Limited Reevaluation Report
Appendix F:
Geotechnical

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INTRODUCTION

The Geotechnical Appendix completed as part of the New York and New Jersey Harbor Navigation Study provided a comprehensive summary of the geology of the Port of New York and New Jersey. The geotechnical aspects of the feasibility of dredging the harbor to fifty feet and sixty feet were provided so that the economics of the possible construction projects could be determined. Ultimately, it was determined that the fifty-foot channel (Figure 1) is economically viable whereas the sixty-foot channel could not be justified. This interim report focuses in greater detail on the geotechnical aspects of the fifty-foot channel. New data has been included and aspects of the project that were not apparent at the time of the original study have been addressed.

OBJECTIVES

In order to prepare accurate plans and specifications for the dredging contracts that will be awarded as part of the fifty-foot channel project a number of factors need to be resolved. These factors include the volumes of the various materials that will dredged, the physical properties, the suitability for ocean disposal, the type of dredging equipment to be used, and the potential affects on nearby culture and habitat. To accurately quantify the materials and identify their properties a number of investigations were conducted. A summary of the investigations that were conducted and their objectives are:

- Construct regional maps of the project area to define the regional distribution of soil and rock types that will be encountered.
- Construct profiles, cross-sections, and subcrop maps of the individual channels showing detailed stratigraphy of the material to be excavated in each channel
- Evaluate the dredgeability of the strata that will be encountered in each channel using computer programs, previous dredging records, and test dredge results
- Evaluate the applicability of new technologies such as geophysical data and geoprobes as means of mapping and quantifying the various soil and rock types that will be encountered
- Evaluate the affect that blasting will have on nearby structures
- Evaluate and define stable side slopes based on the stratigraphy and soil properties that will be encountered along each channel

REGIONAL GEOLOGY AND PHYSIOLOGY

New York and New Jersey Harbors are divided into navigation channels. These channels include: Ambrose, Anchorage, Bay Ridge, Port Jersey, Kill Van Kull, Newark Bay, Elizabeth, South Elizabeth, and Arthur Kill channels. Figure 1[1] and Figure 1A (Ambrose Channel) are index maps showing the channel alignments for the fifty-foot project and boring locations for the harbor.

The project area is part of the Newark Basin and the Atlantic Coastal Plain of the Piedmont Lowlands physiographic province. The project area can be divided into two main areas based on depositional settings in recent geologic history. The Kills are comprised primarily glacial sediments, while Ambrose, Anchorage, and the outer portion of Port Jersey consist of fluvial deposits worked by long shore and tidal currents. Near surface stratigraphy can be divided into three major units: Bedrock, Pleistocene Sediments, and Holocene Sediments. A Subcrop map (Figure 2 and Figure 2a) was drawn to show the sediment and rock types that will be encountered when the channels are dredged to –48.5 feet MLW (-44.5 feet in Arthur Kill and at the existing channel elevations in Ambrose, Anchorage, and Bay Ridge channels). The map is used to define dredging areas and the volumes of various material types that will be dredged.

Bedrock Stratigraphy

Three rock groups make up the bedrock complex that underlies the project area: the Manhattan Prong of the New England Uplift (Cambrian), the Brunswick Formation (Jurassic) of the Newark Basin Physiographic Province, and Atlantic Coastal Plain Physiographic Province (Tertiary-Cretaceous). The Manhattan Prong consists of metamorphic rocks such as the schist that underlies Manhattan Island and the serpentinite that underlies the highlands along the eastern portion of Staten Island. The schist and serpentinite are exposed along the channel floor in the eastern portion of Kill Van Kull. Schist also underlies the eastern portion of Port Jersey Channel but has not been exposed by previous dredging.

The Newark Basin Group formed as a rift basin during the breakup of Gondwana 260 million years ago. During the Triassic period the rift basin filled with sediments, forming sandstone and shale. These sedimentary rocks are part of the Newark Basin group, which includes the Brunswick, Stockton, Lochatong, and Passaic formations. The rock sequence is thought to be 30,000 feet thick in the middle of the basin. Sandstone and shale members of the Newark Basin Group are exposed along Arthur Kill and Newark Bay channels. The diabase that occurs along the western end of Kill Van Kull and southern portion of Newark Bay is an igneous rock that formed during rifting and mountain building episodes during the Triassic and Jurassic periods. Differential weathering of the sedimentary, igneous and metamorphic rocks affects the topography of

[1] Figure 1 is available electronically on CD-ROM along with a Subsurface Index and boring locations.

the region. Valleys are predominately sandstone and shale and ridges are predominantly basalt and diabase.

The Cretaceous rocks of the Atlantic Coastal Plain consist of poorly consolidated sandstone and shale units. The Cretaceous section underlies Ambrose channel, but it has not been encountered to an elevation of –150' MLW in borings. During the Pleistocene, the Hudson River incised or carved a deep channel (Hudson Canyon) into the Cretaceous section.

Pleistocene Sediments

Pleistocene glacial sediments overlie the bedrock complex. During the Pleistocene epoch the area was affected by the last major glaciation, which caused the erosion of Triassic and Jurassic rocks and the deposition of glacial sediments, including lacustrian silt and clays, fluvial sands and silts, and till. The glacial sediments lay above the bedrock, and are approximately 100 to 200 feet thick. The sediments range in size from microscopic clay particles to very large boulders or erratics. A terminal moraine exists along southern edge of Staten Island and up to the Narrows, it appears again in Bay Ridge, Brooklyn continuing out to Nassau County, Long Island where it splits and ends at Montauk and Orient Points. The southern part of the terminal moraine is known as Ronkonkoma and the northern section is known as Harbor Hill. Southeast of the terminal moraine are outwash deposits of sand and gravel that extend under Lower New York Bay. Outwash deposits are transported by ice melt water that carries sediments beyond the terminal moraine. Behind the terminal moraine are ground surface moraine deposits consisting of an unsorted mixture of sand, silt, clay, gravel, cobbles, and boulders; materials picked up by the glacier as it advanced and dropped as the ice melted. Within the ground moraine glacial features known as eskers and kames are found, these are fluvial deposits that developed from water moving beneath the glacier. As the glacier retreated, the terminal moraine became a natural dam and lacustrian deposits of varved silt and clay developed. These deposits are over one hundred feet (100') thick in some areas. As the lakes became shallow, sand was deposited over the silt and clay. Eventually the terminal moraine was breached and the lakes drained. As a result, alluvial deposits of sand formed along the perimeter of the lakebed. Pleistocene sediments are normally red to brown, rarely contain shells, and are relatively dense when compared to Holocene sediments, which are normally gray to black and frequently contain shells. Pleistocene sediments usually occur approximately twenty feet (20') below mean low water (MLW).

Holocene Sediments

Due to sea level rise over the past 20,000 years the study area has become a tidal estuary. A layer of recent Holocene sediments has been deposited, these sediments include: poorly graded sand, silty sand, slightly organic silt, and peat. The thickness of the Holocene sediments ranges from a few feet to a few hundred feet in the Hudson River escarpment. As indicated on the subcrop map (Figure 2) the Holocene sediments are predominantly fine-grained silt and clay inside the Verazanno Bridge and predominantly

sand-sized sediments outside the Verazanno Bridge. The upper sections of the Holocene sediments often have a petroleum odor and contain manmade debris including toxic chemicals and heavy metals. This is particularly true for the inner harbor where the contaminated sediments are predominantly black, organic silt and clay sediments and are commonly referred to as "black mayo." The Holocene sands found in Ambrose Channel are typically suitable for ocean disposal.

The distribution of the black silt in the Kills and Newark Bay is shown in Figure 3. The map was prepared in segments by dredging contract so that the volume of non-HARS suitable material could be estimated. Most of the black silt was transported into the area via rivers such as the Passaic, Hackensack and Elizabeth. A second source is the adjacent flats that slump and fail as the channels are dredged. In geologic terms the black silt in the channels is considered to be in "temporary storage". It will eventually be carried to sea when the next major flood (100 yr +) or storm occurs. The map shows that in areas where current velocity is high, such as the confined channel portions of Arthur Kill and Kill Van Kull, very little or no black silt is deposited. In areas where current velocity decreases as the channels enter a larger body of water (i.e. Newark Bay) the black silt is deposited. Assuming that the hydrology of the area has not significantly changed then black silt should accumulate in the same areas as it did prior to dredging the forty-five foot channel.

CHANNEL STRATIGRAPHY and DREDGEABILITY

Soil Profiles and Cross Sections

Soil profiles illustrate the distributions of soils and rocks that will be encountered in the channel (Figures 4 through 12). Soils were grouped using several attributes; soils with similar characteristics that are difficult to differentiate were grouped together (i.e. Silty Sand and Silty Gravel or Silty Clay and Clayey Silt) to define stratigraphic units. Soil color was also used to determine stratigraphic units. As mentioned previously, Pleistocene sediments are generally reddish-brown and Holocene sediments are usually gray, tan, or black. While a unit may be described as a Pleistocene silt and clay, the stratigraphy may include minor sand and gravel sub-units. The soil profiles were used to sub-divide the channels into reaches of similar material where dredging conditions would be fairly uniform. This is an important factor to consider where dredging contract limits are defined.

Cross-sections show the soil and rock types that occur along the channel floor and channel slopes (Figure 4 through Figure 12). Profiles and cross-sections were constructed for each channel in order to show the stratigraphy of each channel in detail. The illustrations show the distribution and relative quantities of the various materials to be removed during the next phase of dredging.

Dredgeability Summary

The suitability of sediments for dredging was determined using a computer program called DREDGABL, developed by WES. The program predicts what dredges and procedures are conducive to dredging specific soil types. Data about the soils, based on the Unified Soil Classification System (USCS), are entered into the program, along with other parameters, which include: fineness (grain size), consistency (e.g. soft or hard), compactness (density), angularity, and plasticity and liquidity indices. Compressible sediments, such as organic and inorganic clays and silts, require information about consistency, plasticity, and liquidity to be entered. Coarse sediments such as sand and gravel require information on fineness, compactness, and angularity. The program will run without all of the data being entered, however the analysis is more accurate if all of the information is entered. DREDGABL also provides information about rock and shale fragments, cemented soils, shells, and debris. A locality specific database may also be developed if desired.

Characteristics of Hopper, Mechanical, and Pipeline Dredges.

DREDGE TYPE	% SOLIDS IN SLURRY BY WEIGHT	TURBIDITY	OPEN WATER OPERATION	RANGE OF PRODUCTION CU.YD./HR.	DREDGING DEPTH RANGES (FT)	WAVE HEIGHT LIMITS (FT)	LIMITING CURRENTS
HOPPER DREDGE	10 to 20	HIGH	YES	500 - 2000	10 to 80	<7	7 KNOTS
MECHANICAL DREDGE	IN SITU	AVERAGE	YES	30 - 500	0* to 100	<3	3 KNOTS
PIPELINE DREDGE	10 to 20	AVERAGE	Depends on Type	25 - 10000	3 to 14	<3	3 to 7 KNOTS

* Zero draft is used along waterway.

The dredges readily available in the New York area are the Bucket Hopper, Mechanical Backhoe, Clamshell, Power Shovel, and the Cutter Suction Pipeline. Dredges most commonly used for dredging in the harbor are mechanical clamshell and backhoe dredges. The type of dredge used depends on several factors, including: potential environmental contamination, turbidity, overflow, disposal, availability, and economics.

Dredging Rates

Using dredging records for Elizabeth and Kill Van Kull Channels an analysis was performed to find the average daily dredging production rate performed by a particular dredge type using a particular bucket size on a specific material. The analysis was done on three different areas: Areas 3 and 5 in Kill Van Kull and Area 7 in Elizabeth Channel. Results of the analysis are shown in Table 1. The objective of the analysis was to determine the range of dredging production rates in various materials when different dredge types are used. The data will be used to estimate production and the cost of future projects. The table will be revised as additional production records become available.

The data used to perform the analysis was broken down by day showing the specific area dredged each day (based on stations and offsets), the gross volume dredged, and the number of hours worked that day. The type of dredge and bucket used on that day were also given. Based on a subcrop map (Figure 2) and the dredge location the type of material that was dredged was determined.

Table 1. Table showing daily dredging production rates in Kill Van Kull and Elizabeth Channels.

	Bucket Type (CY)	Dredge	Soil Type	Hours Dredged	Avg. Hours Dredged (Daily)	Volume Dredged	Dredging Rate (CY/hr)	Avg. Daily Prod.
AREA 7								
1	16	Michigan	Holocene Black silt	908	13.16	229,249	252.48	6,059
2	8	Michigan	Hard Clay, Sand & Gravel	523	16.34	67,518	129.10	3,098
3	8	Newark Bay	Hard Clay, Sand & Gravel	651	16.69	83,628	128.46	3,083
4	8	Michigan	Pleistocene Silty Clay	3,573	16.54	726,795	203.41	4,882
5	8	Newark Bay	Pleistocene Silty Clay	1,601	15.25	214,316	133.86	3,213
AREA 5								
1	39	Dredge 54	Holocene Black silt	53.99	9.00	29,850	552.88	13,269
2	9.5	Maricavor	Diabase Fractured	128.41	16.05	11,350	88.39	2,121
3	13	New York	Diabase Fractured	103.68	11.52	36,625	353.25	8,478
4	13	Tauracavor	Diabase Fractured	36.59	9.15	5,900	161.25	3,870
5	7	Maricavor	Glacial Till	200.23	18.20	16,445	82.13	1,971
6	13	New York	Glacial Till	53.92	13.48	14,100	261.50	6,276
7	13	Tauracavor	Glacial Till	19.17	19.17	3,100	161.71	3,881
8	13	New York	Pleistocene Silty Clay	29.42	9.81	5,100	173.35	4,160
9	13	New York	Glacial Outwash	14.08	14.08	2,900	205.97	4,943
AREA 3								
1	12	Dredge 54	Glacial Outwash	18.00	18.00	2,500	138.89	3,333
2	13	New York	Glacial Outwash	1,444.03	17.61	476,745	330.15	7,924
3	13	Tauracavor	Glacial Outwash	20.08	20.08	6,500	323.71	7,769
4	17	New York	Glacial Outwash	30.58	15.29	14,000	457.82	10,988
5	17	Tauracavor	Glacial Outwash	870.09	16.42	316,985	364.31	8,744
6	12	Dredge 54	Glacial Till	26.17	13.09	5,150	196.79	4,723
7	13	New York	Glacial Till	193.51	14.89	90,025	465.22	11,165
8	17	Tauracavor	Glacial Till	35.66	17.83	9,520	266.97	6,407
9	17	New York	Pleistocene Silty Clay	19.08	19.08	4,900	256.81	6,164
10	18	Tauracavor	Pleistocene Silty Clay	182.38	15.20	60,495	331.70	7,961

The total operating hours and total volume dredged were used to calculate hourly and daily production rates. A summary of the average daily production rate of the various dredges using different bucket sizes on a particular soil are shown in Table 2. If more than one type of material was dredged on any given day, then that data was not factored into the analysis, because there is no information telling how long it took to dredge one material as opposed to the other; therefore, a production rate cannot be determined for either material, and the data is useless for the analysis.

The dredges used to dredge material in Kill Van Kull and Elizabeth Channels were clamshells and backhoes. The Michigan dredge and the Newark Bay dredge are relatively small clamshell dredges. Dredge 54 is a relatively large clamshell dredge. The Tauracavor and New York dredges are backhoe dredges and the Maricavor is an excavator dredge. Table 2 shows the production rates by dredge type dredging in different soil types.

Table 2. Production rates by dredge type and bucket size dredging different materials.

Dredge Type	Bucket Size	Holocene Black silt	Pleistocene				Rock
			Silty Clay	Hard Clay S+G	Glacial Till	Glacial Outwash	
Clamshell							
Michigan	16	6,059					
	8		4,882	3,098			
Newark	8		3,213	3,083			
Dredge 54	39	13,269					
	12				4,723	3,333	
Bucket							
Tauracavor	13				3,881	7,769	3,870
	17					8,744	
	18		7,961				
New York	13		4,160		6,276	4,943	8,478
					11,165	7,924	
	17		6,164		7,961	10,988	
Maricavor	9.5						2,121
	7				1,971		

CHANNEL STRATIGRAPHY

Ambrose Channel

Ambrose Channel (Figure 4) is the entrance channel to New York Harbor. Poorly consolidated Sandstone and Shale of the Atlantic Coastal Plain underlies Ambrose Channel. The channel is comprised primarily of reworked fluvial sediments of sands (SP or SW) with little or no silt and clay. The dominant sediment type is fine to medium, poorly graded sand of loose to medium density. Silt and Clay are found in distinct stratigraphic layers in small, isolated pockets. The amount of Silt and Clay increases in the northern end of channel. Although bedrock was not encountered in this investigation, poorly consolidated Sandstone and Shale of the Atlantic Coastal Plain underlies Ambrose Channel. During the Pleistocene, when sea level was much lower, the Hudson River carved a deep channel into the Coastal Plain strata. Sand and Gravel that was carried into the area by longshore currents have since filled the channel. The total volume of material to be dredged from Ambrose Channel is estimated to be 8 million CY.

Table 3. Results of DREDGABL program for Ambrose Channel.

SOIL TYPE	CUTTERHEAD PIPELINE DREDGE	BUCKET HOPPER DREDGE	BACKHOE MECHANICAL DREDGE	CLAMSHELL MECHANICAL DREDGE	POWER SHOVEL MECHANICAL DREDGE
SW	Very good – easy cutting; fairly low pumping energy.	Good – easy digging; very little overflow of fines.	Good – easy digging; very little overflow of fines.	Fair digging – little fines overflow.	Good – easy digging; very little overflow of fines.
SP	Very good – easy cutting; fairly low pumping energy.	Good – easy digging; very little overflow of fines.	Good – easy digging; very little overflow of fines.	Easy to Hard digging – need heavy bucket; little fines overflow.	Good – easy digging; very little overflow of fines.
SM/SC	Very good – easy cutting; low pumping energy.	Poor to Good – easy to difficult digging; much overflow of fines.	Poor to Good – easy to difficult digging; much overflow of fines.	Easy to Hard digging – need heavy bucket, appreciable fines overflow.	Poor to Good – easy to difficult digging; much overflow of fines.

The DREDGABL database shows that all of the dredge types are suitable for Ambrose Channel (see Table 1). The best dredge for all three-soil types is the Cutterhead Pipeline dredge, with easy cutting and low pumping energy. Overflow of fines might be a problem in areas comprised of SM/SC, sand with silt and/or clay. The most commonly used dredges used in the harbor are clamshell and backhoes. For Ambrose channel, a backhoe dredge may give the best results. In the past a hopper dredge was used to dredge the channel, this dredge type would perform well in areas containing few fines.

Anchorage Channel

Anchorage Channel (Figure 5) is the primary channel in the Upper Bay. The channel is predominantly made up of Holocene material with a small percentage of Pleistocene Silt and Clay. Table 4 shows the volumes of rock and non-rock material found in Anchorage to –52' MLW with a 1.5ft over dig (table shows –53.5 feet MLW). The channel contains silt and clay (OH or MH) that is very soft-to-soft with medium to high plasticity and sand (SP or SM) that is fine to medium grained, sub angular, with medium compactness. Anchorage Channel is similar to Ambrose Channel in that no bedrock is anticipated. Deep borings in Anchorage Channel and the adjacent anchorages indicate that during the Pleistocene the Hudson River incised downward into the exposed bedrock more than 200 feet. Since the Pleistocene the channel has filled with fluvial sand and restricted marine (silt and clay) sediments. Pleistocene sediments are limited to the edge of the channel.

Table 4. Volumes of Rock and Non-Rock Material in Anchorage Channel.

	Total Rock Volume	Volume Pleistocene Silt and Clay	Volume Pleistocene Sand and Gravel	Volume Holocene Sand	Volume Holocene Silt	New Channel Upland
AN-1				622,710	1,060,290	205,439
AN-2				1,020,460	1,737,540	550,312

Table 5. Results of DREDGABL program for Anchorage Channel.

SOIL TYPE	CUTTERHEAD PIPELINE DREDGE	BUCKET HOPPER DREDGE	BACKHOE MECHANICAL DREDGE	CLAMSHELL MECHANICAL DREDGE	POWER SHOVEL MECHANICAL DREDGE
MH	Well suited – low cutting energy; easy pumping.	Easy digging – little suction; fines may wash out.	Easy digging – little suction, fines may wash out.	Easy digging – fines may wash out.	Easy digging – little suction, fines may wash out.
SP	Very good – easy cutting; fairly low pumping energy.	Good – easy digging; very little overflow of fines.	Good – easy digging; very little overflow of fines.	Easy to Hard digging – need heavy bucket; little fines overflow.	Good – easy digging; very little overflow of fines.
SM	Very good – easy cutting; low pumping energy.	Poor – difficult digging; much overflow of fines.	Poor – difficult digging; much overflow of fines.	Hard digging – need heavy bucket; much fines overflow.	Poor – difficult digging; much overflow of fines.

The output of the DREDGABL database (Table 5) indicates that all dredge types are suitable for MH, inorganic Silt, removal, although fines may wash out causing turbidity issues. All of the dredges are good for dredging the clean Sand (SP) with some hard digging indicated for the Clamshell dredge. For the Sand with Silt (SM) the best dredge is the Cutterhead dredge with poor to hard digging using the other dredge types. There may be a problem with overflow of fines. An Environmental (Clamshell) bucket will be required to reduce wash out of sediments that are unsuitable for disposal at the HARS. Either a backhoe or clamshell dredge may be used in Anchorage with easy to good digging.

Bay Ridge Channel

Bay Ridge Channel (Figure 6) is adjacent to the South Brooklyn waterfront; it runs from the Narrows to Bay Ridge Avenue. The types of material found in the channel are Holocene aged Silt and Clay and Sand and Gravel. Table 6 breaks down the volumes of the materials from the existing channel elevation to –53.5 feet MLW. Black silt and clay overlying silty sand (SM) that is fine to medium grained, medium dense to dense is found in the northern section of the channel. Stiff, Pleistocene silt and clay are located in the northern and eastern portions of the channel. The southern section of the channel is comprised of fine to medium grain, medium dense sand with pockets of silty sands. Bay Ridge Channel is situated along the edge of the Hudson River Channel escarpment and Pleistocene sediments occur immediately to the east of the channel. Some dense Pleistocene material may be encountered. Additional subsurface data should be acquired to better define the location and extent of the Pleistocene sediments.

Table 6. Volumes of Rock and Non-Rock Material in Bay Ridge Channel.

	Total Rock Volume	Volume Pleistocene Silt and Clay	Volume Pleistocene Sand and Gravel	Volume Holocene Sand	Volume Holocene Silt	New Channel Upland
BR-1		240,650		2,021,460	2,550,890	1,853,000

Table 7. Results of DREDGABL program for Bay Ridge Channel.

SOIL TYPE	CUTTERHEAD PIPELINE DREDGE	BUCKET HOPPER DREDGE	BACKHOE MECHANICAL DREDGE	CLAMSHELL MECHANICAL DREDGE	POWER SHOVEL MECHANICAL DREDGE
SM	Very good – easy cutting; low pumping energy.	Poor – difficult digging; much overflow of fines.	Poor – difficult digging; much overflow of fines.	Hard digging – need heavy bucket; much fines overflow.	Poor – difficult digging; much overflow of fines.
MH	Well suited – low cutting energy; easy pumping.	Easy digging – little suction; fines may wash out.	Easy digging – little suction, fines may wash out.	Easy digging – fines may wash out.	Easy digging – little suction, fines may wash out.
CH	Well suited – low cutting energy; easy pumping.	Easy digging – high suction, medium overflow losses.	Easy digging – high suction.	Easy digging	Easy digging – high suction.

The results from the DREDGABL database are outlined in Table 7. The best dredge for the silty Sand is the Cutterhead Pipeline. Any of the dredges listed on the table are suitable for dredging the Silts and Clays. An Environmental (Clamshell) bucket will probably be used to reduce wash out. For dredging in Bay Ridge, backhoe and clamshell dredges should have easy digging in the clays, however they may encounter problems digging in the Silty Sand.

Port Jersey Channel

Port Jersey Channel (Figure 7) is located in Bayonne, New Jersey between the Military Ocean Terminal to the south and the Global Marine Terminal and the Northeast Automobile Terminal to the north along the western edge of the Hudson River escarpment. Table 8 shows the volumes of non-rock material for Port Jersey from the mud line to –53.5 feet MLW. The western interior portion of the channel is comprised primarily of dense to very dense, fine to medium grained, Pleistocene red-brown Silty Sand (SM) with lenses of stiff Silt and Clay and occasional Gravel. The eastern portion is comprised of Holocene sediments about half Silt and Clay (OH and MH) and half Sand (SP).

Table 8. Volumes of Rock and Non-Rock Material in Port Jersey Channel.

	Total Rock Volume	Volume Pleistocene Silt and Clay	Volume Pleistocene Sand and Gravel	Volume Holocene Sand	Volume Holocene Silt	New Channel Upland
PJ-1	5,500	622,800	731,200		214,000	111,000
PJ-2				1,022,000	2,052,000	724,000
PJ-2A				615,000	879,000	555,000
PJ-2B				407,000	1,173,000	169,000

Table 9. Results of DREDGABL program for Port Jersey Channel.

SOIL TYPE	CUTTERHEAD PIPELINE DREDGE	BUCKET HOPPER DREDGE	BACKHOE MECHANICAL DREDGE	CLAMSHELL MECHANICAL DREDGE	POWER SHOVEL MECHANICAL DREDGE
SM	Very good – easy cutting; low pumping energy.	Poor – difficult digging; much overflow of fines.	Poor – difficult digging; much overflow of fines.	Hard digging – need heavy bucket; much fines overflow.	Poor – difficult digging; much overflow of fines.
MH	Well suited – low cutting energy; easy pumping.	Easy digging – little suction; fines may wash out.	Easy digging – little suction, fines may wash out.	Easy digging – fines may wash out.	Easy digging – little suction, fines may wash out.
OH	Well suited -- low cutting energy; easy pumping.	Easy digging -- little suction; high overflow losses.	Easy digging -- little suction; fines may wash out.	Easy digging -- fines may wash out.	Easy digging -- little suction; fines may wash out.
SP	Very good – easy cutting; fairly low pumping energy.	Good – easy digging; very little overflow of fines.	Good – easy digging; very little overflow of fines.	Easy to Hard digging – need heavy bucket; little fines overflow.	Good – easy digging; very little overflow of fines.

The results from the DREDGABL database are shown in Table 9. The best dredge type to use when dredging the Sand with Silt (SM) is the Cutterhead dredge. All of the dredges are suitable to dredge the Silt and Clay (MH and OH), although fines may wash out. An Environmental (Clamshell) bucket will probably be used to reduce wash out. The program shows that all of the dredge types are suitable to dredging the clean Sand (SP) with some hard digging indicated in the use of the Clamshell dredge.

Kill Van Kull Channel

Kill Van Kull Channel (Figure 8) is located north of Staten Island, New York and south of Bayonne, New Jersey. The channel connects Upper New York Harbor with Arthur Kill Channel and the Newark Bay Complex. Table 10 shows the volumes of rock and non-rock material in the channel from the existing channel elevation to –53.5 feet MLW. Pleistocene sand and gravel and rock are the main material types in the channel. Metamorphic and igneous rocks of serpentine, gneiss, and schist are exposed along the channel floor in the eastern part of the channel. Diabase is exposed along the channel floor in western Kill Van Kull. The Kills are comprised primarily of glacial till overlying bedrock. The channel is comprised of serpentine bedrock, Pleistocene red-brown, fine to medium grain, dense to very dense Sand (SP), diabase bedrock, and in the eastern portion of the channel Holocene silt and sand.

Table 10. Volumes of Rock and Non-Rock Material in Kill Van Kull Channel.

	Total Rock Volume	Volume Pleistocene Silt and Clay	Volume Pleistocene Sand and Gravel	Volume Holocene Sand	Volume Holocene Silt	New Channel Upland
KVK-1	783,000	126,323	453,926	276,226	589,525	84,000
KVK-2	771,000	72,021	1,360,979			

Table 11. Results of DREDGABL program for Kill Van Kull Channel.

SOIL TYPE	CUTTERHEAD PIPELINE DREDGE	BUCKET HOPPER DREDGE	BACKHOE MECHANICAL DREDGE	CLAMSHELL MECHANICAL DREDGE	POWER SHOVEL MECHANICAL DREDGE
SP	Very good – easy cutting; fairly low pumping energy.	Good – easy digging; very little overflow of fines.	Good – easy digging; very little overflow of fines.	Easy to Hard digging – need heavy bucket; little fines overflow.	Good – easy digging; very little overflow of fines.
SM/GM	Good – moderately hard cutting, needs high pumping energy.	Good – moderately difficult digging; large overflow.	Good – moderately difficult digging, large overflow.	Good – moderately difficult digging, large overflow.	Good – moderately hard cutting, large overflow.
ML	Well suited – low cutting energy, easy pumping.	Easy digging – little suction, high overflow losses.	Easy digging – little suction, fines way wash out.	Fairly hard digging – fines may wash out.	Easy digging – little suction, fines may wash out.

The results of entering soil data for Kill Van Kull Channel into the DREDGABL database are shown in Table 11. The Clamshell dredge is the best dredge to use when removing clean Sand (SP) with some hard digging indicated. All of the dredges are good for the Sand and Gravel with Silt (SM/GM), however overflow of fines might be a problem in all cases. All of the dredges, except for the Clamshell dredge, are appropriate for the removal of the Silt (ML); fines may wash out. Dredging records (Table 1) show that clamshells and backhoes have good success in dredging material in Kill Van Kull. Based on isopach mapping (Figure 3) non-HARS suitable black silt will accumulate along the western portion of Kill Van Kull in the Bergen Point to Shooters Island area. An Environmental Clamshell bucket will be required to remove the black silt.

Newark Bay Channel

Newark Bay (Figure 9) is located north of the junction of Kill Van Kull and Arthur Kill Channels and extends northward to the New Jersey Turnpike Extension Bridge in Jersey City, New Jersey. Table 12 shows the volumes of rock and non-rock material in the channel from the existing channel elevation to –53.5 feet MLW. Diabase is found in western Newark Bay. Sedimentary rocks (shale and sandstone) are present. The volume of material shown in the Holocene Black Silt category is based on the existing schedule and estimated sedimentation rates. The channel is comprised of dense to very dense, fine to medium grain, red-brown Pleistocene silty sand (SM) and Pleistocene red-brown silt and clay (ML or CL) that are stiff to very stiff. There are pockets of rock in the channel.

Table 12. Volumes of Rock and Non-Rock Material in Newark Bay Channel.

	Total Rock Volume	Volume Pleistocene Silt and Clay	Volume Pleistocene Sand and Gravel	Volume Holocene Sand	Volume Holocene Silt	New Channel Upland
NB-1	54,000	2,024,724	38,276			
NB-2	117,000	1,381,800	592,200		292,000	106,000

Table 13. Results of DREDGABL program for Newark Bay Channel.

SOIL TYPE	CUTTERHEAD PIPELINE DREDGE	BUCKET HOPPER DREDGE	BACKHOE MECHANICAL DREDGE	CLAMSHELL MECHANICAL DREDGE	POWER SHOVEL MECHANICAL DREDGE
SM	Very good – easy cutting; low pumping energy.	Poor – difficult digging; much overflow of fines.	Poor – difficult digging; much overflow of fines.	Hard digging – need heavy bucket; much fines overflow.	Poor – difficult digging; much overflow of fines.
ML	Well suited – low cutting energy, easy pumping.	Easy digging – little suction, high overflow losses.	Easy digging – little suction, fines way wash out.	Fairly hard digging – fines may wash out.	Easy digging – little suction, fines may wash out.
CL	Well suited – medium cutting energy, easy pumping.	Fair digging – medium suction, medium overflow losses.	Fair digging – medium suction.	Fairly hard digging.	Fair digging – medium suction.

Dredging evaluation from the DREDGABL program is shown in Table 13. The best dredge to use in the removal of the Sand with Silt (SM) is the Cutterhead Pipeline dredge; the other dredges have poor and hard digging properties with much overflow of fines. The Cutterhead is also the best dredge for the removal of the Clay (CL) with fairly hard to fair digging indicated for the other dredge types. All of the dredges except for the Clamshell dredge are well suited with easy digging for the dredging of the Silt (ML). Based on the black silt isopach map (Figure 3) significant volumes of black silt will accumulate in Newark Bay Channel. An Environmental Clamshell bucket will be required to remove the non-HARS suitable material.

Elizabeth Channel

Elizabeth Channel (Figure 10) is located on the western side of Newark Bay in Elizabeth, New Jersey between the Elizabeth Port Authority Marine Terminal and Port Newark. Table 14 shows the volumes of rock and non-rock materials in the channel from the existing elevation to –53.5 feet MLW. Sedimentary rocks (shale and sandstone) are found in Elizabeth Channel. The channel is composed of red-brown Pleistocene Silt and Clay (CL-ML) that are stiff to very stiff. Bedrock is located along the western edge of the channel.

Table 14. Volumes of Rock and Non-Rock Material in Elizabeth Channel.

	Total Rock Volume	Volume Pleistocene Silt and Clay	Volume Pleistocene Sand and Gravel	Volume Holocene Sand	Volume Holocene Silt	New Channel Upland
E-1	28,000	879,640	18,360			

Table 15. Results of DREDGABL program for Elizabeth Channel.

SOIL TYPE	CUTTERHEAD PIPELINE DREDGE	BUCKET HOPPER DREDGE	BACKHOE MECHANICAL DREDGE	CLAMSHELL MECHANICAL DREDGE	POWER SHOVEL MECHANICAL DREDGE
CL-ML	Well suited – medium cutting energy, easy pumping.	Medium excavation – no suction, medium overflow losses.	Medium excavation – no suction, fines may wash out.	Hard digging – need heavy grab bucket.	Medium excavation – no suction, fines may wash out.
GM	Good – moderately hard cutting, needs high pumping energy.	Good – moderately difficult digging; large overflow.	Good – moderately difficult digging, large overflow.	Good – moderately difficult digging, large overflow.	Good – moderately hard cutting, large overflow.

The results from the DREDGABL database are shown in Table 15. The best dredge for the removal of the Silt and Clay (CL-ML) is the Cutterhead Pipeline dredge, with medium to hard digging indicated for the other dredge types. All of the dredge types are good for removing the Gravel with Silt (GM). Based on the black silt isopach map (Figure 3) significant volumes of black silt will accumulate in Elizabeth Channel. An Environmental Clamshell bucket will be required to remove the non-HARS suitable material.

South Elizabeth Channel

The South Elizabeth Channel (Figure 11) is located on the western side of Newark Bay in Elizabeth, New Jersey south of the Elizabeth Port Authority Marine Terminal. Sedimentary rocks (Shale and Sandstone) are found in South Elizabeth Channel. The channel is comprised of red-brown, Pleistocene, stiff to very stiff Silt and Clay (ML and CL). Bedrock is located on the eastern edge of the channel. The channel also has a layer of contaminated black silt overlying the Pleistocene sediments.

Table 16. Results of DREDGABL program for South Elizabeth Channel.

SOIL TYPE	CUTTERHEAD PIPELINE DREDGE	BUCKET HOPPER DREDGE	BACKHOE MECHANICAL DREDGE	CLAMSHELL MECHANICAL DREDGE	POWER SHOVEL MECHANICAL DREDGE
ML	Well suited – low cutting energy, easy pumping.	Easy digging – little suction, high overflow losses.	Easy digging – little suction, fines way wash out.	Fairly hard digging – fines may wash out.	Easy digging – little suction, fines may wash out.
CL	Well suited – medium cutting energy, easy pumping.	Fair digging – medium suction, medium overflow losses.	Fair digging – medium suction.	Fairly hard digging.	Fair digging – medium suction.
GM	Good – moderately hard cutting, needs high pumping energy.	Good – moderately difficult digging; large overflow.	Good – moderately difficult digging, large overflow.	Good – moderately difficult digging, large overflow.	Good – moderately hard cutting, large overflow.

DREDGABL results for South Elizabeth are shown in Table 16. All of the dredge types, except the Clamshell dredge are well suited with easy digging for the removal of the Silt (ML), although in all cases fines may wash out. The best dredge type for dredging the Clay (CL) is the Cutterhead Pipeline dredge with fairly hard to fair digging indicated for the other dredge types. All of the dredges are good for the removal of Gravel with Silt (GM) with a large overflow of fines. Based on black silt isopach map (Figure 3) and previous deposition patterns significant amounts of black silt will accumulate in South Elizabeth channel. An Environmental Clamshell bucket should be used to remove non-HARs suitable material from the channel.

Arthur Kill Channel

Arthur Kill Channel (Figure 12) is located west of the Kill Van Kull between New York and New Jersey extending south to Gulfport, Staten Island, New York. Sedimentary rocks (Shale and Sandstone) are exposed along the channel floor along most of Arthur Kill Channel. The Kills are comprised primarily of glacial till overlying bedrock. Table 17 shows the volumes of rock and non-rock materials in the channel. The channel is comprised of Brunswick Formation bedrock and very soft to soft Holocene silt and clay overlying Pleistocene dense to very dense, fine to medium grained, red-brown silty sand with gravel.

Table 17. Volumes of Rock and Non-Rock Material in Arthur Kill Channel.

	Total Rock Volume	Volume Pleistocene Silt and Clay	Volume Pleistocene Sand and Gravel	Volume Holocene Sand	Volume Holocene Silt	New Channel Upland
AK-1	409,000	260,562	43,438			
AK-2	332,000	231,066	157,934			
AK-3	1,405,000	190,575	241,425			

Table 18. Results of DREDGABL program for Arthur Kill Channel.

SOIL TYPE	CUTTERHEAD PIPELINE DREDGE	BUCKET HOPPER DREDGE	BACKHOE MECHANICAL DREDGE	CLAMSHELL MECHANICAL DREDGE	POWER SHOVEL MECHANICAL DREDGE
ML	Well suited – low cutting energy, easy pumping.	Easy digging – little suction, high overflow losses.	Easy digging – little suction, fines way wash out.	Fairly hard digging – fines may wash out.	Easy digging – little suction, fines may wash out.
CL	Well suited – medium cutting energy, easy pumping.	Fair digging – medium suction, medium overflow losses.	Fair digging – medium suction.	Fairly hard digging.	Fair digging – medium suction.
SM	Very good – easy cutting; low pumping energy.	Poor – difficult digging; much overflow of fines.	Poor – difficult digging; much overflow of fines.	Hard digging – need heavy bucket; much fines overflow.	Poor – difficult digging; much overflow of fines.

Results from the DREDGABL database data for Arthur Kill are shown in Table 18. The best dredge to use in the removal of the Sand with Silt (SM) is the Cutterhead Pipeline dredge; the other dredges have poor and hard digging properties with much overflow of fines. The Cutterhead is also the best dredge for the removal of the Clay (CL) with fairly hard to fair digging indicated for the other dredge types. All of the dredges except for the Clamshell dredge are well suited with easy digging for the dredging of the Silt (ML). Previous black silt deposition patterns and the black silt isopach map (Figure 3) indicate that there will be a significant accumulation of black silt in Arthur Kill Channel. An Environmental Clamshell bucket should be used to remove the non-HARS suitable material from the channel.

EVALUATION OF EXISTING TECHNOLOGY & INTERIM PROJECTS

Very accurate mapping is required to determine the volumes of rock, non-rock material suitable for the HARS and upland material. The maps necessary to determine these quantities include top of rock, top of Pleistocene and black silt thickness (isopach maps). A relatively large number of borings have been acquired over the years for various projects and the types of material and where they occur is relatively well defined. However, a large percentage of the borings were acquired in preparation for the forty-foot (-40' MLW) and forty-five foot (-45' MLW) channels and they did not go deep enough to describe the material that will be dredged in the fifty-foot project. In order to map the soil and rock layers to the degree of accuracy desired for the project a relatively large number of borings and vibracores would be required. In order to reduce the number of new borings and vibracores, geophysical methods are being considered and evaluated.

SIDE SCAN SONAR

Black Silt Accumulations

Determining the location and thickness of the black silt covering a large portion of the inner harbor will be a fundamental objective during construction of the fifty-foot channel. The black silt is unsuitable for the HARS disposal, so it is very costly to dispose of; with an estimated cost of $40 to $60 more per cubic yard than HARS suitable material so it is a significant component of the project cost.

The principle of the side-scan sonar is similar to multibeam bathymetry. Side-scan and multibeam send out ultrasonic (100 to 500 kHz) signals at various angles of incidence and listen for backscattered reflections from the channel floor. Multibeam measures the two-way travel-time (or phase shift) of the signal to the channel floor and back. The travel time is used to calculate the channel bathymetry assigned to a given location on the floor. The amplitude of the ultrasound is ignored in multibeam but is the basis of side-scan. The side-scan measures the amplitude of the ultrasound and assigns a brightness value to a given location on the channel floor.

The backscatter amplitude is sensitive the bottom material and slope of the channel floor. Because the angle of incidence is equal to the angle of reflection a steep slope facing the signal source will produce a loud backscatter and a bright pixel. A slope facing away from the signal source will produce a low backscatter and a dark pixel. The backscatter amplitude can distinguish the material on the channel floor such as mud or rock. If the slope is constant, the reflectivity depends solely on the fractional difference in the impedance (material density times the compressional velocity) between the bay water and the bottom material. Diabase will produce a loud backscatter and a bright pixel. Black silt will produce a low backscatter and a dark pixel.

Side-scan mosaics are produced by: (1) acquiring several side-scan images in strips, (2) normalizing intensities, and (3) placing the strips onto a map. High quality mosaics in Kill Van Kull, Newark Bay and Arthur Kill were obtained by acquiring the data at an unusually high density and overlap. Intensities were calibrated and the data processed so that the mosaics are lit only from one direction. That is, all of the shadows stretch in the same direction. This procedure produces images that are more intuitive and easier to interpret than state-of-the-art bi-directional side-scan mosaics.

