that the seepage would need to travel. This modification would be restricted to the river side since more land is available than on the land side.

List of Attached Data

1. Boring Logs/Locations
2. UTexas4 Graphs/Runs
3. Boring Cross Sections
4. Seepage Analysis

SUBSURFACE EXPLORATION NOTES

1. NOTES:

FOR BORING LOCATIONS SEE PLAN SHEETS.

SOILS WERE VISUALLY CLASSIFIED ACCORDING TO THE "UNIFIED SOIL CLASSIFICATION SYSTEM."

SUBSURFACE EXPLORATION WAS CONDUCTED BY NY DISTRICT, U.S. ARMY CORPS OF ENGINEERS

STANDARD PENETRATION TEST (SPT) METHODS AND PROCEDURES (140# HAMMER, THIRTY-INCH DROP, AND TWO-INCH SPLIT SPOON) WERE EMPLOYED TO COLLECT SAMPLES, EXCEPT WHERE NOTED

GEOPROBES ARE NOTED ON LOGS. BS = Bag Samples

DATUM = NAVD88

2. CLASSIFICATION AND TERMS

BEDROCK: NATURAL SOLID MINERAL MATTER (ROCK) OCCURRING IN GREAT THICKNESS AND EXTENT IN ITS NATURAL LOCATION. NORMALLY UNDERLIES SOIL.

SOILS: SEDIMENT OR OTHER UNCONSOLIDATED PARTICLES PRODUCED BY THE PHYSICAL AND CHEMICAL WEATHERING OF ROCKS, AND WHICH MAY CONTAIN ORGANIC MATTER. SOILS ARE TYPICALLY CLASSIFIED AS FOLLOWS:

BOULDER ... larger than 8"
COBBLE OR SMALL STONE 8" - 3"
GRAVEL: coarse...3" to ¾"
medium...3/4" to 4.76 mm
SAND: coarse...4.76 mm to 2 mm
medium...2 mm to 0.42 mm
fine.....0.42 mm to 0.074 mm
SILT and CLAY...finer than 0.074 mm

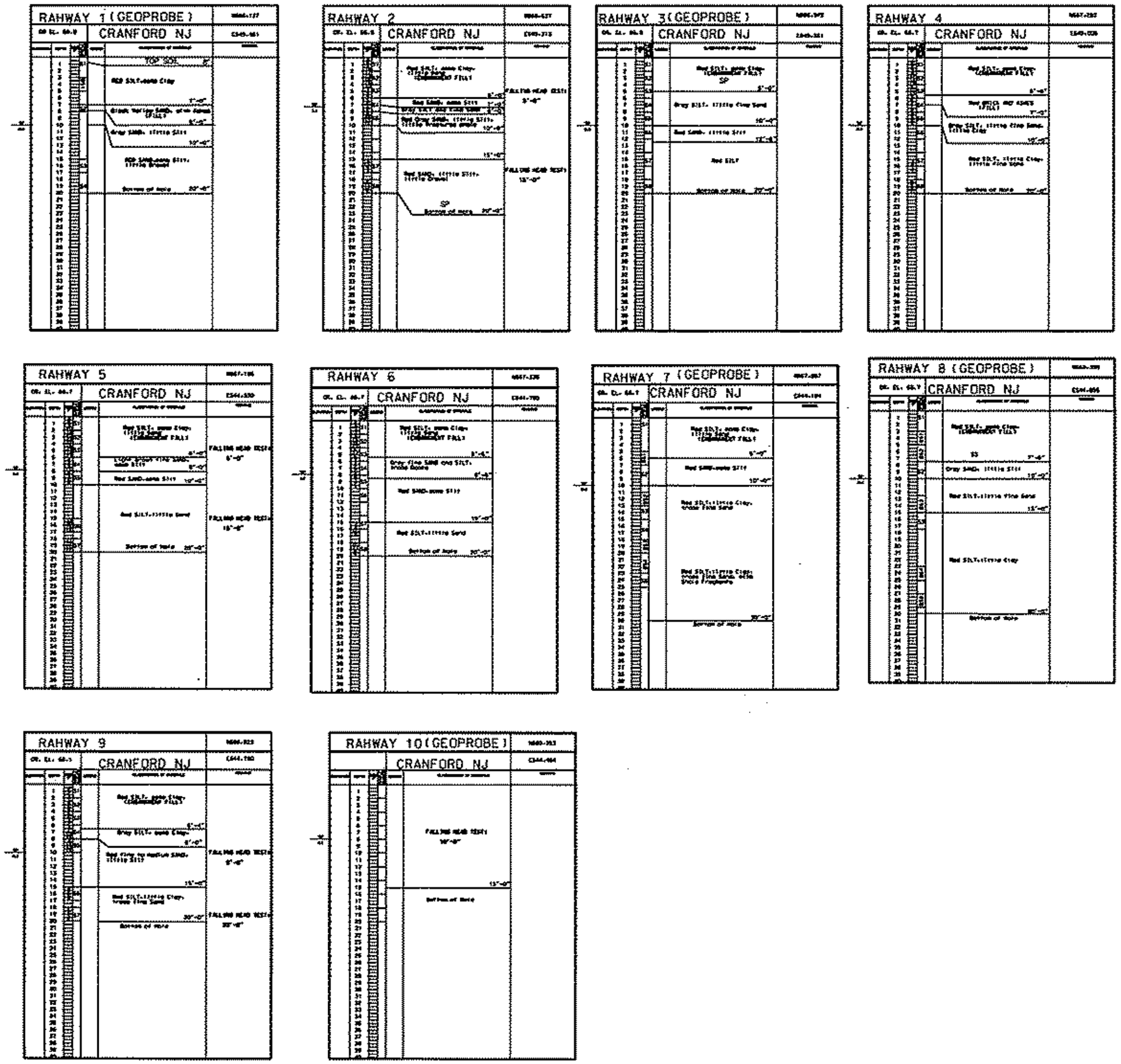
Major soil size component is shown with all letters CAPITALIZED. Minor component % in terms of the total sample are as follows:

and.....40 to 50%
some....40 to 20%
little..20 to 10%
trace...10 to 1%

3. ABBREVIATIONS

WOR = WEIGHT OF RODS WOH = WEIGHT OF HAMMER
NR = No Recovery NS = No Sample
TABLE OF SOIL TESTING - ABBREVIATIONS
USCS = Unified Soil Classification Symbol
% G = Percent Gravel-sized particles
% S = Percent sand-sized particles
% F = Percent fines (silt and clay)
LL = Liquid Limit PL = Plastic Limit
PI = Plasticity Index (LL - PL)
% H2O = Water Content (Wt H2O / Wt Dry Soil)
SG = Specific Gravity