Data were collected in several channels (Newark Bay, Kill Van Kull and Arthur Kill) where there are known shoals in order to evaluate side scan sonar as a method of delineating black silt accumulations. The data was collected, processed and presented by Earthworks LLC. Figures 13 through 16 are side scan mosaics of KVK (Newark Bay) Contract Area 6, KVK (Southern Newark Bay) Contract Areas 5 and 8, Kill Van Kull Contract 4B and, a portion of Arthur Kill. The data clearly defines the location or footprint of the black silt in these areas. The data was so definitive that it was used to delineate the location of material (black silt) that is unsuitable for the HARS on several Phase II contract drawings. The contractor was instructed to use an environmental bucket in these areas. Although side scan sonar mosaics can be used to determine the relative degree of shoaling it does not provide a thickness. Methods of determining the thickness of the silt will be discussed in a later section.

Side Slope Analysis

During the coarse of reviewing the side scan mosaics several distinct anomalies were identified along the side slopes. The anomalies in South Elizabeth and Newark Bay were very well defined and clearly resemble slump features (Figure 17 through 19). As part of an effort to evaluate the anomalies as well as the side slopes in general, an exploration program was designed. In the first phase of the program side scan data was acquired along the side slopes throughout the KVK, Newark Bay and Arthur Kill. The data was reviewed and a number of anomalies were identified and prioritized. In the second phase of the investigation sub-bottom profiles and standard penetration test borings were acquired to define the stratigraphy near the anomalies. Sub-bottom profile lines were positioned at right angles to the anomalies and borings were located as close to the lines as possible. Data was collected both in the flats and along the toe of the channel. The profiles and borings were used to construct detailed geologic cross-sections at each of the

side slope anomalies. In the third phase of the investigation slope stability analysis was performed. Typical sub-bottom profiles, cross-sections and detailed slope stability analysis are presented in later sections.

In addition to providing a means of evaluating side slopes the mosaics revealed a number of other features along the channel floor including debris, pilings, rock outcrops, and pipe trenches. Figure 20 shows back-filled pipeline trenches in southern Newark Bay as well as possible bridge footing. The data can be used in association with bathymetry to identify potential obstructions on the channel floor.

SUB-BOTTOM PROFILE AND SEISMIC REFLECTION

Sound or compression waves generated by a source on land or in water can be used to map the stratigraphy and structure of the earth's crust. Waves generated at a source travel downward into the earth's crust are reflected off of interfaces and then travel back to the surface where they are recorded at receivers or geophones. The difference in the time between when the wave is generated and when it returns is recorded. The seismic event that is recorded at the receiver has a wavelet character that (ideally) can be correlated from one location another. The wavelet character depends on the density contrast between the upper and lower layer. For instance a strong reflection would be expected in a case where water overlies bedrock. A weaker reflector would occur when water overlies organic silt. Based on the average velocity of the material(s) that the wave has passed through its possible to determine the approximate depth of the interface. When the data is gathered and correlated at a number of locations it is possible to construct a map about a certain seismic event. That event corresponds to a geologic interface such as the top of bedrock.

Seismic data has been used extensively in the petroleum industry for more than forty-five years to map stratigraphy and hydrocarbon accumulations at depths of up to thirty thousand feet. The data is commonly gathered in marine environments at water depths of greater than one thousand feet. Considering the "sophisticated" state of the geophysical technology it would seem that mapping near surface bedrock in shallow water would not be a problem. However, there are many factors complicating data collection and interpretation in an area such as New York Harbor. The harbor is very noisy due to ship traffic, much of the channel floor is covered with a low velocity silt layer that causes a loss of signal, and since the water depth is shallow water bottom multiples occur in the interval to be interpreted. These factors and others cause challenges in designing a program that collects the most useful data.

A test project was conducted in southern Newark Bay to evaluate the how well geophysical data such as sub-bottom profiling and seismic reflection can image the subsurface (Figure 22). The primary objectives were to map the top of bedrock and thickness of the black silt. Southern Newark Bay was selected, because the interval to be dredged was known to include bedrock, Pleistocene sediments and black silt. The

contractor (Earthworks LLD) was given the task of designing a program that would focus on the near surface interval to a depth of seventy feet below mean low water (-70' MLW). The project consisted of five long lines (profiles) and ten (10) cross lines (cross-sections). Representative borings were provided so that the seismic events could be tied to the stratigraphy.

In order to evaluate the quality or strength of the data (to an untrained observer) the contractor was instructed to provide a copy of the raw data as well as a processed and interpreted profile. An example of the raw data as well as the processed and interpreted data is shown on Figure 21.

Top of Bedrock and Stratigraphy

Earthworks discovered that the low frequency pulses (swept frequencies from 500 Hz to 5 kHz) were best suited for defining the top-of-rock, because the attenuation of the sound wave is greater at higher frequencies, the low frequency pulses penetrate the bottom better than higher frequency pulses. The towfish used was an Edgetech SB512. The topside acquisition computer used was an Edgetech X-Star II controller. In order to maximize the signal-to-noise ratio, the pulse rate was set to 8 pulses per second, and the surveys were conducted at the minimum boat speed, varying from 1-3 knots depending on the tide. After processing, Earthworks determined that the depth of penetration exceeded 30ft in the Pleistocene sediments to an elevation of roughly -70 ft. However, because the target depth was –60ft, the towfish was towed at a depth of 12 to 15ft. The surface multiple, or echo from the bay surface, begins at a two-way travel time equivalent to -60ft. The multiple is a concern because it obscures the interpretation below -60ft; so, the -60ft elevation is a good estimate of the maximum depth for good interpretation of the sub-bottom seismic.

In order to determine and extract the location of the interfaces (i.e., horizons), seismic data had to be processed, filtered, interpreted and digitized before applying the velocity model and calculating thickness and top-of-rock. This step is by far the most time-consuming procedure in the chain. The existing algorithms supplied by equipment and software manufactures were inadequate, and many new algorithms and utilities were developed by Earthworks to meet the requirements of the project.

Figure 22 shows the Top of Rock Structure Map constructed by Earthworks from the interpreted sub-bottom profiles and the boring logs provided. In order to evaluate the degree to which the map reflects the actual top of rock a number of borings that were not provided were compared to the predicted top of rock (Table 19). Only those borings that are located less than fifty-feet from the lines were used in the comparison. In some cases the boring did not go deep enough to see the top of rock so the difference is included as a minimum distance. The differences are shown as + or – depending on whether the estimated top of rock was too high or to low. The average difference of the Δ Top of Rock is –1.03 feet. This number is relatively small and is probably due to the offset of

positive and negative numbers. The absolute value of the Δ Top of Rock may be a more reliable estimate of the accuracy of the tool. The average difference of the absolute values is 7.3 feet. Although the average difference in absolute values is considered large for our purposes it is thought to reflect a relatively small number of areas where the top of rock was misinterpreted due to a strong reflector at the base of the black silt. In general the overall trends (high and low areas) do reflect the top of rock but not to the degree of accuracy that is required.

Table 19. Comparison Top of Rock and Seismically Predicted Top of Rock

Boring	Top of Rock Log	ProjectedTop of Rock	Δ Top of Rock	Abs Value of ΔTOR	Distance from Line
DH-819	52.0	59.0	7.0	7.0	16'S of 11
SE-99-8-4	53.9	56.0	2.1	2.1	31'S of 11
SE 01-02	**63+**	50.5	**-12.5**	**12.5**	31'S of 11
NB-99-8-4	57.1	63.5	6.4	6.4	0' from C
PA 2-426	50.8	58.0	7.2	7.2	39'E of D North
NBN-01-14	61.5	48.5	-13.0	13.0	16'N of 1
NBN-01-13	**58.9***	47.0	**-11.9**	**11.9**	0' from E; 16'N of 2
NB-99-8-5	52.0	62.5	10.5	10.5	47'E of A
DH-823	66.0	63.0	-3.0	3.0	31'S of 3
NBN-01-12	**61.6+**	58.5	**-3.1**	**3.1**	0' from D North; 55'S of 3
PA 2-490	63.5	55.0	-8.5	8.5	0' from B
PA 2-491	64.0	61.0	-3.0	3.0	47'S of 5; 117'W of A
PA 2-489	69.0	61.0	-8.0	8.0	31'N of 6; 94'S of P2
NBS-01-10	61.5	55.0	-6.5	6.5	31'E of A
DH-28	51.7	63.0	11.3	11.3	0' from P1
NBS 01-4	**60.4+**	42.5	**-17.9**	**17.9**	0' from 8; 47'E of A
NBS 01-5	**61+**	58.5	**-2.5**	**2.5**	16'W of B; 39'S of 8
KVK 3-10	45.5	47.0	1.5	1.5	47'E of D South; 39'N of 8
4B-12	**50+**	48.0	**-2.0**	**2.0**	0' from 10; 31'W of C
KVK 3-21	**50.2+**	50.0	**-0.2**	**0.2**	47'W of B; 94'N of 10
KVK 99-5-20	46.6	53.0	6.4	6.4	0' from 10
4B-4	50.0	45.5	-4.5	4.5	47'W of B
KVK 99-5-19	44.2	64.5	20.3	20.3	23'W of A
Average			-1.03	7.3	

As part of a subsequent investigation Earthworks was asked to collect sub-bottom and seismic reflection data in Port Jersey Channel. In addition to continuing to evaluate the applicability of using geophysical data to map stratigraphy and structure, Earthworks was tasked to see how accurately they could identify the location of the Passaic Valley Sewage Tunnel that underlies the channel. The Passaic Valley Sewage Tunnel is a twelve-foot (12') diameter concrete pipe that was constructed in the early 1920's. The tunnel was completed prior to construction of Port Jersey and the Military Ocean Terminal at Bayonne and could not be accurately located. The tunnel conveys a very large volume of treated effluent and its location and depth are an obvious concern. In order to verify that the tunnel is below the level of excavation and better define its alignment ten (10) sub-bottom lines were planned (Figure 22).

The results of the investigation were mixed in that no obvious anomaly was detected on the geophysical sections. Knowing that the sewage tunnel was in the immediate vicinity indirect evidence (diffractions) were used to define the location of the pipe. Diffractions are seismic events that generally originate from a point source and arc downward forming something that looks like an inverted half-moon or saucer. The crest or top of the arc is the approximate location of the structure or point source. Most of the lines had an obvious diffraction that was interpreted to be the top of the tunnel. When plotted in plan view the location diffractions did form a straight line adding confidence to the interpretation. Earthworks interpreted the top of the tunnel to traverse the channel at an elevation of sixty feet (60') to sixty-three feet (63') below mean low water.

Figure 23 shows an interpreted and un-interpreted sub-bottom profile that runs the length of the channel. All of the borings in Port Jersey were provided and were used in the interpreted section. It is apparent from the un-interpreted section that the data is very good along the western end of the channel. The Pleistocene silt and clay and Pleistocene sand and gravel can be readily discerned. The top of rock event is not as easily identified. The low frequency source that was used to map these deeper events does not detect the black silt as well as higher frequency data.

Figure 24 is a reflection profile of a portion of Arthur Kill. The upper panel identifies the top of rock event and dipping strata. The lower panel is an interpreted version of the profile showing the top of the black silt, base of the black silt and the top of rock. Any material between the base of the black silt and rock is generally considered to be Pleistocene. The top of rock event is not a strong, consistent event. The velocities of shale bedrock (2,500-3,500 m/s), weathered shale bedrock (~2,500 m/s) and Pleistocene sediments (1,800-2,500m/s) are so similar, that there is very little velocity contrast and as a result there is no discrete top of rock event that carries across the length of the profile. However, with the aid of boring logs to tie or identify the top of rock event, and using other factors such as the termination of the dipping reflectors, it is possible to approximate the top of rock along portions of the profile. The interpreted segments can be connected to yield near top of rock surface that can be used for mapping.

Based on the seismic data that has been collected to this point in the various projects described and illustrated in the previous sections it is possible to make the following general conclusions.

1. The top of rock seismic event is not a strong, consistent and continuous peak or trough that can be readily identified and mapped. The strength of the event and its continuity depends on a number of factors that vary from area to area such as velocity contrast and the presence or absence of the energy absorbing black silt. Interpreting the data is not straightforward and requires considerable time and effort by an experienced interpreter and even then can be misleading.

2. Sub-bottom reflection profiles can be a useful tool when used in conjunction with borings to identify and map the approximate top of rock. There are limitations as to the accuracy of the data and therefore to its applicability. The data should be used as a screening technique to identify areas where rock may be encountered and where to acquire additional borings.

Side Slope Stratigraphy

A number of anomalies were identified along the side slopes using side scan sonar. Several of the anomalies look remarkably like slump or side slope failures. In order to evaluate the anomalies and to facilitate slope stability analysis sub-bottom profiles were acquired and geological cross-sections were constructed.

Figure 25 shows the bathymetry, sub-bottom profile and geologic cross-section prepared for the side scan anomaly shown on Figure 17. The sub-bottom data was interpreted in order to construct the geologic cross-section. An un-interpreted version is presented so that the quality of the data and strength of the events can be evaluated. Borings were used to tie the stratigraphy to seismic events. As discussed previously, in shallow water sub-bottom data is complicated and to some degree obscured by multiples. The water bottom multiple in the channel portion of the profile occurs at about .030 seconds and at about .008 seconds outside the channel. The multiples are repeated at regular intervals. In the channel portion of the section the first multiple occurs below the interval of interest. However, in the shallow portion of the section the first, second and perhaps third water bottom multiples occur in the interval of interest. Although the multiples do present a problem there is stratigraphy and structure that can be discerned. There are no strong events that mark the contacts between one stratigraphic unit and another and it is necessary to interpret the data by gross character or interval. The Pleistocene silt and clay interval has relatively smooth texture whereas the underlying till or bedrock has a rough or chaotic texture. The black silt also has a smooth texture and could best be identified using higher frequency data. There is a well-defined surface feature and strata dipping into the slope. Although no apparent failure surface is defined it can be interpreted from the termination of strata dipping toward the slope. If the terminations are connected to form a surface then it intersects the mudline at the location of the surface anomaly. These characteristics are consistent with a rotated slump block.

Figure 26 shows the bathymetry, sub-bottom profile, and geologic cross-section prepared for the side scan anomaly shown on Figure 18. As noted on the previous figure the contacts between the stratigraphic units are not sharp or discrete. The stratigraphic intervals can be identified by gross characteristics with support from the borings. As on the previous section there is a surface expression associated with the anomaly as well as strata dipping into the slope. A failure surface could be interpreted by connecting the terminations. The inferred failure surface intersects the mudline at the location of the surface anomaly. These characteristics are consistent with a rotated slump block.

Figure 27 shows the bathymetry, sub-bottom profile, and geologic cross-section prepared for the side scan anomaly shown on Figure 19. As noted on the previous two figures there are no strong, continuous reflectors that can be identified as the top of the varved Silt and Clay, top of glacial till or top of bedrock. The interpretation is based on interval characteristics with help from the borings. In the shallow portion of the section the first, second and third water bottom multiple occur in the zone of interest. There is a surface feature associated with the anomaly. The strata adjacent to the slope are relatively flat and do not indicate rotation. In this case it appears that the block may have dropped without rotating.

Black Silt Thickness

The cost of disposing of the black silt is said to be about sixty dollars ($60.00) more than the cost of disposal of HARS suitable material. When the forty-foot channel was completed most of the black silt that covered KVK, Newark Bay and Arthur Kill had been removed and the underlying Pleistocene was exposed along the channel floor. This was predictable from the borings that were acquired prior to the forty-foot channel and was confirmed by borings that were acquired during and after the contracts were finished. Borings that were acquired as part of the various reports (LRR and Harbor Navigation) and for the forty-five foot contracts frequently encountered a surficial layer of black silt above the Pleistocene. In preparation of the plans for the forty-five foot channel these borings and vibracores were used and correlated to shoaling areas to construct a black silt isopach map (Figure 3). In order to illustrate the location and thickness of the black silt it is necessary to construct a map on the base of the black silt or top of the Pleistocene. Since most of the inner channels were dredged well into the Pleistocene the top of the Pleistocene was equivalent to the mudline immediately after dredging. The difference between the after dredging surveys from the forty-foot channel and pre-dredging surveys for the forty-five foot channel would have been the best way to estimate shoaling and the thickness of the black silt. Unfortunately, the after dredging surveys from the forty-foot contracts were not available. As a result it was necessary to estimate the after dredging depth in order to approximate the thickness of the black silt. As a consequence the location (footprint) and volume of black silt was not as accurate as desired. When the forty-five foot channel is completed there should be a complete database of after dredging surveys to use to determine shoaling and the thickness of the black silt. However, the thickness of the black silt indicated on logs acquired prior to dredging the forty-five foot channel will be not be valid because essentially all black silt will have been removed. In order to calibrate and verify the differences indicated between the after dredge and pre dredge surveys a relatively large number of borings and vibracores would be required. Other methods of determining the location and thickness of the black silt that could be used in association with the survey data such as geophysical methods or geoprobes are evaluated in the following sections.

The low frequency pulses most suitable for determining top of rock fail to resolve the black silt (recent contaminated sediment). The thickness of the black silt is less than one foot (1') over most of the channel floor in the area of interest and reaches several feet (5+) in a few areas. Earthworks conducted a second set of sub-bottom seismic profiles at higher frequencies along the tractlines shown on Figure 29. The higher frequency pulses, swept frequencies from 2 to 10 kHz, were required to determine the thickness of the black silt. Real-time measurement of the compressional velocity was determined from samples on the drill-rig. The purpose of the real-time procedure was to measure the velocity in the black silt and Pleistocene sediments under near in-situ conditions, while they were still saturated with bay water and before they dried out. The velocity of these materials is a basic parameter required if thickness is to be determined. The ultrasonic velocity system consists of a state-of-the-art Panametrics 5058 ultrasonic pulser-receiver, 500 kHz ultrasonic transducers, and a Hewlitt-Packard digital oscilloscope.

Newark Bay – Black Silt Thickness

Figure 28 is an example of the sub-bottom image of the black silt overlying hard material (glacial till or bedrock). The location of the data is along cross-line 8 shown on Figure 29 in southern Newark Bay. Although the reflector is weak it is clearly a discrete and mappable unit. The black silt was identified on each of the profiles and extrapolated between lines to construct the isopach (thickness) map shown on Figure 29. Representative borings were provided so that the geophysical characteristics of areas with and without black silt could be compared and the thickness tied to the data.

In order to evaluate the geophysical isopach map all of the available borings and vibracores within twenty-five feet (25') of the seismic lines were compared to the predicted thickness. Table 20 shows the predicted thickness, based on the nearest boring and the difference. The borings and vibracores generally indicate a thickness that is greater than that predicted by the seismic data. The average difference is approximately three-fourths of a foot (.75'). The average of the absolute values is just less than a foot (.92'). It should be noted that the seismic data accurately reflect trends. Areas where the black silt is predicted by the seismic data to be thick and those where the silt was interpreted to be thin compare very well with the boring and vibracore data.

Table 20. Comparison of Seismically Predicted Black Silt thickness to nearby borings in Newark Bay.

Boring	Dist. from Line	Black silt Thickness	Predicted Silt Thickness	Δ Silt Thickness	Abs Val of ΔThickness
C8-R1-87	0' from 11	4.6	1.0	-3.6	3.6
C8-R1-88	13'S of 11	3.0	4.0	1.0	1.0
DH-820	7'E of G; 54'S of 11	1.2	0.5	-0.7	0.7
C8-R1-92	27'S of 11	0.8	0.8	0.0	0.0
C8-R3-97	0' from E; 27'S of 2	2.0	1.0	-1.0	1.0
NBN-01-13	20'E of E; 40'S of 2	2.5	1.2	-1.3	1.3
NBN-01-17	0' from E	2.9	1.4	-1.5	1.5
C8-R2-02	27'E of D North	0.1	0.1	0.0	0.0
NBN-01-12	13'W of D North	2.0	1.2	-0.8	0.8
4B-20	27'W of A	0.5	0.8	0.3	0.3
NBS-01-10	0' from A	1.5	1.1	-0.4	0.4
4B-19	0' from 6; 54'E of A	1.2	1.0	-0.2	0.2
C8-R3-108	13'E of A	3.5	1.8	-1.7	1.7
Average		1.98	1.22	-.76	.92

Port Jersey Channel (Contract 1) – Black Silt Thickness

In addition to collecting geophysical data to identify and locate the Passaic Valley Sewage Tunnel, data was also gathered with the secondary objective of determining the thickness of the black silt. Representative seismic and sub-bottom data is illustrated in Figure 30. Both interpreted and un-interpreted data are provided so the quality of the events can be determined. Expanded or blown-up segments are provided to illustrate the wavelet characteristics of the upper and lower contacts of the black silt. Both the seismic and sub-bottom data show that the polarity of the channel floor interface reverses when the black silt is thin or absent. Figure 31 shows the location of the lines where data was gathered and thickness contours. The thickness of the black silt was determined on each line and interpolated between lines to construct an isopach or thickness map. The map indicates that the black silt is generally thin (less than a foot thick) along the southern side of the channel and thickest (up to 2.5') in the shallow water north of the channel. These trends are consistent with the subsurface data, but the predicted thickness is not as thick as the borings indicate.

Arthur Kill – Black Silt Thickness

Arthur Kill was dredged to its current depth prior to 1975, because most if not all of the black silt that covers the channel floor was deposited within the last forty years it is highly probable that it is all contaminated. The low velocity black silt directly overlies dense Pleistocene sediments or bedrock there is a strong velocity contrast that should be well defined seismically. Figure 32 is a representative high frequency, sub-bottom profile (cross-section) of Arthur Kill. The data clearly shows a layer of black silt along the channel floor and perched on the top of the side slope. A number of gravity samples were taken to calibrate the thickness.

In order more accurately quantify the black silt in Arthur Kill Contract 2-3 approximately sixty, gravity cores, vibracores and geoprobes were collected. This data was used in conjunction with existing borings and bathymetric data to construct an isopach (thickness) map of the black silt in Arthur Kill. The thickness indicated from isopach mapping was compared to the seismically predicted thickness. It is clear that the thickness trends (thicks and thins) agree very well. However, there is a consistent tendency for the seismically predicted thickness to be less that observed in borings, cores and probes.

BLACK SILT – CONTAMINATED INTERVAL

Port Jersey Contract 2B – Black Silt Thickness

In the outer portion of Port Jersey (Contract Area 2B) the black silt is up to twenty feet (20') thick. Most of the silt interval was deposited well before the environment was contaminated; the contaminated interval typically contains hydrocarbons. Because the presence of gas in sediments dramatically reduces velocity it is possible that the hydrocarbon-bearing interval (contaminated sediments) can be identified using geophysical data. Figure 33 shows two high frequency, chirp sonar lines that were acquired in Contract Area 2B that will be dredged in an upcoming contract. A clearly defined low velocity layer is present on both lines. The thickness of the low velocity layer is relatively uniform in the channel. In the flats outside of the channel the low velocity layer is relatively thick on the east side near the Hudson River and thins or even pinches-out in shallow flats.

In order to identify the contaminated interval chemical testing was conducted from three vibracores that were positioned directly on Line PJ-06. Samples were collected at one-foot depth increments and were tested for a number of common contaminants including total petroleum hydrocarbons and volatile organic compounds. The contaminated (hydrocarbon) interval as identified by chemical testing was compared to the low velocity layer to see if it can be predicted from geophysical data. The chemical data located along Line PJ–06 (Figure 33) was collected at three locations. The eastern test site, located in the low velocity layer, contained elevated levels (50 to 90 ppm) of hydrocarbons in the

upper six to eight feet (6-8'). The other chemical test sites, located in the shallow flats where no low velocity layer is apparent, showed a markedly lower (5-23 ppm) level of hydrocarbons. This trend appears to confirm that the seismic is responding to the presence of hydrocarbons. The seismically predicted thickness follows the same trend as the chemical data but is consistently thinner.

South Elizabeth Channel – Black Silt Contaminated Interval

As part of the fifty-foot project the South Elizabeth Channel will be widened approximately five hundred feet (500'). The black silt interval in the flats outside the channel is up to fifteen-feet (15') thick. Like the thick layer of gray-black silt at Port Jersey it is very likely that only the upper part of the interval is contaminated. Geophysical data was collected to see if the hydrocarbon interval could be identified. Figure 34 is a high frequency (Chirp Sonar), sub-bottom profile in the project area just south of the existing channel. In order to identify the contaminated (hydrocarbon-bearing) interval chemical testing was conducted from two vibracores positioned directly on the seismic lines. Samples were collected at one-foot depth increments and were tested for a number of common contaminants including total petroleum hydrocarbons and volatile organic compounds. The contaminated (hydrocarbon) interval was compared to the hydrocarbon-bearing interval to see if it can be predicted from geophysical data. The geophysical data shows a well-defined low velocity layer that thins from west to east. The chemical testing at a location on the west end of the line showed very high (195 to 1,800 ppm) levels of hydrocarbons in the upper fourteen feet (14'). Similar testing on the east end of the line showed relatively low (7 to 96 ppm) levels in the upper five feet (5'). This trend is appears to be in agreement with the geophysical data and indicates that the seismic is responding to the hydrocarbon-bearing interval. The seismically predicted thickness ranges from zero to seven feet (0-7') and is consistently less than the chemical and probe data indicate. The chemical data and probes are discussed in a later section.

Northern Newark Bay – Contaminated Black silt

As part of a subsurface investigation to determine the feasibility of constructing confined disposal facilities in northern Newark Bay the Port Authority of New York and New Jersey conducted extensive chemical testing at a number of locations. Samples were collected down to a depth of twenty-feet and were tested for a number of common contaminants including total petroleum hydrocarbons and volatile organic compounds. The contaminated interval was determined to vary between ten and fourteen feet. In order to take advantage of the existing data and to farther evaluate the possibility of using geophysical data to predict and map the contaminated interval additional sub-bottom profile data was acquired. Figure 35 shows two, high frequency (chirp sonar) profiles collected in the project area. The data shows a very well defined low velocity layer that varies in thickness. Based on the expanded section the thickness of the low velocity layer ranges from three to five feet in thickness. The contaminated interval as determined from

chemical testing generally ranges from 8 to 12 feet whereas the seismic indicates thickness of up to seven feet (7'). In this case there are enough uncertainties in the method used to collect samples for chemical testing that it is uncertain which method actually yields the most reliable thickness. Additional discussion of the thickness of the contaminated interval is included in a later section on geoprobes.

DREDGEABILITY OF BEDROCK

The northern portion of the Arthur Kill extending from Shooters Island to approximately one-half mile south of the Gothels Bridge will be dredged to elevations of –43.0' to the Howland Hook Terminal (500' north of the Gothels) and to –42.0' in the southern segment. In a later phase the channel will be deepened to an elevation of approximately –52.0' to the Howland Hook Marine Terminal. A very significant portion of the material to be excavated will be sandstone and shale bedrock. The cost of blasting the rock is a major factor to consider in the cost of the projects. In order to predict the portion of the rock that can be dredged without blasting several methods have been attempted including test digs and mapping of rock properties.

Test digs using a clamshell dredge at five locations in Arthur Kill had limited success. The first objective to reach an elevation of –43' MLW was attained at four of the five locations. At the fifth location (near Shooters Island) no progress was made. The four locations where the first objective was obtained were in shale areas whereas the fifth (totally unsuccessful) area was sandstone. The second objective was to reach an elevation of –47' MLW. This objective was not attained at any of the locations. The Port Authority conducted a test dig in "no mans land" near the Howland Hook Marine Terminal. Using an excavator dredge the Port Authority had little trouble digging the shale to a depth of –52' MLW.

Rock properties such as rock quality designation (RQD) and unconfined compressive strength used in association with the test dig information is a useful technique for predicting dredge-ability. These rock properties are determined at the test dig location before the test dig is conducted. If the dig is successful then area with similar rock properties should be dredge-able as well. This method has been used with some degree of success in small areas such as the Serpentinite in Kill Van Kull. However, in Arthur Kill the limited number of locations and lack of testing yields a less than desirable level of confidence. In order to create a map showing the dredge-ability of the Arthur Kill rock area, to the desired level of confidence, a large number of locations and extensive testing would be required. If it were possible to use a remote sensing method such geophysical data to determine rock properties then a much better determination of dredge-ability could be attained. Relatively well-defined relationships between compressive strength and compressive velocity have been published and have been used to predict rip-ability of bedrock. The cross-plots indicate that rocks with a compressive strength of 3,000 psi have a velocity of 10,000 fps and can be dredged with a clamshell dredge. Rocks with a compressive strength of 7,500 psi or compressive velocity of up to 14,000 fps can be

dredged with an excavator. Rocks with compressive strength greater than 7,500 psi and a corresponding velocity of 14,000 fps generally require blasting or some other method of pretreatment. The velocity of soil, rock and other materials can be determined using geophysical methods. Using these assumptions a scope of work was prepared and contract let to evaluate the method in Arthur Kill.

The contractor (Earthworks) adapted an oilfield method of towing a multi-channel receiver array and using two different sources to expand the frequency range. The two sources used to create a pulse of sound were a 5.0 kHz piezoelectric boomer and a 0.1-1.0 kHz pneumatic air-gun. The seismic technique measures the travel-time of the reflected compressional wave. The measurement varies (1) as a function of distance (or angle) from the source-to-receiver at a given position, and (2) as a function of the displacements of the source and receiver array as it is towed from position to position. The shots of sound are separated along the survey tracklines by roughly one (1) foot. The continuous sequence of traces (at an interval of 1 per foot for thousands of feet) produces a cross-sectional image of the subsurface. The sixteen channels produce a set of traces that can be analyzed to yield the velocity of the rock as a function of depth.

Figure 36 shows the interval velocity superimposed on a stacked seismic section of a portion of eastern Arthur Kill. Low velocity material (<10,000 fps) shaded blue, green, yellow or orange is interpreted to be dredge-able without blasting. The area that is shaded red is thought to require blasting (or other pretreatment) before dredging. Dense sandstone is located along the eastern (right) side of the illustrated area. The dense sandstone has high compressive strength and relatively high velocity that agrees well seismic velocity. The sandstone is generally considered to require blasting. The west (left) side of the area shown is predominantly shale. The shale has a lower compressive strength and relatively low velocity that also agrees relatively well with the seismic velocity.

Velocities determined from core measurements and seismic were used to construct the profile of Arthur Kill shown in Figure 37. The values were determined at various depths along the profile and contoured to present a continuous interpretation of the data. Those areas where no values are given represent areas where there are no core velocities or the seismic was lower quality. The –43 and –52 mean low water elevations are shown so that the viewer can determine the relative amount of material that can be dredged without blasting. The area that is shaded red is interpreted to require blasting.

MAGNETOMETER AND GRADIOMETER

A magnetometer survey was conducted in southern Newark Bay to evaluate how accurately petroleum pipelines that cross the channel could be located. Earthworks used a Geometrics 881 Cesium magnetometer that can detect the presence of ferromagnetic materials such as steel in pipes and rebar in concrete. Over 120,000 points were taken. The background amplitudes of the magnetic field ranged from 53500 gammas in the

south to 53800 in the north of the area of interest. Figure 38 shows the contoured magnetometer data superimposed on a side scan mosaic. The data shows a series of local anomalies that align very well with the trenches identified on the sidescan. Two additional anomalies are apparent along the alignment of the abandoned railroad bridge. These anomalies are interpreted to be possible bridge footings. There are no apparent local anomalies over the PSEG gas pipeline in the Newark Bay segment but there is a strong anomaly in Port South Elizabeth. The PSEG pipeline is more than a hundred feet below MLW in the Newark Bay segment and less than sixty feet in the South Elizabeth segment indicating that depth of burial is a significant factor in magnetometer readings

A gradiometer survey (Figure 39) was acquired in Port Jersey Channel to see if the Passaic Valley Sewage Tunnel could be detected and its alignment determined. A gradiometer measures the difference between two measured magnetic fields. The two magnetometers were constructed so that the upper magnetometer was a few feet below the surface and the other was four feet (4') directly below it. The gradiometer removes the diurnal variation, any wave noise and the deep-seated geology, it is sensitive to small variations along the alignment and is more sensitive than a magnetometer. A relatively low order, but definitive anomaly was observed over the location of the relief shaft on the south side of Port Jersey Channel. However, no apparent anomaly was observed over the tunnel alignment under the channel.

GEOPROBE TECHNOLOGY

As noted in an earlier section a blanket of Holocene (Recent) silt covers a very large portion of New York Harbor. This layer of black silt ranges from a few inches (or less) in areas that were recently dredged to as much as thirty feet (30') in areas that have never been dredged. In areas where the silt layer is thick and has not been dredged, there is a significant need to determine how much of the layer is contaminated (unsuitable for ocean disposal). The gray to black silt is thought to have accumulated in the harbor for more than 3,000 years. Since most of the contamination occurred during the industrial age (the last 200 years) it is very likely that only the upper few feet is contaminated. Visual and physical characteristics (color, texture, odor, etc.) cannot be employed to accurately differentiate the contaminated interval from the clean interval. Under the current circumstances relatively expensive chemical testing would be required to differentiate the contaminated interval from the clean interval. It would be presumptuous to assume that the contaminated interval is a constant thickness, so a relatively large number of locations would be required to map the aerial distribution of the contaminated interval. Depending on the size of the project the number of test locations necessary to define the contaminated interval could be very large and expensive.

Due to the large number of tests and the expense of performing them, it is highly important to determine if there are non-conventional methods that can be employed to quickly and accurately predict the contaminated interval. Emerging technological methods such as Membrane Interface Technology (MIT) and Laser Induced Fluorescence

(LIF) may be able to accurately define the contaminated interval in less time and at a lower cost. These technologies employ a probe that is pushed into the subsurface to collect and chemically analyze samples as the tool is advanced. The probes measure among other things total petroleum hydrocarbons (TPH) and volatile organic compounds (VOC). Since these are two of the major contaminants, their presence in measurable quantities may be used to define the contaminated interval. The presumption is that hydrocarbons were deposited during the same time interval (last 100-200 years as opposed to the last 20,000) as the other contaminants. The concentration of heavy metals or PCBs may not be determinable but the interval where they are concentrated may be directly related to the presence of hydrocarbons. The hydrocarbon and non–hydrocarbon subunits as predicted using the probes could then be tested separately for ocean disposal.

As part of an investigation to evaluate potential sites for construction of a new Confined Disposal Facility (CDF) the Port Authority of New York and New Jersey has collected and analyzed samples at twelve locations. The samples were tested at one to two foot increments to a depth of twenty feet (20') in order to determine the base and thickness of the contaminated interval. The analysis includes all of the common contaminants including metals, non-metals, total petroleum hydrocarbons and volatile organic compounds. The Corps of Engineers collected similar chemical data in the flats adjacent to Port Jersey and South Elizabeth Channels in an effort to determine the depth of contamination. Some of the contaminants including volatile organic compounds (i.e. chlorinated solvents and total petroleum hydrocarbons (TPH)) can be detected using MIT and LIF technology and provided an opportunity to evaluate the applicability of the tools. Geoprobe (LIF, MIP-Conductivity) data was collected at the locations where the chemical data was obtained in order to determine if the probes could detect the hydrocarbons and volatiles.

Geoprobe Data – Port Jersey

Chemical data was collected at three locations in the flats to the north of Port Jersey. Two of the locations showed very low levels of contamination and total petroleum hydrocarbons (TPH) of less than 20 ppm. The other location in deeper water showed higher levels of contamination and total petroleum hydrocarbons in the range of 20 to 90 ppm. Figure 40 is a comparison of the stratigraphy, chemical testing and laser induced fluorescence (LIF) data acquired at a location near the site where the higher level of contamination occurred. Although the response was small there is a definitive increase in the level of fluorescence. All of the data indicates that the base of the contaminated interval occurs at an elevation of –26' to –27' below mean low water (MLW). The chemical data indicates a thickness of approximately eight feet (8') and the LIF indicates a thickness of nine and one-half feet (9.5'). LIF data was collected at four locations in Port Jersey and those conducted in deeper water showed relatively high levels of fluorescence while those conducted in shallow water had little or no response. This trend agrees well with both the chemical data and geophysical data described in an earlier section (Figure 32).

Geoprobe Data – Northern Newark Bay

Laser Induced Fluorescence probes were advanced at four locations where chemical data was collected in northern Newark Bay. Figure 41 is a representative comparison of the stratigraphy, chemical testing and the LIF response. It should be noted that there was no recovery of the black silt in the upper four feet when samples were collected for chemical testing so that interval was not tested. Therefore, the thickness of the contaminated interval based on chemical testing is approximately ten and one-half feet (10.5'). Contamination appears to occur in both the upper black silt as well as the gray silt. The LIF probe shows a very definitive response and indicates a thickness of approximately eight feet (8'). The thickness indicated by the LIF probe ranged from three feet (3') to nine feet (9') at the four probe locations. In general the thickness indicated by the LIF was consistently less than that determined from chemical testing.

Geoprobe Data – South Elizabeth

Chemical data was collected at two locations in the flats adjacent to South Elizabeth Channel. At one of the locations relatively high levels (200 to 1,800 ppm) of total petroleum hydrocarbons were measured to a depth of fourteen feet (14') below the mudline. At the other location relatively low levels (7 to 96 ppm) of TPH were detected in the upper five feet (5'). Figure 42 is a comparison of the stratigraphy, chemical data and the LIF response at the location where higher TPH was recorded. The LIF shows a definite response in the upper eight to ten feet (8-10') and corresponds well with stratigraphy (the geologic description) but is not as thick as the interval indicated from chemical testing. A review of the sample description indicates that some of the high TPH readings occurred in the Pleistocene interval and may be due to problems with the sampling procedure. The LIF probe was advanced at five locations in the South Elizabeth Flats. A relatively low level of response in the upper five to seven feet (5-7') was recorded in the eastern portion of the area. In the western portion of the area a relatively high response was recorded in the upper ten to eighteen feet (10 to 18'). This response is consistent with the fact that the probes along the western portion of the area were located in an abandoned and filled turning basin.

Geoprobe Data – Arthur Kill

There are many areas in the Harbor where the black silt has been deposited since the last phase of dredging. In many cases the recently deposited black silt directly overlies dense Pleistocene or bedrock. Several sampling methods are currently used to determine the thickness of the silt but they are all less accurate than desired. For instance, with the vibracore samples it is hard to keep the tool perfectly vertical and recovery is almost always less than one hundred percent (100%). In order to evaluate how accurately and quickly the probes (LIF and MIP) could measure the thickness of the black silt data was collected in Arthur Kill nine locations. No chemical data was available for comparison and unfortunately the core and probe data could be as much as fifty feet from one another. In Arthur Kill a few feet can make a substantial difference in black silt thickness

so a direct comparison cannot be made. The LIF tool showed a very definitive, relatively high level of fluorescence at all of the locations in Arthur Kill. Figure 43 shows a typical plot of the LIF response and a nearby gravity core**.**

TEST DREDGE SERPENTINE AREA

Test dredging was conducted in the Serpentinite bedrock in Kill Van Kull to determine if dredging the bedrock is possible without blasting or if blasting will be required prior to dredging. Geophysical and subsurface explorations were conducted to define the characteristics of the rock and to predict the dredgeability of the Serpentinite. The project was contracted to URS Corporation (URS) who subcontracted out the geophysical and bathymetric survey tasks to Alpine Ocean Seismic Survey, Inc. and test dredging out to Bean Stuyvesant, LLC (Bean). Bean used the Tauracavor (an hydraulic excavator) to dredge the bedrock.

Initially, the plan called for six test dig locations in the Serpentinite. Side scan sonar data was gathered to define the location of shoals and black silt accumulations. The test dredge locations were limited to areas where there was less than six inches of black silt accumulation due to disposal issues and other environmental concerns. The black silt areas were also avoided because they present geophysical interpretation problems. The side scan mosaics were not completed until after the project was complete, so they were not used to plan the test dig sites. A grid of sub-bottom profile data was collected and interpreted. Based on the geophysical reflectivity of the material exposed along the channel floor three types of areas were defined:

1) Areas that were hard (unweathered, competent not fractured) or smooth.
2) Areas that are soft (weathered, fractured) or irregular.
3) Intermediate areas.

Type 2 areas were interpreted to be dredgeable whereas Type 1 areas were thought to require blasting. Type 3 areas were less diagnostic. Based on the geophysical properties, two test dig locations were selected in each type of material. Grab samples were taken at each of the six test dig locations to determine if the black silt layer was less than six inches thick. After screening the sites for black silt, two standard penetration test borings were taken at each test location. Split spoon samples were taken to refusal (greater than 50 blows per foot) and at refusal a rock core was taken to an elevation of –55’ MLW. Drill rate, fractures per foot, longest core segment and rock quality designation (RQD) were determined. Rock cores were also tested for unconfined compressive strength. After reviewing the boring logs two of the sites were eliminated because the borings indicated the presence of more than six inches of black silt. Of the four remaining sites, two were thought to be dredgeable without blasting; one would require blasting and one was intermediate.

Dredging was to commence and continue until all of the rock within a 50’ X 50’ area had been removed to an elevation of –52 feet MLW or until the material was no longer dredgeable. The operator was not to stay at a test location for more than 12 hours. The average time spent dredging at each test location was four hours with the shortest time being 1.67 hours and the longest time being 6.84 hours. In practice, the dredge operator made the decision to stop when he believed an economic limit had been obtained. Although a significant volume of rock was removed from each site the operator only reached the objective elevation of –52’ MLW at one site. It should be noted that the operator was able to reach an elevation of -51’ MLW at three of the four locations. The one location that was dredged to an elevation of –52’ MLW was considered from geophysical data to require blasting. Therefore the reflectivity method does not appear to be a useful method of predicting dredgeability.

In order to evaluate the results of the test dig all of the drilling and dredging data has been reviewed. The most useful information appears to be rock quality designation and unconfined compressive strength. Strength and structure of the rock are the primary factors in determining whether rock can be dredged. Rock quality data (RQD) derived in the field and unconfined compressive strength (UCS) determined in the laboratory are two methods of determining the strength and structure of rock.

Areas where blasting may not be necessary were defined by rock quality data (RQD) from previous core borings in the Serpentinite. The rock area was broken into three main categories: one where the RQD was less that 30%, one where RQD was greater than 30%, and one where the RQD was 0%. Areas that have lower RQD values are believed to be more easily dredged than areas with higher RQD values. Figure 44 shows the areas.

Unconfined compressive strength (UCS) of rock may also be used to determine the qualities of the rock to be dredged. Rock with unconfined compressive strengths less than 7,000psi is considered dredgeable (Table 21).

Table 21. Unconfined Compressive results for Serpentinite in KVK.

Depth	B2b	B7a	B7b	G3a	G3b	W1a	W1b	W3a
50-51	9105	4553				2006		7950
51-52	11101		3585		7919			6293
52-53	795			3816	15312			
	5933			11509	3074			
53-54	8004		3262		4491	10449	8356	
			981					
54-55	1101			2680	9109		7571	
	3696							
55-56							10060	
							12250	
							7083	
56+							6798	
						12819		
							7928	
							5315	
							10658	

NOTE: Test digs were performed in B2, G3, W1, and G1 (not listed).

The UCS of the Serpentinite rock concurs with the RQD data. The areas where the RQD are low are areas where the UCS is also low, indicating good dredging conditions. Test dig location B-2 reached the required depth of –52 feet MLW and fits the conditions of low RQD and UCS below 7000psi, while test dig W-1 did not reach the proposed depth of –52 feet MLW and had high values for RQD and high values for UCS. Therefore, rock quality data (RQD) and unconfined compressive strength (UCS) are considered good indications of whether rock may be dredged.

Using the available data (relying primarily on RQD data) possible dredging and possible blasting areas were defined (Figure 44). According to the map, approximately 54% of the Serpentinite outcrop may be dredged without blasting. This figure is an estimate due to the lack of data available. A similar project conducted prior to dredging of the forty-five foot channel indicated that more than 80% of the rock could be dredged without blasting. All of the Serpentinite was dredged without blasting during that project.

The data set can be improved in the future by taking borings in the area to a greater depth (-60'MLW or more), recording data about rock quality, and performing detailed unconfined compressive strength testing in the laboratory. New borings should be taken in areas where the previous borings do not go beyond –54' MLW and where old borings do not have RQD or laboratory testing data. Recommended locations are shown on Figure 44.

BLASTING ANALYSIS

URS Corporation and Louis Berger Group, Inc. working together as Master Harbor Partnership (MHP) conducted a Structural Investigation/Blast Analysis for forty-eight (48) structures near the Arthur Kill and Kill Van Kull channels for the Corps of Engineers Harbor Deepening (-50ft MLW) Project. Blasting analysis was subcontracted to Contract Drilling and Blasting, Inc. The blasting analysis was done on the Serpentinite in eastern Kill Van Kull and Diabase in western Kill Van Kull and Sandstone and Shale in Arthur Kill.

Reviews of previous investigations and public records were conducted to determine the Peak Particle Velocity (PPV) criteria for structures and utilities along the navigation channel. PPV lines were established for 2.0, 1.0, 0.5, and 0.3 inches/second and were delineated on harbor maps. These PPV lines were established assuming standard blasting patterns without any blast reducing features. Structures requiring reduced blasting vibrations to insure their safety were identified and recommended blasting patterns to reduce vibrations were made. The new PPVs and recommended blasting patterns were tabulated and added to the maps.

The structural investigation involved collecting field data and using empirical methods to determine the potential impacts on structures from blast vibrations. Field data included: location of the structure, type of structure (building, bulkhead, bridge, etc.), type of construction (concrete, steel, wood, masonry), overall condition, and photographs. The structures were evaluated relative to Peak Ground Acceleration (PGA) resulting from blast vibrations. PGAs vary depending on the type of construction and foundation support. Empirically relating PGA and PPV data from the structural investigation to that derived from the blasting analysis, structural stability could be defined. From this data it was determined that of the forty-eight (48) structures, thirteen (13) will not be affected by the blasting vibrations from standard blasting patterns; twenty-nine (29) will require reduced blasting vibrations to maintain their structural integrity; six (6) may need further structural analysis to insure their safety. Table 22 shows the blasting classification of structures. Associated blasting patterns for cautious and extremely cautious blasting are shown in Figures 45, 46, and 47.

Table 22. Blasting Classification of Structures.

Structure No.	Location	Distance To Channel	Production Blasting	Non-Production Blasting	No Blasting	Basis For Classification
AK-023	Marina, 71 Front St; Elizabeth	275	•			Structure is greater than 150 feet from edge of navigation channel; Regulatory PPV is 2.0 in/sec.
AK-033	Loizeaux Construction Building; Elizabeth	60		•		Structure is less than 150 feet from edge of navigation channel; Regulatory PPV is 2.0 in/sec.
AK-036	330 S. Front Street; Elizabeth	120		•		Structure is less than 150 feet from edge of navigation channel; Regulatory PPV is 2.0 in/sec.
AK-037	South of AK-36; Elizabeth	120		•		Structure is less than 150 feet from edge of navigation channel; Regulatory PPV is 2.0 in/sec.
AK-039	South of AK-37; Elizabeth	165	•			Structure is greater than 150 feet from edge of navigation channel; Regulatory PPV is 2.0 in/sec.
AK-283	Stone/ Debris shoreline; Arthur Kill	110	•			No critical structure present; Regulatory PPV does not apply.
AK-284	Elizabeth Port Marina; Elizabeth	25		•		Structure is less than 150 feet from edge of navigation channel; Regulatory PPV is 2.0 in/sec.
AK-285	Elizabeth Park - Steel Sheeting	60		•		Structure is less than 150 feet from edge of navigation channel; Regulatory PPV is 2.0 in/sec.
AK-286	Elizabeth Park - Boardwalk	75		•		Structure is less than 150 feet from edge of navigation channel; Regulatory PPV is 2.0 in/sec.
AK-288	Loizeaux Building Supply	90		•		Structure is less than 150 feet from edge of navigation channel; Regulatory PPV is 2.0 in/sec.
AK-289	Chevron Bayway Lubricants	95		•		Structure is less than 150 feet from edge of navigation channel; Regulatory PPV is 2.0 in/sec.
AK-290	Crown Oil Tank Property	90		•		Structure is less than 150 feet from edge of navigation channel; Regulatory PPV is 2.0 in/sec.
AK-302	Goethals Bridge- NJ side	140		•		Structure is less than 150 feet from edge of navigation channel; Regulatory PPV is 2.0 in/sec.
AK-308	Goethals Bridge Pier- NY side	10			•	Structure is less than 25 feet from edge of channel; As built foundation is unknown; Structure's response to vibration has not been determined.
AK-311	Howard Hook Terminal	180	•			Structure is greater than 150 feet from edge of navigation channel; Regulatory PPV is 2.0 in/sec.
AK-315	Arthur Kill Lift Bridge	10			•	Structure is less than 25 feet from edge of channel; As built foundation is unknown; Structure's response to vibration has not been determined.
AK-316	Proctor & Gamble Property	20	•			Structure is a wood-pile pier in disrepair. No regulatory PPV applies;
KVK-003	404 Richmond Terr. Greek Revival Temple; Staten Island	460		•		Structure is greater than 150 feet from edge of navigation channel; Structure is a historical structure
KVK-004	Foot of Bank St; Staten Island	290	•			Structure is greater than 150 feet from edge of navigation channel; Regulatory PPV is 2.0 in/sec.
KVK-005	Bank St. Staten	300	•			Structure is greater than 150 feet

Structure No.	Location	Distance To Channel	Production Blasting	Non-Production Blasting	No Blasting	Basis For Classification
	Island- Concrete Pillars					from edge of navigation channel; Regulatory PPV is 2.0 in/sec.
KVK-006	15 Bank St; Staten Island	340	•			Structure is greater than 150 feet from edge of navigation channel; Regulatory PPV is 2.0 in/sec.
KVK-011A	Across from 500 Richmond Terr; Staten Island	75		•		Structure is less than 150 feet from edge of navigation channel; Regulatory PPV is 2.0 in/sec.
KVK-011B	Continuation of KVK-011A	90		•		Structure is less than 150 feet from edge of navigation channel; Regulatory PPV is 2.0 in/sec.
KVK-087	St. Mary's Church	450	•			Structure is greater than 150 feet from edge of navigation channel; Monitoring during previous blasting satisfied regulatory PPV's
KVK-088	St. Mary's Rectory	455	•			Structure is greater than 150 feet from edge of navigation channel; Monitoring during previous blasting satisfied regulatory PPV's.
KVK-089	St. Mary's Hall; Sharp Ave and Richmond	460	•			Structure is greater than 150 feet from edge of navigation channel; Monitoring during previous blasting satisfied regulatory PPV's.
KVK-299	Scaramix Bulkheads	400	•			Structure is greater than 150 feet from edge of navigation channel; Regulatory PPV is 2.0 in/sec.
KVK-301	Junkyard, East of Bayonne Bridge	235	•			No critical structure present; Building previously present was demolished; Regulatory PPV does not apply.
KVK-302	Construction Company	170	•			Structure is greater than 150 feet from edge of navigation channel; Regulatory PPV is 2.0 in/sec.
KVK-303	Faber Park	260	•			Structure is greater than 150 feet from edge of navigation channel; Regulatory PPV is 2.0 in/sec.
KVK-304	Atlantic Express Bus Company	120		•		Structure is less than 150 feet from edge of navigation channel; Regulatory PPV is 2.0 in/sec.
KVK-305	3 Buildings between Atlantic Express & Constr. Company	300	•			Structure was demolished since 1997 survey. Regulatory PPV does not apply.
KVK-306	KVK Construction Company	180	•			Structure is greater than 150 feet from edge of navigation channel; Regulatory PPV is 2.0 in/sec.
KVK-307	Building north of Construction Company	450	•			Structure is greater than 150 feet from edge of navigation channel; Regulatory PPV is 2.0 in/sec.
KVK-309A	Atlantic Salt Company and Building to East	210	•			Structure is less than 150 feet from edge of navigation channel; Regulatory PPV is 2.0 in/sec.
KVK-309B	Continuation of KVK-309A	100	•			Structure is less than 150 feet from edge of navigation channel; Regulatory PPV is 2.0 in/sec.; Buildings appear to be collapsing.
KVK-309C	Continuation of KVK-309B	175	•			Structure is less than 150 feet from edge of navigation channel; Regulatory PPV is 2.0 in/sec.
KVK-310A	Shoreline east of old warehouse (KVK-309) to S.I. Ferry	200	•			No critical structure present; Regulatory PPV does not apply.
KVK-310B	Continuation of KVK-310A	430	•			Structure is greater than 150 feet from edge of navigation channel;

Structure No.	Location	Distance To Channel	Production Blasting	Non-Production Blasting	No Blasting	Basis For Classification
						Regulatory PPV is 2.0 in/sec.
KVK-310C	Continuation of KVK-310B	760	•			Structure is greater than 150 feet from edge of navigation channel; Regulatory PPV is 2.0 in/sec.
KVK-313	Exxon- Western Pier	234	•			Structure is greater than 150 feet from edge of navigation channel; Regulatory PPV is 2.0 in/sec.
KVK-323A	Shoreline from Lord St. to Bayonne Bridge	225	•			Structure is greater than 150 feet from edge of navigation channel; Regulatory PPV is 2.0 in/sec.
KVK-323B	Continuation of KVK-323A	250	•			Structure is greater than 150 feet from edge of navigation channel; Regulatory PPV is 2.0 in/sec.
KVK-323C	Continuation of KVK-323B	285	•			Structure is greater than 150 feet from edge of navigation channel; Regulatory PPV is 2.0 in/sec.
KVK-324	Bayonne Bridge	240	•			Structure is greater than 150 feet from edge of navigation channel; Regulatory PPV is 2.0 in/sec.
KVK-328	Staten Island Ferry	800	•			Structure is greater than 150 feet from edge of navigation channel; Regulatory PPV is 2.0 in/sec.
KVK-329	Staten Island (Minor league) Yankee Baseball Stadium	1250	•			Structure is greater than 150 feet from edge of navigation channel; Regulatory PPV is 2.0 in/sec.
KVK-330	Verrazano Narrows Bridge	>15,000	•			Structure is greater than 150 feet from edge of navigation channel; Regulatory PPV is 2.0 in/sec.

The table, Blasting Characteristics of Structures, shows whether normal blasting techniques, modified blasting techniques or no blasting is recommended based on the structures' distance from the navigation channel and blasting. The Structural Investigation/Blasting Analysis shows that blasting for the majority of the forty-eight (48) structures is allowable using the recommended blasting patterns. However, calibration of the seismic environment is necessary during actual blasting. Thirty-five (35) of the forty-eight (48) structures are unlikely to need special blasting techniques during the current phase of dredging. The structures meet the following criteria: located more the 150 feet from the edge of the navigation channel and regulatory PPVs have not been exceeded in the past. Sixteen (16) of the forty-eight (48) structures are likely to need special blasting techniques. These are structures that are closer than 150 feet from the navigation channel. Six (6) structures are recommended for further analysis: the Goethals Bridge, Arthur Kill Lift Bridge, Bayonne Bridge, Staten Island Ferry, and the Verrazano Narrows Bridge. These structures were determined to be highly critical, because of the large number of people using them.

SLOPE STABILITY ANALYSIS

Slope stability analyses were performed in the Arthur Kill, Kill Van Kull, Newark Bay, Port Elizabeth and South Elizabeth Channel as part of the New York Harbor Study. The analysis was performed for the channel sides to ensure that the deepening of the harbor at these waterways would not create unstable conditions along the shoreline or nearby structures. Many analyses were performed at the same location as the side scan survey profile lines. The Earthworks Survey Company performed the sidescan survey. The surveys were done to determine the condition of the surfaces of the channel bottom and sides especially within the softer soils along the channel alignment. Other slope stability analyses were done at 14 structures that were nearest to the shoreline channel edge. The bottom of the channel in all of the analyses was equal to –55 mean low water (MLW). The slopes or angles of the channel sides are 1 vertical to 3 horizontal or 1 on 3. Major factors that affected the stability of the channel embankment or sides were type of soil or rock, strength properties of soil/rock, and the slope or angle of the channel sides. Other factors to a lesser extent that affect the stability are thickness of soft or dense soils and height of the channel embankment or sides.

The Corps software program, UTEXAS4, was use to compute the slope stability for all of the locations. A singular circular arc or surface was inputted into the analysis by the designer or generated by the program by performing a circular search. UTEXAS4 calculated the safety factor against sliding of the channel sides when channel bottom is deepen to depth of –55 feet MLW. Circular arcs generated by the program would be determined by a circular search to find the lowest safety factor. A few analyses were performed using non-circular surfaces to compute the safety factor against sliding instead of a circular surface. These were done mainly in areas where there were shallow layers of soft soils on top of bedrock or hard dense soils such as glacial tills. The area of the channel above the circular arc or non-circular surface was divided into slices to determine the forces driving and resisting the sliding along the surface. The program used the Spencer Method to compute the safety factor for most areas or sections. In the Spenser Method, the resultant side force is inclined at a fixed angle at the default value of 15 degrees. At a few the locations the method was the Lowe and Karafaith where the channel embankment height was relatively low or shallow. In this method, the resultant side force inclination is equal to the angle of the slope of the section.

The safety factor values along with the location of the analyses are listed in Tables 23. These tables also indicate where the program that generated the arc of the computed safety factor performed circular searches.

SOIL AND ROCK STRENGTH PROPERTIES

The properties of the soil and rock were determined from subsurface exploration and the lab testing. Table 1 lists the soil and rock strength properties used in the stability analysis. Table 24 lists the testing results on selected samples across the Arthur Kill, Kill

Van Kull, Newark Bay, Port Elizabeth, and South Elizabeth Channel. The selected samples for testing were taken almost entirely in the soft cohesive soils. Tables 25 lists the borings that encountered soft black silt with no N Values or weight of the rods.

SLOPE STABILITY OF CHANNELS AND STRUCTURES

Arthur Kill Channel

Ten slope stability analyses were performed in the Arthur Kill at the locations of the Earthworks Side Scan Survey. The stability analyses are shown in Figures 49 through 58, 172 and 173. These were done at Profile lines 1, 4, 6, and 7. The soils and rock existing at the survey lines in the Arthur Kill are as follows:

<u>Profile Line 3</u>

Black Silt
Gray Silt and Sand
Red-brown Silty Clay
Red-brown Till (Sand and Gravel)
Red Shale and Sandstone

<u>Profile Line 4</u>

Black Silt
Gray Silt and Sand
Brown Sand with Peat
Red-brown Till (Sand and Gravel)
Red Shale and Sandstone

<u>Profile Line 6</u>

Gray Silt and Sand
Red Shale and Sandstone

<u>Profile Line 7</u>

Gray Silt and Sand
Red brown Till
(Sand and Gravel)
Red Shale and Sandstone

The safety factors against slope failures results ranged in value from .118 to 22.562. One of the lowest value is at Profile Line 4 with a safety factor of 1.366. The circular arc for

the lowest safety factor runs through the softer soils of Black Silt, Gray Silt and Sand, and Brown Sand with peat. Another area of concern is shown in Figure 173 where the critical circular arc has the lowest safety factor of 0.118. This area in the Arthur Kill is located at Earth Work Survey Line 7. This area should be investigated in the next phase of this project. Most of the channel slopes at the above profile lines are relatively steep from the toe of the channel slope to the top of the slope. The results of the slope stability analysis in the Arthur Kill Channel indicate that 1 on 3 side slopes are stable when the depth of the channel is deepened to 55 feet MLW.

Kill Van Kull Channel

Twenty nine (29) slope stability analyses were performed along the Kill Van Kull Channel at the locations of the Earth Works Side Scan Survey Profile Lines 21, 22, 23, 24, 26, and 28. The stability analyses are shown in Figures 59 through 87,174 through 180. The soils and bedrock existing at survey profile lines along the Kill Van Kull are as follows:

<u>Profile Line 21</u>

Gray Silt
Gray Silt and Sand
Boulders and Till
Basalt Bedrock

<u>Profile Line 22</u>

Brown Sand and fine Gravel
Red Brown to Brown Till

<u>Profile Line 23</u>

Gray Silt and Sand
Red brown Till

<u>Profile Line 24</u>

Gray Silt and Sand
Brown Sands
Red-brown Till (Sand and Gravel)
Red Shale and Sandstone

<u>Profile Line 26</u>

Black Silt
Gray Silt and Sand
Gray Coarse Sand and fine Gravel
Red Shale and Sandstone
Profile Line 28

Black Silt
Gray Silt and Sand
Red-brown Clayey Silt
Serpentinite

The safety factor values for the slope stability ranges from 0.246 to 64.010. One of the lowest value was at Profile Line 26 where the critical circular arc runs entirely through the soft black silt layer. Another area of concern is shown in Figure 180 where the critical circular arc has the lowest safety factor of 0.246. This area in the Kill Van Kull is located at Earth Work Survey Line 13. This area should be investigated in the next phase of this project. The results of the stability analysis indicated that 1 on 3 side slopes in soil and 1 on 1 in rock are relatively stable for most areas along the Kill Van Kull. Most of the safety factors were above 2, which is above the recommended safe value of 1.5. The height of the slopes along many areas of the Kill Van Kull is relatively steep.

Newark Bay Channel

Five slope stability analyses were done in Newark Bay at the locations of the Earth Works Side Scan Survey Lines 14, 15, 16, and 17. The stability analyses are shown in Figures 88 through 92. The soils and rock existing within Newark Bay Channel are as follows:

Profile Line 14

Gray and Black Silt
Pleistocene Clay
Pleistocene Sand and Gravel
Triassic Sandstone and Basalt

Profile Line 16

Gray Silt and Sand
Red-brown Clayey Silt
Triassic Gray Sandstone

Profile Line 17

Black Silt
Holocene Gray Silt
Red Clay
Sandstone

The safety factors range in values from 2.006 to 10.041 with the lowest value equal to 2.006. The critical circular arc lies in the Pleistocene clay, which is a relatively stiff cohesive soil. Very thin layers of Black Silt or Gray Silt exist in Newark Bay so that the critical circular surface is limited in these soils or non-existence in these layers. The height of the slopes is relatively shallow or low. The results of the stability analysis indicated channel side slopes of 1 on 3 were stable with safety factors against failure of 2.311 or greater.

Port Elizabeth Channel

Eight slope stability analyses were performed in Port Elizabeth Channel at Earth Works Survey Lines 9,10,11,13. The stability analyses are shown in Figures 93 through 101. The exiting soil and rock layers at the survey lines are in Port Newark are as follows:

Profile Line 9

Gray Silt and Sand
Pleistocene Red-brown Clayey Silt
Triassic Sandstone and Siltstone

Profile Line 10

Holocene Gray to Brown Silt and Sand
Pleistocene Red-brown Clayey Silt (Varved)
Triassic Sandstone and Siltstone

Profile Line 11

Holocene Gray to Brown Silt and Sand
Pleistocene Red-brown Clayey Silt
Triassic Sandstone and Siltstone

Profile Line 13

Black Silt
Gray to Brown Silt and Sand
Varved Silt and Clay

The values for the safety factor range from 2.116 to 18.290 with the lowest value equal to 2.116. The critical circular arc in this analysis runs within the Pleistocene Clays and Silts, which are relatively stiff cohesive soils. The slope heights are relatively steep. The results of the stability analysis indicated that 1 on 3 side slopes are stable with a safety factor against slope failures above 2.1.

Port Jersey Channel

The stability analyses are shown in Figures 181 through 182. The existing soil and rock at the location of the profile is as follows:

Black Silt
Gray Silt with little to trace Sand
Red-brown Sand and Gravel

The values for the safety factor range from 0.979 to 2.057, where the lowest value of 0.979 has a critical circular arc that runs within the Black Silt and Gray Silt layers. Stability analysis in the Port Jersey Channel indicated the side slopes would be stable for 1 on 3 with a channel depth elevation of 55 feet mean sea level except in the areas that have thick soft layers of Black Silt and Gray Silt layers. This soil layers should be investigated for further analysis in the next phase of this project.

South Elizabeth Channel

Only one survey was performed in this channel. The stability analyses are shown in Figures 102 through 106. The existing soil and rock at the location of the profile is as follows:

Black Silt
Gray Silt and Sand
Red-brown Till (Varved)
Red-brown Till (Silt and Gravel)
Red-brown Sandstone and Shale

The analysis was performed at survey profile line 8. The value for the safety factor is equal to 4.468, which is well above the recommended value of 1.5. Stability analysis in the South Elizabeth Channel indicated the side slopes were be stable for 1 on 3 with a channel depth elevation of 55 feet mean sea level.

Allied Signal Pier in South Elizabeth

Slope stability was performed at a pier that is located toward the western end of the South Elizabeth Channel. The slope stability analysis is shown in Figure 112. The soil and rock profile at this pier are as follows:

Black Silt
Red Brown-to-Brown Silty Clay
Brown Sand
Red Shale

The result of the stability analysis or safety factor computed at this facility equals 2.026. This value is above the recommended value for stability of 1.5. The height of the slope is relatively fairly steep.

Atlantic Salt Company Storage Area

Six slope stability analyses were performed at this facility. The slope stability analyses are shown in Figures 159 through 164. The following soils exist at this location:

Fill Material
Red-brown Silt and Clay
Red-brown Sand

The result of the analysis indicated the safety factors were above 1.9 for slopes of 1 on 3. This would indicate that the new channel deepening would not make the soils next to this facility unstable. The lowest factor of safety was equal to 1.901.

Bayonne Bridge

Five slope stability analyses were performed in the Kill Van Kull underneath the Bayonne Bridge. The stability analyses are shown in Figures 113 through 117. The stability analysis was performed on the Staten Island abutment, which is nearest to the channel deepening. The abutment was assumed to be resting on the basaltic bedrock. The result of the analysis indicated the safety factor against channel side slope failure is above 7.00.

B&O Transfer Bridge in Kill Van Kull

Eight slope stability analyses were performed at the pier next to the Baltimore and Ohio Railroad Transfer Bridge at the Eastern End of the Kill Van Kull. The stability analyses are shown in Figures 118 through 125. The following soils and rock exists at this facility:

Black Silt
Red-brown Sand and Gravel
Serpentinite

The result of the analyses ranges from 1.327 to 59.531. The lowest value occurs when the critical circular arc runs within the Black Silt Layer. The analysis indicated that 1 on 3 slopes are relatively stable for the channel deepening.

Chevron Plant Wharf

Three stability analyses were performed at this Pier located in the Arthur Kill. The stability analyses are shown in Figures 126 through 128. The soil and rock profiles at this facility are as follows:

Fill Material
Riprap
Black Silt
Red Shale Bedrock

The values for the safety factors range from .623 to 1.880 The lowest value of .623 is in the Black Silt layer where the critical circular surface runs through this soil. Although the lowest safety factor is less than one, the pier most likely is seated on top of the Red Shale Bedrock. Deepening the channel with 1 on 3 side slopes would not affect the stability of the structure if the foundation or piling were seated on the Red Shale Bedrock. Structural Analysis of this facility show little movement and no stabilization would be required but further investigation of the black silt layer should be performed in the next phase of the New York Harbor Channel Deepening Project. The channel alignment along this facility was moved away from the Chevron Wharf where there would no affect of the dredging on this facility.

Elizabeth Marina Pier

Four slope stability analyses were performed at this pier structure. The stability analyses are shown in Figures 129 through 132. The existing soils and bedrock at this pier are as follows:

Dark Gray Sand and Silt
Red Brown Silt and Clay
Red Brown Shale

Most of the safety factor values were around 0.5 where the failure circular surface lies in a thick black silt layer. The piles for this facility lie below the black silt layer and rest on bedrock. Structural Analysis of this facility show little movement and no stabilization would be required but further investigation of the black silt layer should be performed in the next phase of the New York Harbor Channel Deepening Project. The channel alignment along this facility was moved away from the Chevron Wharf where there would no affect of the dredging on this facility.

Getty Gas Station on Staten Island

Stability analysis was performed for the Getty Gas Station Building next to the Staten Island Shore along the Kill Van Kull. The existing soils at this pier are as follows:

Gray Silt and Sand
Brown Sands
Red-brown Till (Sand and Gravel)
Red Shale and Sandstone

Two analyses were performed where the safety factor against slope failure was above 1.8. This indicated that 1 on 3 side slopes in soils would be stable against slope failure.

IMTT (Exxon) Pier 3

Five stability analyses performed at the IMTT EXXON Pier 3 to indicate the safety factor for this facility for slopes of 1 on 3. The stability analyses are shown in Figures 135 through 139. The soils and bedrock existing at this pier are as follows:

Gray Sand
Brown Silty Sand (SM)
Red-brown to Brown Silty Gravel

The values for the slope stability range from 3.732 to 3.910. The values are well above the recommended minimum value 1.5. The safety factors indicate that 1 on 3 side slopes are stable at this facility.

Military Ocean Terminal Berth

Four stability analyses were performed at the North Berth of the Military Ocean Terminal near the Kill Van Kull. The stability analyses are shown in Figures 140 through 143. The following soils exist at the North Berth of the Ocean Terminal:

Black Silt
Brown Sand
Red-brown Silty Clay

The result of the analysis indicates that 1 on 3 side slopes for the North Berth is stable for the new channel deepening. The values are above 2.0 for the above soils located at the North East Corner of the Military Ocean Terminal.

Park in Bayonne next to Kill Van Kull Channel

Three slope stability analyses were performed for the pier and bulkhead at the park in Bayonne, New Jersey. The stability analyses are shown in Figures 144 through 146. The soil/rock profile for the park area is as follows:

Black Silt
Red-Brown Sand and Gravel
Diabase Bedrock

The safety factor values for the park stability range from 1.915 to 2.087. These values indicate that 1 on 3 side slopes are stable for a channel deepening of –55 MLW.

Pipeline Crossing in Kill Van Kull

Four stability analyses were performed at the pipe crossing in the Kill Van Kull for the channel side slopes of 1 on 3. The stability analyses are shown in Figures 153 through 156.

The stability analysis was performed with the following soil and rock:

Black Silt
Red-brown Silt and Clay
Red-brown Sand and Gravel
Red Shale and Sandstone

The results of the analysis indicate the safety factor against slope failure or sliding is above 1.8. This indicated that 1 on 3 side slopes are stable against slope failure in the area of the pipeline crossing.

Proctor and Gamble Pier

Two slope stability analyses were performed at the Proctor and Gamble Pier in the Arthur Kill. The stability analyses are shown in Figures 157 through 158. The following soils exists at this facility and properties were inputted into the analysis:

Black Silt
Red brown to Brown Silty Clay
Red Shale

The result of the analysis indicated that slopes of 1 on 3 for very stable with safety factors well above 5.0 for the soil/rock layers present at the Pier.

Richmond Terrace Road

Four slope stability analyses were performed next to Richmond Terrace Road in the Kill Van Kull. A segment of the road lies nearest to the top of the channel slope. The stability analyses are shown in Figure 166. The soil for the channel slope consists of Glacial Till. The values for the stability analysis range from 2.585 to 19.861, which is well above the recommended minimum value of 1.5. The safety factor values indicated that 1 on 3 channel slopes with a channel depth of –55 MLW are relatively stable.

Standard Tank located in Kill Van Kull

One analysis was performed for this location right next to the Standard Tank. The slope stability analysis is shown in Figure 169. The soil profile at the Standard Tank is as follows:

Black Silt
Red Brown Sand (SP)
Red brown to Brown Silty Clay (CL)

The safety factor value for the channel section next to the Standard equals 2.210. This value is above the recommended value of l.5 indicating that a 1 on 3 slopes is stable for a bottom channel deepening of –55 MLW.

Texaco Pier

Five analyses for slope stability were performed at the Texaco Pier to determine the stability of the soils after the channel deepening next to the Pier. The stability analyses are shown in Figures 107 through 111. The following soils and bedrock exist at this Pier and were incorporated into the input file for the slope stability:

Black Silt
Red-brown Silty Clay
Red-brown Sand and Gravel
Basalt and Diabase Bedrock

The results of the analyses indicated the soil/rock layers would be stable after the channel deepening of 55 feet with 1 on 3 side slopes. The lowest value determined equal to 3.606, well above the recommended stability of 1.5.

SLOPE STABILITY RESULTS

The entire list of the slope stability values is show in Table 23 along with the locations of the profile lines and the structures. Reviewing Table 23 indicates that most of the values are above 1.5. This shows that 1 on 3 channel sides slopes for most of the shoreline in the above channels would be stable after the channel deepening or dredging down to a depth of –55 MLW. The safety factors for few areas and at two structures were lower than 1.5. These low value safety factors occur when the critical circular surface or non-circular surface runs through the soft black silt or gray silt and sand layer. These types of soils have relatively low strength properties and are found in the upper portion of the channel soil profiles. To increase the stability of The City of Elizabeth Marina Pier and Chevron Wharf Piers, they may have to be replaced or rebuilt. Other methods maybe to place riprap in front of the pier to add greater stability to the structure after the channel deepening.

GEOTECHNICAL SUMMARY AND CONCLUSIONS

This interim report focuses in greater detail on the geotechnical aspects of the fifty-foot channel project for New York and New Jersey harbors. New data has been included and aspects of the project that were not apparent at the time of the original study have been addressed.

In order to prepare accurate plans and specifications for the dredging contracts that will be awarded as part of the fifty-foot channel project a number of factors need to be resolved. These factors include: the volumes of the various materials that will dredged, the physical properties of the materials, the suitability of the material for ocean disposal, the type of dredging equipment to be used, and the potential affects on nearby culture and habitat.

To accurately quantify the materials and identify their properties a number of investigations were conducted. Regional maps were constructed to define the distribution of soil and rock types that will be encountered. Profiles, cross-sections, and subcrop maps of individual channels showing detailed stratigraphy of the material to be excavated were produced. The dredgeability of the strata that will be encountered was evaluated using computer database, previous dredging records, and test dredge results. New technologies such as the use of geophysical data and geoprobes were evaluated to see if they are affective means to map and quantify soil and rock types in the harbor. The affect of blasting on nearby structures was evaluated. Side slope stability was evaluated based on stratigraphy and soil properties encountered along each channel.

Soil profiles, cross-sections and subcrop maps were prepared for each channel. This data can and has been used to estimate the various types and volumes of sediments and rock that will be encountered. The types of dredging equipment that are most applicable in various reaches within the channels were determined from the distribution of the various soil and rock types. The data will serve as a guide to plan more detailed analysis for HARS and upland disposal testing.

Estimating the volume of sediments that are unsuitable for disposal at the HARS is a major task and component of the cost of most of the future dredging contracts. In view of the fact that these sediments are continually being deposited and move from area to area, it is important to plan the timing of subsurface exploration (surveys, borings, geophysical data and geoprobes) so the data is gathered as close to the onset of dredging as possible. In order to make sure that the data can be gathered, in a timely manner, contractual agreements with companies should be in place.

Various seismic methods such side scan sonar, sub-bottom profiles, and seismic reflection have been evaluated in terms of their applicability of mapping various soil and rock layers. Side scan sonar was determined to be an excellent tool for defining the footprint of recent black silt accumulations along the channel floor, detecting slope failures and identifying channel floor features and for detecting possible obstructions.

Sub-bottom profiles were determined to be 1) a good lead or reconnaissance tool for delineating potentially high rock areas 2) a useful tool for detailing the stratigraphy of side slope and 3) a very good method of mapping the relative thickness of the black silt. Seismic reflection using multiple receivers was used to determine the velocity and dredge-ability of near surface rock areas. The method will be used along with test digs and rock properties to estimate areas that can be dredged without blasting. The reliability of the method will be determined in upcoming projects. The magnetometer and gradiometer were evaluated (along with sub-bottom profiles and seismic reflection) as possible methods to screen for and to identify underground utilities. The magnetometer proved to be a good screening tool particularly in Newark Bay.

Laser induced fluorescence (LIF) and membrane interface technology (MIT) probes were evaluated as a method of detecting hydrocarbons and indirectly sediments that are unsuitable for ocean disposal. The hydrocarbon interval was compared to chemical testing including total petroleum hydrocarbons (TPH) and volatile organic compounds (VOC). Although there were differences between the interval identified by chemical testing as probably unsuitable and that defined by the LIF as hydrocarbon bearing the probes do give consistent and mappable responses. The probes will be used in South Elizabeth to delineate contaminated (unsuitable for the HARS) and probably uncontaminated sediments. The probes were also evaluated and shown to be an excellent method for accurately determining the thickness of the black silt areas where these unsuitable sediments are known to be concentrated.

An analysis was conducted to determine the affects that blasting will have on nearby structures. Forty-eight nearby structures were identified and evaluated using peak particle velocity and peak ground acceleration as criteria to determine potential damage. Of the forty-eight structures analyzed, thirteen (13) will not be affected by the vibrations from standard blasting patterns; (29) will require reduced blasting vibrations to maintain their structural integrity; and (6) will require further structural analysis to insure their safety.

A test dig was conducted to determine if the Serpentinite in Kill Van Kull could be dredged without blasting. The results of the test dig indicated that approximately twenty-five percent (25%) of the area could be dredged. A follow-up program to better define the areas that can and cannot be dredged was recommended and is in progress.

Slope Stability Analysis indicates that 1 on 3 channel sides slopes will be stable after the channel is dredged to a depth of –55 MLW. The safety factors for a few areas and at two structures were lower than 1.5. These low value safety factors occur when the critical circular surface or non-circular surface runs through the soft black silt or gray silt and sand layer. These types of soils have relatively low strength properties and are found in the upper portion of the channel side slopes. Some of this soft soil layers are near pier structures such the Elizabeth Marina Pier Facility and the Chevron Warf. Further investigation and analysis, including slope stability, is recommended for areas containing thick layers of black or gray silt, especially in the Arthur Kill, Kill Van Kull, Port Jersey,

Newark Bay and South Elizabeth Channels. This can be performed during the plans and specifications phase of the New York Harbor Channel Deepening Project.