4. Drilling Company: Subsurface Inc.



US Army Corps of Engineers New York District

BORING LOGS

Sheet reference number: B-601

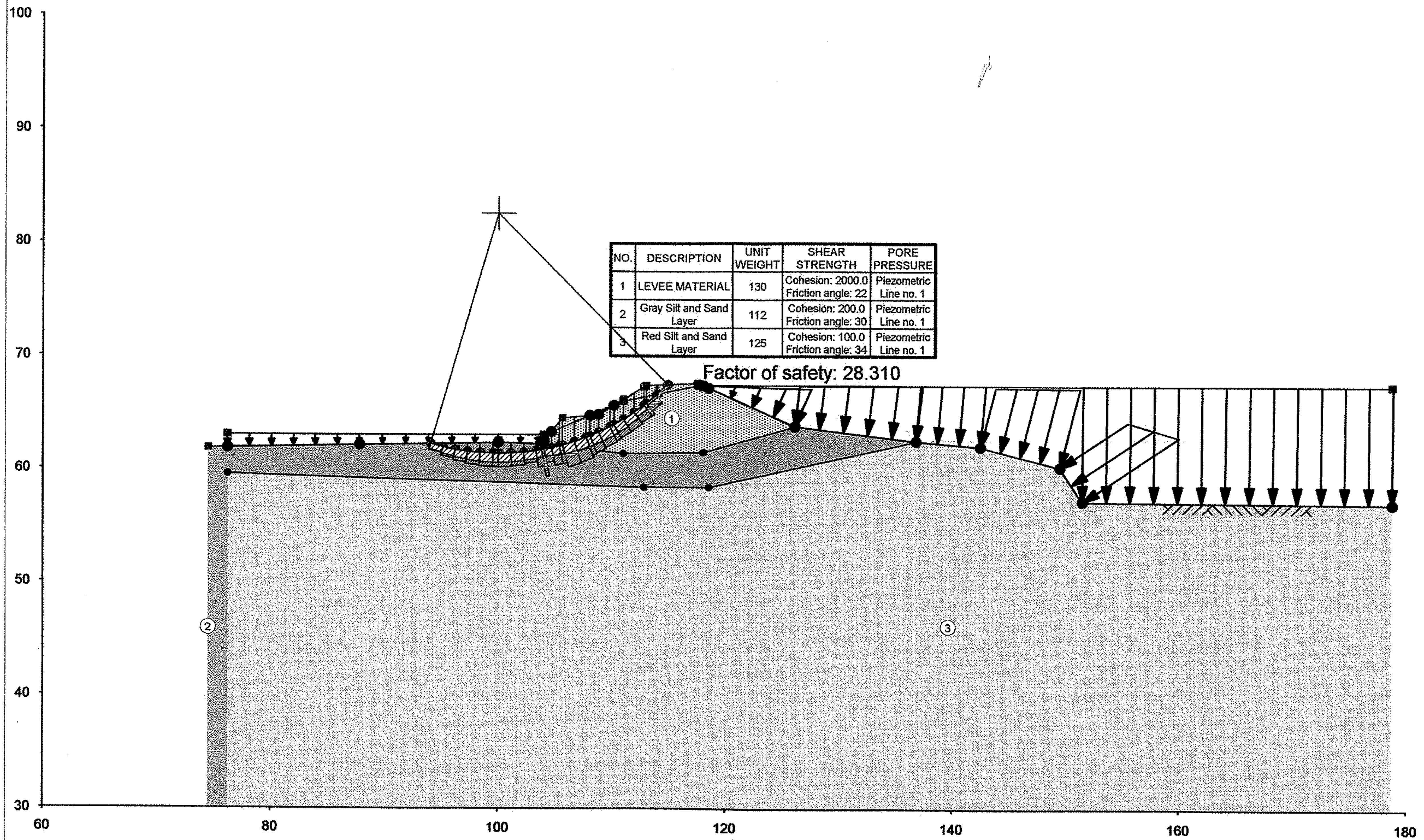
SHEET of

SUBMITTED BY: USERNAME PLOT DATE: DD-MMM-YYYY HH:MM FILE NAME

Boring Log #6
E544,765
Boring Log #5
E544,?30
Boring Log #3
N 666,946
E 545,351
Boring Log #2
E 545,313
FALLING HEAD TEST
Boring Log #1
N 666,137
E 545,461

Boring # 10 Moved to New Location
Boring Log #10
Boring Log #9
N 668,823
E 544,790
Boring Log #8
N 668,390
E 544,855
Boring Log #7
N 667,867
E544,184
FALLING HEAD TEST

Rahway River



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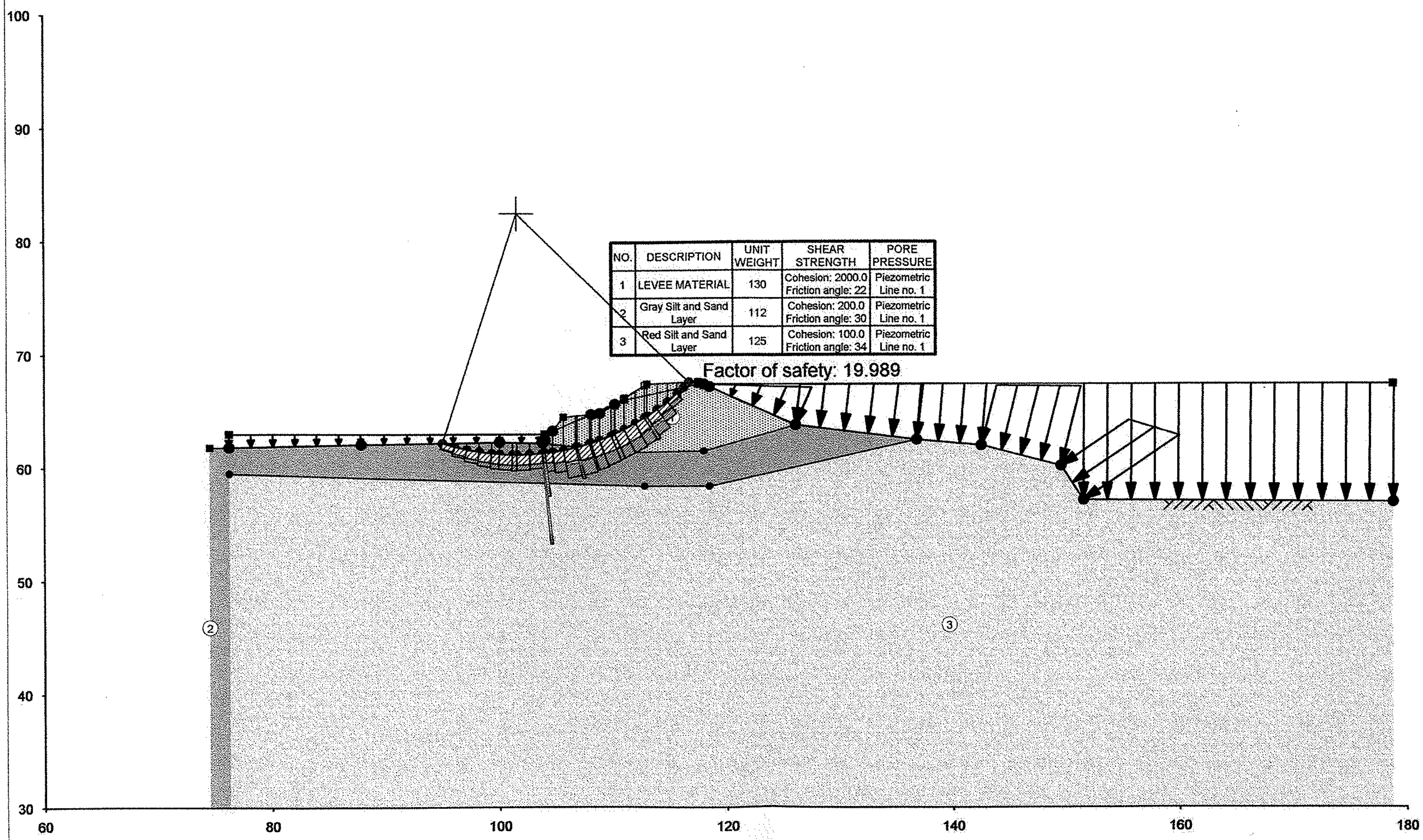
Rahway River



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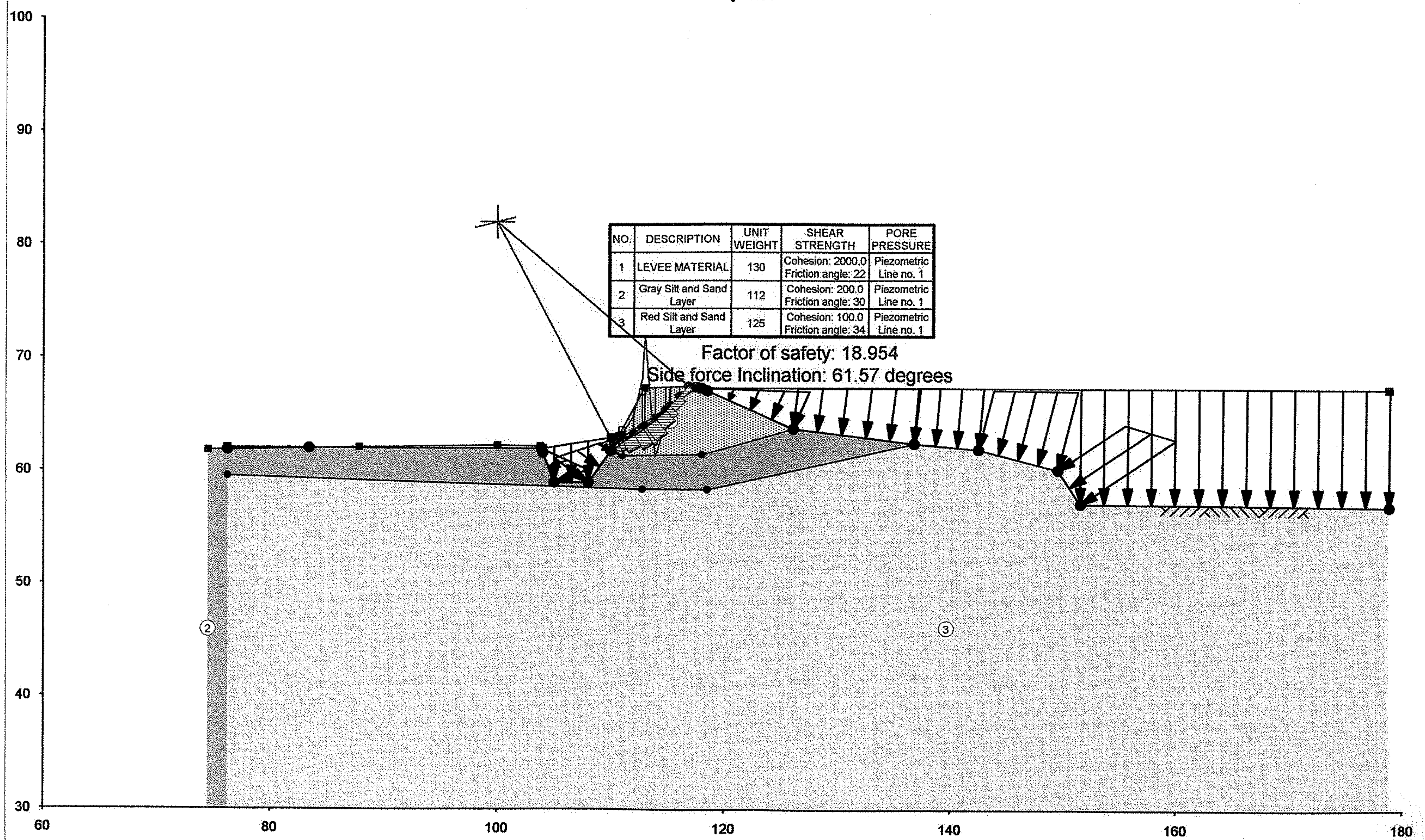
Rahway River



NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	LEVEE MATERIAL	130	Cohesion: 2000.0 Friction angle: 22	Piezometric Line no. 1
2	Gray Silt and Sand Layer	112	Cohesion: 200.0 Friction angle: 30	Piezometric Line no. 1
3	Red Silt and Sand Layer	125	Cohesion: 100.0 Friction angle: 34	Piezometric Line no. 1

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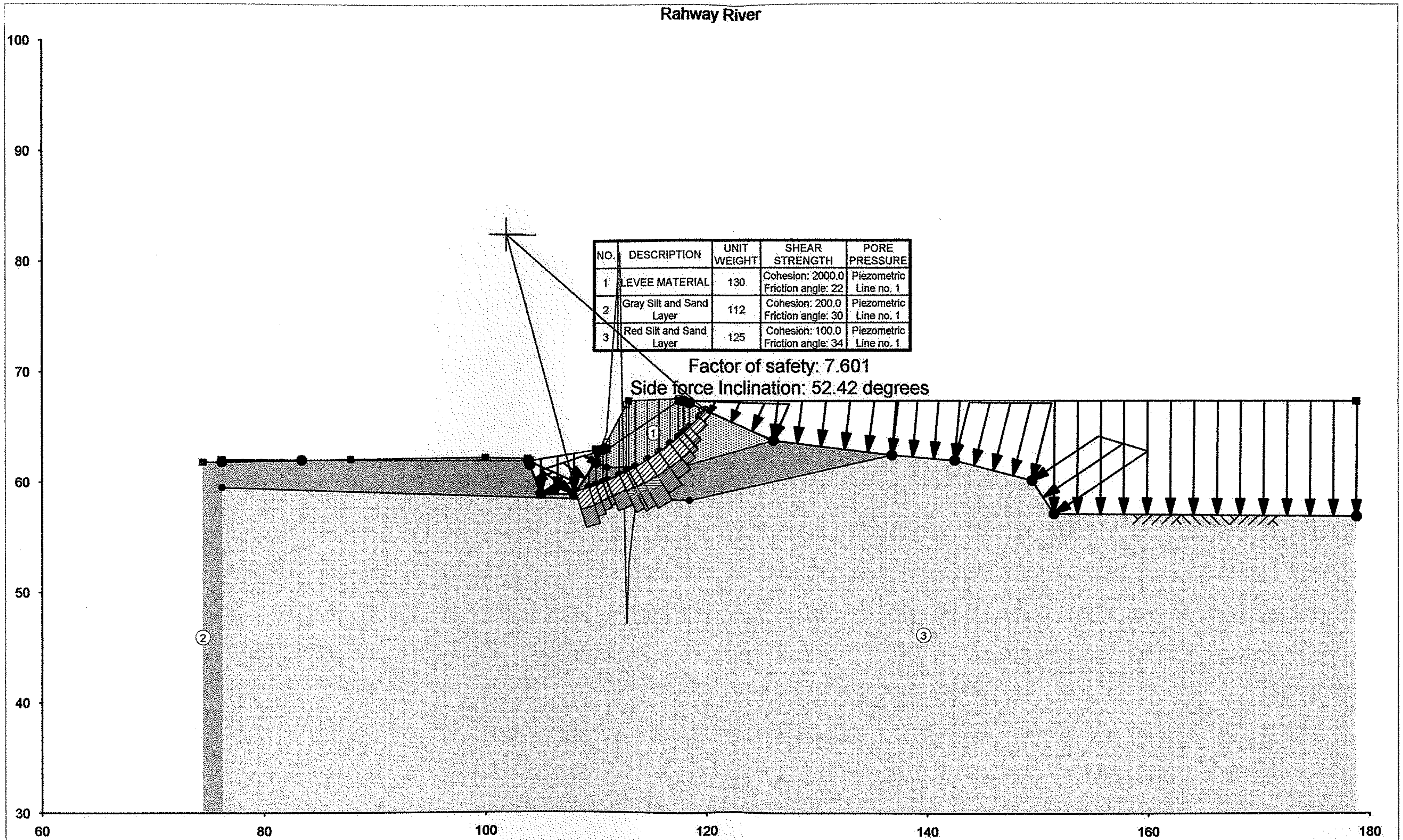