TABLE 23
SAFETY FACTOR VALUES FOR SLOPE STABILITY

CHANNEL	FILE NAME	FIGURE NO.	SLOPE STAB	CIRCULAR SEARCH
Arthur Kill	AKProf3a.ut4	49	9.233	NO
Arthur Kill	AKProf3a2.ut4	50	3.650	YES
Arthur Kill	AKProf4.ut4	51	3.862	NO
Arthur Kill	AKProf4a.ut4	52	3.944	NO
Arthur Kill	AKProf4a-1.ut4	53	1.366	NO
Arthur Kill	AKProf6.ut4	54	4.306	YES
Arthur Kill	AKProf6a.ut4	55	4.270	YES
Arthur Kill	AKProf7f.ut4	56	6.272	YES
Arthur Kill	AKProf7fw.ut4	57	1.964	Non-Circular Surface
Arthur Kill	AKProf21.ut4	58	59.058	NO
Kill Van Kull	AKProf21aR.ut4	59	5.854	NO
Kill Van Kull	AKProf21bnwrev.ut4	60	3.276	Non-Circular Surface
Kill Van Kull	AKProf21brev.ut4	61	5.819	NO
Kill Van Kull	AKProf21f.ut4	62	15.165	NO
Kill Van Kull	AKProf22rev.ut4	63	7.597	NO
Kill Van Kull	AKProf22arev.ut4	64	3.002	YES
Kill Van Kull	AKProf22brev.ut4	65	2.806	YES
Kill Van Kull	AKProf23arev.ut4	66	4.319	YES
Kill Van Kull	AKProf23nwrev.ut4	67	5.107	NO
Kill Van Kull	AKProf23nw1rev.ut4	68	3.718	YES
Kill Van Kull	AKProf23nw2rev.ut4	69	5.062	Non-Circular Surface
Kill Van Kull	AKProf23nw3rev.ut4	70	1.289	Non-Circular Surface
Kill Van Kull	AKProf23nw4rev.ut4	71	1.359	Non-Circular Surface
Kill Van Kull	AKProf24rev.ut4	72	3.630	YES
Kill Van Kull	AKProf24arev.ut4	73	3.631	NO
Kill Van Kull	AKProf24brev.ut4	74	2.207	YES
Kill Van Kull	AKProf26.ut4	75	3.630	NO
Kill Van Kull	AKProf26a.ut4	76	3.728	NO
Kill Van Kull	AKProf26b.ut4	77	1.402	YES
Kill Van Kull	AKProf26c.ut4	78	0.971	YES
Kill Van Kull	AKProf26d.ut4	79	1.906	YES
Kill Van Kull	AKProf26w.ut4	80	3.096	NO
Kill Van Kull	AKProf26w1.ut4	81	0.873	Non-Circular Surface
Kill Van Kull	AKProf28a.ut4	82	39.730	YES
Kill Van Kull	AKProf28b.ut4	83	42.289	YES
Kill Van Kull	KVKProf26.ut4	84	2.230	YES
Kill Van Kull	KVKProf27.ut4	85	2.572	NO
Kill Van Kull	KVKProf27a.ut4	86	20.696	NO
Kill Van Kull	KVKProf27c.ut4	87	64.010	NO
Newark Bay	KVK4BPR14frev.ut4	88	2.311	NO
Newark Bay	KVK4BPR14f1.ut4	89	2.311	NO
Newark Bay	KVK4BPR14f2rev1.ut4	90	2.006	YES

TABLE 23
SAFETY FACTOR VALUES FOR SLOPE STABILITY

CHANNEL	FILE NAME	FIGURE NO.	SLOPE STAB	CIRCULAR SEARCH
Newark Bay	KVK4BPR16arev.ut4	91	6.788	YES
Newark Bay	KVK4BPR17rev.ut4	92	10.041	YES
Port Elizabeth	KVK4BPR9f.ut4	93	4.143	YES
Port Elizabeth	KVK4BPR10f.ut4	94	3.434	YES
Port Elizabeth	KVK4BPR10f1.ut4	95	3.968	NO
Port Elizabeth	KVK4BPR11.ut4	96	2.349	NO
Port Elizabeth	KVK4BPR11a.ut4	97	1.939	YES
Port Elizabeth	KVK4BPR11b.ut4	98	2.517	YES
Port Elizabeth	KVK4BPR13b.ut4	99	18.290	NO
Port Elizabeth	KVK4BPR13c.ut4	100	2.767	NO
Port Elizabeth	KVK4BPR13d.ut4	101	2.116	YES
South Elizabeth	kvk4_8nw.ut4	102	7.484	Non-Circular Search
South Elizabeth	kvk4b8nw.ut4	103	8.180	Non-Circular Search
South Elizabeth	kvk4BPR8.ut4	104	15.295	NO
South Elizabeth	kvk4BPR8a.ut4	105	4.468	NO
South Elizabeth	kvk4BPR8b.ut4	106	6.719	NO
Texaco, Pier 9 Newark Bay	KVKTEXP9.ut4	107	3.147	YES
Texaco, Pier 9 Newark Bay	KVKTEXP9a.ut4	108	6.969	NO
Texaco, Pier 9 Newark Bay	KVKTEXP9B.ut4	109	5.615	NO
Texaco, Pier 9 Newark Bay	KVKTEXP9B1.ut4	110	3.522	YES
Texaco, Pier 9 Newark Bay	KVKTEXP9c.ut4	111	4.241	YES
South Elizabeth	Allied Signal Pier	112	2.026	YES
Kill Van Kull	BAY1.ut4	113	12.349	NO
Kill Van Kull	BAY1a.ut4	114	7.427	YES
Kill Van Kull	BAY1b.ut4	115	7.360	YES
Kill Van Kull	BAY1c.ut4	116	7.360	YES
Kill Van Kull	BAY2aby.ut4	117	13.189	YES
Pier Near B&O Transfer Bridge, Richmond Terrace Kill Van Kull	RichBOBR.out	118	12.657	NO
Pier Near B&O Transfer Bridge, Richmond Terrace Kill Van Kull	RichBOBR1.ut4	119	59.531	NO

TABLE 23
SAFETY FACTOR VALUES FOR SLOPE STABILITY

CHANNEL	FILE NAME	FIGURE NO.	SLOPE STAB	CIRCULAR SEARCH
Pier Near B&O Transfer Bridge, Richmond Terrace Kill Van Kull	RichBOBR1a.ut4	120	3.490	YES
Pier Near B&O Transfer Bridge, Richmond Terrace Kill Van Kull	RichBOBR1b.ut4	121	3.149	YES
Pier Near B&O Transfer Bridge, Richmond Terrace Kill Van Kull	RichBOBR2.ut4	122	2.650	YES
Pier Near B&O Transfer Bridge, Richmond Terrace Kill Van Kull	RichBOBR3a.ut4	123	2.313	YES
Pier Near B&O Transfer Bridge, Richmond Terrace Kill Van Kull	RichBOBRa.ut4	124	2.558	YES
Pier Near B&O Transfer Bridge, Richmond Terrace Kill Van Kull	RichBOBRb.ut4	125	2.561	YES
Arthur Kill	Chevron 17b.ut4	126	1.964	Non-Circular Surface
Arthur Kill	Chevron 17b1.ut4	127	.623	Non-Circular Surface
Arthur Kill	Chevron 17f.ut4	128	1.880	Non-Circular Surface
Arthur Kill City of Elizabeth Marina 16-3	ElizaMarina16-3a.ut4	129	3.102	YES
Kill Van Kull City of Elizabeth Marina 16-4 Marina 16-1	ElizaMarina16-4.ut4	130	0.827	YES
Kill Van Kull City of Elizabeth Marina 16-1	ElizaMarina2a.ut4	132	.494	YES
Kill Van Kull Staten Island Shore Getty Gas Station	Getty.ut4	133	1.867	YES

TABLE 23 SAFETY FACTOR VALUES FOR SLOPE STABILITY				
CHANNEL	FILE NAME	FIGURE NO.	SLOPE STAB	CIRCULAR SEARCH
Kill Van Kull Staten Island Shore Getty Gas Station	Gettya.ut4	134	2.471	YES
Kill Van Kull IMTT (Exxon) Pier 3	KVKIMTTExxonPier3b.ut4	135	3.910	NO
Kill Van Kull IMTT (Exxon) Pier 3	KVKIMTTExxonPier3c.ut4	136	3.732	NO
IMTT (Exxon) Pier 3 Salt Storage, Richmond Terrace	Richmdsalt5b.ut4	137	1.632	YES
IMTT (Exxon) Pier 3 Salt Storage, Richmond Terrace	Richmond1.ut4	138	154.078	NO
IMTT (Exxon) Pier 3 Salt Storage, Richmond Terrace	Richmond12.ut4	139	1.545	YES
Kill Van Kull Motby Berth	Motbynberth1.ut4	140	2.158	NO
Kill Van Kull Motby Berth	Motbynberth2.ut4	141	2.492	YES
Kill Van Kull Motby Berth	Motbynberth2a.ut4	142	2.514	NO
Kill Van Kull Motby Berth	Motbynberth2b.ut4	143	2.492	YES
Kill Van Kull	KVK4Park8.ut4 KVK4Park8-1.ut4	144	2.087	YES YES
Kill Van Kull	KVK4Park8a.ut4	145	1.915	YES
Kill Van Kull	KVK4Park8b.ut4	146	2.087	YES
Kill Van Kull	KVKTbox8.ut4	147	2.087	YES
Kill Van Kull	KVKTbox8a.ut4	148	2.328	YES
Arthur Kill	KVKTbox8b.ut4	149	10.092	YES
Arthur Kill	KVKTbox8c.ut4	150	0.842	YES
Name of Box 17	KVKBOX17.ut4	151	6.182	NO
Name of Box 17	KVKBOX17a.ut4	152	2.102	NO
Kill Van Kull	Pipelinea.ut4	153	1.818	YES
Kill Van Kull	Pipelineb.ut4	154	2.167	YES
Kill Van Kull	Pipelinec.ut4	155	2.152	YES
Kill Van Kull	Pipelinec1.ut4	156	2.152	YES
Arthur Kill Proctor & Gamble	Proctor&Gamble Pier.ut4	157	10.096	YES

TABLE 23
SAFETY FACTOR VALUES FOR SLOPE STABILITY

CHANNEL	FILE NAME	FIGURE NO.	SLOPE STAB	CIRCULAR SEARCH
Arthur Kill Proctor & Gamble	Proctor&Gamble Pier1.ut4	158	7.710	YES
Kill Van Kull Salt Storage, Richmond Terrace (5A)	RichSalt5b.ut4	159	9.328	YES
Kill Van Kull Salt Storage, Richmond Terrace (5B)	RichSalt5-bC.ut4	160	9.328	YES
Kill Van Kull Salt Storage, Richmond Terrace (5B)	RichSalt5b-1.ut4	161	1.901	YES
Kill Van Kull Salt Storage, Richmond Terrace (5A)	Richsalt5c.ut4	162	9.328	YES
Kill Van Kull Salt Storage, Richmond Terrace (5A)	Richsalt5e.ut4	163	2.282	YES
Kill Van Kull Salt Storage, Richmond Terrace (5A)	Richsalt5f.ut4	164	15.022	NO
Richmond Terrace	RICHTERR1.ut4	165	19.861	NO
Richmond Terrace	RICHTERR1a.ut4	166	12.707	NO
Richmond Terrace	RICHTERR1b.ut4	167	2.585	NO
Richmond Terrace	RICHTERR1c.ut4	168	3.675	YES
Kill Van Kull Standard Tank	Standardtank7.ut4	169	2.210	YES
Newark Bay	KVKTEXPier9.ut4	170	8.243	YES
Newark Bay	KVKTEXPier9A.ut4	171	3.685	YES
Arthur Kill Channel	AkProf7ba.ut4	172	22.562	YES
Arthur Kill Channel	AkProfrev7b	173	.118	YES
Kill Van Kull	KVK4BPR8c	174	1.488	YES
Kill Van Kull	KVK4BPR8c1	175	3.220	YES
Kill Van Kull	KVK4BPRF13b	176	5.642	YES
Kill Van Kull	KVK4BPRF13c	177	1.488	YES
Kill Van Kull	KVK4BPRF13c	178	6.608	YES

TABLE 23
SAFETY FACTOR VALUES FOR SLOPE STABILITY

CHANNEL	FILE NAME	FIGURE NO.	SLOPE STAB	CIRCULAR SEARCH
Kill Van Kull	KVK4BPR13cr1	179	.246	NO
Kill Van Kull	KVK4BPR13cr2	180	.246	NO
Port Jersey	PortJersey	181	2.057	YES
Port Jersey	PortJerseya	182	.979	YES

Table 24

LAB TEST RESULTS FOR SELECTED SOIL SAMPLES

Boring Log #	Line Profile	Depth	Sample #	Description	Moisture Content (%)	Moist Unit Weight	Cohesion	Phi Angle
AK 95-1	7 & 19	7.5 - 8.5'	2	SM, red brown sand				
AK 95-2	7 & 19	8 - 11'	2	SM-ML				
AK 95-8	5 & 6	0 - 8.9'	1	MH				
AK 95-12	4 & 5	0 - 9.6'	1	MH-CH				
AK 95-15	3b & 4	10.1 - 11'	2	CL-ML				
AK 95-18	3a & 3b & 4	9 - 10'	4	SC				
AK 95-21	1 & 2	1.5 - 3'	2	CH				
		9.5 - 10.5'	5	CL				
AK 95-24	1 & 2	3.9 - 6.2'	2	CL-ML				
AK 95-26	near 1	0 - 10'	1	MH				
		10 - 12'	2	CL				
		12 - 12.5'	3	CL				
		13 - 15'	4	CL				
		15 - 16.5'	5	CL				
		16.5 - 18'	6	CL				
AK 95-28	near 1	4.3 - 8.5'	1	SM				
		9 - 12'	2	SM				
AK 95-64	out	1 - 3.9'	1	MH				
AK-95-67	off	1.7' - 3'	1	ML, brown silt				
AK 01-SFI-5	7	5' (21.9')	3	OH, soft gray organic	62	101.3	0.081	24.7
		5' (21.9')	3	OH, soft gray organic		101.6		
KVK 95-21	24 & 25	1.5 - 3'	2	CH				
KVK 95-53	17 & 16	0 - 1'	1	MH, CH				
KVK 95-58	out	6 - 8'	3	SP				
KVK 95-60	out	0 - 3'	1	MH				
KVK 95-65	off	3.2 - 5'	3	GC				
NB 98-23	16	12 - 14'	4	ML				

Table 24

LAB TEST RESULTS FOR SELECTED SOIL SAMPLES

Boring Log #	Line Profile	Depth	Sample #	Description	Moisture Content (%)	Moist Unit Weight	Cohesion	Phi Angle
AK 95-22	1 & 2	6.5 - 8'	3	CL				
AK-95-78	off	0 - 1.5'	1	MH, GC				
AK-98-3	2 & 3a	7.85'	UD-1E	CL-ML, gray organic	99	90	0.08/0.070	1.6/11.3
		7.4'	UD-1D	CL-OL, gray organic	99.2	89.9		
		7.1'	UD-1C	CL-OL, gray organic	99.9	89.3	0.11	13.4
		6.65'	UD-1B	CL-OL, dark brown organic	86.5	93.7		5.71
AK-98-10	4 & 5	28.35'	UD-1C	CL-ML, gray	72.1	99.3	0	11.8
	4 & 5	27.45'	UD-1A	CL-ML, gray	69.4	103.4	0.00	11.7/11.8
AK-98-11A*	???	3.20'	UD-1A	CL-OL, gray organic	102.0	91.5	0/0.210	0.18/1.48
		5.20'	E	CL-OL, gray organic	108.1	90.7	0.21	1.48
		3.7'	1B	CL-OL, gray organic	99	91	0.12	13.9
		4.3'	1C	CL-OL, gray organic	110.9	88.4		
		4.8'	1D	CL-OL, gray	120.1	87.3		
AK 01-SFI-1	1	9.2' (21.9')	5A	OH	80			
		9.9' (23.7')	6	OH, m. gray organic	71	99.4	0.182	15.1
AK 01-SFI-2	3a	7' (13.4')	4	OH, soft gray organic	75	96.7	0.048	25.6
		7' (13.4')	4	OH, soft gray organic		99.3		
AK 01-SFI-3	4	7' (11.1')	4	SC, gray organic	59	110.1	0.017	30.9
		7' (11.1')	4	SC, gray organic		101.2		
		15' (19.1')	8		21			
AK 01-SFI-4	5	5' (8.8')	3	OH, soft gray organic	75	97.6	0.035	29.2
		5' (8.8')	3	OH, soft gray organic		99.3		
		9' (12.8')	5	OH	72			
		19' (22.8')	10	SP	19			
AK 01-SFI-6	7	8.4' (23.9')	9	OH, medium gray organic	71	99.6	0.169	14.5
		8.4' (23.9')	9	OH, medium gray organic		98.3		
		18.4' (13.9')	4	OH, soft gray organic	59	103.0	0.066	18.3
		18.4' (13.9')	4	OH, soft gray organic		103.1		
E-01-SFI-1	9	13' (10.8')	3	SM, gray organic	47	107.2	0.048	27.4
		13' (10.8')	3	SM, gray organic		110.8		
		39' (36.9')	16	CL		130.9	0.530	15.1
		36.9' ()	16	CL	24	128.9		
E-01-SFI-2	11	10.5' (32.4')	6	CL, stiff red-brown	28	127.0	0.104	

Table 24

LAB TEST RESULTS FOR SELECTED SOIL SAMPLES

Boring Log #	Line Profile	Depth	Sample #	Description	Moisture Content (%)	Moist Unit Weight	Cohesion	Phi Angle
		10.5' (32.4')	6	CL, stiff red-brown		126.6		
KVK 95-9	off	3.5'	2	GC				
KVK 98-11	21 & 22	22.5 - 23.7'	6	SP-SM				
KVK 01-SFI-1	18	3' (9.7')	2A	OH				
		5' (11.7')	3A	SM				
		7' (13.7')	4	SM				
		11.3' (18.0')	6	CL				
		21.3' (28.0')	10	ML				
		29.4' (35.9')	14	SM				
KVK 01-SFI-2	19	4.8' (10.5')	3	SC, gray	141	80.7	0.017	29.2
		4.8' (10.5')	3	SC, gray		78.3		
		.8' (6.5')	1A					
		2.8' (8.5')	2					
		6.8' (12.5')	4					
		8.8' (14.5')	5					
		10.8' (16.5')	6A					
KVK 01-SFI-2A	19	13.8' (19.5')	8	SC				
KVK 01-SFI-2B	19	13.8' (19.5')	8	SC				
KVK 01-SFI-3	21	3' (34.9')	2	SP-SC				
		11.3' (43.4')	6	SC				
KVK 01-SFI-5	23	2.9' (19.3')	2B	SC				
		4.9' (21.3')	3	SC				
		8.9' (25.3')	5	SP-SC				
KVK 01-SFI-4	22	1' (35.4')	1A	SP-SM				
		3' (37.4')	2	SP-SM				
		7.5' (41.9')	4	SP-SM				
KVK 01-SFI-6	26	31.4' (37.5')	11	SC, gray organic	45	107.3	0.070	21.3
	26					108.5		
KVK 01-SFI-6B	26	23.1' (29.2')	B3	OH, medium gray organic	68	92.9	0.130	13.4
		23.1' (29.2')	B3	OH, medium gray organic		94.7		
		28.2' (34.3')	B5B					
		50.1' (56.2')	B9	SP-SM				
KVK 01-SFI-7	28	3.2' (32.6')	2	SP-SM				
KVK 01-SFI-8	28	7' (22.1')	4	OH				
KVK 01-SFI-8A	28	18.1' (33.2')	9					
		34.8' (49.9')	15B					
KVK 01-SFI-8B	28	18.1' (33.2')	9	SP				
		34.8' (49.9')	15B	SP				
NB 98-36	16	8 - 10'	5	CH				
NBN 01-SFI-1	15	3.1' (14.6')	2A					
		5.1' (16.6')	3A	SM				
		7.1' (18.6')	4A	ML				
		14.7' (26.3')	8	CL				
NBN 01-SFI-2	15	16.5' (22.9')	9	CL, stiff red-brown	22	133.3	0.410	22.7
		16.5' (22.9')	9	CL, stiff red-brown		129.2		
		4.8' (11.3')	3	SC, gray	27	126.4	0.018	43.2

Table 24

LAB TEST RESULTS FOR SELECTED SOIL SAMPLES

Boring Log #	Line Profile	Depth	Sample #	Description	Moisture Content (%)	Moist Unit Weight	Cohesion	Phi Angle
NBN 01-SFI-2 (cont.)		4.8' (11.3')	3	SC, gray		125.2		
		1' (7.4')	1					
		2.8' (9.3')	2	OH				
		6.8' (13.3')	4					
		8.8' (15.3')	5	SM				
		12.7' (19.2')	7B	SC				
		18' (24.4')	10	CL				
		24.1' (30.5')	13	CL				
NBN 01-SFI-3	16	11.5' (19.1')	6	CL, stiff red-brown	26	127.1	0.502	11.8
		5.8' (13.3')	3	SC, gray organic	40	110.6	0.076	12.9
		3.8' (11.3')	2A					
		7.8' (15.3')	4					
		13' (20.5')	7	CL				
		17.5' (26.1')	9	CL				
NBN 01-SFI-4	17	7' (35.3')	4	OH, soft black organic	94	90.1	0.036	18.2
		7' (35.3')	4	OH, soft black organic		88.7		
		23' (51.3')	11	ML, red brown	35	121.4	0.182	15.1
		23' (51.3')	11	ML, red brown		117.9		
		1' (29.3')	1					
		3' (31.3')	2A	OH				
		5' (33.3')	3	SC				
		13' (41.3')	7A	SC				
		19' (47.3')	9	CL				
NBN 01-SFI-5	17	9' (15')	5	SC, gray	38	111.9	0.017	26.5
		9' (15')	5	SC, gray		111.4		
		3' (9')	2	SM				
		7' (13')	4	CH				
		11' (17')	6	SM				
		13' (19')	7A					
		17' (23')	9	SP-SM				
NBN 01-SFI-5B	17	27' (33')	15	ML, red brown	30	122.0	0.418	13.4
		27' (33')	15	ML, red brown		122.8		
		29' (35')	16	CL				
		49' (55')	26	CL				
SE 01-SFI-01	8	22.7' (37.2')	12	CL, medium red brown	35	118.4	0.167	16.6
						118.6		
		2.7' (17.2')	2	CL				
		6.7' (21.1')	4A	SM				

Table 25

SOFT BLACK SILT WITH NO N-VALUES

		BLACK SILT (WOR)		BLACK CLAYEY SILT (WOR/WOH)	
Boring Log #	**Line Profile**	**Depth**	**Sample #**	**Depth**	**Sample #**
AK 95-1	7 & 19	--	--	0 - 7.4'	1
AK 95-2	7 & 19	--	--	0 - 8'	1
AK 95-3	near 7	--	--	.5 - 6.5'	1
AK 95-8	5 & 6	--	--	0 - 8.9'	1
AK 95-9	4 & 5	--	--	0 - 9.2'	1
AK 95-10	4 & 5	--	--	0 - 5'	1
AK 95-12	4 & 5	--	--	0 - 9.6'	1
AK 95-13	4 & 5	--	--	0 - 9.7'	1
AK 95-14	4 & 5	--	--	0 - 7.1'	1
AK 95-15	3b & 4	--	--	0 - 10.1'	1
AK 95-16	3a & 3b & 4	--	--	0 - 4.1'	1
AK 95-18	3a & 3b & 4	--	--	0 - 5.5'	1
AK 95-20	1 & 2	--	--	0 - 5.7'	1
AK 95-21	1 & 2	--	--	0 - 7.2'	1
AK 95-24	1 & 2	--	--	0 - 3.9'	1
AK 95-25	1 & 2	--	--	0 - 6'	1
AK 95-26	near 1	--	--	0 - 9.5'	1
AK 95-28	near 1	--	--	4.3 - 8.5'	1
AK 95-30	out	--	--	0 - 2.5'	1
AK 95-33	out	--	--	0 - 3'	1
AK 95-41	out	--	--	0 - 2.5'	1
AK 95-52	out	--	--	0 - 1.4'	1
AK 95-53	out	--	--	0 - 2.5'	1
AK 95-64	out	--	--	1 - 3.9'	1
AK-95-67	off	0 - 1'	none	--	--
AK-95-70	off	0 - 3'	none	--	--
AK-95-77	off	0 - 1.5'	none	--	--
AK-98-5	2 & 3a	0 - 11.5'	1, 2, 3, 4, 5, 6	--	--
AK-01-1	7	0 - 2'	1	--	--
AK 01-SFI-5	7	0 - 1'	1	--	--
E-98-13	out	0 - 2'	1	--	--
E 00-7-3	out	0 - .5'	1	--	--
E 00-7-4	out	0 - 1.7'	1	--	--
E 00-7-5	out	0 - .5'	1	--	--
E 01-4	out	0 - 1'	1	--	--
KVK 95-21	24 & 25	--	--	0 - .9'	1
KVK 95-42	18 & 19	0 - 5'	none	--	--
KVK 95-52	17 & 16	0 - 4.5'	1	--	--
KVK 95-53	17 & 16	0 - .5'	1	--	--
KVK 95-54	out	0 - 6.8'	none	--	--
KVK 95-55	out	0 - 4.5'	1	--	--
KVK 95-56	out	--	--	0 -3.7'	1
KVK 95-57	out	0 - 3'	1	--	--
KVK 95-58	out	0 - 5'	1	--	--
KVK 95-60	out	0 - 2.3'	1	--	--
KVK 95-61	out	0 - 0.5'	1	--	--
KVK 95-62	out	0 - 0.5'	1	--	--
KVK 95-64	out	--	--	0 - 1.2'	1
KVK 95-65	off	--	--	0 - 1.7'	1
KVK 95-66	off	0 - 0.5'	1	--	--
KVK 95-69	off	0 - 0.5'	1	--	--
KVK 99-1-1	off	0 - 2.5'	1, 2	--	--
KVK 99-1-2	off	0 - .5'	1	--	--
KVK 99-1-4	off	0 - .5'	1	--	--
KVK 99-4-17	18 & 19	--	--	0 - 6'	1
NB 00-8-1	17 & 18	0 - 3'	none	--	--
NB 00-8-2	17 & 18	0 - 2'	none	--	--
NBN-01-11	17 & 18	0 - 1.5'	1	--	--
NBN-01-12	17 & 18	1 - 2'	1	--	--

Table 25

SOFT BLACK SILT WITH NO N-VALUES

		BLACK SILT (WOR)		BLACK CLAYEY SILT (WOR/WOH)	
Boring Log #	**Line Profile**	**Depth**	**Sample #**	**Depth**	**Sample #**
NBN 01-13	17 & 18	0 - 2.5'	1	--	--
NBN 01-14	17 & 18	0 - 0.5'	1	--	--
NBN 01-16	17 & 18	0 - 0.5'	1	--	--
NBN 01-17	17 & 18	0 - 2.6'	1	--	--
NBN 01-18	17 & 18	0 - .3'	1	--	--
NBN- 01-20	17 & 18	0 - .5'	none	--	--
NBN 01-21	17 & 18	0 - 4.5'	1, 2	--	--
NBN 01-22	no	0 - 9'	none	--	--
NBS 01-10	out	0 - 0.7'	1	--	--
NBS 98-31	no	0 - 2'	1	--	--
PA 2-453	out	0 - 1.5'	1	--	--
	out	2.5 - 4'	2	--	--
	out	5 - 6.5'	3	--	--
	out	7.5 - 9'	4	--	--
PA 2-484	17 & 18	--	--	40 - 41.5'	1
PN 98-3	no	0 - 1.3'	1	--	--
PNP 98-19	off	0 - 1.3'	1	--	--
SE 01-03	near 8	0 - 2'	none	--	--
27	out	0 - 5'	1, 2, 3	--	--
28	out	0 - 6'	1, 2, 3	--	--
35	out	0 - 4'	1, 2	--	--

Table 25

SOFT BLACK SILT WITH NO N-VALUES

		BLACK SILT (WOR)		BLACK CLAYEY SILT (WOR/WOH)	
Boring Log #	**Line Profile**	**Depth**	**Sample #**	**Depth**	**Sample #**
AK 95-22	1 & 2	--	--	0 - 4.4'	1
AK-95-44	out	0 - 2.6'	1	--	--
AK 95-51	out	--	--	0 - .5'	1
AK-95-78	off	0 - 1'	1	--	--
AK-98-3	2 & 3a	0 - 6'	1, 2, 3	--	--
AK-98-10	4 & 5	0 - 2'	1	--	--
	4 & 5	2 - 2.5'	2	--	--
AK-98-11A*	???				
AK 01-SFI-1	1	0 - 3.5'	1, 2	--	--
AK 01-SFI-2	3a	0 - 1'	1	--	--
AK 01-SFI-3	4	0 - 3'	1, 2	--	--
E 01-5	out	0 - 4'	1, 2	--	--
E-01-SFI-1	9	0 - 1.5'	1	--	--
E-01-SFI-2	11	0 -.7'	1	--	--
KVK 95-9	off	0 - 3'	1	--	--
KVK 98-11	21 & 22	0 - 4'	1	--	--
KVK 01-16	20 & 21	--	--	0 - 2'	1
KVK 01-SFI-1	18	0 - 3'	1, 2	--	--
KVK 01-SFI-2	19	0 - 11.3'	1, 2, 3, 4, 5	--	--
KVK 01-SFI-6	26	0 - 14'	1, 2, 3, 4, 5, 6, 7	--	--
	26	18.5 - 22'	Sb1, Sb2	--	--
	26	24 - 26'	Sb4	--	--
KVK 01-SFI-7	28	0 - 1'	1	--	--
KVK 01-SFI-8	28	0 - 7.5'	1, 2, 3, 4	--	--
NB 98-35	17 & 18	0 - 14'	1, 2, 3, 4, 5, 6, 7	--	--
NBN 01-SFI-1	15	0 - 2.5'	1, 2	--	--
NBN 01-SFI-2	15	0 - 4'	1, 2	--	--
NBN 01-SFI-3	16	0 - 3.3'	1, 2	--	--
NBN 01-SFI-4	17	0 - 3'	1, 2	--	--
PA 2-454	out	0 - 1.5'	1	--	--
	out	2.5 - 4'	2	--	--
	out	5 - 6.5'	3	--	--
	out	7.5 - 9'	4	--	--
	out	10 - 11.5'	5	--	--
	out	12.5 - 14'	6	--	--
	out	15 - 16'	7	--	--
PA 2-458	off	0 - 1.5'	1	--	--
	off	2 - 3.5'	2	--	--
	off	4.5 - 6'+	3	--	--
PA 2-459	off	0 - 1.5'	1	--	--
	off	2 - 3.5'	2	--	--
PA 2-487	17 & 18	--	--	41.5 - 43'	1
PA 2-494-01	no	0 - 3.5'	1	--	--
SE 01-04	near 8, 17 & 18	0 - 5'	none	--	--
SE 01-SFI-01	8	0 - 2'	none	--	--

FIGURE 1. Index Map

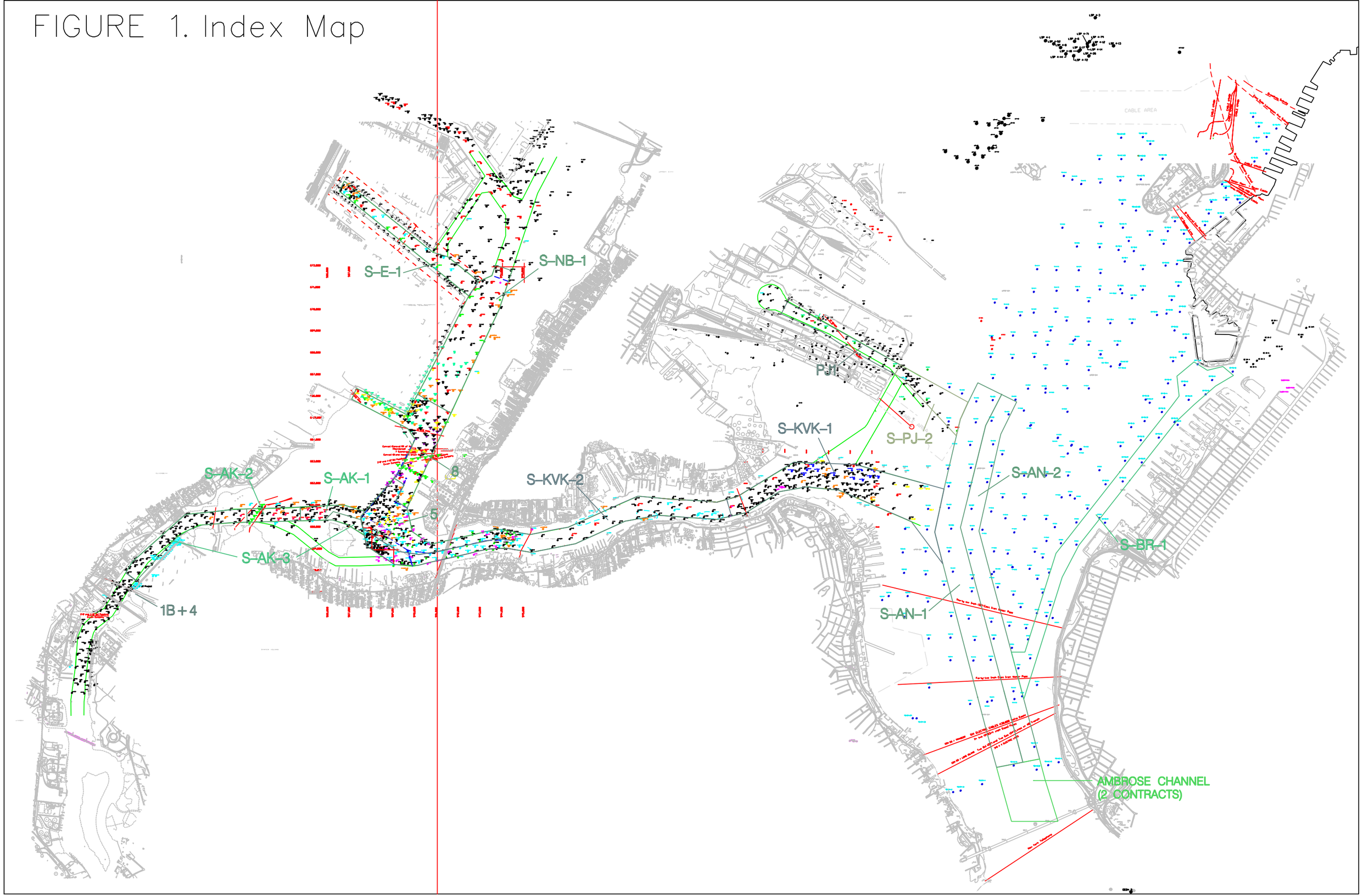


Figure_1.dgn 10/14/2003 11:02:54 AM

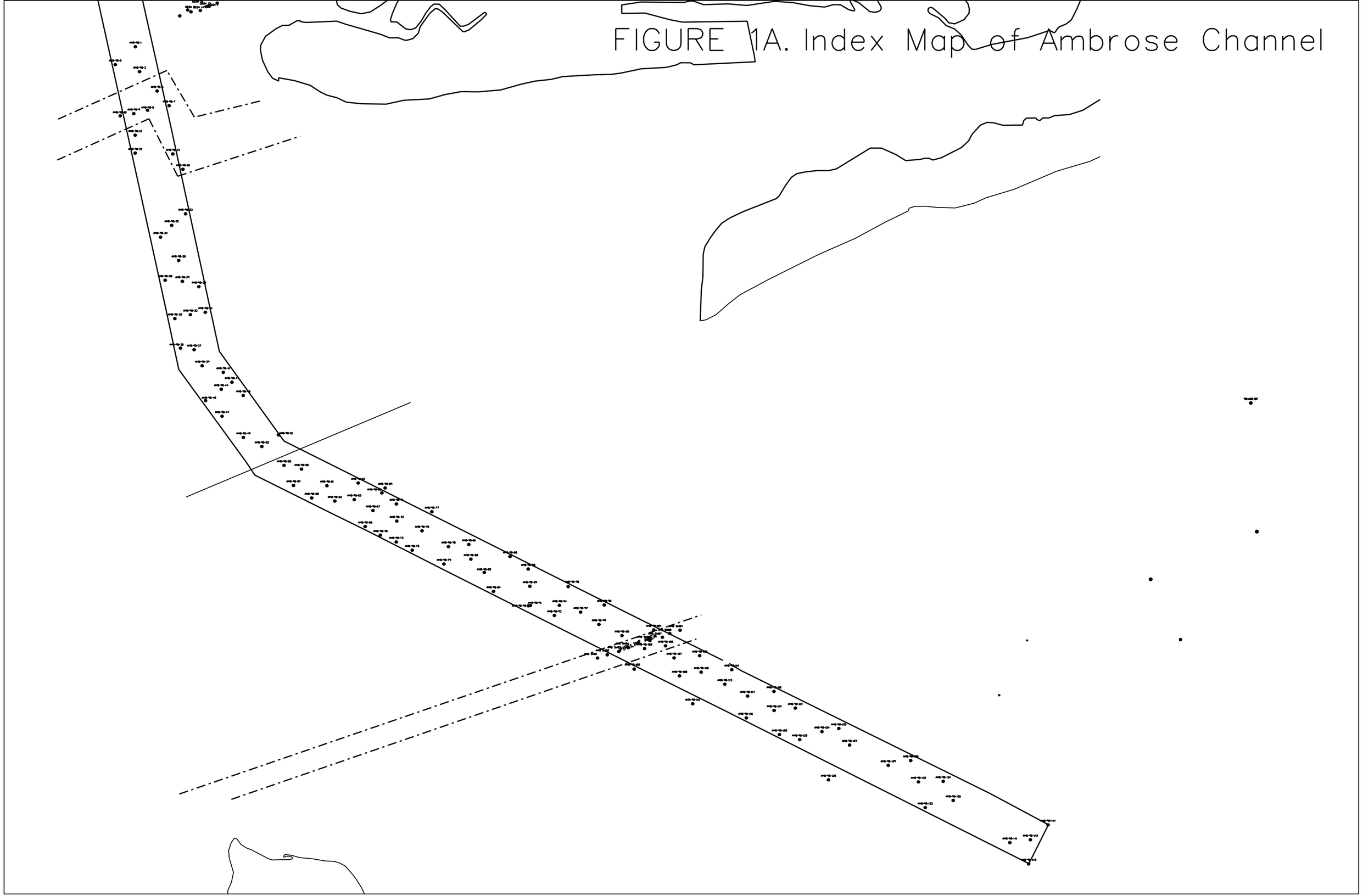
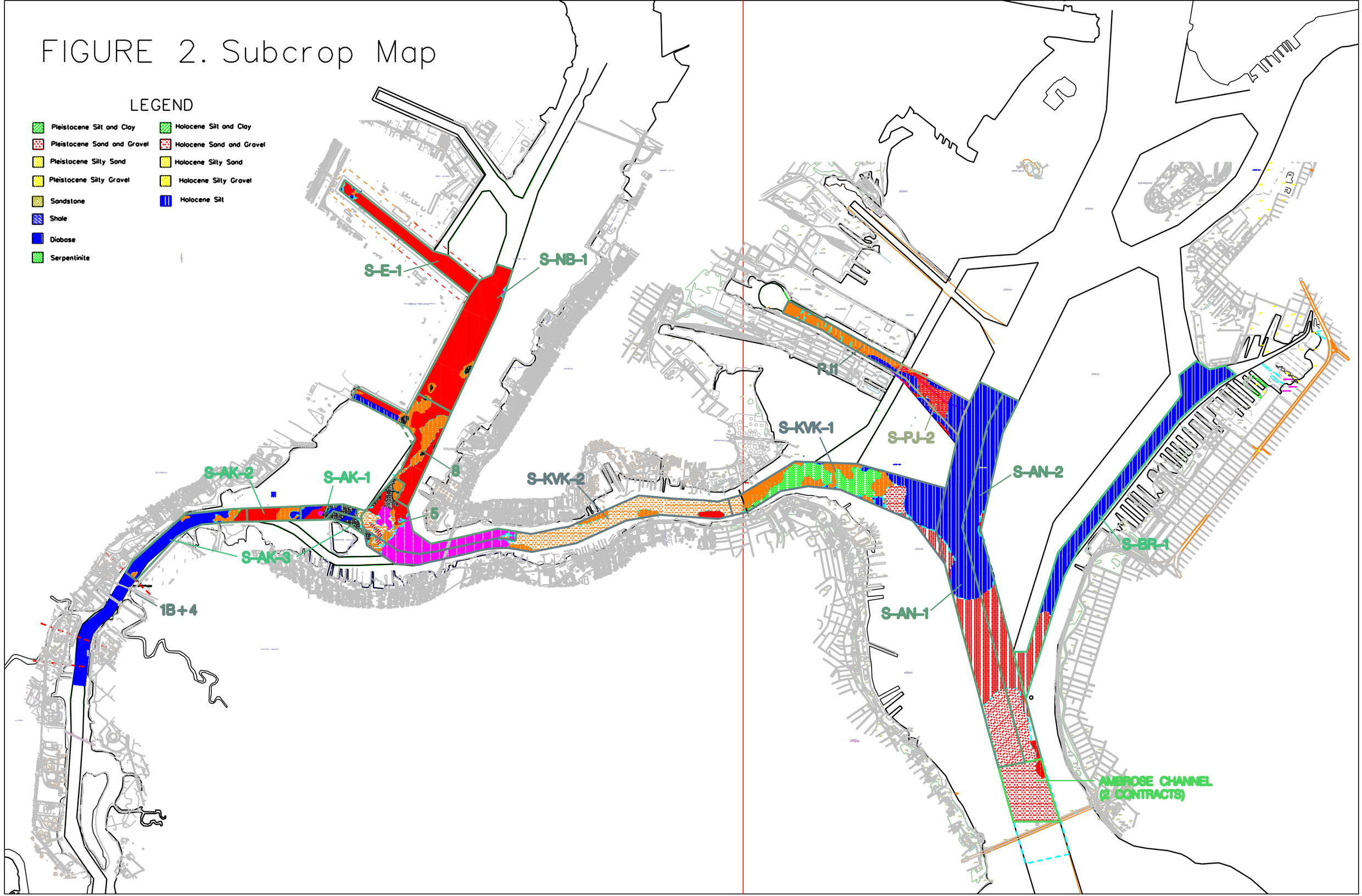


FIGURE 1A. Index Map of Ambrose Channel

Figure_1.dgn 11/03/2003 07:08:08 PM

FIGURE 2. Subcrop Map



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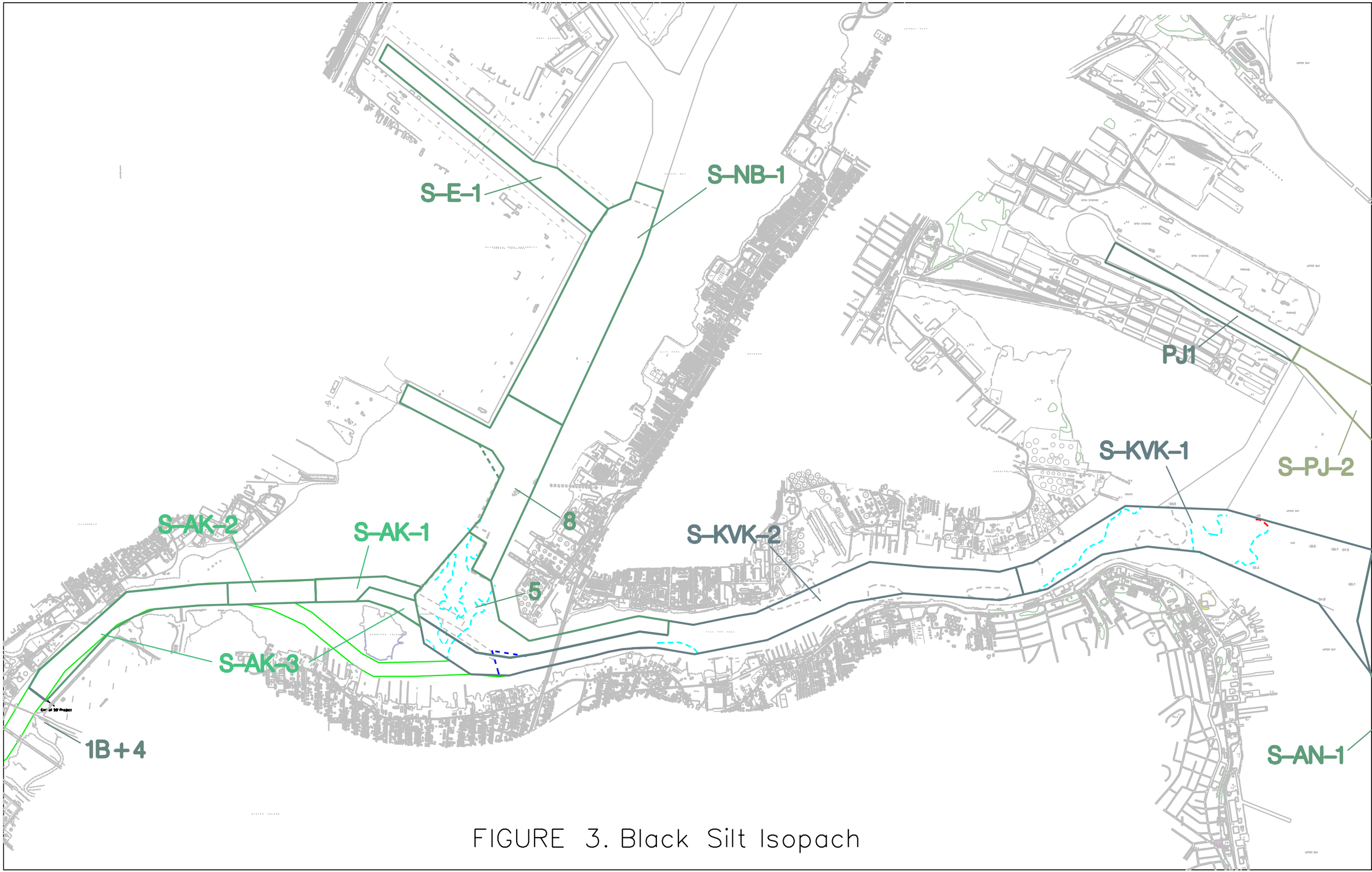
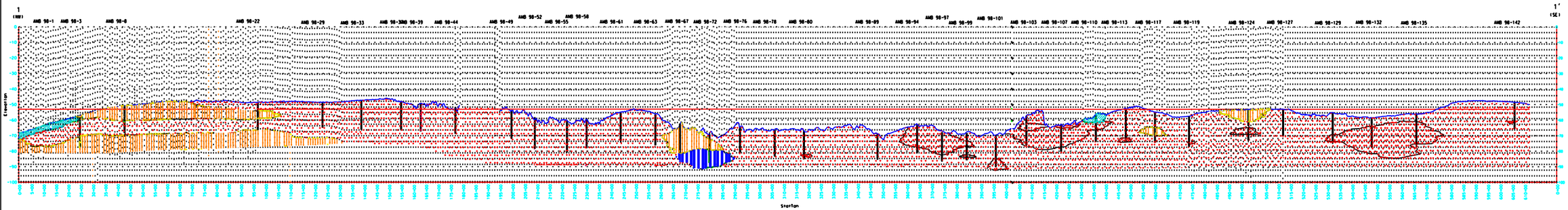
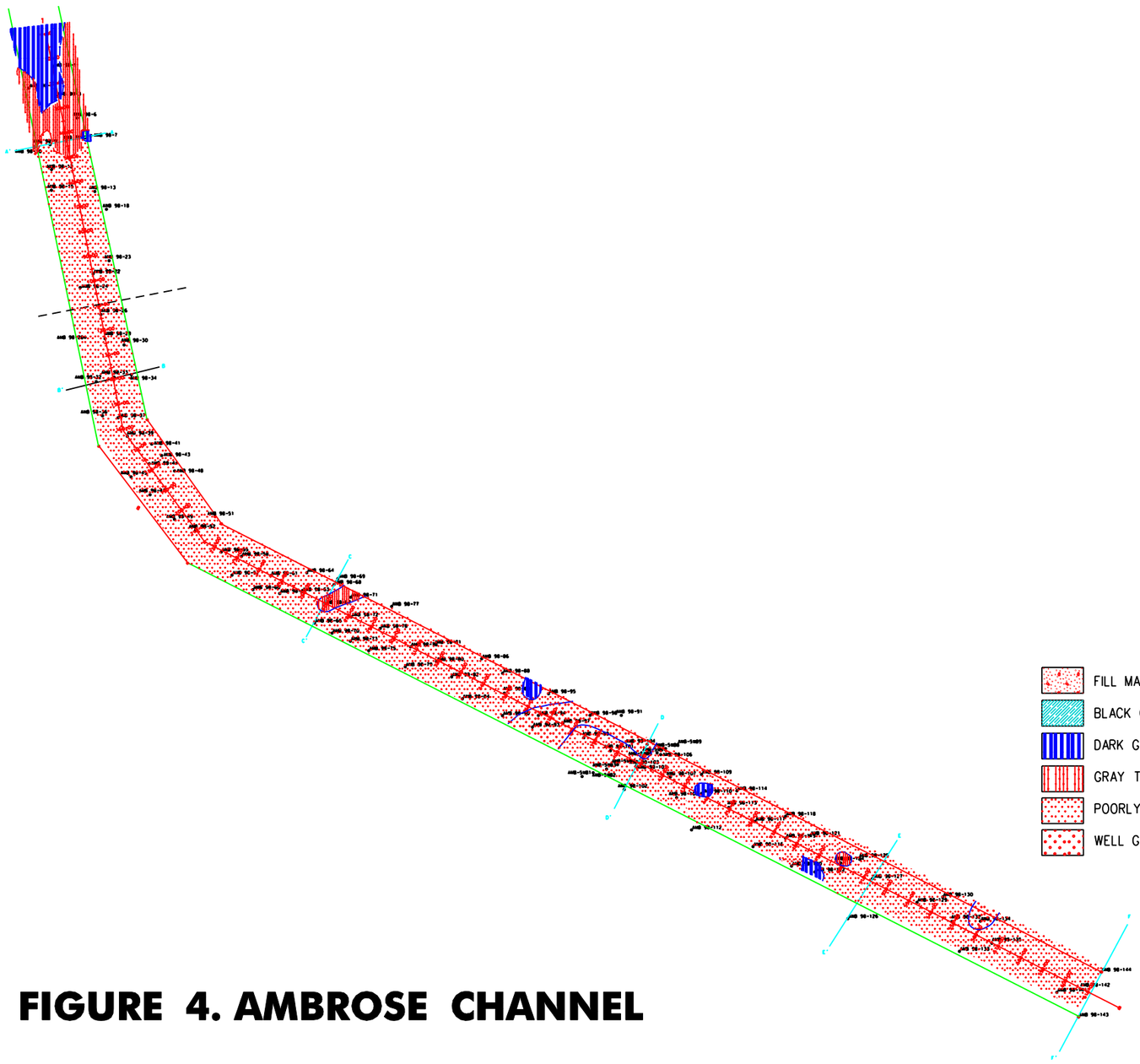