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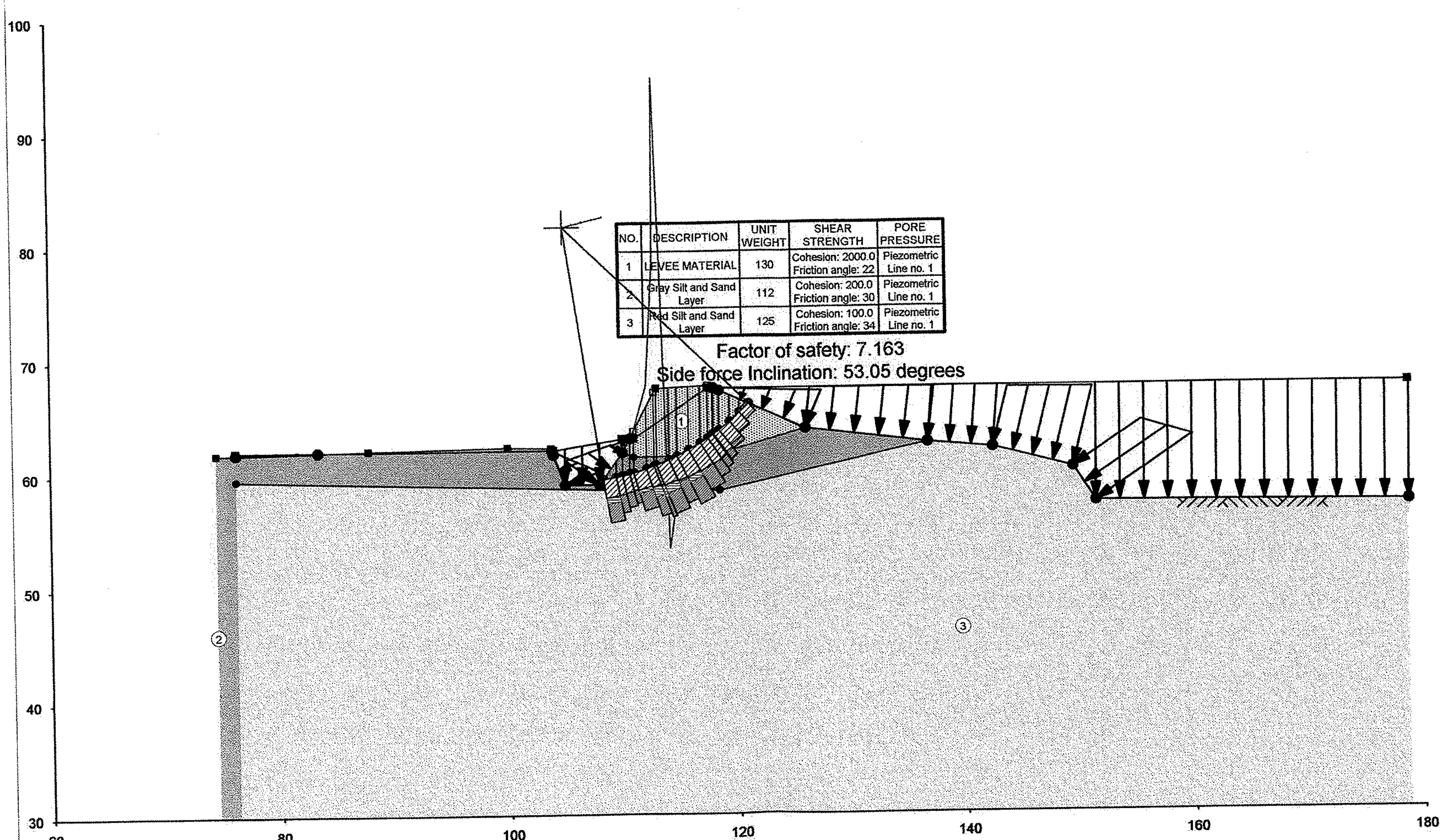
Rahway River



NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
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2	Gray Silt and Sand Layer	112	Cohesion: 200.0 Friction angle: 30	Piezometric Line no. 1
3	Red Silt and Sand Layer	125	Cohesion: 100.0 Friction angle: 34	Piezometric Line no. 1

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Date: Thu Oct 06 2011

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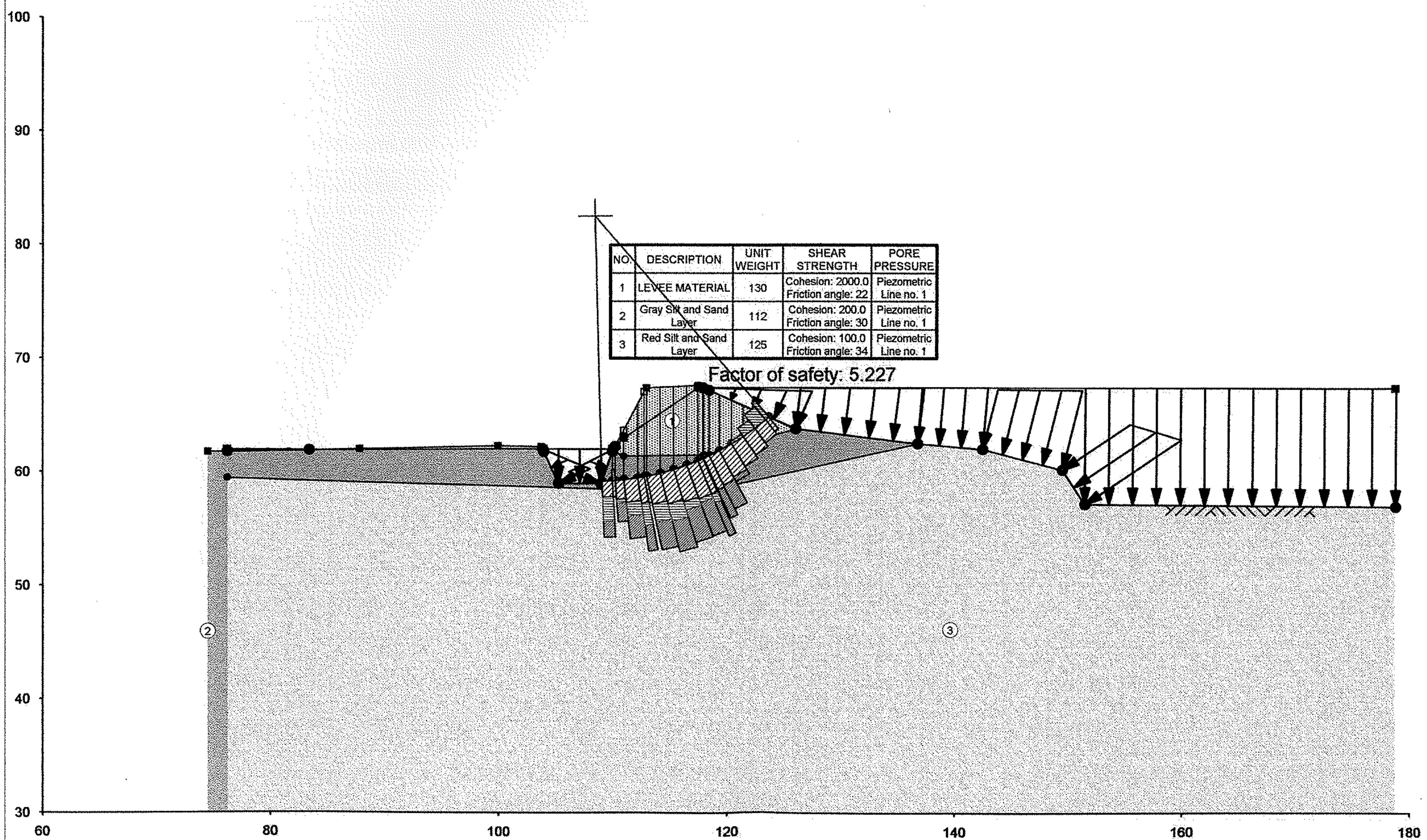
Rahway River



NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
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2	Gray Silt and Sand Layer	112	Cohesion: 200.0 Friction angle: 30	Piezometric Line no. 1
3	Red Silt and Sand Layer	125	Cohesion: 100.0 Friction angle: 34	Piezometric Line no. 1

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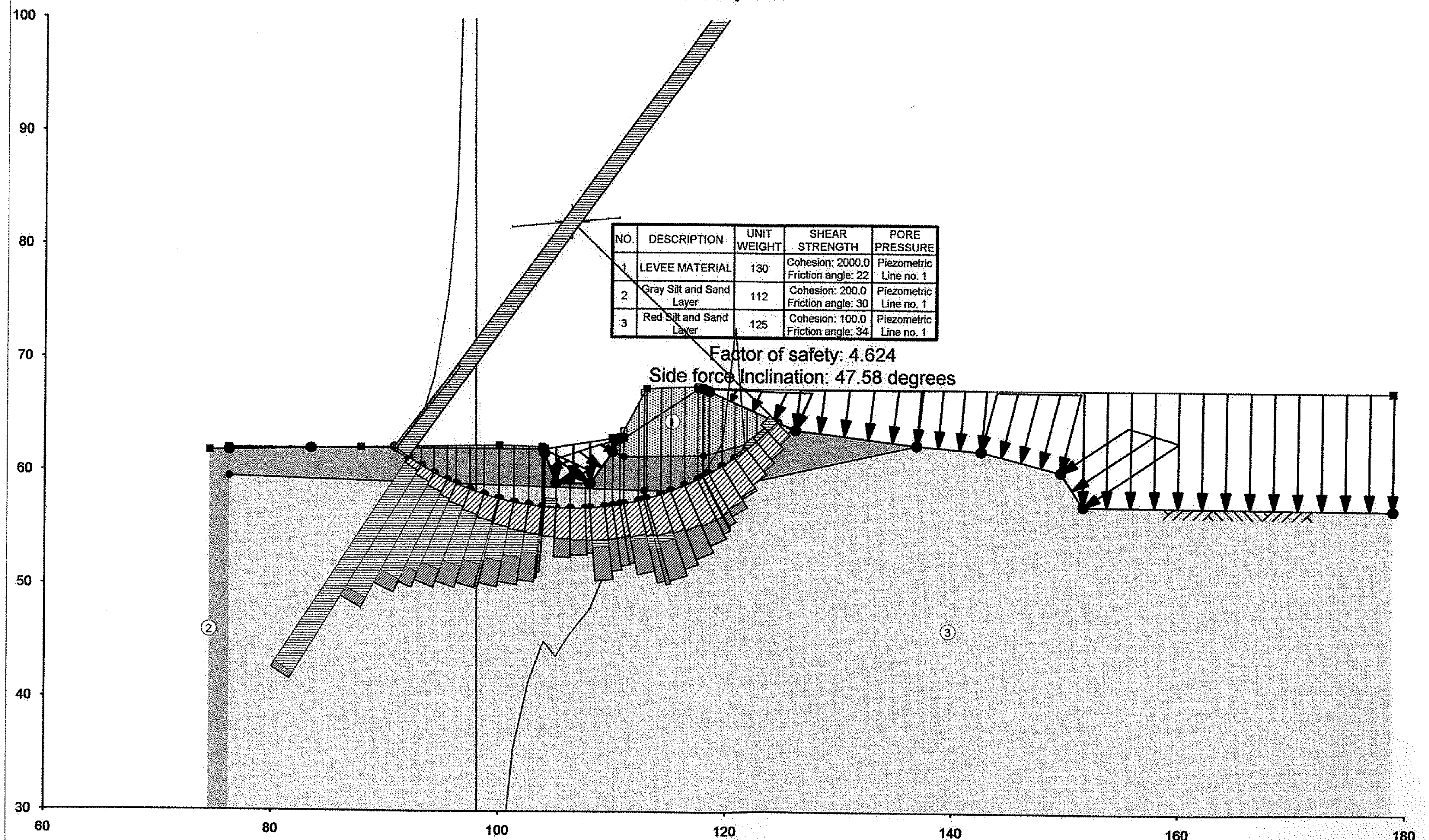
Rahway River