FIGURE 3. Black Silt Isopach

Figure_3.dgn 10/14/2003 11:10:53 AM





LEGEND

HOLOCENE

- FILL MATERIAL
- BLACK ORGANIC SILT AND CLAY
- DARK GRAY SILT AND CLAY
- GRAY TO DARK SILTY SAND
- POORLY GRADED CLEAN SAND
- WELL GRADED CLEAN SAND

PLEISTOCENE

- RED-BROWN SILT AND CLAY
- RED-BROWN SILTY SAND
- RED-BROWN SILTY GRAVEL
- TAN BROWN CLEAN SAND

JURASSIC

- GRAY TO RED-BROWN SHALE
- GRAY TO RED-BROWN SANDSTONE
- DARK GRAY TO BLACK DIABASE
- GRAY TO OLIVE-GREEN SERPENTINITE
- DARK GRAY TO BLACK SCHIST

FIGURE 4. AMBROSE CHANNEL

Figure_4.dgn 10/14/2003 11:11:52 AM

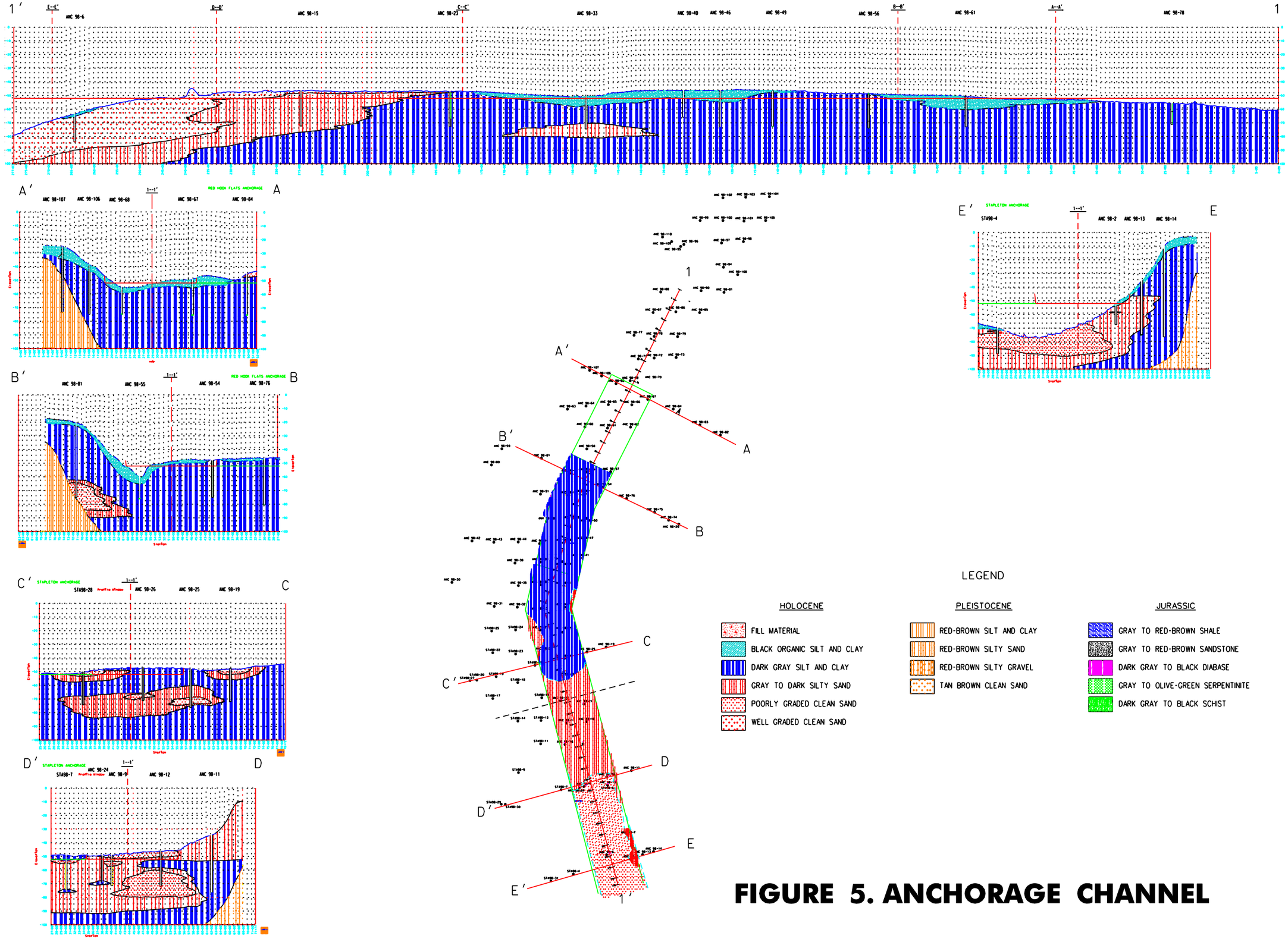


FIGURE 5. ANCHORAGE CHANNEL

Figure_5.dgn 10/14/2003 11:13:25 AM

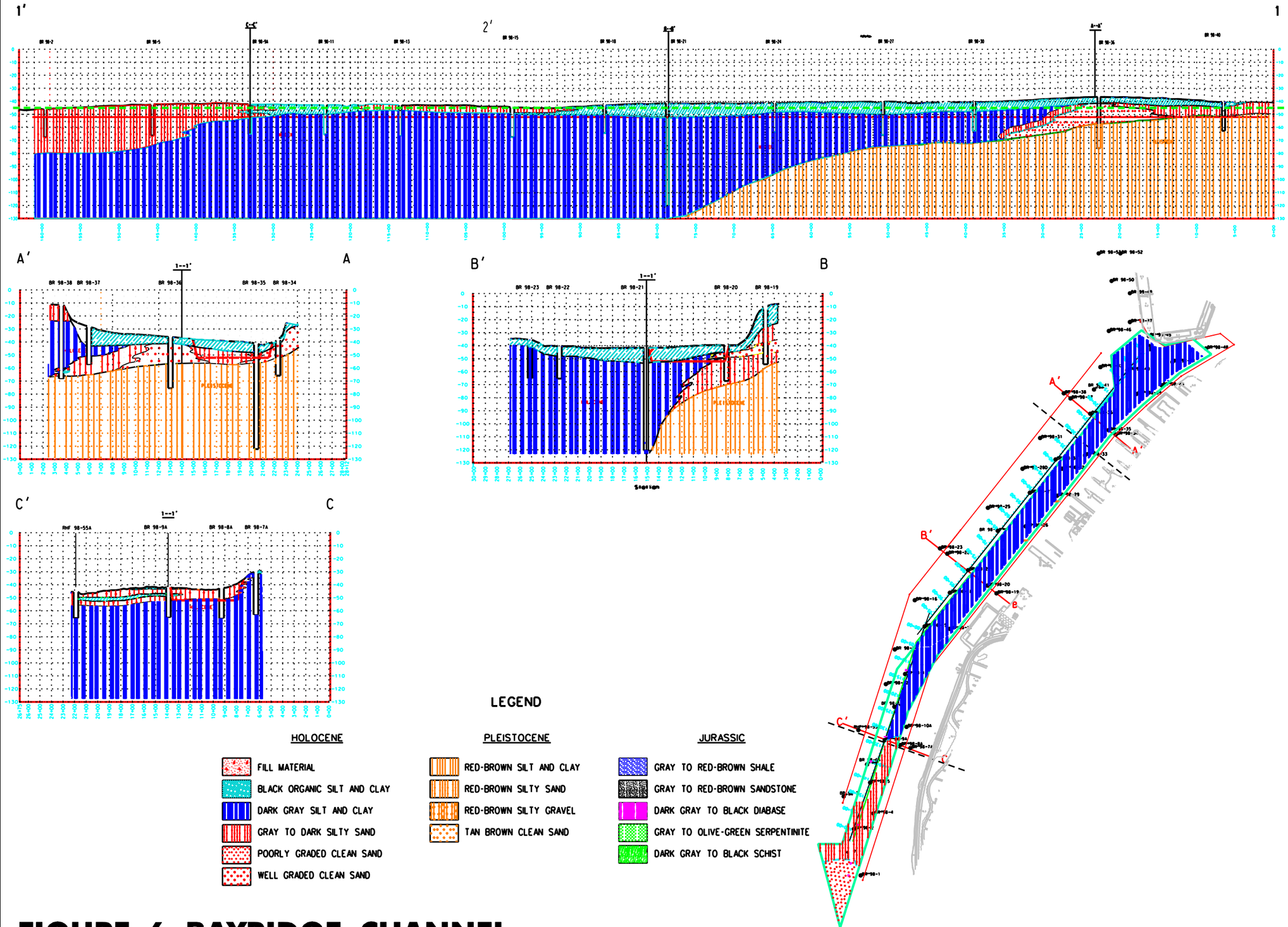


FIGURE 6. BAYRIDGE CHANNEL

FIGURE 7. PORT JERSEY CHANNEL

LEGEND

HOLOCENE

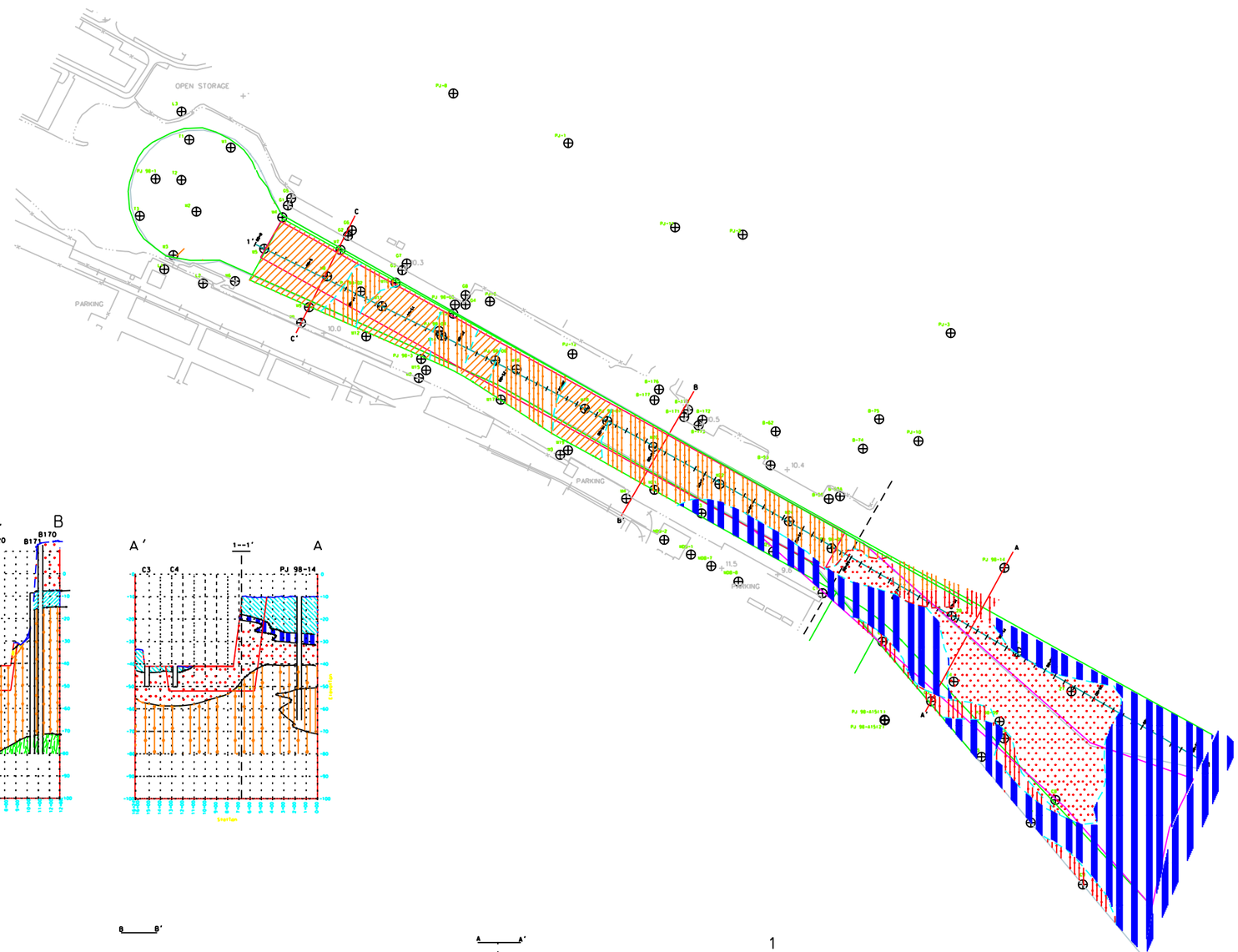
- FILL MATERIAL (GW)
- BLACK ORGANIC SILT AND CLAY (OH)
- DARK GRAY SILT AND CLAY (MH)
- GRAY TO DARK SILTY SAND (SM)
- POORLY GRADED CLEAN SAND (SP)
- WELL GRADED CLEAN SAND (SW)

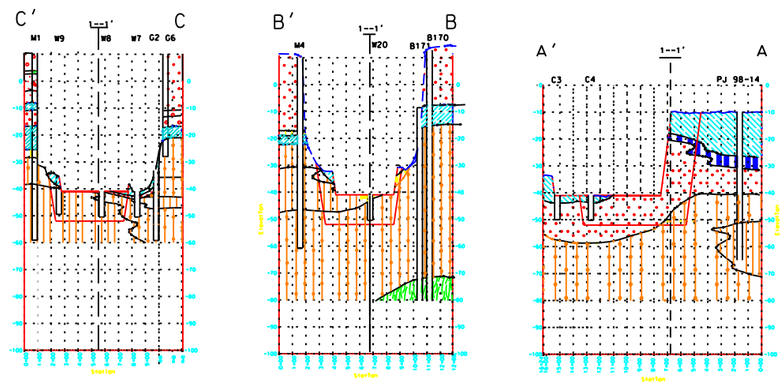
PLEISTOCENE

- RED-BROWN SILT AND CLAY (ML)
- RED-BROWN SILTY SAND (SM)
- RED-BROWN SILTY GRAVEL (GM)
- TAN BROWN CLEAN SAND (SW)

JURASSIC

- GRAY TO RED-BROWN SHALE
- GRAY TO RED-BROWN SANDSTONE
- DARK GRAY TO BLACK DIABASE
- GRAY TO OLIVE-GREEN SERPENTINITE
- DARK GRAY TO BLACK SCHIST





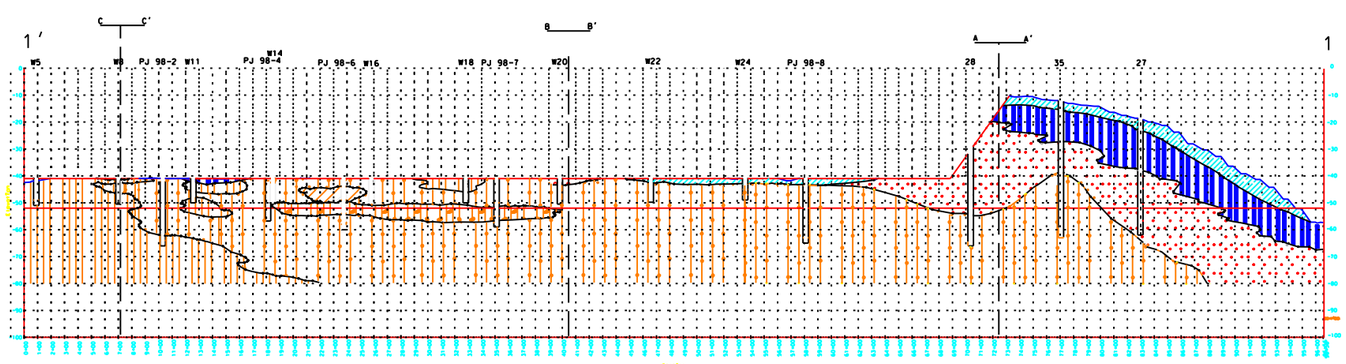
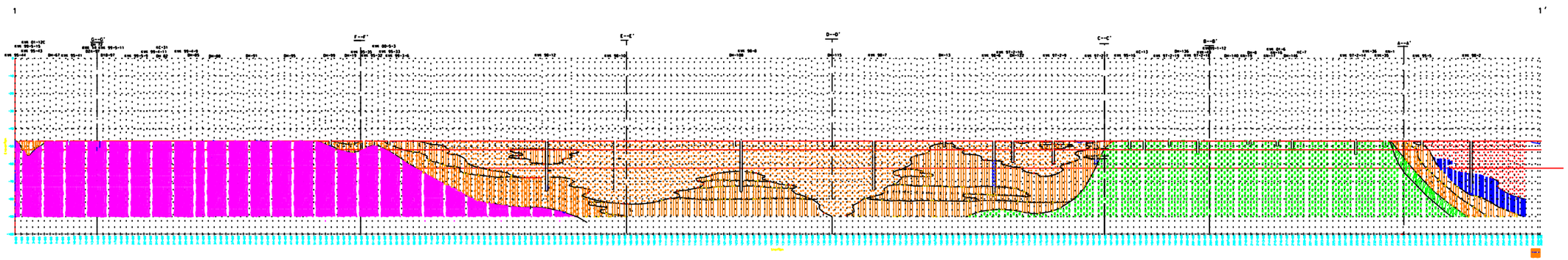
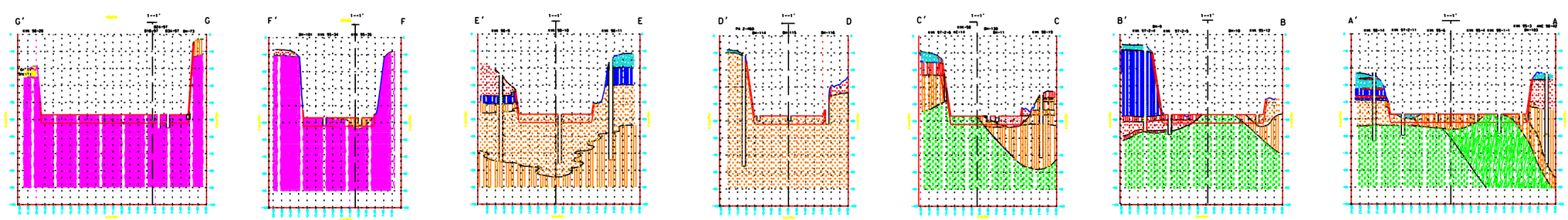


Figure_7.dgn 10/14/2003 11:15:14 AM

FIGURE 8. KILL VAN KULL CHANNEL





LEGEND

HOLOCENE

- FILL MATERIAL
- BLACK ORGANIC SILT AND CLAY
- DARK GRAY SILT AND CLAY
- GRAY TO DARK SILTY SAND
- POORLY GRADED CLEAN SAND
- WELL GRADED CLEAN SAND

PLEISTOCENE

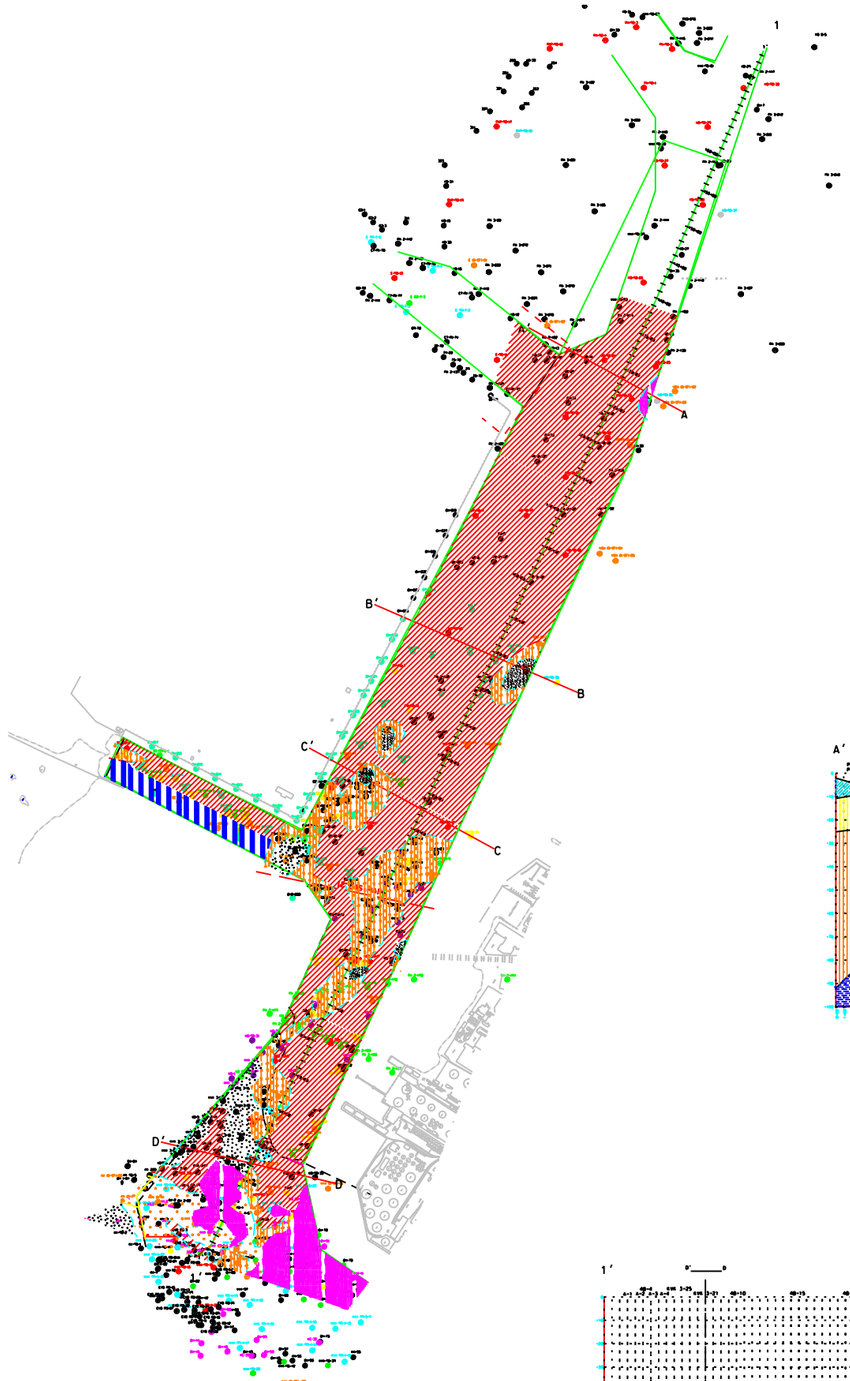
- RED-BROWN SILT AND CLAY
- RED-BROWN SILTY SAND
- RED-BROWN SILTY GRAVEL
- TAN BROWN CLEAN SAND

JURASSIC

- GRAY TO RED-BROWN SHALE
- GRAY TO RED-BROWN SANDSTONE
- DARK GRAY TO BLACK DIABASE
- GRAY TO OLIVE-GREEN SERPENTINITE
- DARK GRAY TO BLACK SCHIST

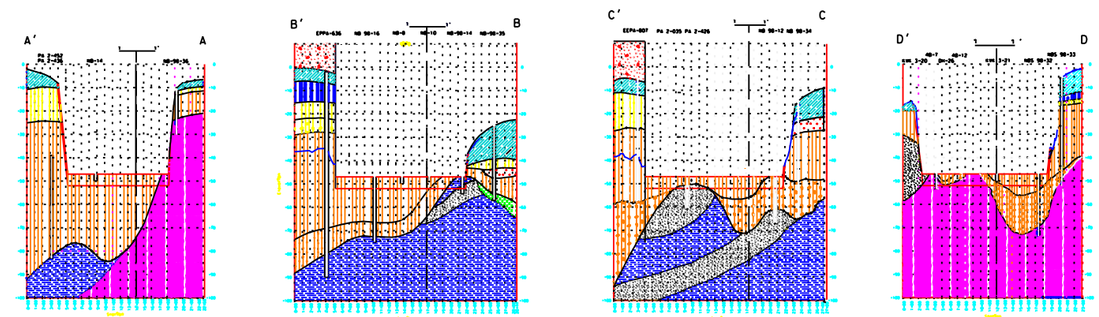
Figure_8.dgn 10/14/2003 11:15:59 AM

FIGURE 9. NEWARK BAY CHANNEL



LEGEND

HOLOCENE	PLEISTOCENE	JURASSIC
FILL MATERIAL	RED-BROWN SILT AND CLAY	GRAY TO RED-BROWN SHALE
BLACK ORGANIC SILT AND CLAY	RED-BROWN SILTY SAND	GRAY TO RED-BROWN SANDSTONE
DARK GRAY SILT AND CLAY	RED-BROWN SILTY GRAVEL	DARK GRAY TO BLACK DIABASE
GRAY TO DARK SILTY SAND	TAN BROWN CLEAN SAND	GRAY TO OLIVE-GREEN SERPENTINITE
POORLY GRADED CLEAN SAND		DARK GRAY TO BLACK SCHIST
WELL GRADED CLEAN SAND		



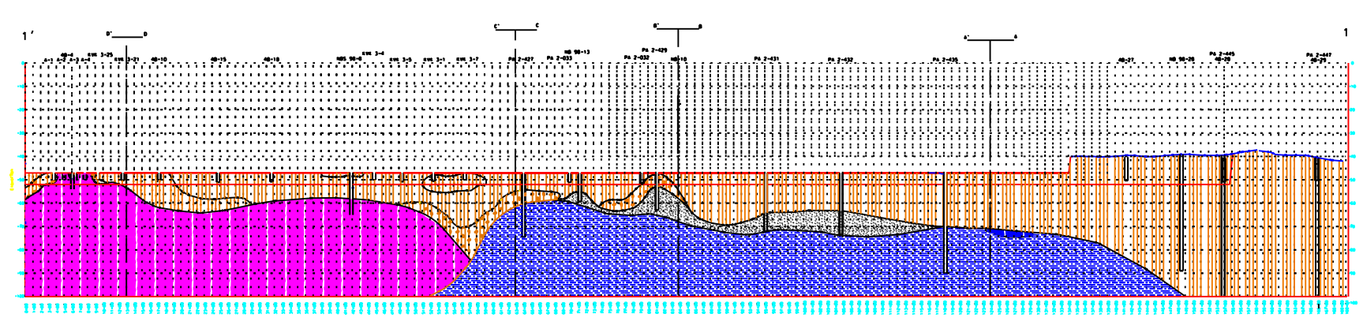
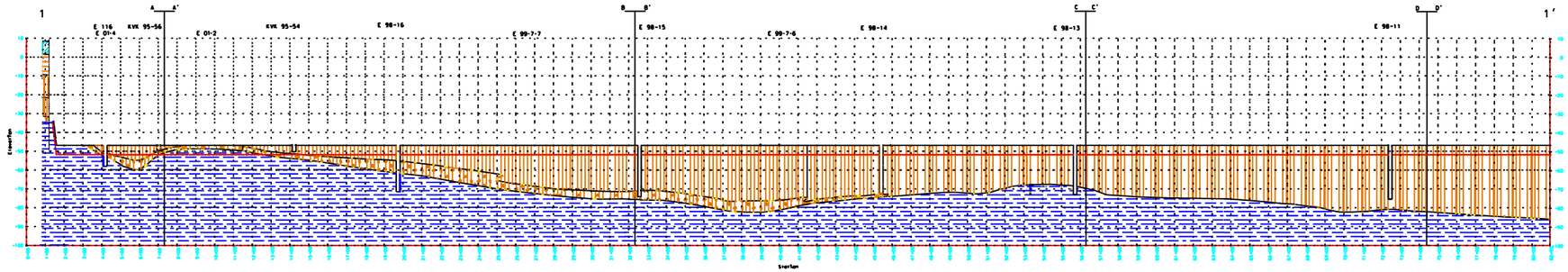
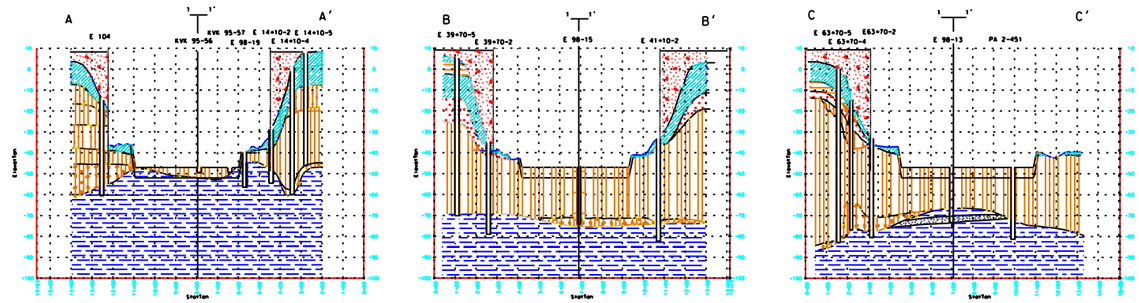
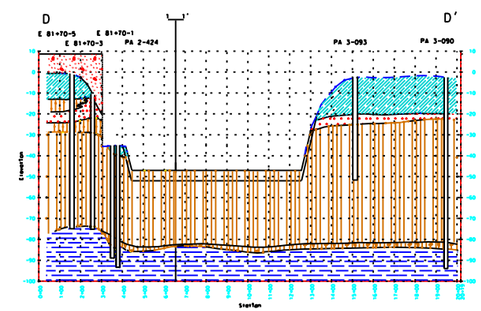
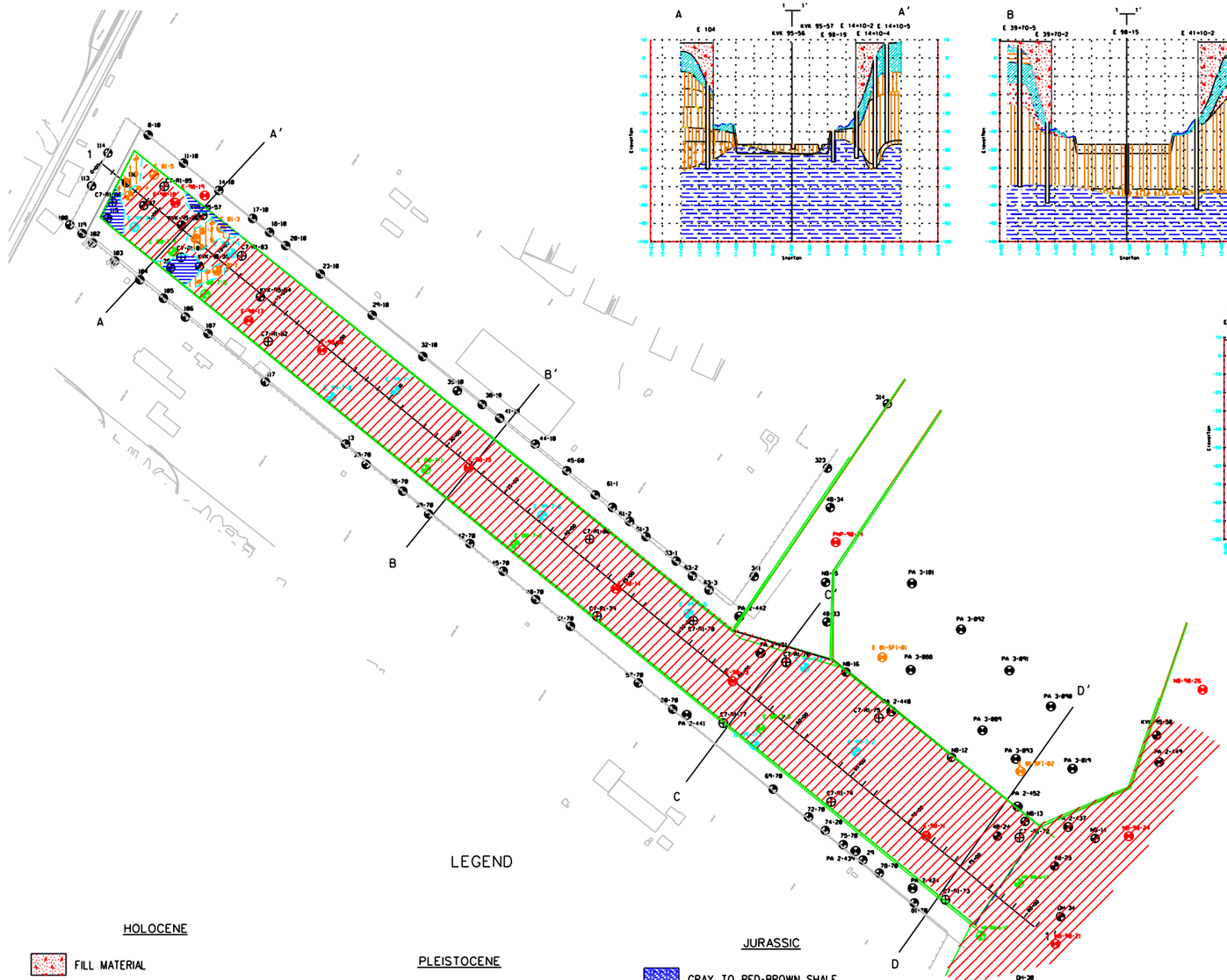


Figure_9.dgn 10/14/2003 11:17:02 AM









LEGEND

HOLOCENE

- FILL MATERIAL
- BLACK ORGANIC SILT AND CLAY
- DARK GRAY SILT AND CLAY
- GRAY TO DARK SILTY SAND
- POORLY GRADED CLEAN SAND
- WELL GRADED CLEAN SAND

PLEISTOCENE

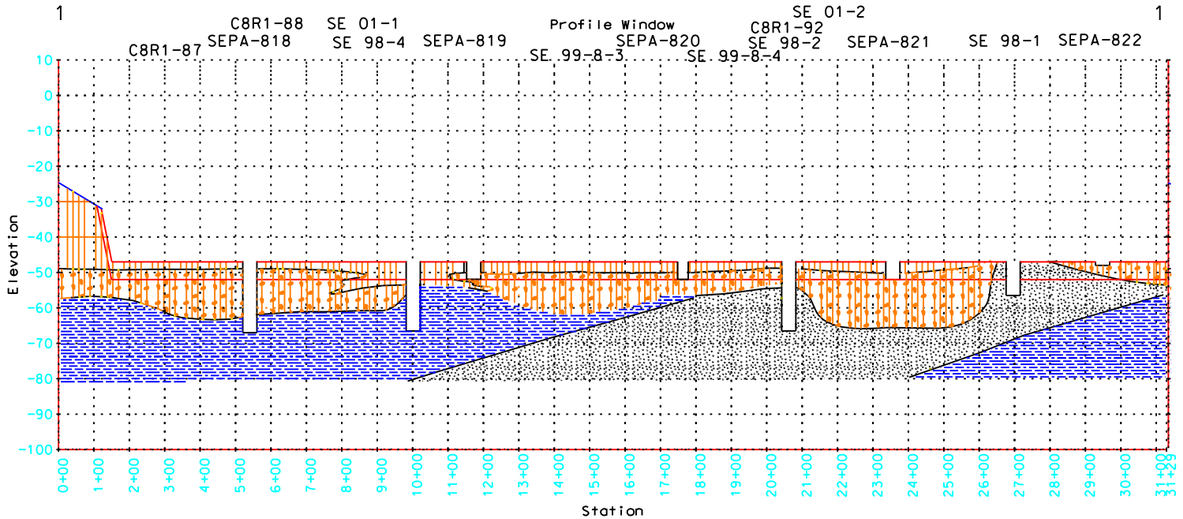
- RED-BROWN SILT AND CLAY
- RED-BROWN SILTY SAND
- RED-BROWN SILTY GRAVEL
- TAN BROWN CLEAN SAND

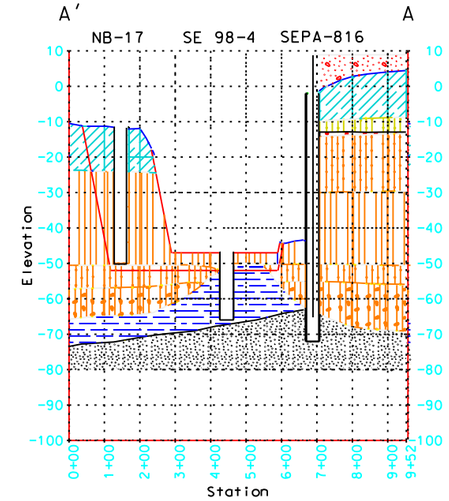
JURASSIC

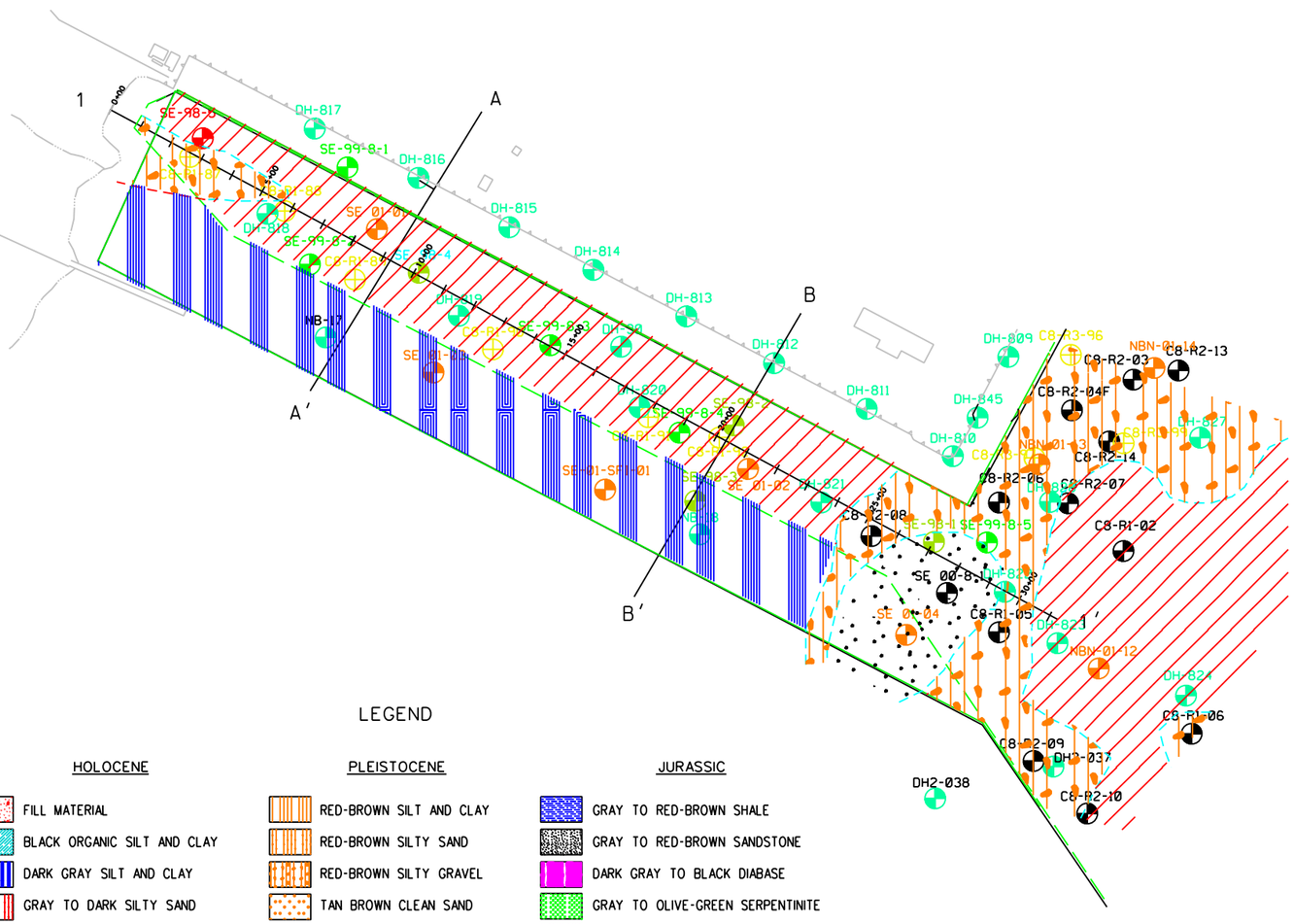
- GRAY TO RED-BROWN SHALE
- GRAY TO RED-BROWN SANDSTONE
- DARK GRAY TO BLACK DIABASE
- GRAY TO OLIVE-GREEN SERPENTINITE
- DARK GRAY TO BLACK SCHIST