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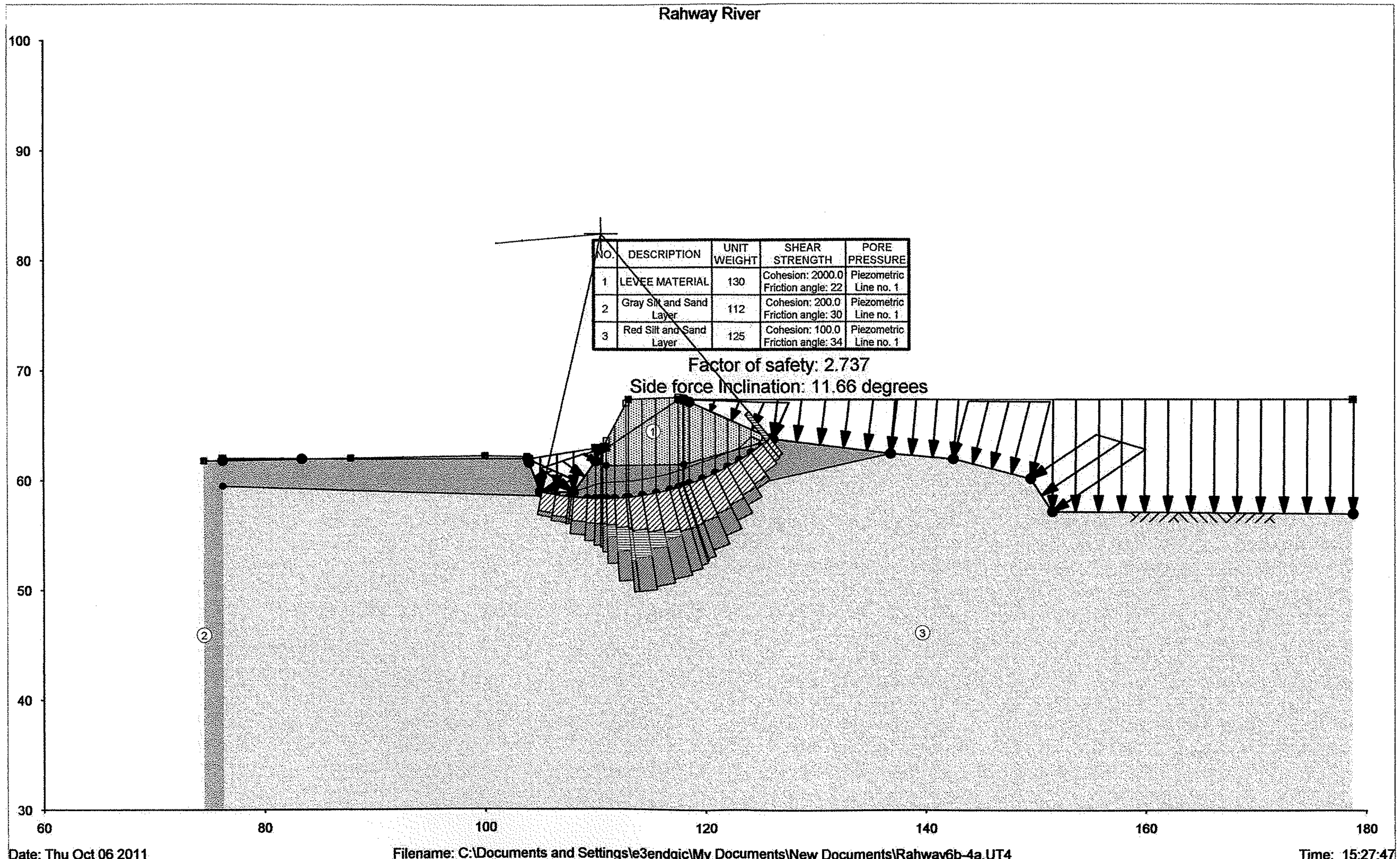
Rahway River
NO. | DESCRIPTION | UNIT WEIGHT | SHEAR STRENGTH | PORE PRESSURE
1 | LEVEE MATERIAL | 130 | Cohesion: 2000.0 Friction angle: 22 | Piezometric Line no. 1
2 | Gray Silt and Sand Layer | 112 | Cohesion: 200.0 Friction angle: 30 | Piezometric Line no. 1
3 | Red Silt and Sand Layer | 125 | Cohesion: 100.0 Friction angle: 34 | Piezometric Line no. 1
Factor of safety: 2.737
Side force Inclination: 11.66 degrees
100
90
80
70
60
50
40
30
60
80
100
120
140
160
180
Date: Thu Oct 06 2011
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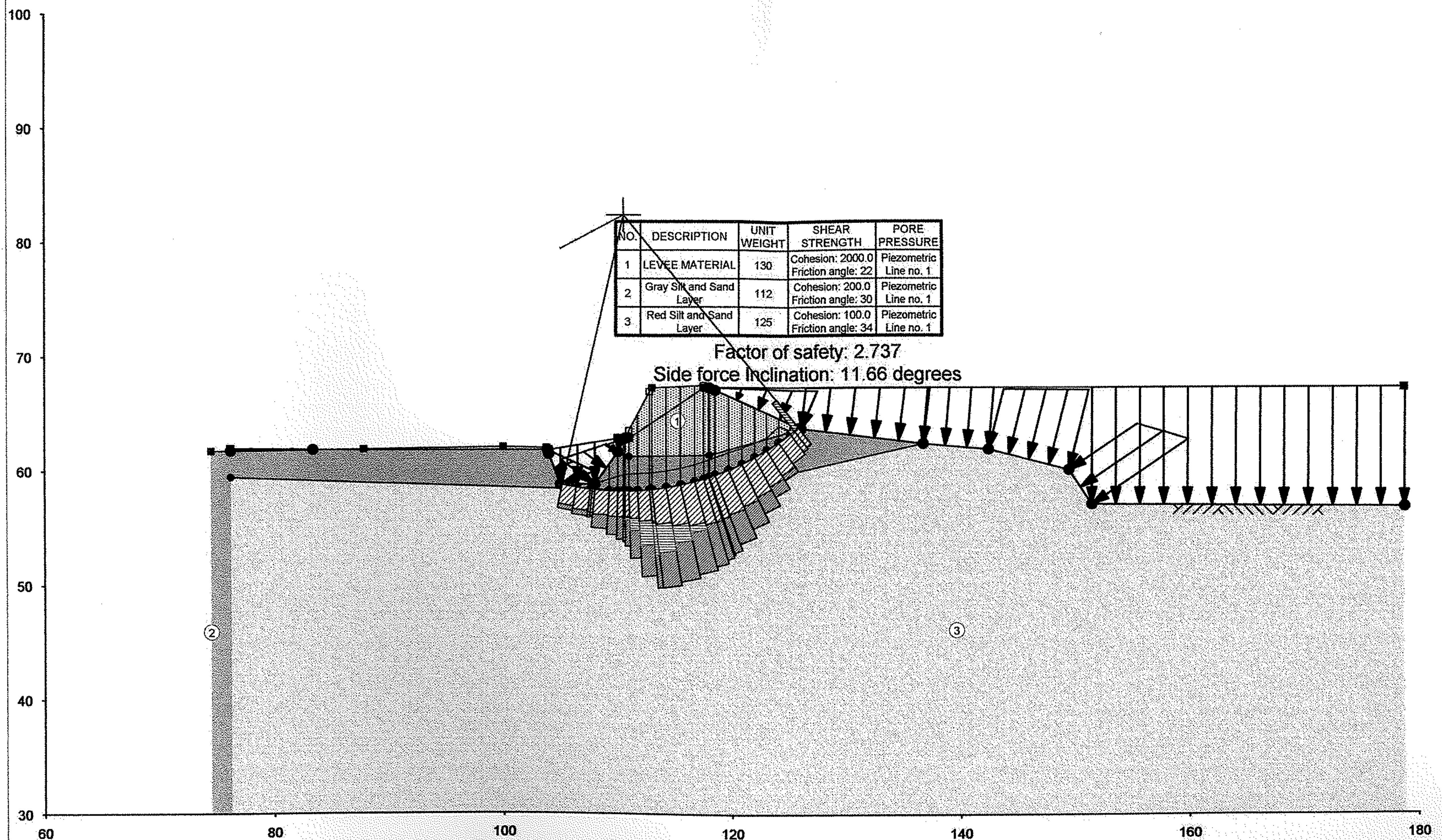
Time: 15:27:47