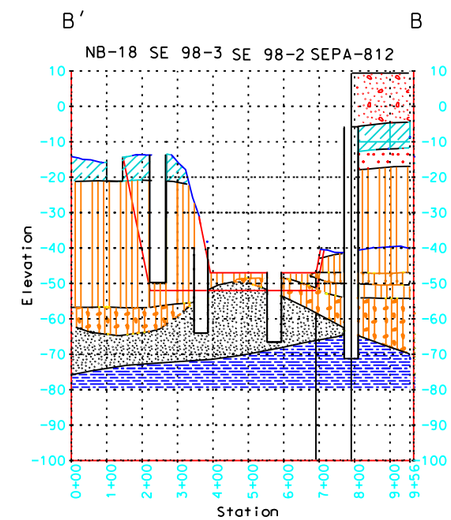
FIGURE 10. ELIZABETH CHANNEL

Figure_10.dgn 10/14/2003 11:19:08 AM









LEGEND

HOLOCENE

- FILL MATERIAL
- BLACK ORGANIC SILT AND CLAY
- DARK GRAY SILT AND CLAY
- GRAY TO DARK SILTY SAND
- POORLY GRADED CLEAN SAND
- WELL GRADED CLEAN SAND

PLEISTOCENE

- RED-BROWN SILT AND CLAY
- RED-BROWN SILTY SAND
- RED-BROWN SILTY GRAVEL
- TAN BROWN CLEAN SAND

JURASSIC

- GRAY TO RED-BROWN SHALE
- GRAY TO RED-BROWN SANDSTONE
- DARK GRAY TO BLACK DIABASE
- GRAY TO OLIVE-GREEN SERPENTINITE
- DARK GRAY TO BLACK SCHIST

FIGURE 11. SOUTH ELIZABETH

Figure_11.dgn 10/14/2003 11:19:56 AM

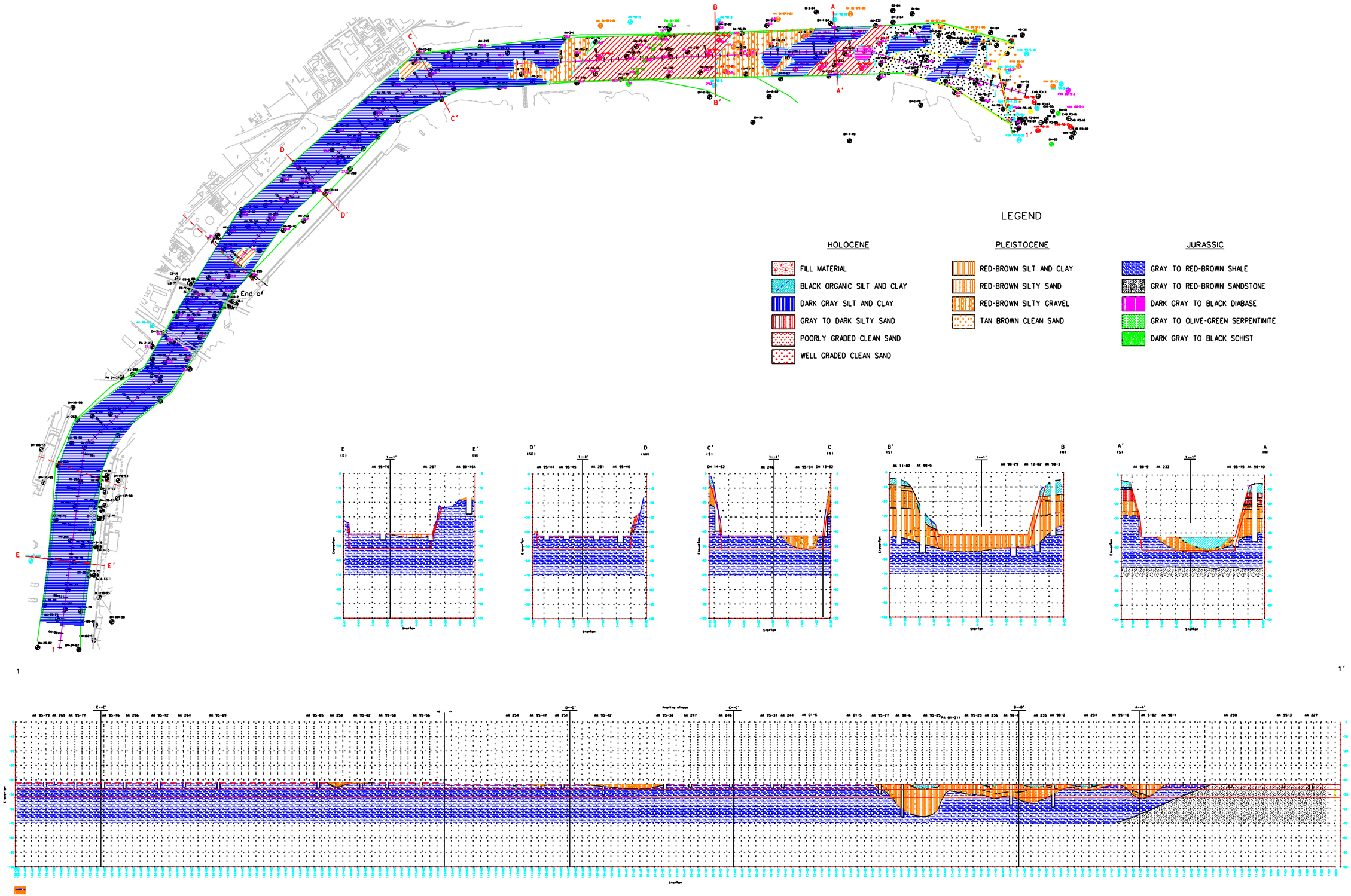


FIGURE 12. ARTHUR KILL CHANNEL

Figure_12.dgn 10/14/2003 11:20:38 AM

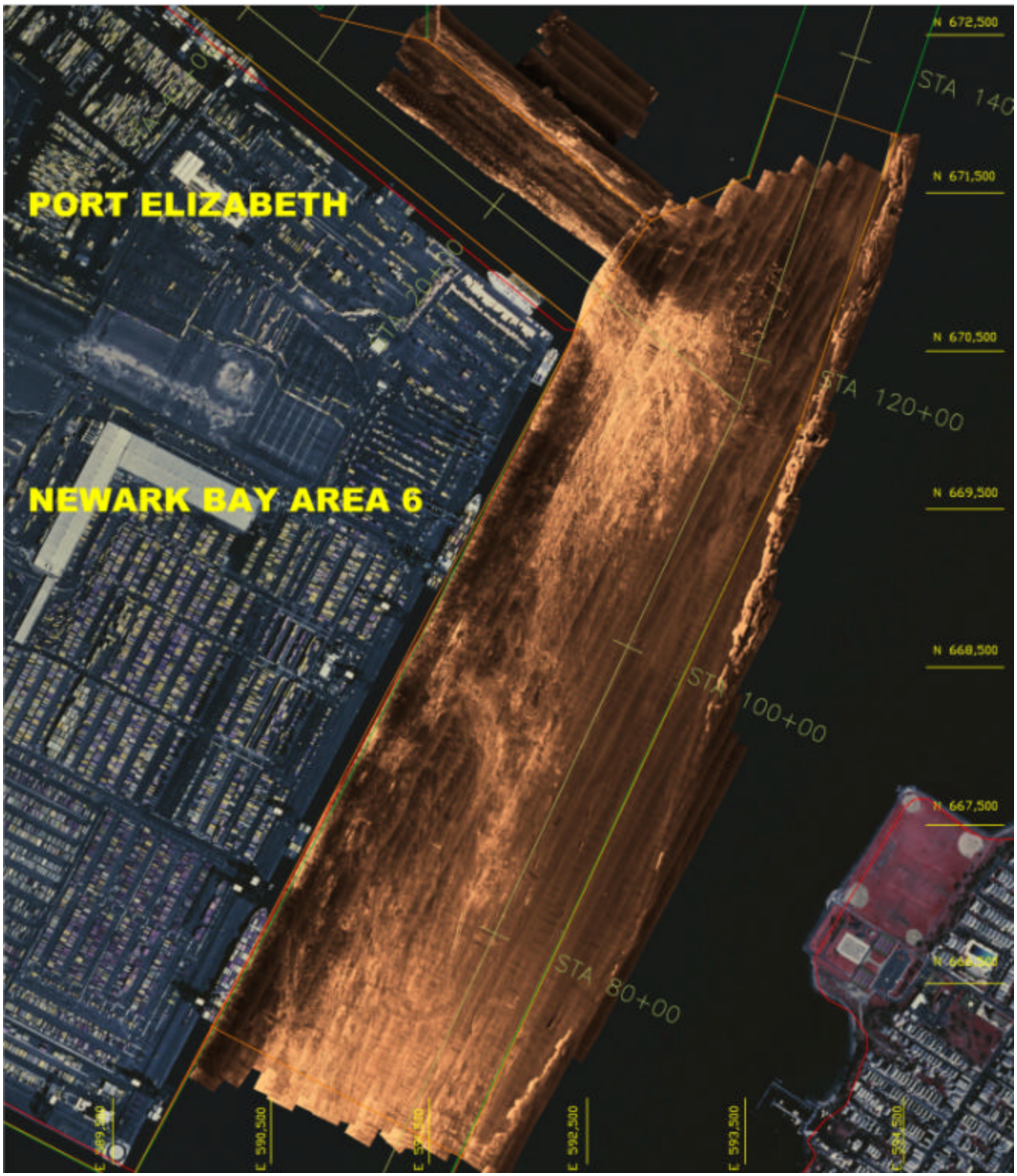


Figure 13. Side Scan Mosaic of Newark Bay Contract 6. Black Silt Shoals (dark brown areas) covering most of the contract. Note clear area where ships turn into Elizabeth Channel.

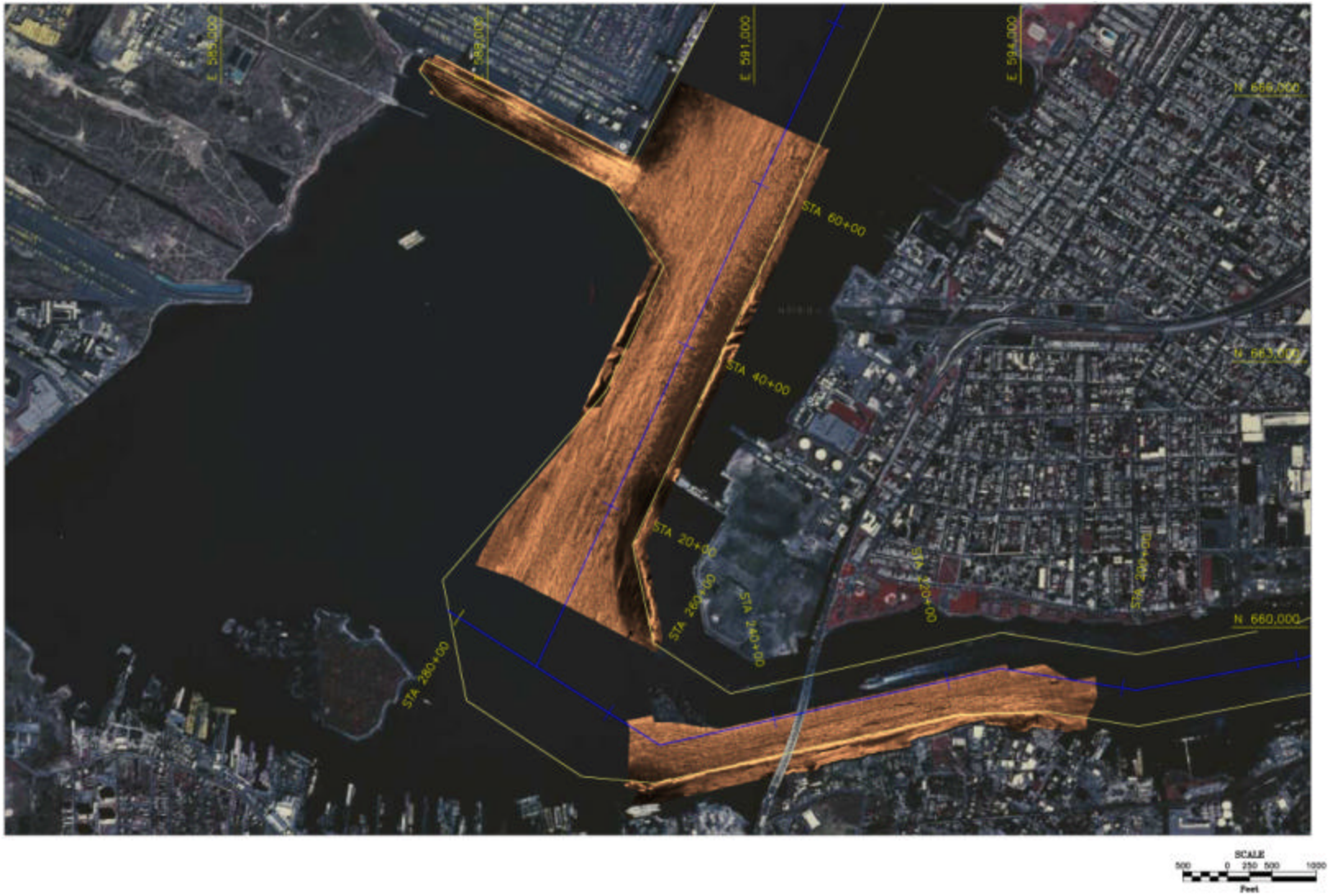


Figure 14. Side Scan Mosaic of Newark Bay Areas 8 and 5. Black Silt Shoals (black areas) along the edge of Newark Channel and southern portion of South Elizabeth Channel.

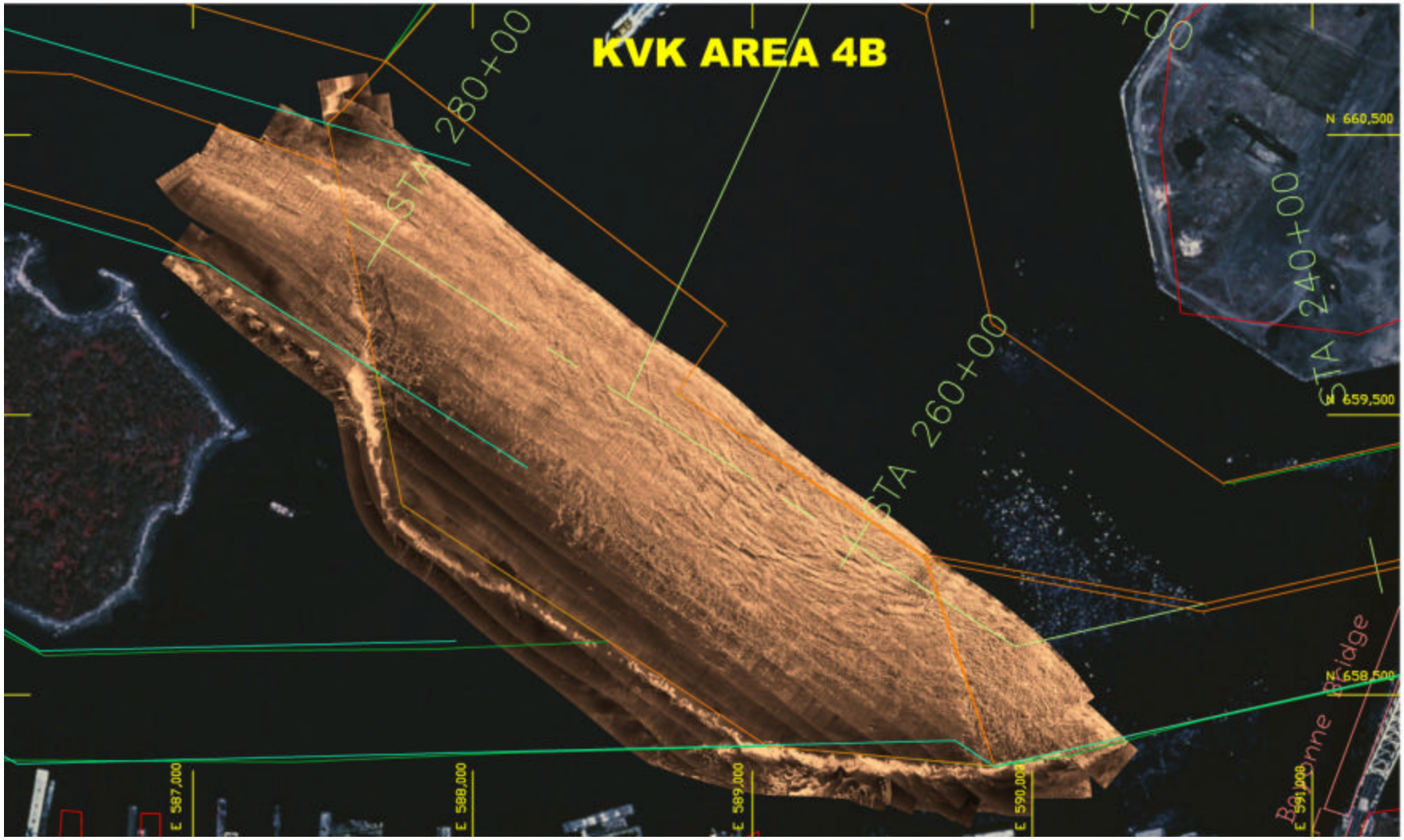


Figure 15. Side Scan Mosaic of KVK Area 4B. Black Silt Shoals (dark brown areas) along the southern edge of the channel.

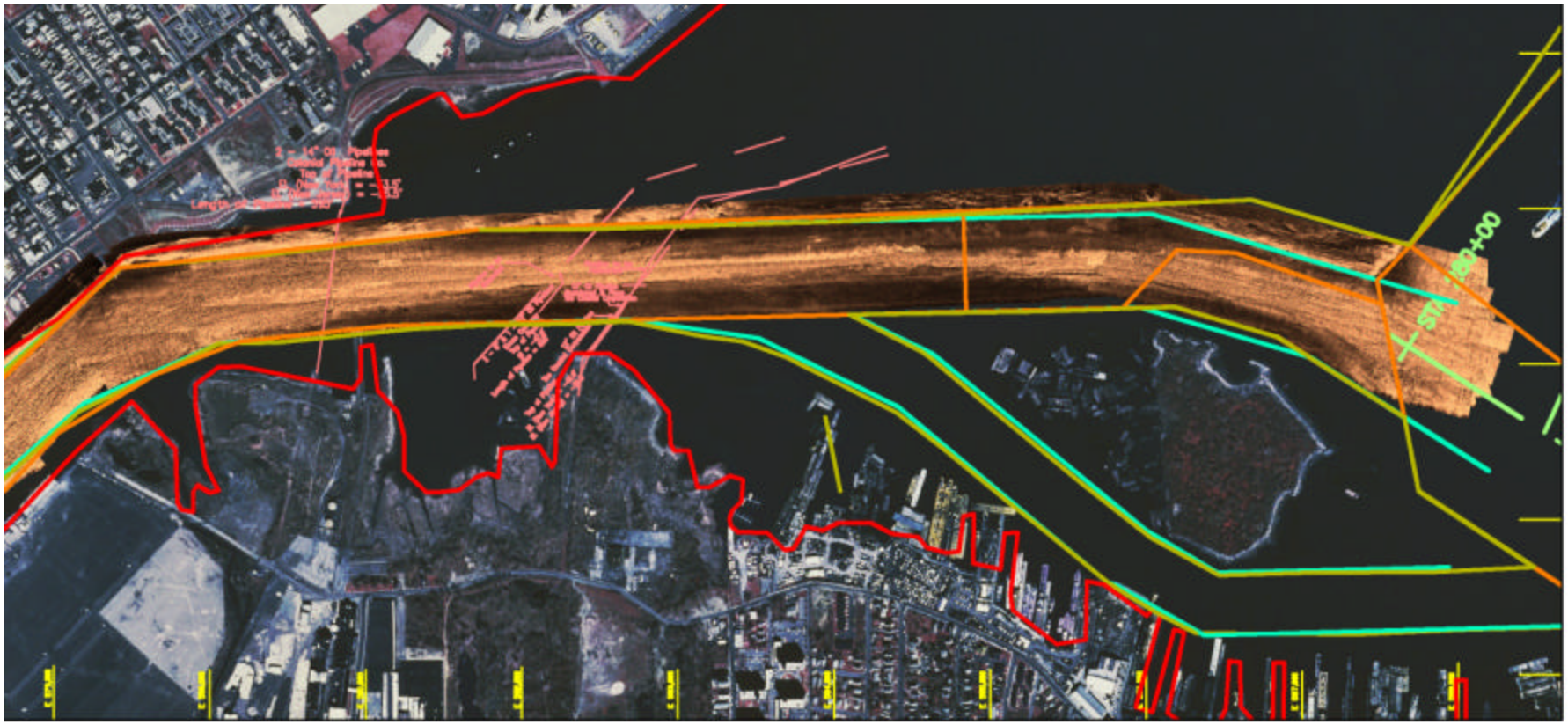


Figure 16. Side Scan Mosaic of Arthur Kill Contract 1-3. Black Silt Shoals (dark brown areas) along the north and south sides of the channel. Ship traffic and turbulence keeps the center of the channel relatively free of black silt.

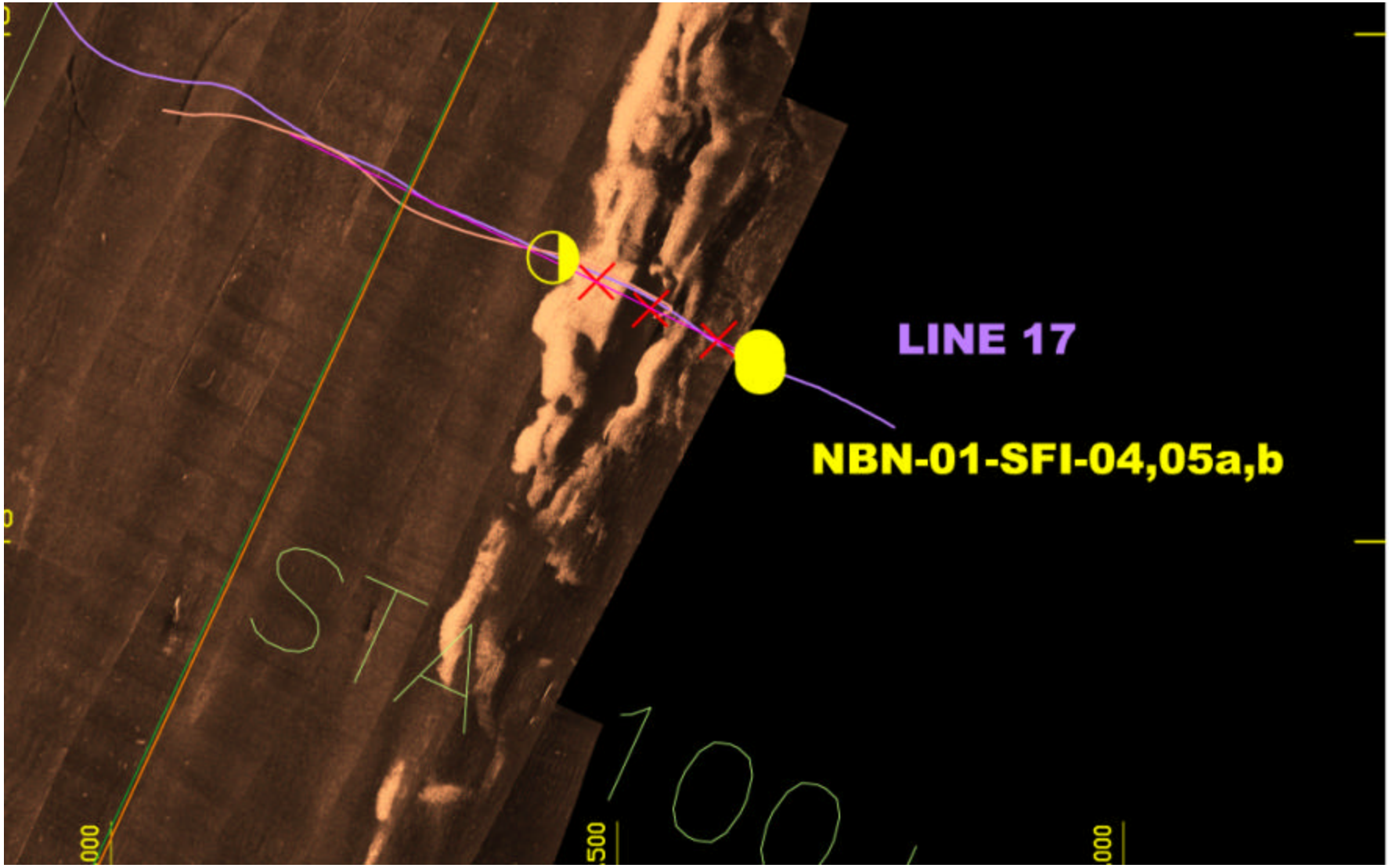


Figure 17. Side Slope Failure in Northern Newark Bay. Sub Bottom Profile data and borings were acquired at the locations shown in order to document the stratigraphy shown in Figure 26.

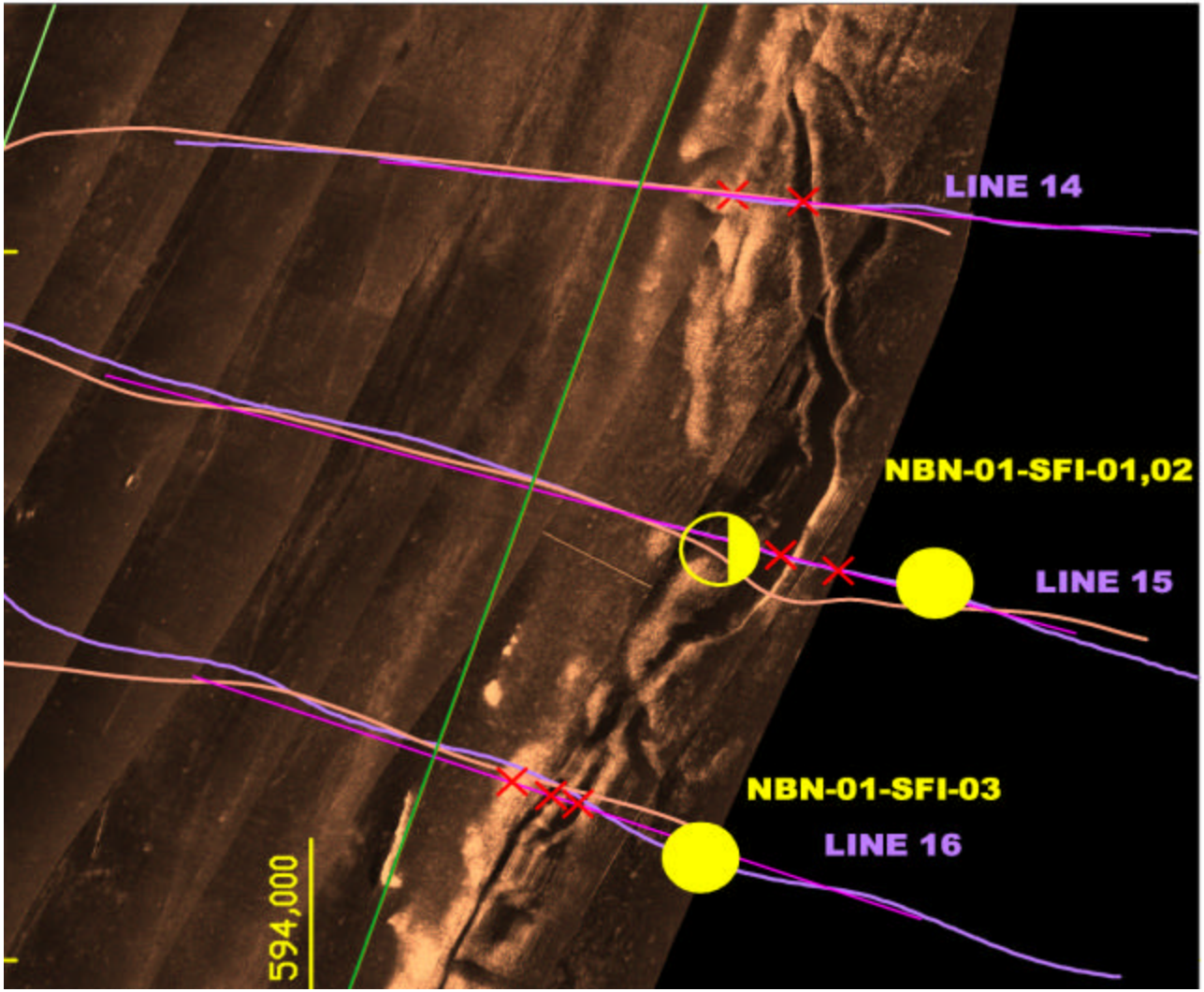


Figure 18. Side Scan Mosaic showing possible Side Slope Failure in Newark Bay. Sub Bottom Profile lines and borings were acquired at the locations indicated in order to document the stratigraphy

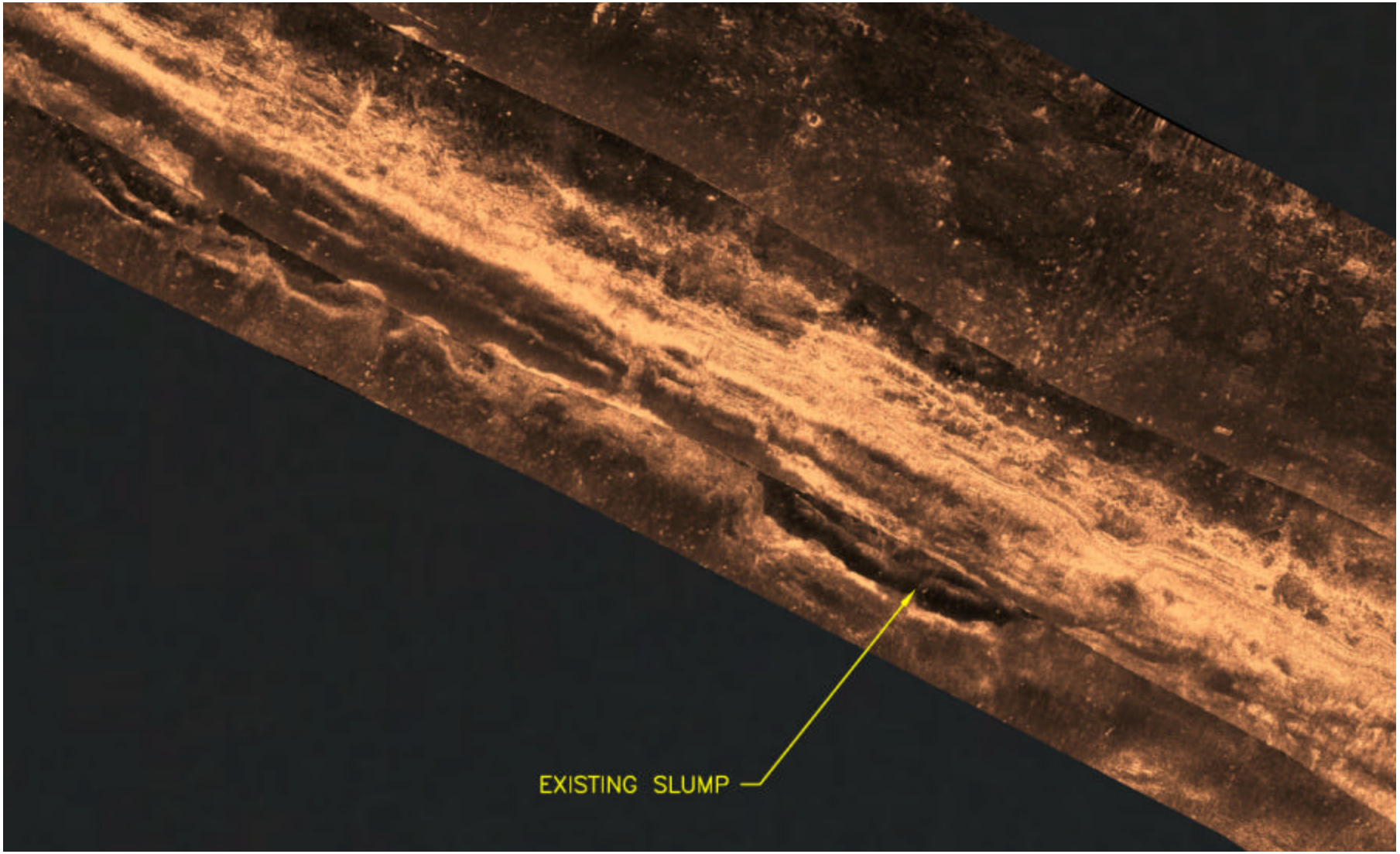


Figure 19. Side Slope Failure in South Elizabeth Channel. Borings and sub-bottom profile data were acquired and used to document stratigraphy shown in Figure 27.

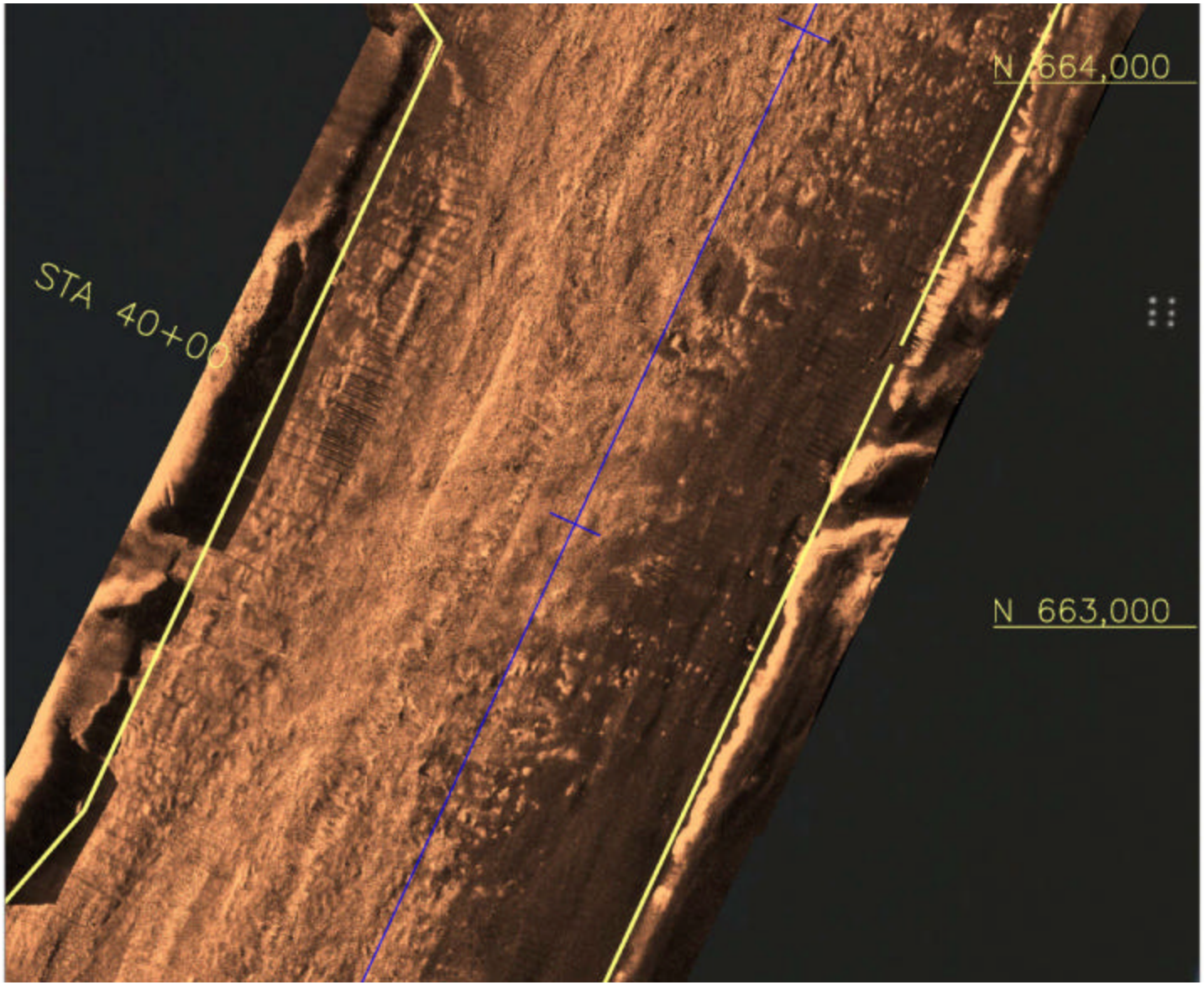


Figure 20. **Side Scan of southern Newark Bay showing pipeline trenches. Feature just north of Station 41 is located on the alignment of the railroad bridge that was removed many years ago and could be a bridge footing.**

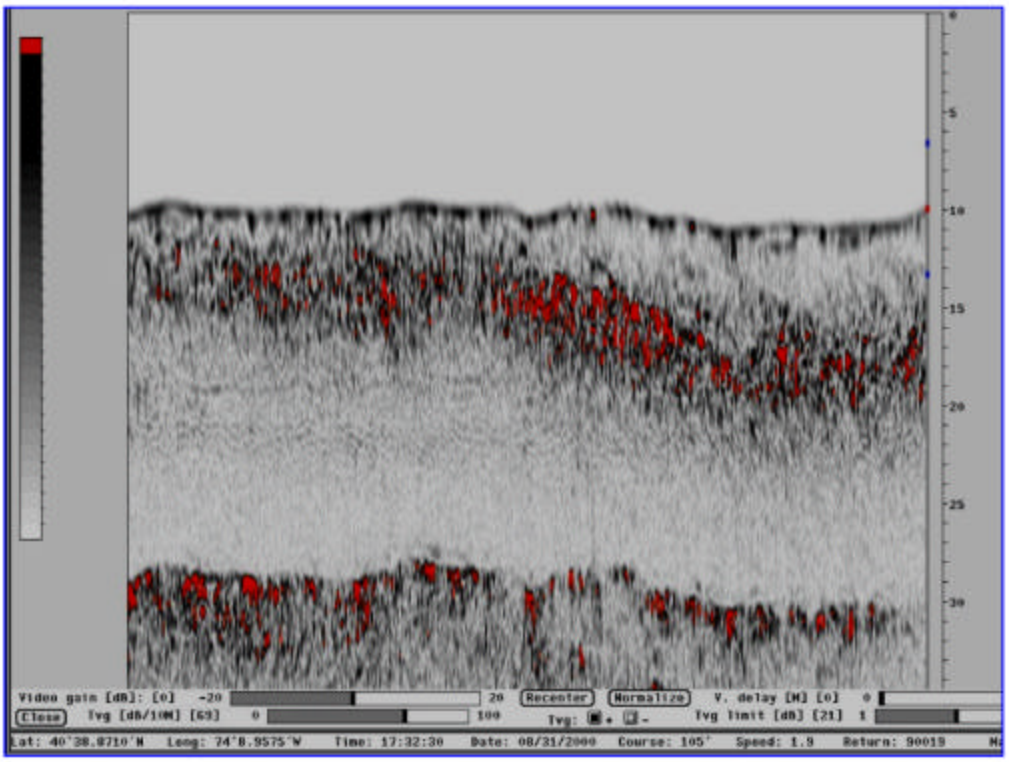


Figure 21A. Portion of cross-line 9 after de-chirp processing but before navigation merge and filtering. Strong water bottom multiple at 30 ms.

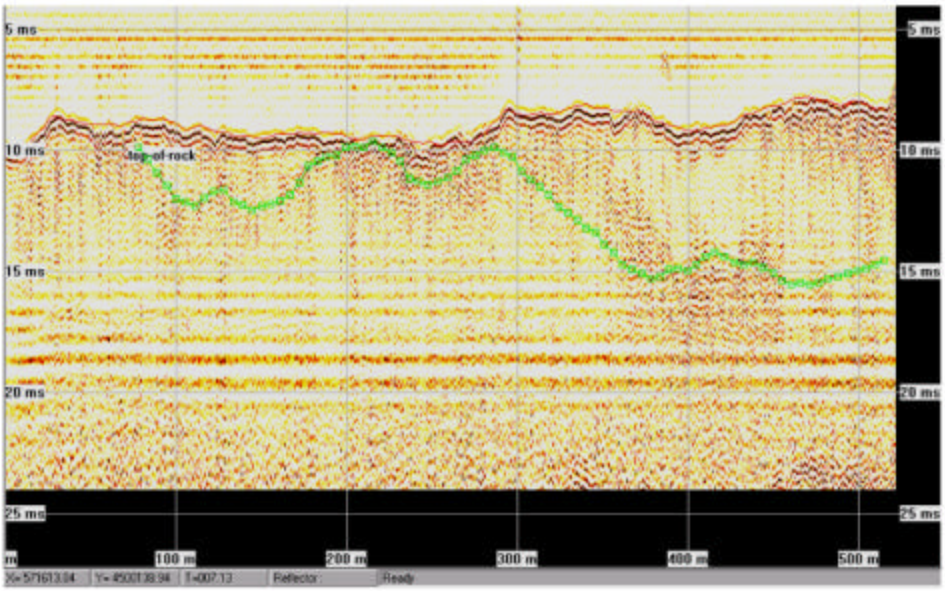


Figure 21B. Post processed and digitized (interpreted) Top of Rock for cross-line 9.

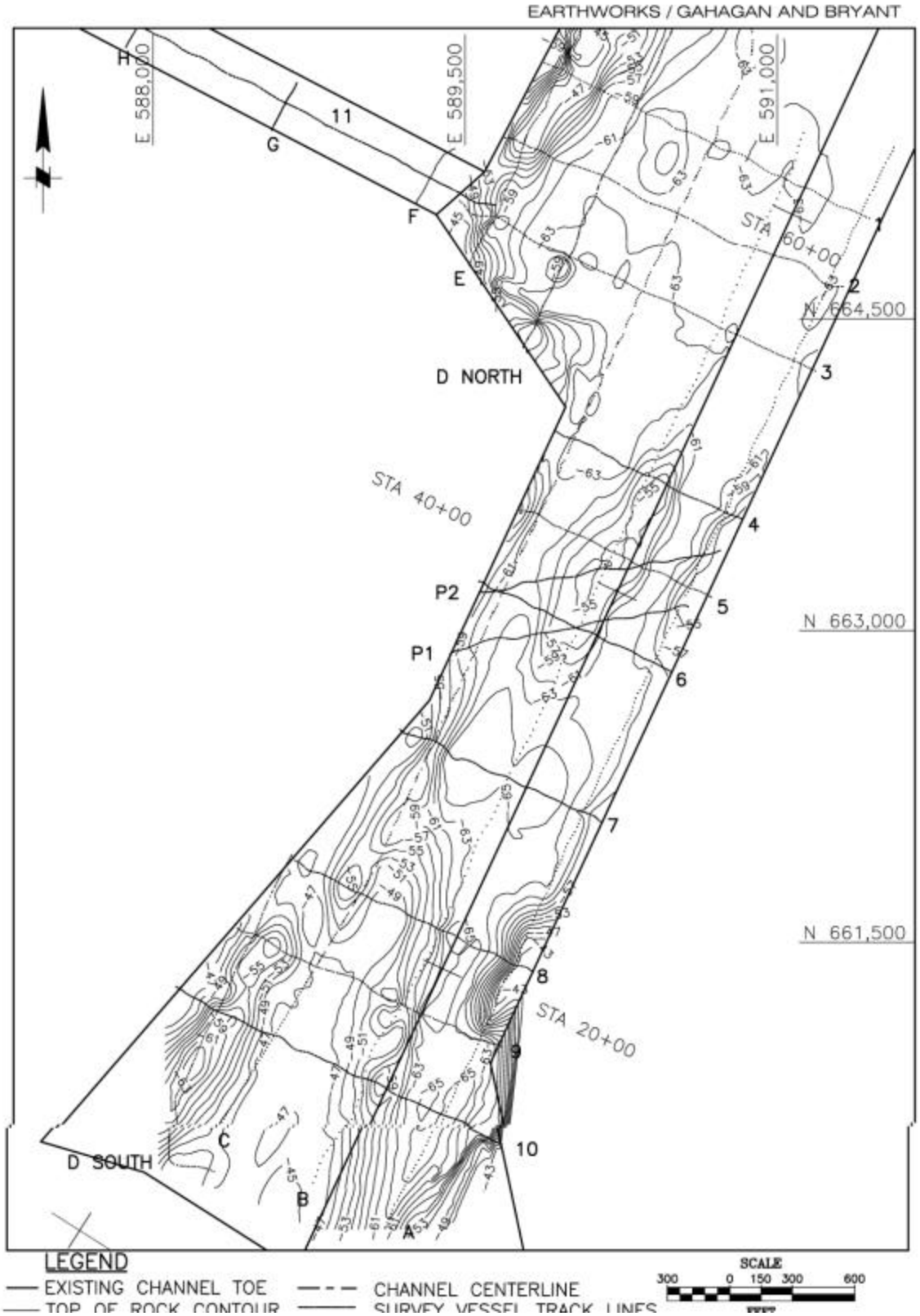


Figure 22. Top of Rock Structure Map. Map was constructed from interpreted sub-bottom profile data at the lines indicated. Representative borings were included in the interpretation and were used to tie the top of rock to the appropriate reflector.

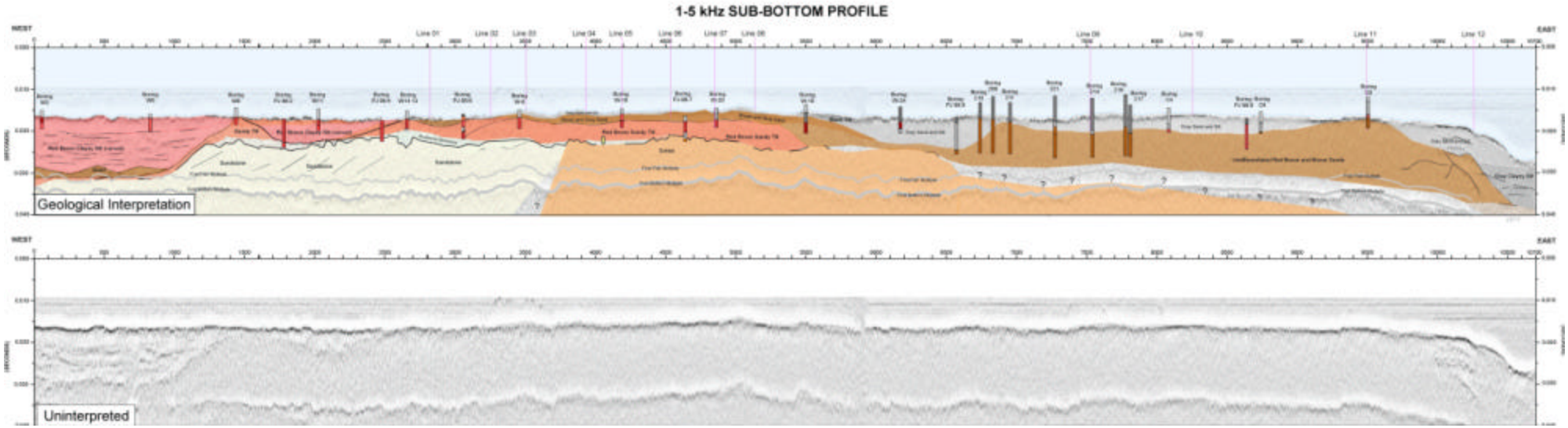


Figure 23. Interpreted and un-interpreted sub-bottom profile data in Port Jersey Channel. The sections extend from the turning basin on the west to the Hudson River escarpment on the east. Borings were used to tie the data to the appropriate reflector. The data is particularly good along the western portion of the channel from location 0' to 2500' where the varved section is clearly distinguishable from the underlying strata. The relative clarity of this section is thought to be due to the absence of black silt.

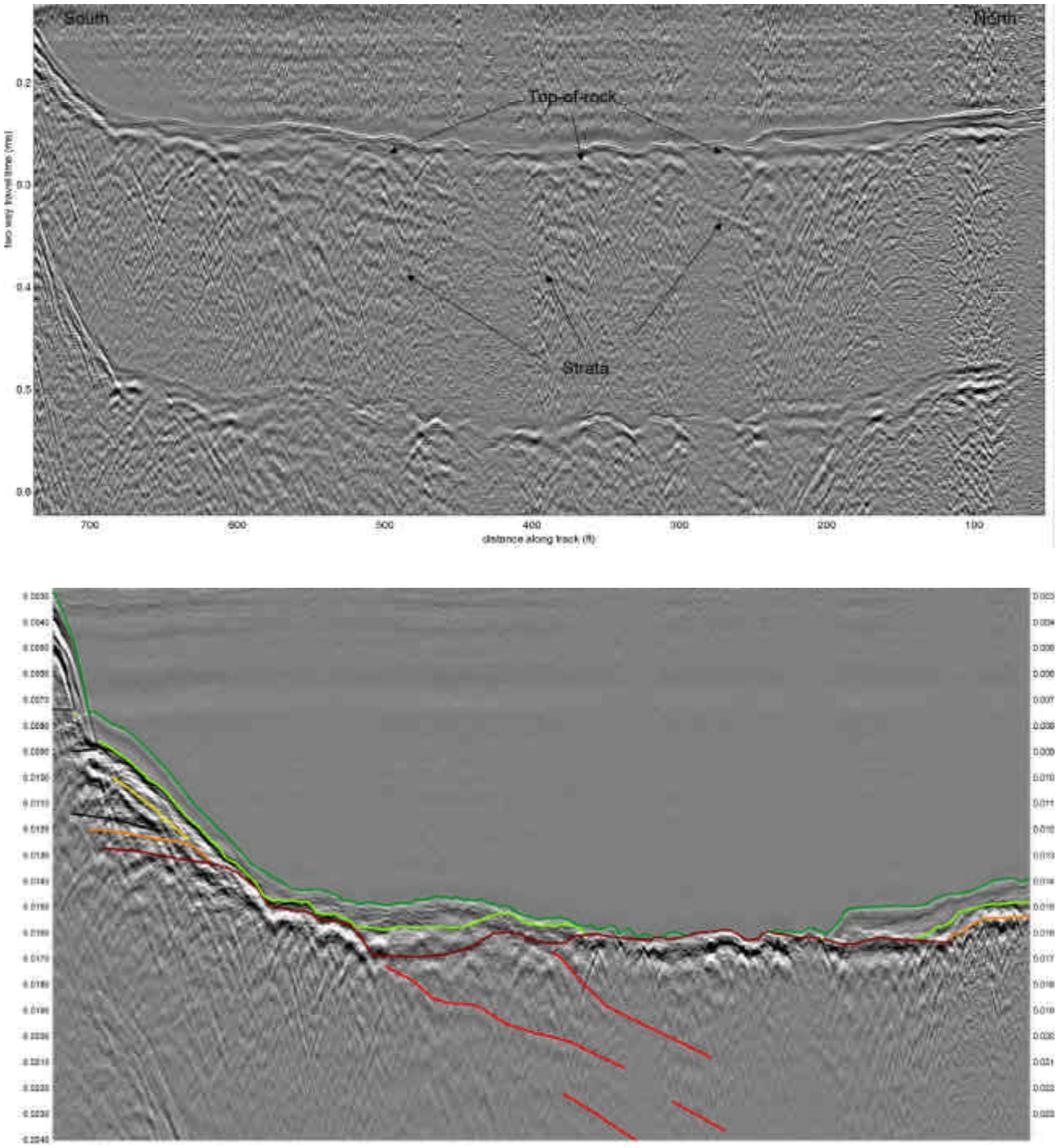


Figure 24. Top – Pulse reflection profile of a portion of Arthur Kill with top of rock reflector and dipping strata noted. Lower – Pulse reflection profile that shows the top of rock (dark red) as well as the top (green) and base (light green) of the black silt. Dipping reflectors within the bedrock are also interpreted.

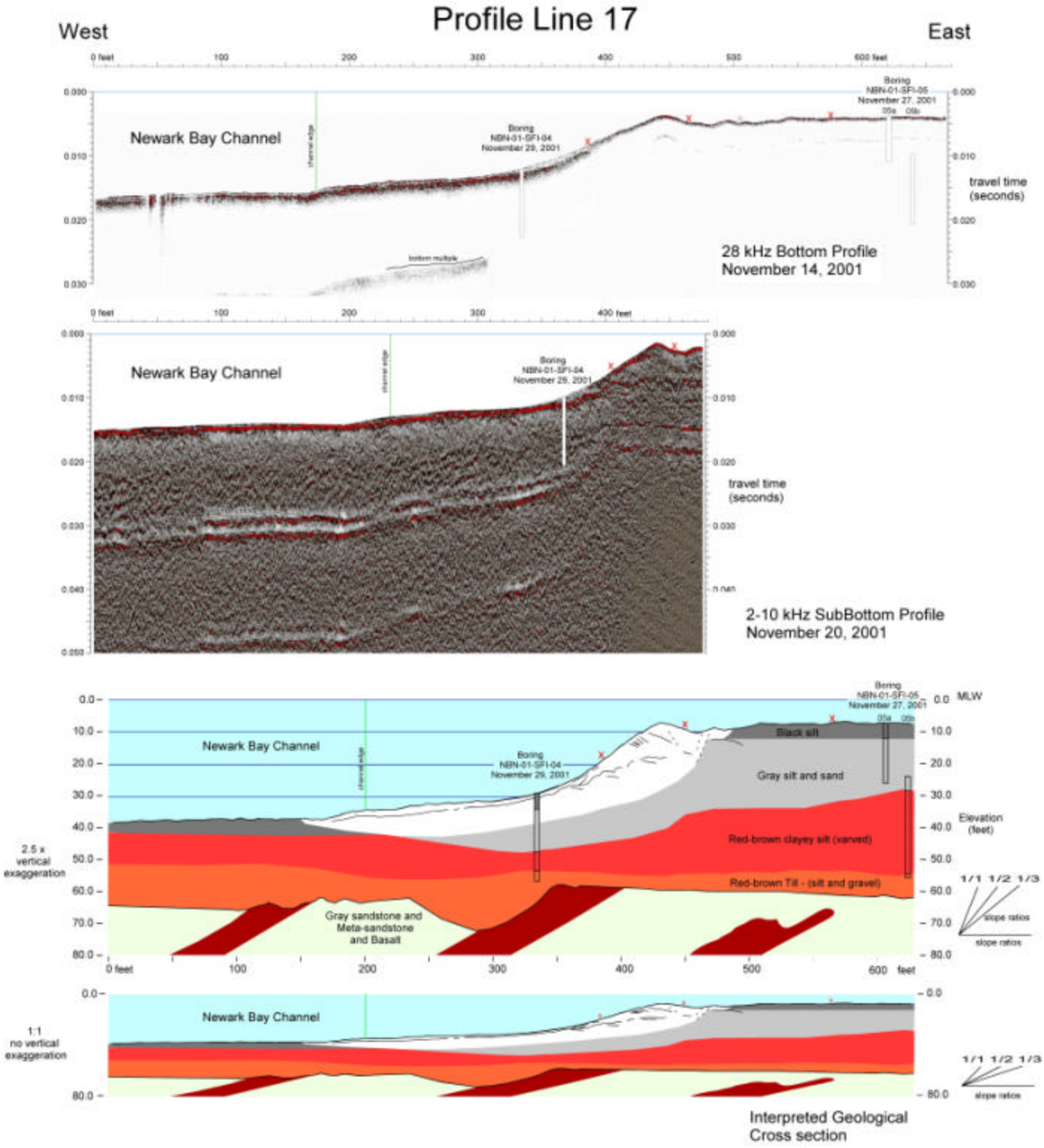


Figure 25. Bottom and Sub-Bottom Profile data in northern Newark Bay. Location of Line 17 coincides with the slope failure shown in Figure 17. The sub-bottom data and borings acquired along the line were used to construct the geological cross-sections shown. The slump or slope failure occurs in an area where the very soft, gray to gray-black silt is unusually thick.

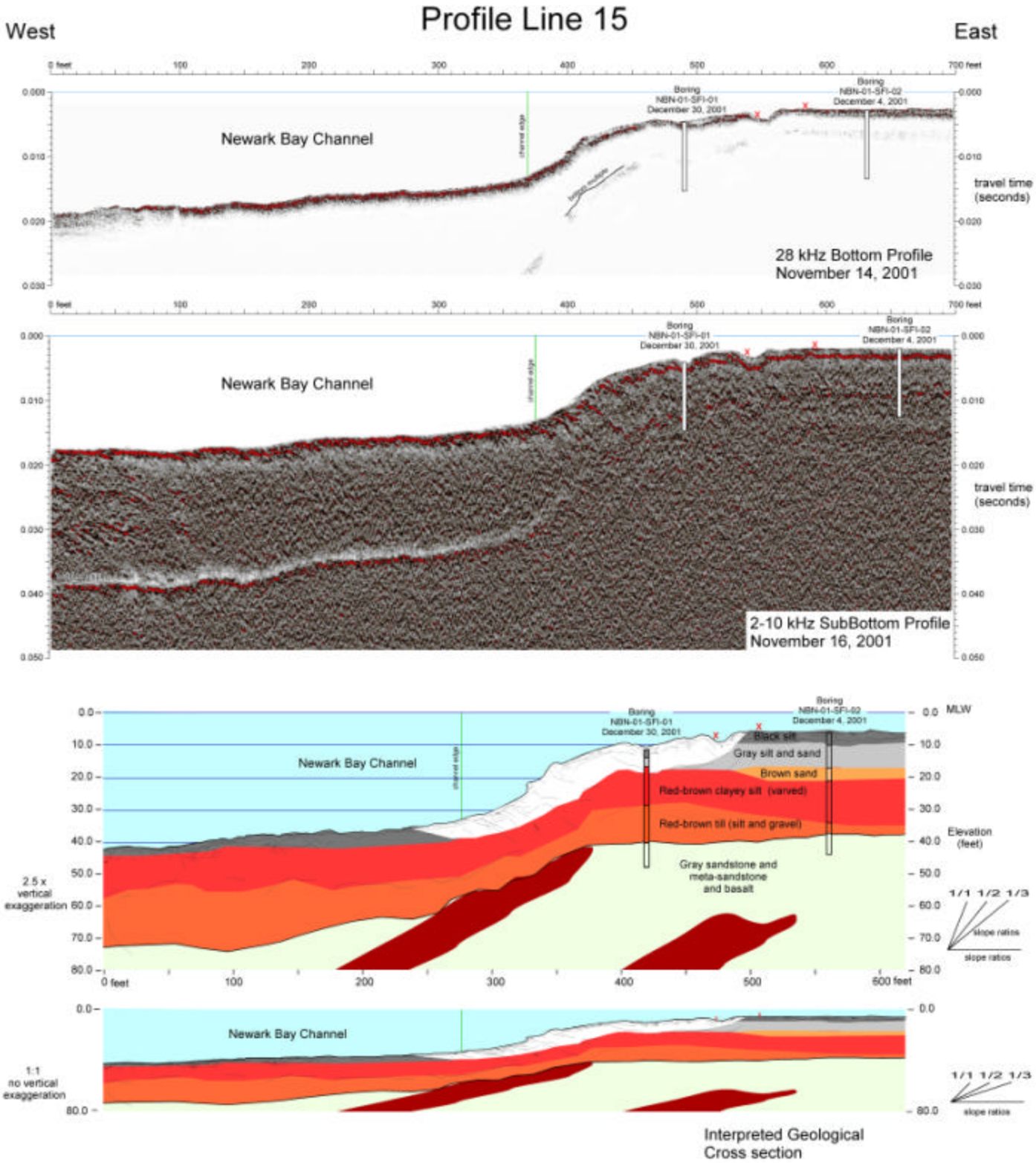


Figure 26. Bottom and Sub-Bottom Profile data in Newark Bay. The location of Line 15 coincides with the slope failure shown in Figure 18. Sub-bottom data and borings acquired along the line were used to construct the geological cross–sections shown. The anomaly shows tilted strata typical of a rotated slump block.

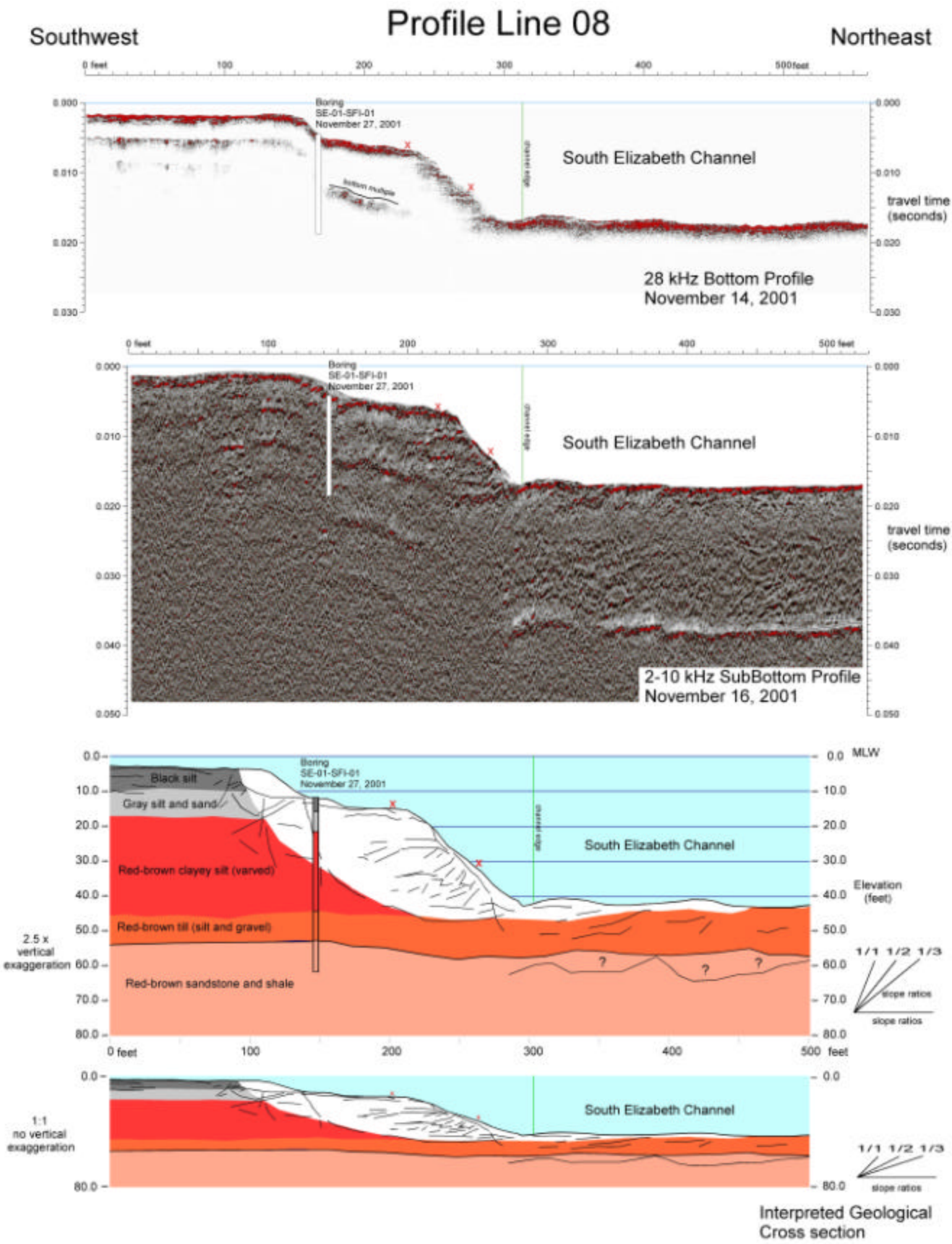


Figure 27. Bottom and Sub-Bottom Profile data in South Elizabeth Channel. The location of Line 8 coincides with the slump failure shown on Figure 19. The geological cross-sections shown were constructed from the sub-bottom profile data and borings. The feature occurs in an area where the black silt is relatively thick and there is an underlying soft gray sand.

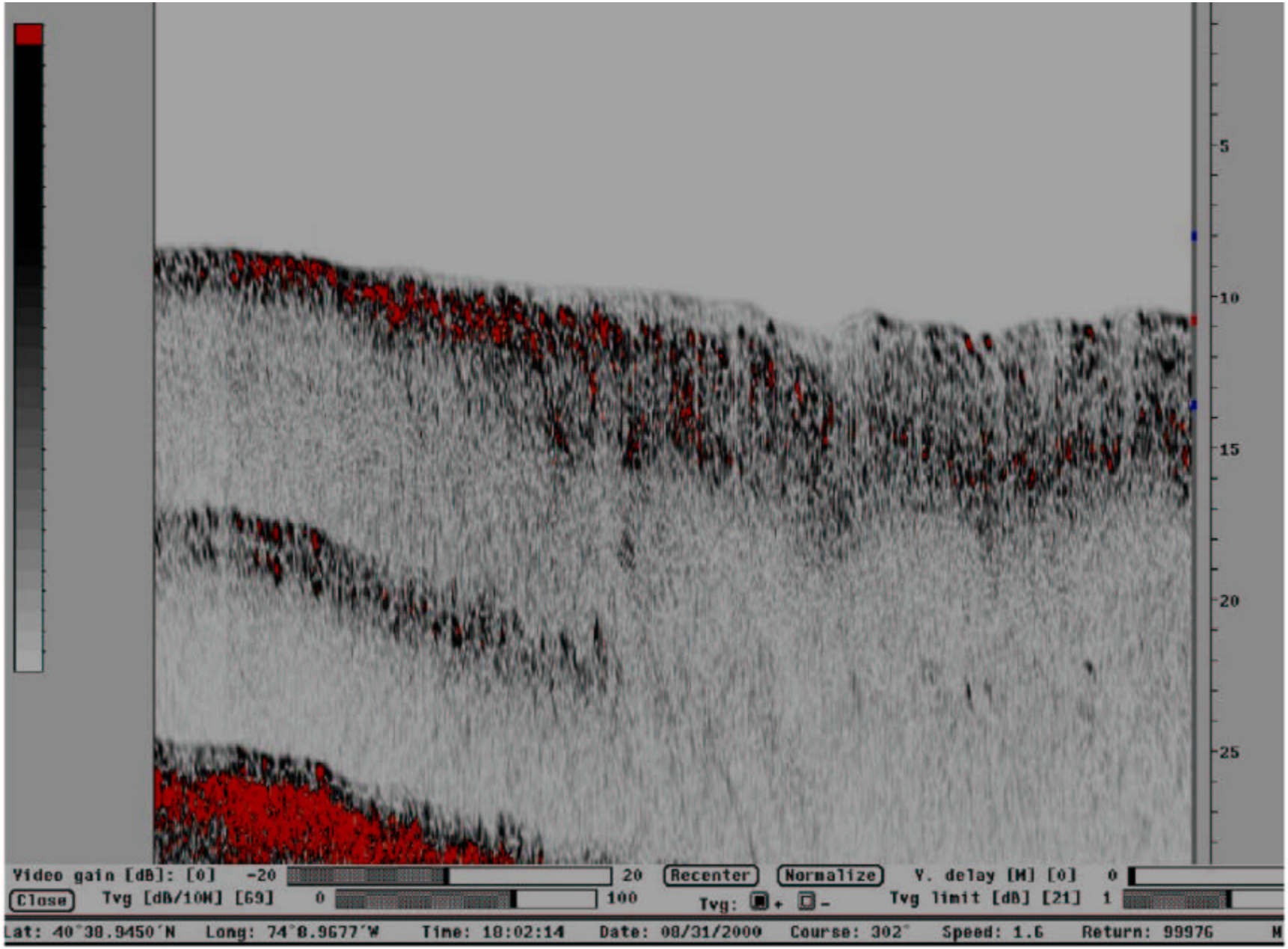


Figure 28. High Frequency (2-10kHz) sub-bottom image of the black silt (weak white reflector) overlying hard material such as Glacial Till or Bedrock.

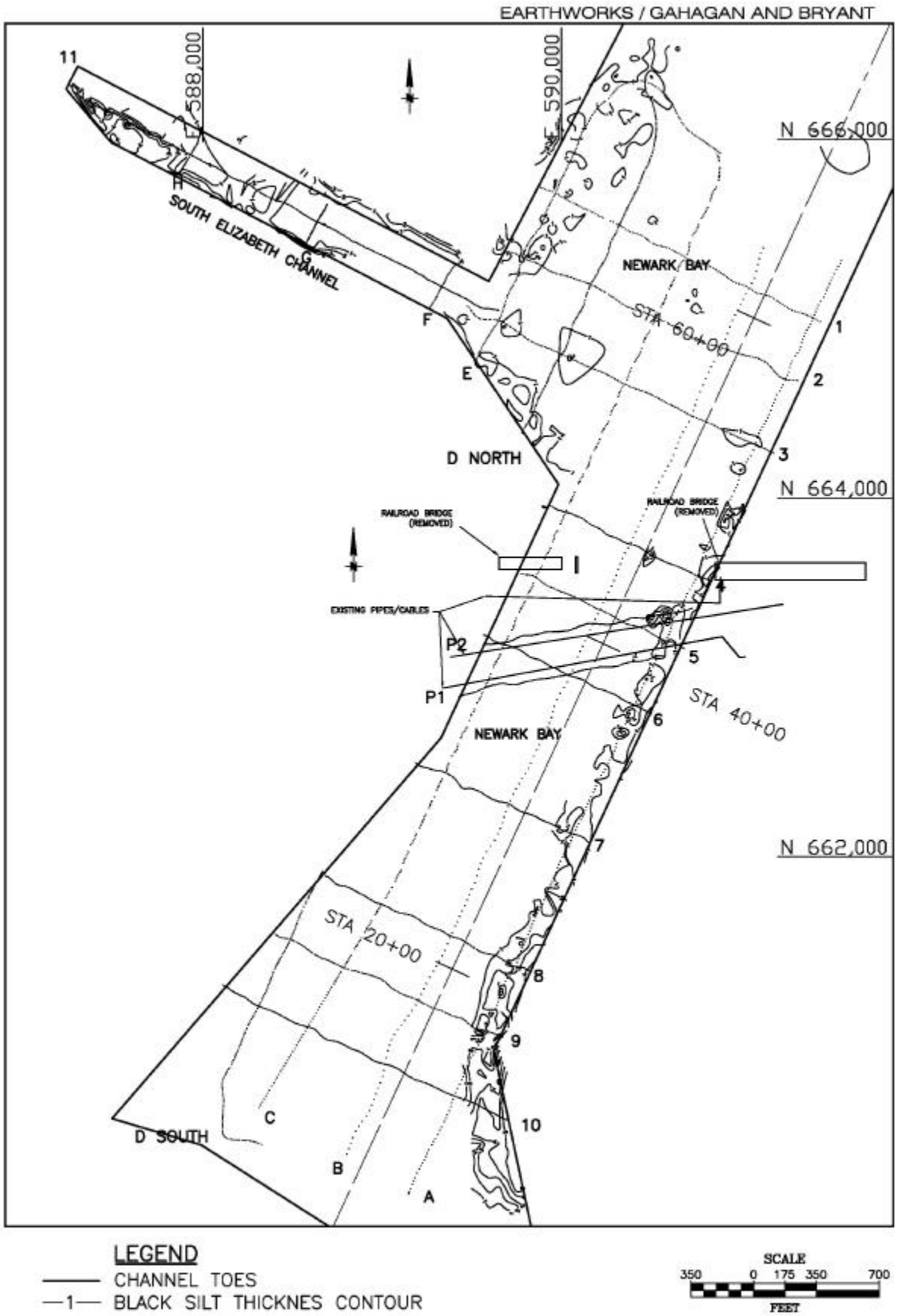


Figure 29. Black Silt Isopach Map of Southern Newark Bay and South Elizabeth Channel. The thickness of the black silt was determined on each of the profile lines shown and was interpolated between lines. Representative borings were included. Areas with less than one foot of black silt were not mapped.

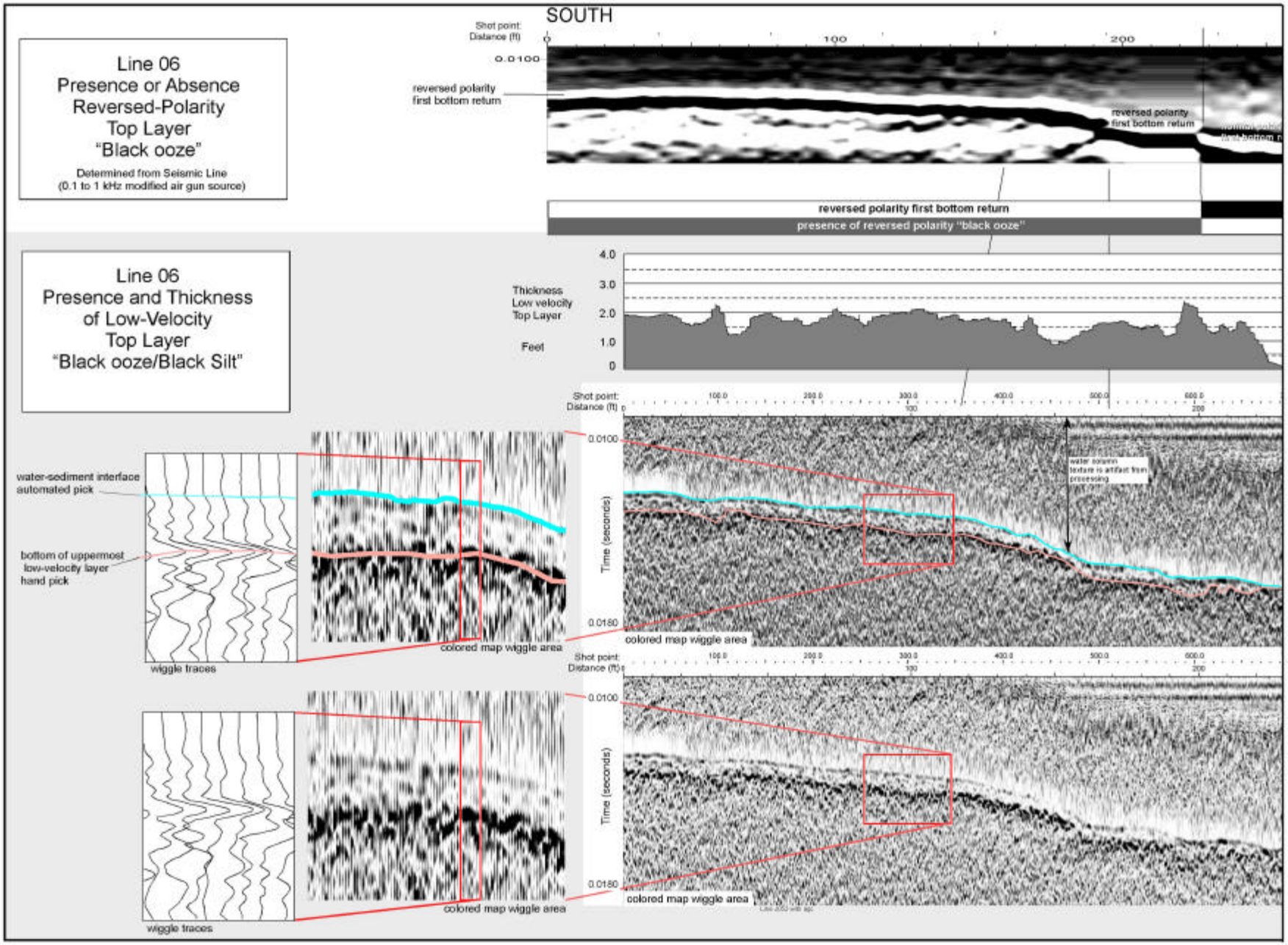


Figure 30. Port Jersey Seismic and Sub-Bottom Profiles. Upper seismic profile was acquired using a modified air gun source. Notice that polarity reverses in the area where the black silt is thin or absent. Lower two lines were obtained using a high frequency (pinger) source. The upper section is interpreted and the lower un-interpreted. Expanded segments are provided to show the detail and quality of the upper and lower events (top and base of the black silt).

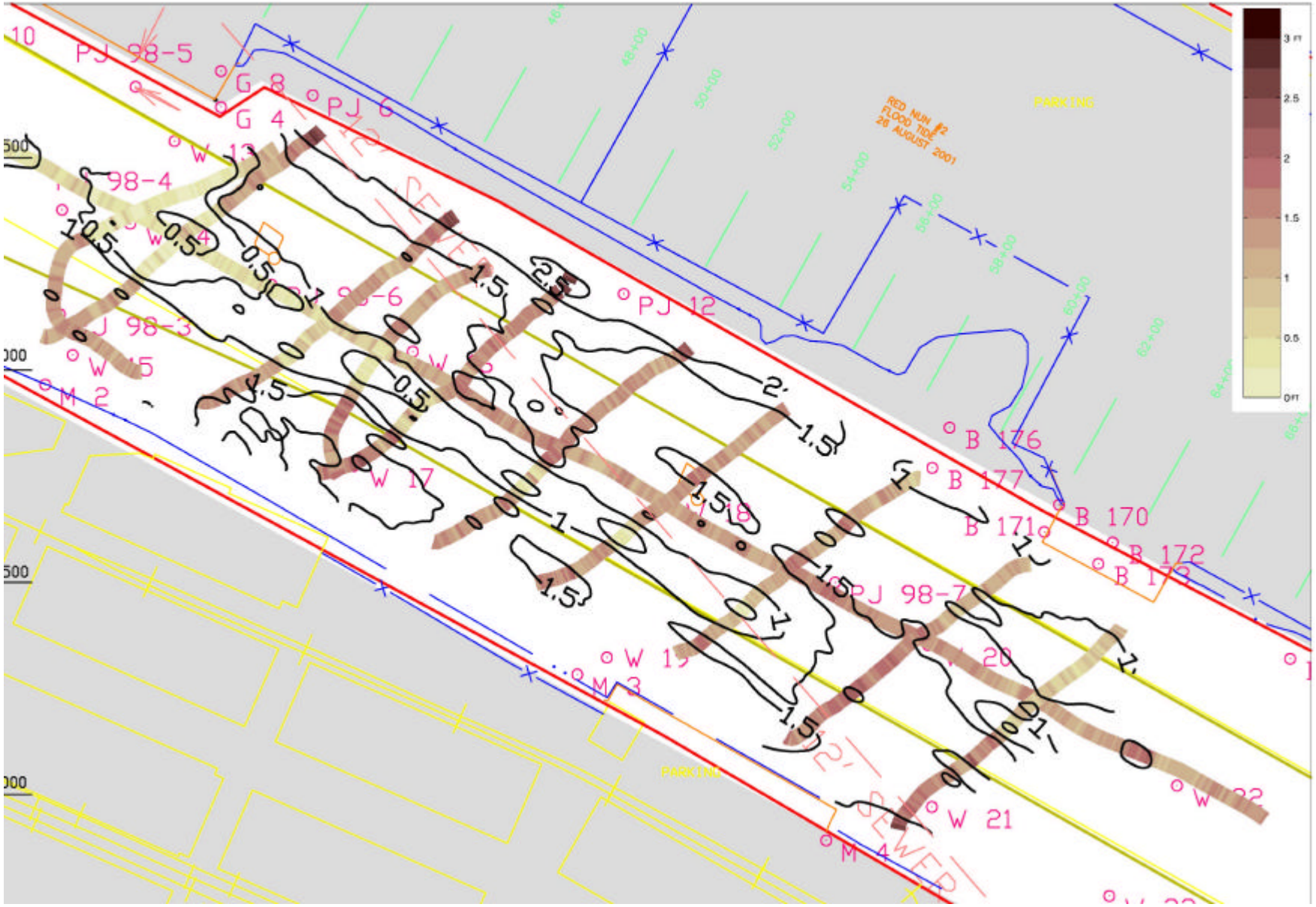


Figure 31. Black Silt Isopach (thickness) Map of a portion of Port Jersey Channel. The thickness of the black silt was determined on each line and was interpolated between lines. More recent borings ('98) were used and older borings were excluded. Contours indicate a thin section along the southern portion of the channel and thick section along the northern edge of the channel.