Rahway River



NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	LEVEE MATERIAL	130	Cohesion: 2000.0 Friction angle: 22	Piezometric Line no. 1
2	Gray Silt and Sand Layer	112	Cohesion: 200.0 Friction angle: 30	Piezometric Line no. 1
3	Red Silt and Sand Layer	125	Cohesion: 100.0 Friction angle: 34	Piezometric Line no. 1

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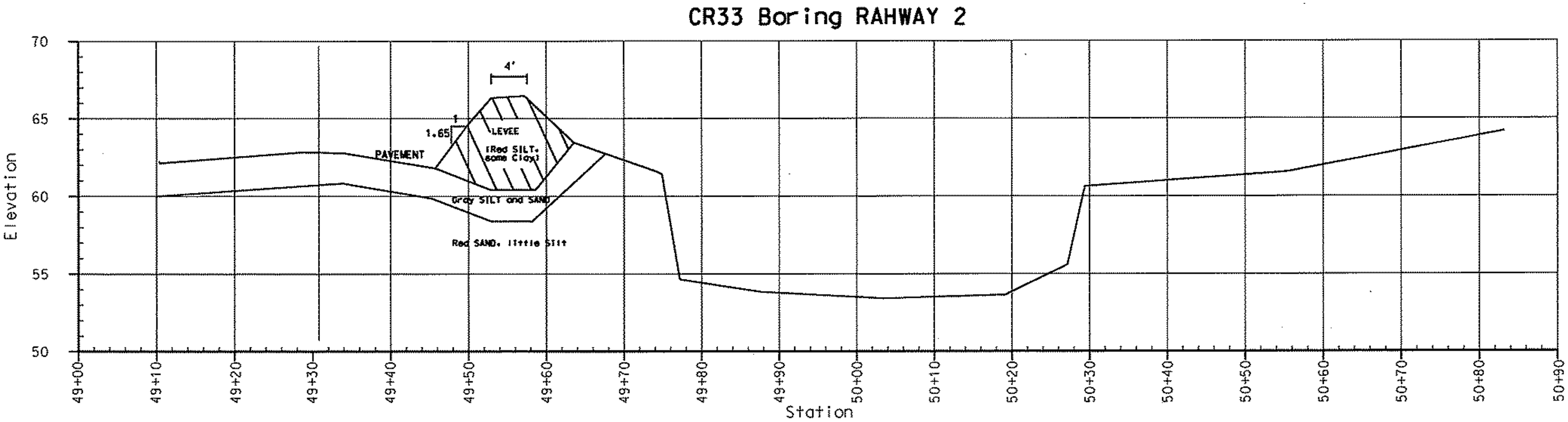
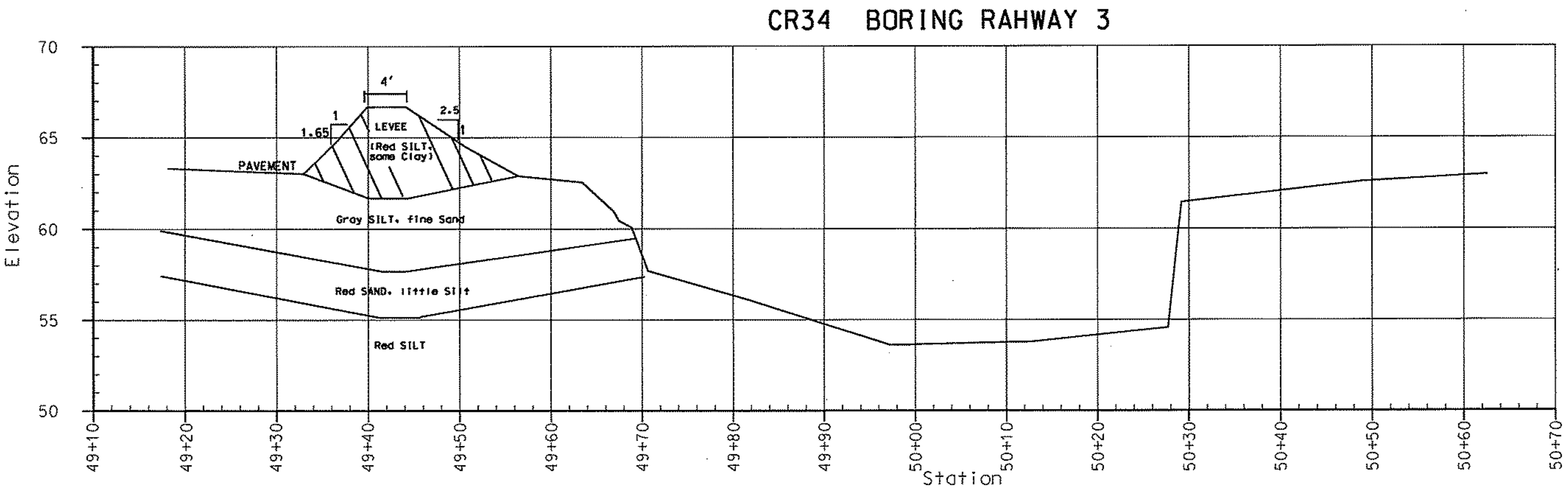


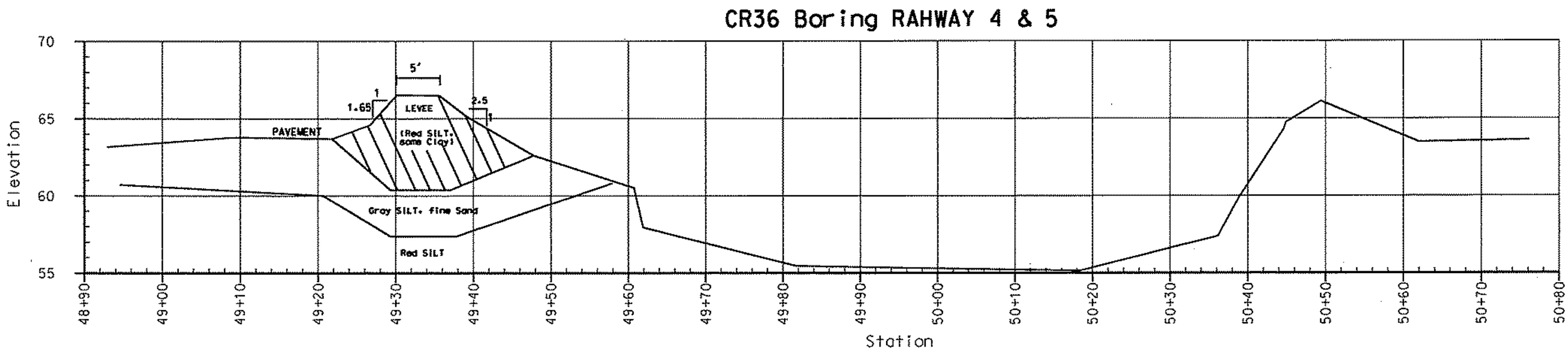
Typical Levee Section at RAHWAY 2

FIGURE 5



TYPICAL LEVEE SECTION AT BORING RAHWAY 3

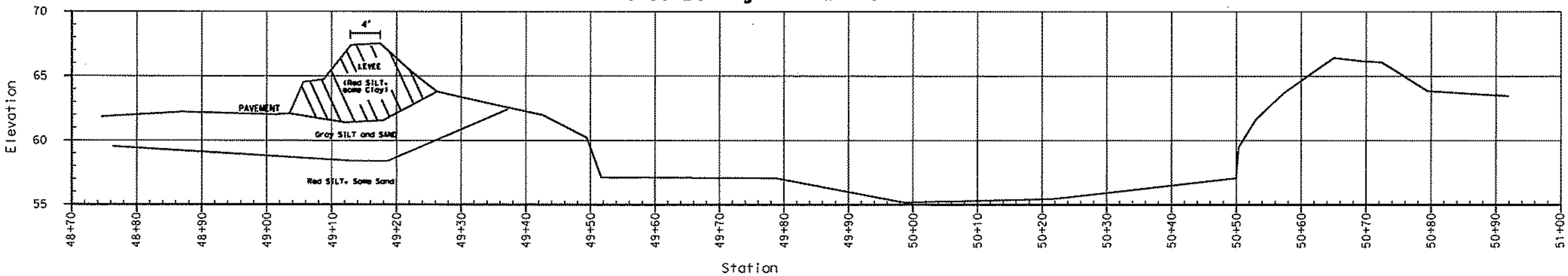
FIGURE 6



TYPICAL LEVEE SECTION BETWEEN Boring RAHWAY 4 & 5

FIGURE 7

CR38 Boring # RAHWAY 6



TYPICAL LEVEE SECTION AT Boring # RAHWAY 6

FIGURE 8

PROJECT NAME : RAHWAY RIVER
STATION : BOR# 2

INITIAL CONDITIONS

X1 = 4.61 FT
X3 = 7.50 FT
M = 0.2713
I = 1.0177
Qs = 6.00 GPM/100 FT

H0 = 2.04 FT
$ = 0.4522

COST SUMMARY FOR ALL CONTROL MEASURES

TYPE	VOLUME CU YD/100 FT	UNIT COST $	TOTAL $
RIVERSIDE BLANKET	0.00	1.20	0.00

CUTOFF

DC/D = 0
DEPTH = 0.00 FT
TOTAL = 0.00 $

RELIEF WELL - LOWEST COST

DEPTH = 0.00 FT
SPACING = 0.00 FT
TOTAL = 0.00 $

PROJECT NAME : RAHWAY RIVER
STATION : BOR# 3

INITIAL CONDITIONS

X1 = 6.00 FT
X3 = 6.13 FT
M = 0.2311
I = 0.7088
Qs = 7.15 GPM/100 FT

H0 = 1.42 FT
$ = 0.1387

COST SUMMARY FOR ALL CONTROL MEASURES

TYPE	VOLUME CU YD/100 FT	UNIT COST $	TOTAL $
RIVERSIDE BLANKET	0.00	1.20	0.00

CUTOFF

DC/D = 0
DEPTH = 0.00 FT
TOTAL = 0.00 $

RELIEF WELL - LOWEST COST

DEPTH = 0.00 FT
SPACING = 0.00 FT
TOTAL = 0.00 $

PROJECT NAME : RAHWAY RIVER
STATION : BOR# 4 & 5

INITIAL CONDITIONS

X1 = 3.73 FT
X3 = 3.74 FT
M = 0.2343
I = 0.2923
Qs = 2.42 GPM/100 FT

H0 = 0.88 FT
$ = 0.0426

COST SUMMARY FOR ALL CONTROL MEASURES

TYPE	VOLUME CU YD/100 FT	UNIT COST $	TOTAL $
RIVERSIDE BLANKET	0.00	1.20	0.00

CUTOFF

DC/D = 0
DEPTH = 0.00 FT
TOTAL = 0.00 $

RELIEF WELL - LOWEST COST

DEPTH = 0.00 FT
SPACING = 0.00 FT
TOTAL = 0.00 $

PROJECT NAME : RAHWAY RIVER
STATION : BOR 6 CR38

INITIAL CONDITIONS

X1 = 8.37 FT
X3 = 8.37 FT
M = 0.1473
I = 1.2324
QS = 22.79 GPM/100 FT

H0 = 1.23 FT
$ = 0.3683

COST SUMMARY FOR ALL CONTROL MEASURES

TYPE	VOLUME CU YD/100 FT	UNIT COST $	TOTAL $
RIVERSIDE BLANKET	0.00	1.20	0.00

CUTOFF

DC/D = 0
DEPTH = 0.00 FT
TOTAL = 0.00 $

RELIEF WELL - LOWEST COST

DEPTH = 0.00 FT
SPACING = 0.00 FT
TOTAL = 0.00 $

PROJECT NAME : RAHWAY RIVER
STATION : BOR 6 CR38

INITIAL CONDITIONS

X1 = 11.05 FT
X3 = 11.89 FT
M = 0.1670
I = 0.9923
Qs = 25.83 GPM/100 FT

H0 = 1.98 FT
$ = 0.4554

COST SUMMARY FOR ALL CONTROL MEASURES

TYPE	VOLUME CU YD/100 FT	UNIT COST $	TOTAL $
RIVERSIDE BLANKET	0.00	1.20	0.00

CUTOFF

DC/D = 0
DEPTH = 0.00 FT
TOTAL = 0.00 $

RELIEF WELL - LOWEST COST

DEPTH = 0.00 FT
SPACING = 0.00 FT
TOTAL = 0.00 $

PROJECT NAME : RAHWAY RIVER
STATION : BOR 6 CR38

INITIAL CONDITIONS

X1 = 13.67 FT
X3 = 16.59 FT
M = 0.1140
I = 0.9452
Qs = 11.76 GPM/100 FT

H0 = 1.89 FT
$ = 0.2072

COST SUMMARY FOR ALL CONTROL MEASURES

TYPE	VOLUME CU YD/100 FT	UNIT COST $	TOTAL $
RIVERSIDE BLANKET	0.00	1.20	0.00

CUTOFF

DC/D = 0
DEPTH = 0.00 FT
TOTAL = 0.00 $

RELIEF WELL - LOWEST COST

DEPTH = 0.00 FT
SPACING = 0.00 FT
TOTAL = 0.00 $