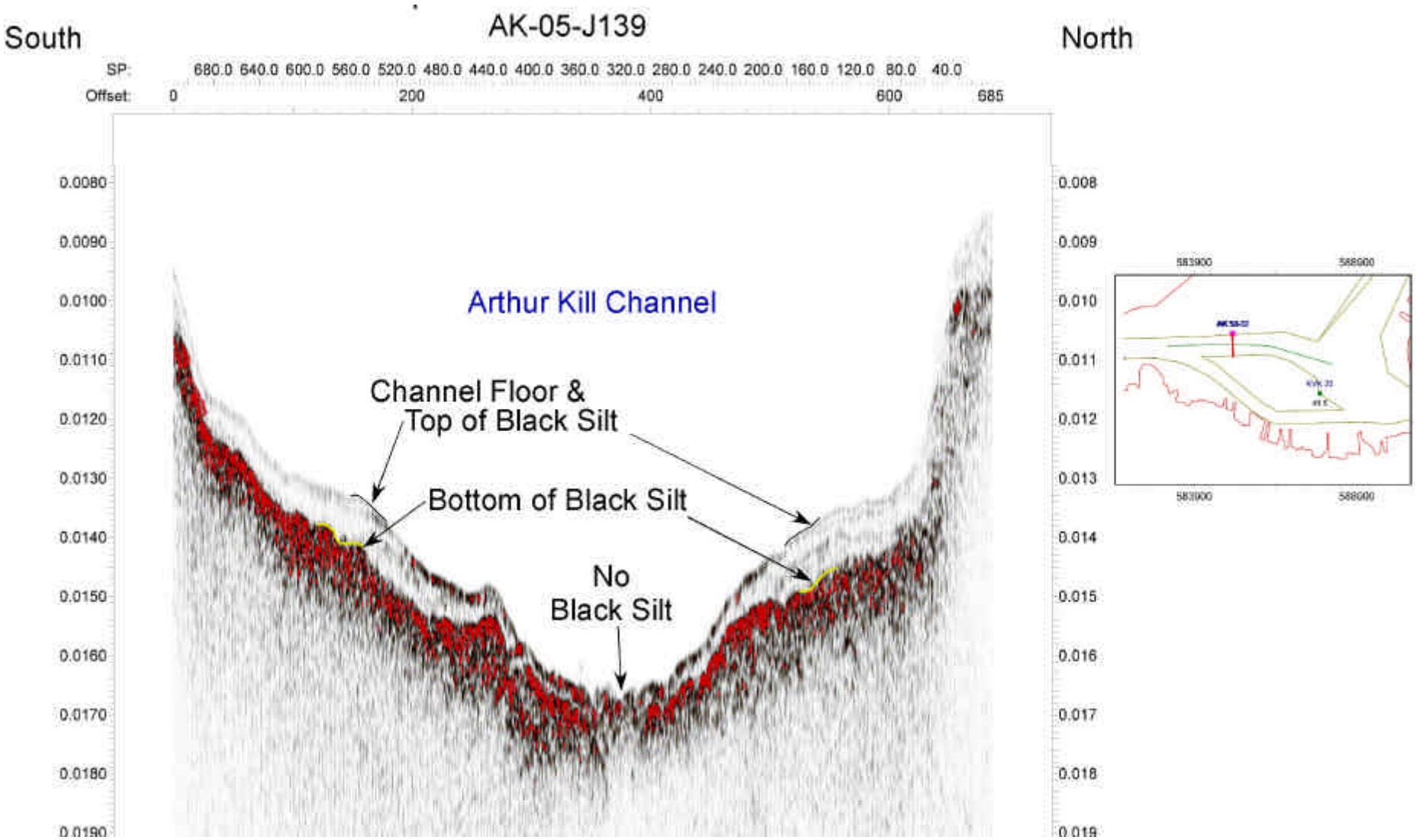


Figure 32. High frequency Sub-bottom Profile in Arthur Kill Channel. Thick black silt accumulations are indicated along the sides of the channel and in the flats on the north side of the channel. Little or no silt is present in the center of the channel.

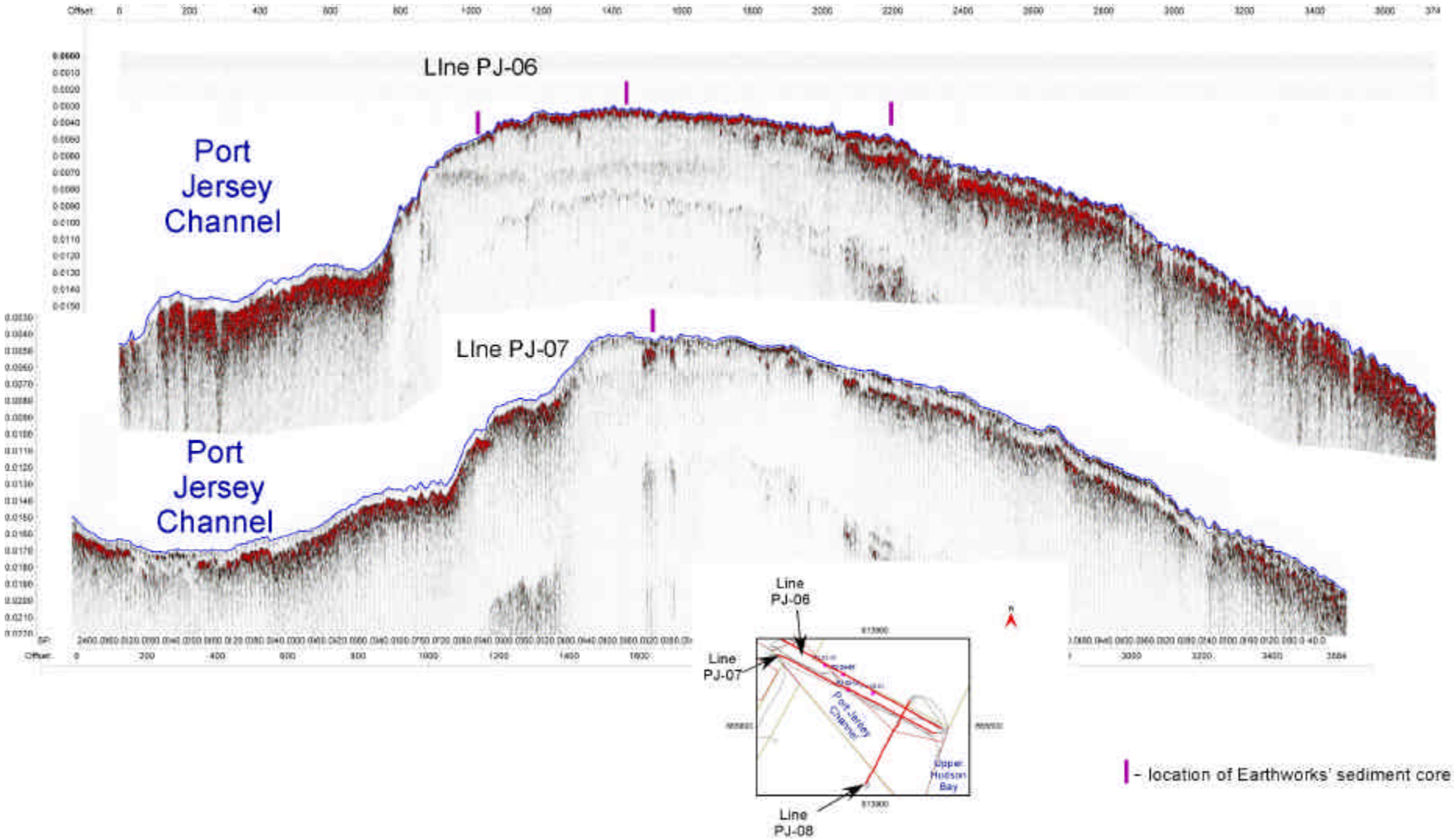


Figure 33. High frequency (Chirp Sonar) Sub-Bottom Profiles in Port Jersey Contract Areas 2A and 2B. The two profiles show a relatively uniform layer of black silt in the channel. In the flats outside the channel the black silt appears to be very thin in the shallowest water and thicker as water depth increases.

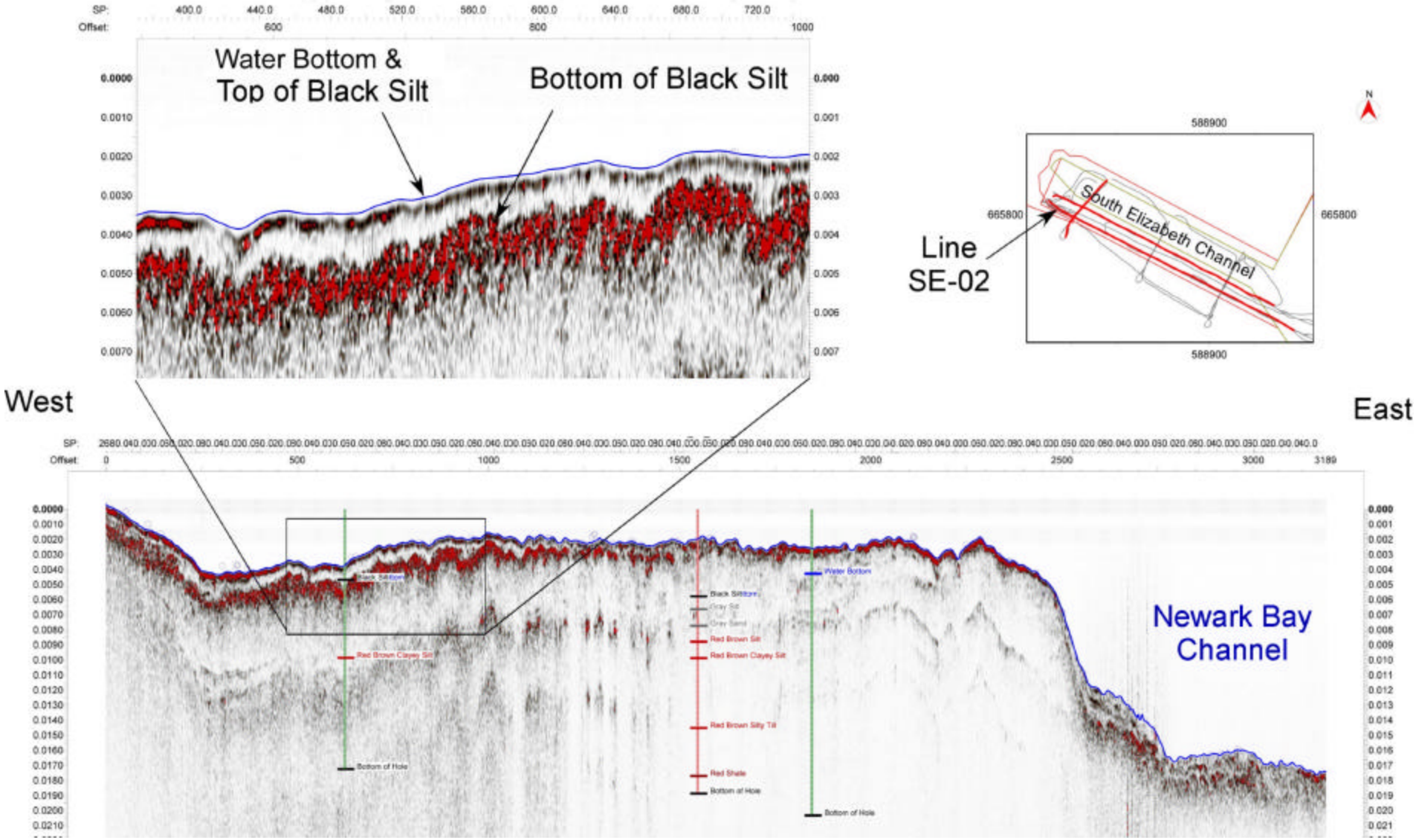


Figure 34. High frequency (Chirp Sonar) Sub-Bottom Profile in the flats just south of South Elizabeth Channel. The lower profile shows a well-defined trend from relatively thick black silt on the west to thin or no silt on the east. The expanded section (top) shows the upper and lower reflectors to be about .001 milliseconds apart in two-way travel time. Assuming a velocity of 5,000 feet per second the thickness of the black silt on the west side is about 2.5 feet.

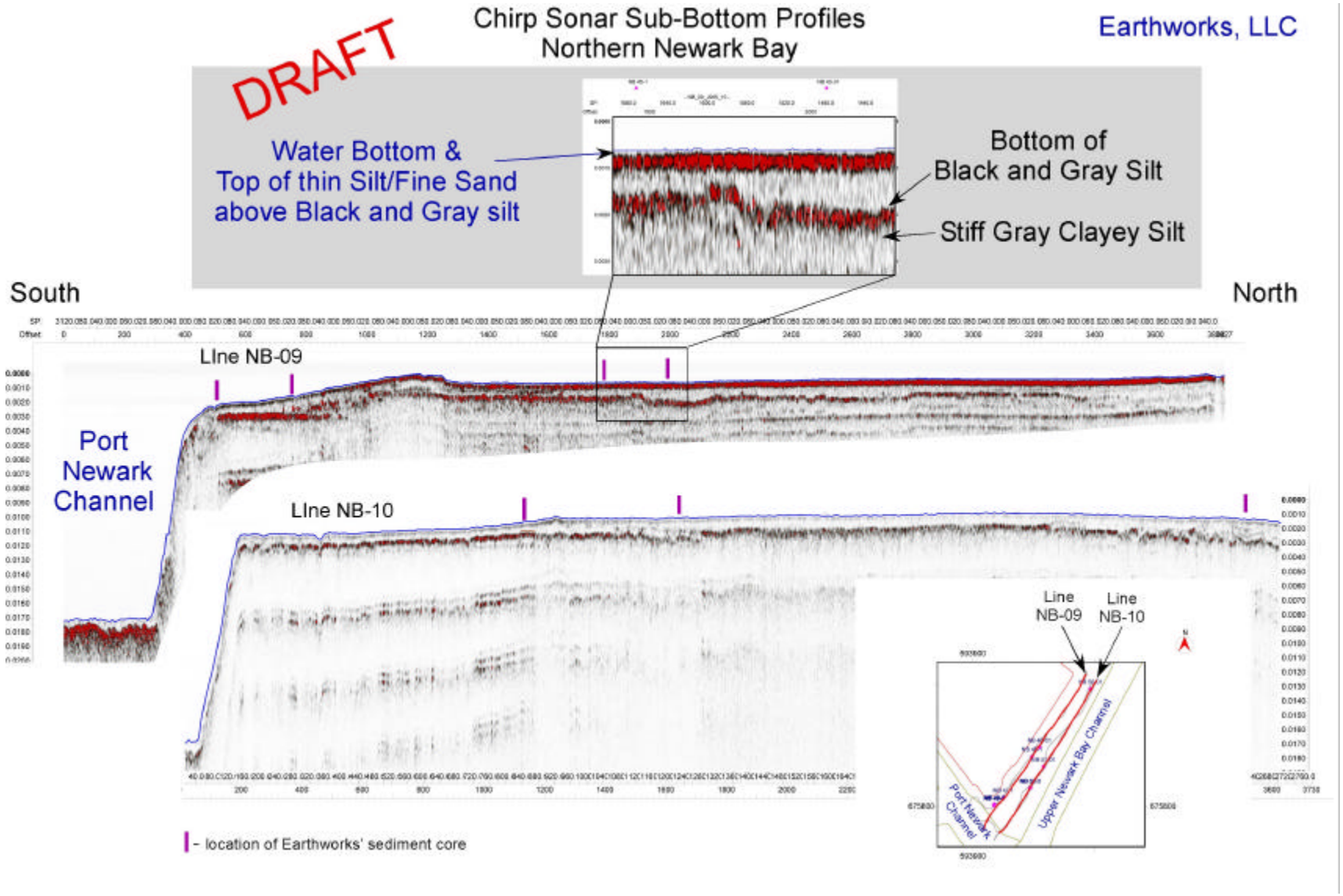


Figure 35. High frequency (Chirp Sonar) Sub-Bottom Profiles in Northern Newark Bay. The profiles indicate a relatively uniform layer of black silt overlying stiff gray clayey silt. Based on the expanded section the thickness of the gray-black silt is 3-5' thick.

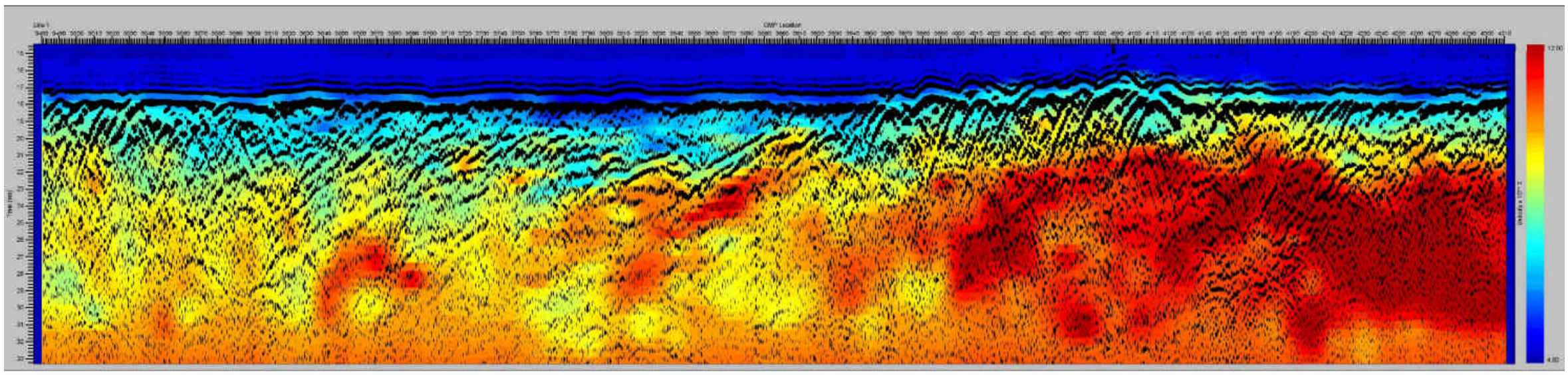


Figure 36. Color-coded interval velocity superimposed on a CMP stacked section in eastern Arthur Kill. Low velocity material (<10,000 fps) shaded orange, yellow, green or blue is interpreted to be dredgable without blasting. High velocity material (>10,000 fps) shaded red is thought to require treatment (i.e. blasting) before dredging.

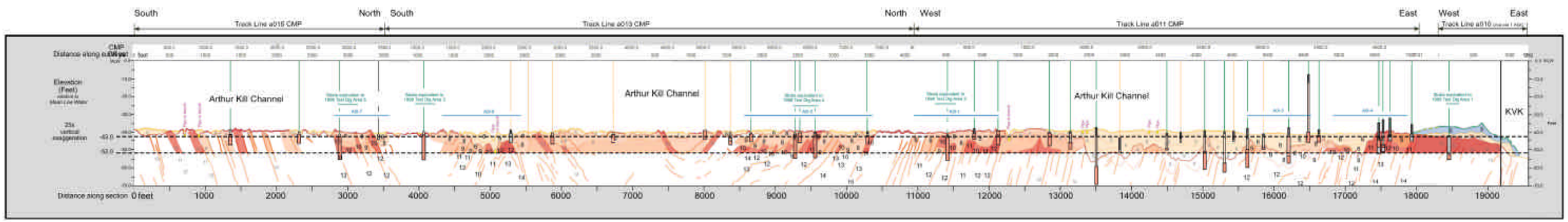


Figure 37. Profile of Arthur Kill showing contoured velocity values. Material (bedrock) with velocities greater than 10,000 fps (shaded red) is interpreted to require treatment prior to dredging. Forty-three foot (-43' MLW) and fifty-two foot (-52' MLW) project elevations are shown so that the relative amount of material that will require blasting can be determined. Velocities were determined from seismic and laboratory testing.

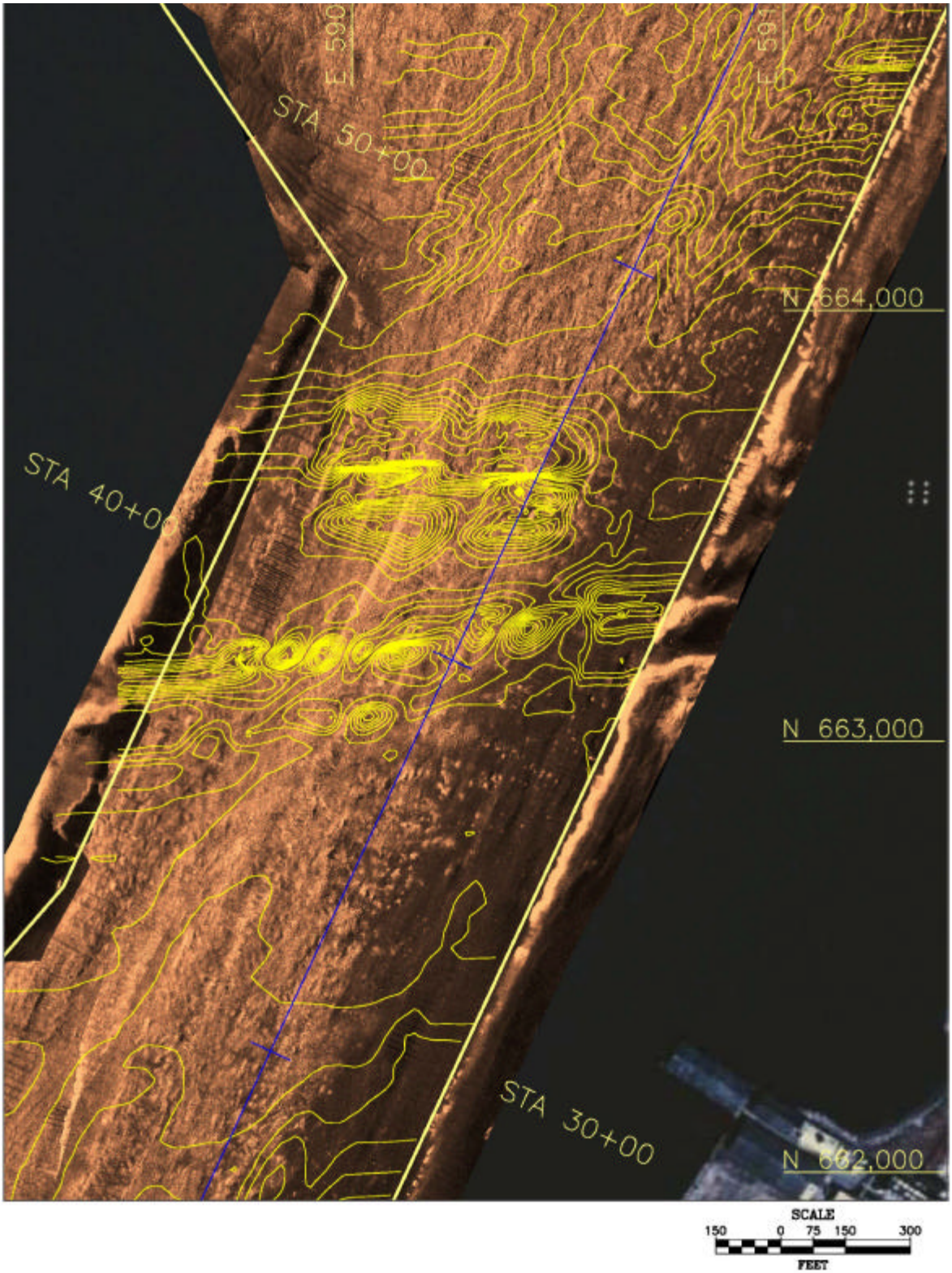


Figure 38. Magnetometer data superimposed on side scan sonar mosaic in Southern Newark Bay. Magnetometer data shows a series of high values that align with the trenches indicated on the side scan mosaic (See Figure 20).

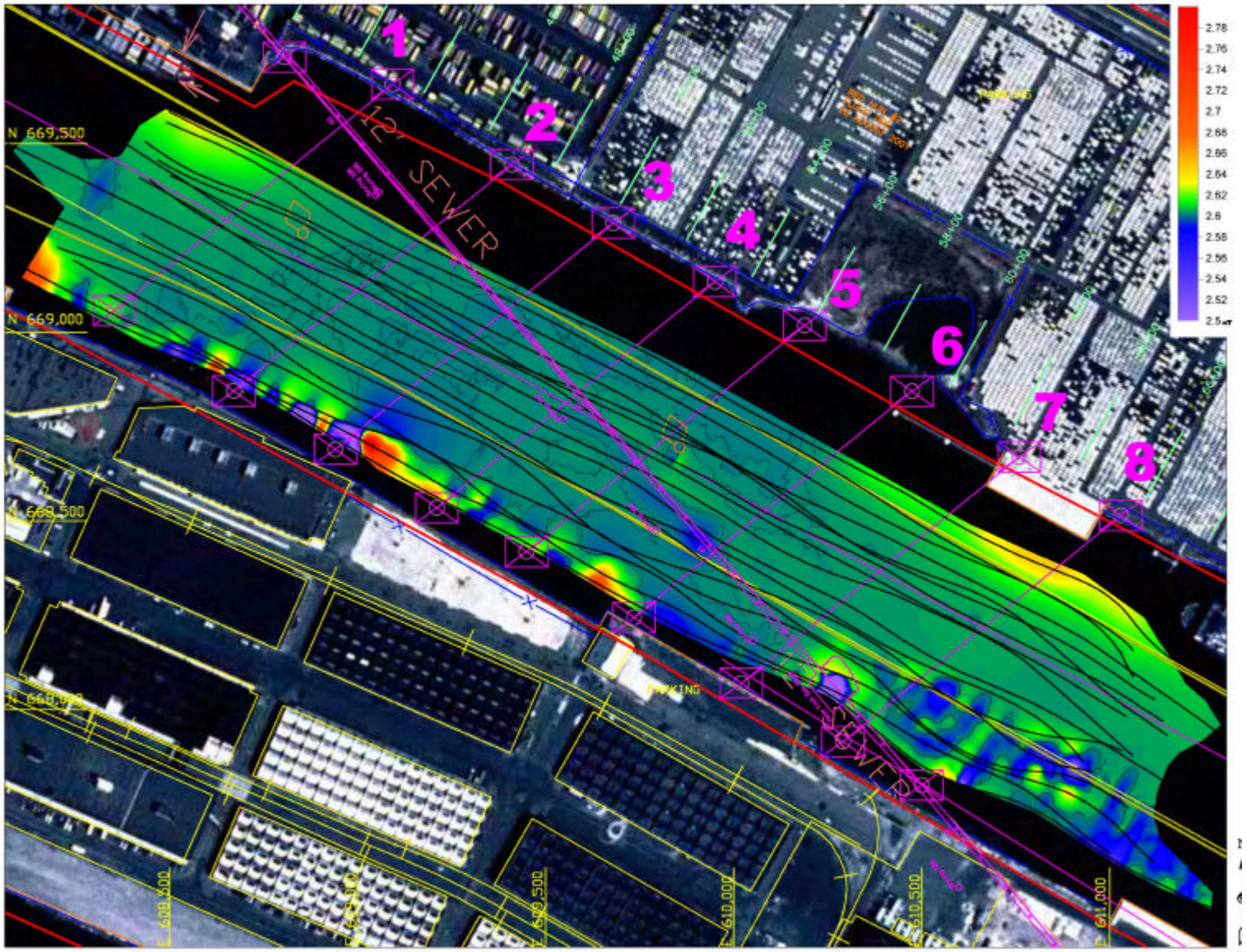


Figure 39. Gradiometer data collected in the vicinity of the Passaic Valley Sewage Tunnel that underlies Port Jersey Channel. A relatively low order anomaly occurs in the vicinity of a relief shaft on the south side of the channel. There is no apparent anomaly associated with the pipeline.

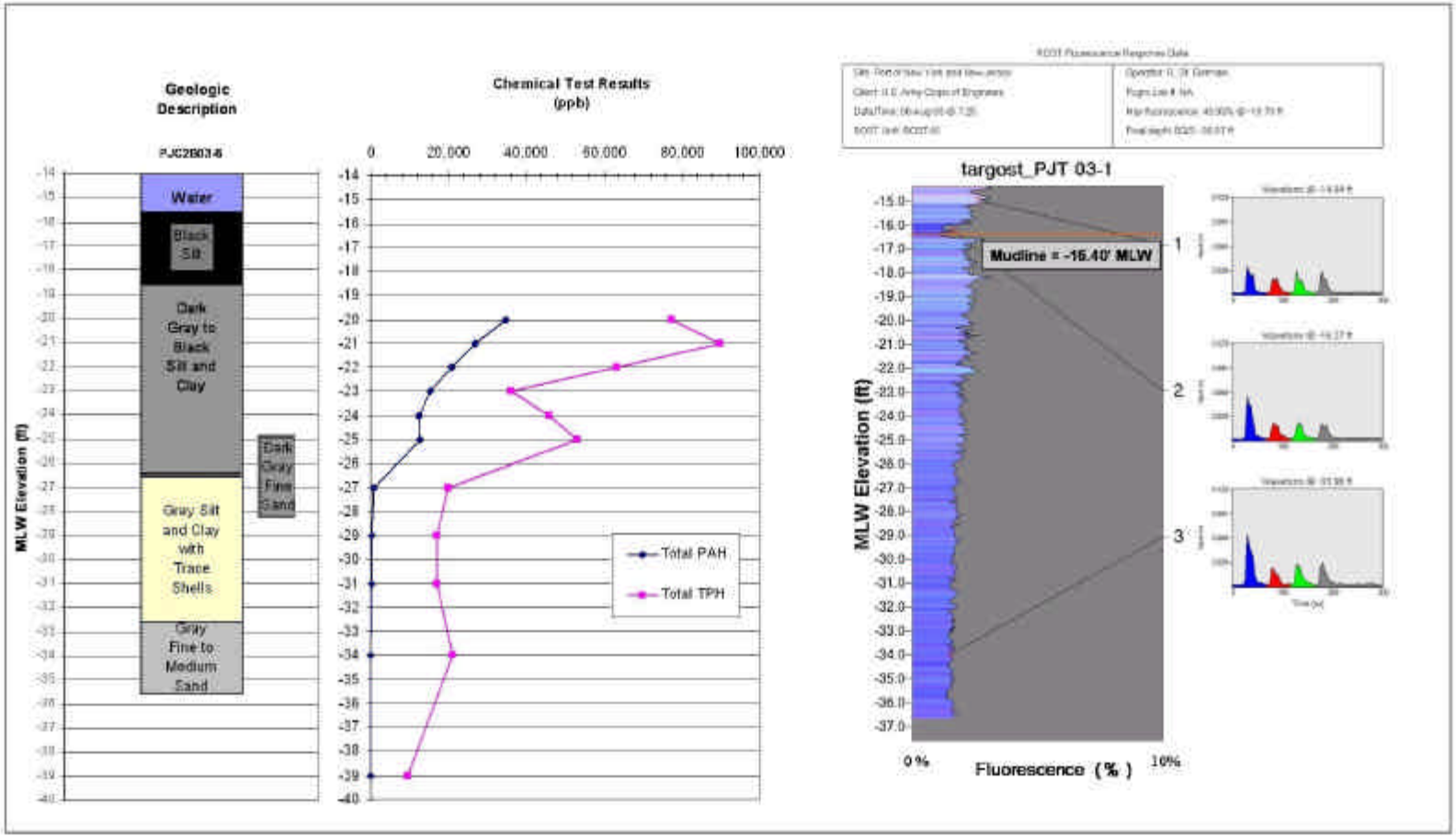


Figure 40. Port Jersey - Comparison of stratigraphy, chemical testing and laser induced fluorescence (LIF) using a targost source. All of the data indicates that the base of the contaminated interval occurs at an elevation of twenty-six to twenty-seven feet below mean low water (-26 to –27' MLW). The stratigraphic section is based on a nearby boring and indicates a mudline similar to that indicated by the probe. The LIF probe shows a low but consistent level of response. Laser induced fluorescence using a rost source showed no response.

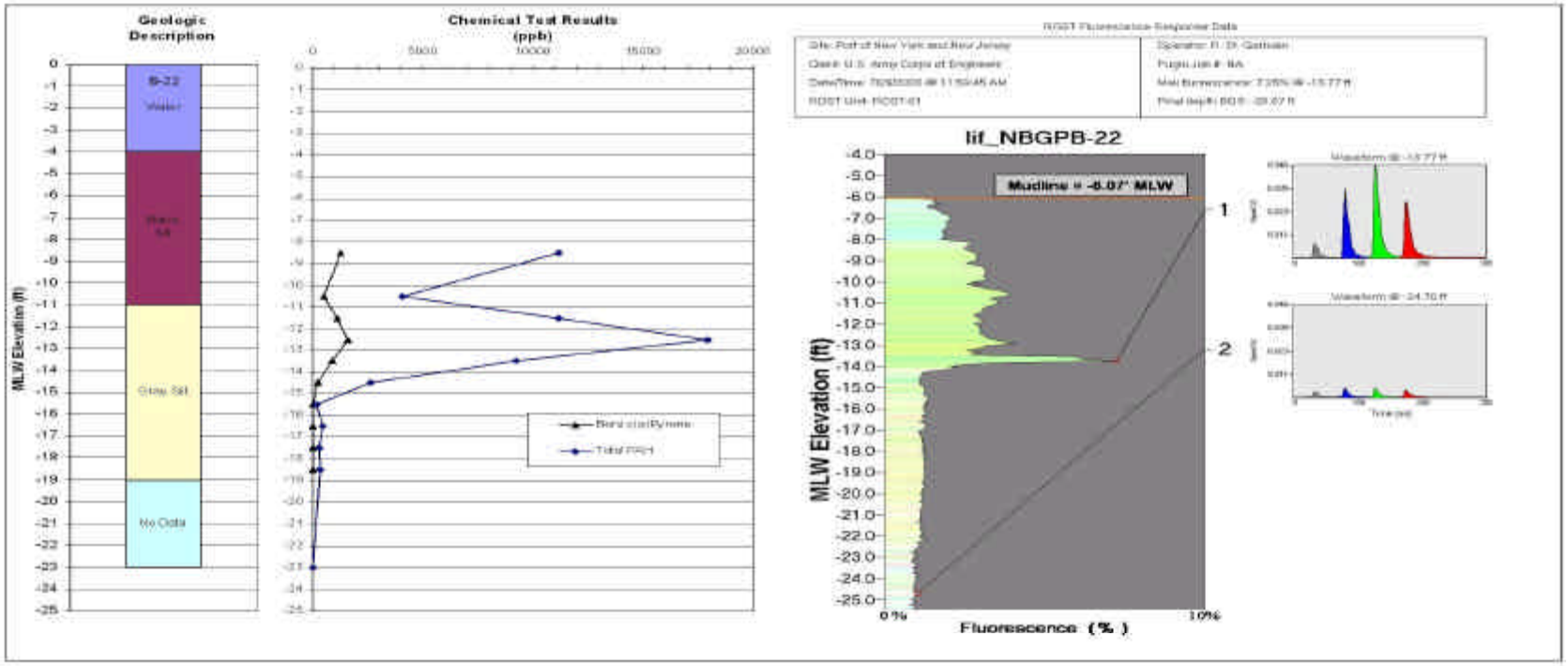


Figure 41. Northern Newark Bay – Comparison of stratigraphy, chemical testing and laser induced fluorescence. Chemical testing was not conducted in the upper four feet because samples could not be recovered. The chemical and probe data are in good agreement that the base of the contaminated interval occurs at in the interval between fourteen feet (-14' MLW) and fifteen feet (-15' MLW). The contaminated interval occurs in both the black and gray silt layers.

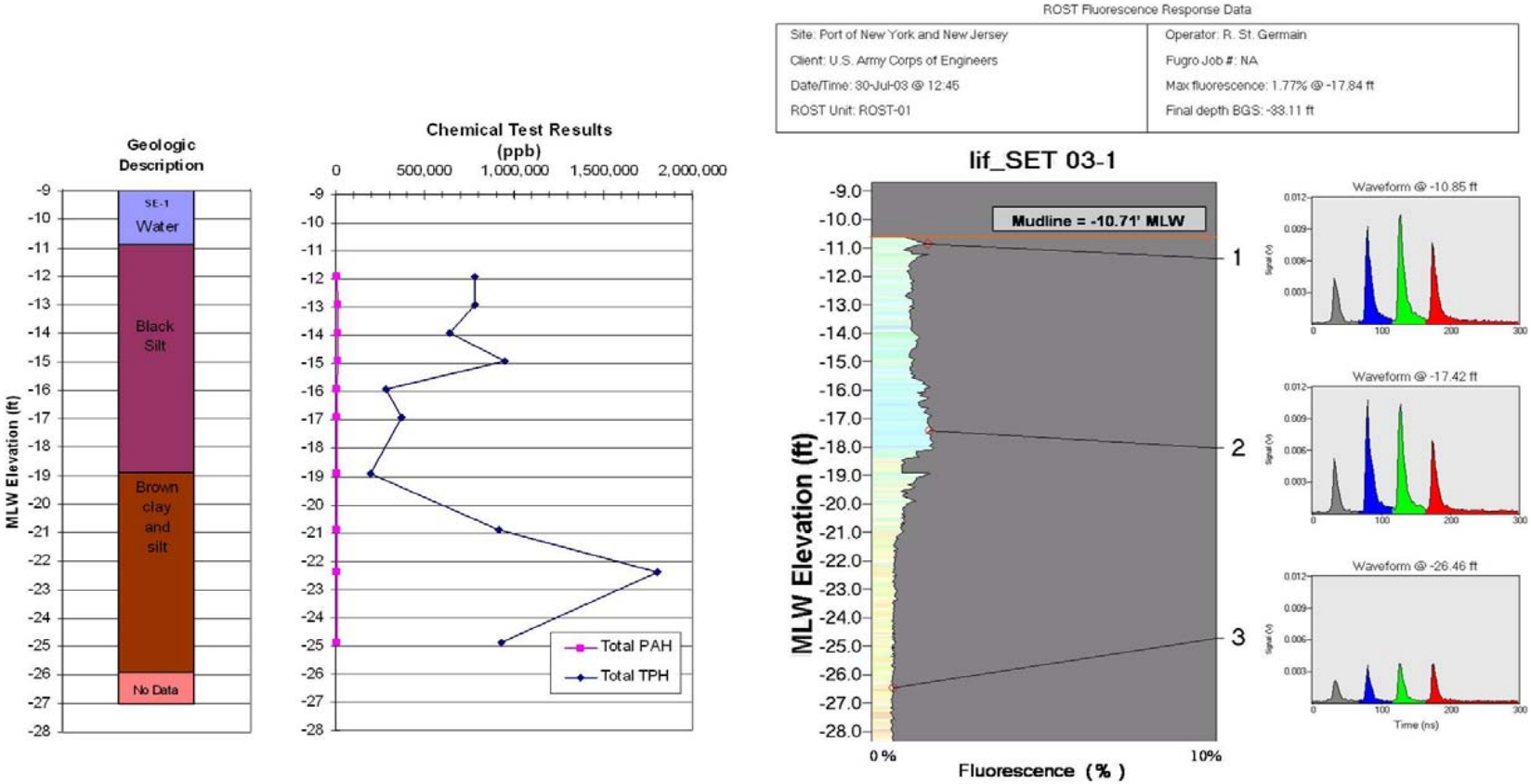


Figure 42. South Elizabeth Channel – Comparison of stratigraphy, chemical testing and laser induced fluorescence (LIF). Stratigraphy and LIF data are in good agreement. The black silt is indicated to be about eight feet (8') thick. The upper portion of the chemical data (above –19') is in good agreement with the LIF and stratigraphy but does not agree below that depth. The Pleistocene shows a higher level of PAH than the black silt. A review of the sample data indicates that the sample procedure may have concentrated contaminates in the upper portion of the Pleistocene.

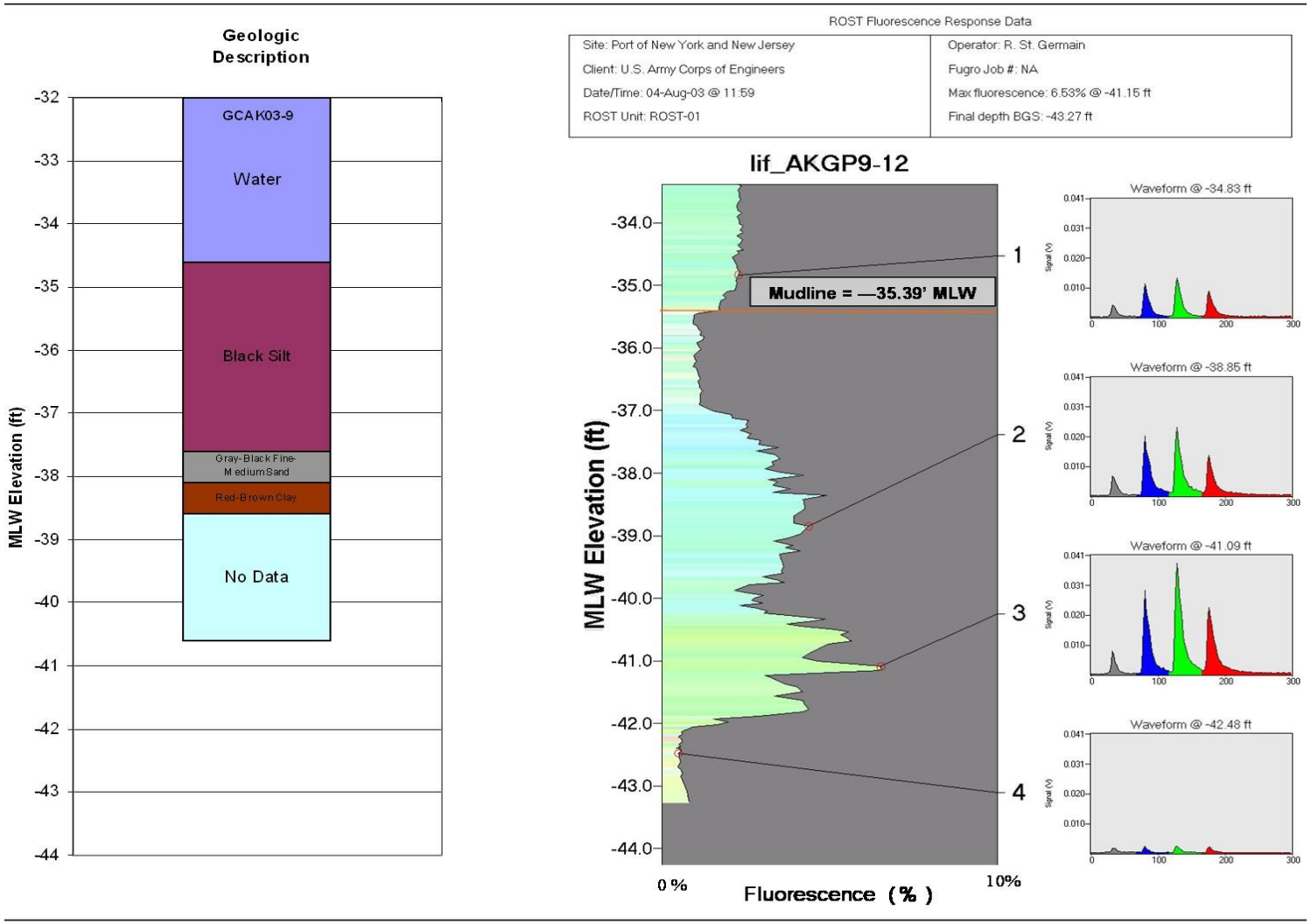


Figure 43. Arthur Kill - Comparison of stratigraphy as indicated by gravity core and laser induced fluorescence. No chemical data is available. The LIF indicates the black silt is approximately seven feet thick whereas the gravity core indicates a thickness of four feet. The difference may be because investigations were as much as fifty feet from one another. Another possibility is that some of the soft black silt was not recovered in the gravity core.

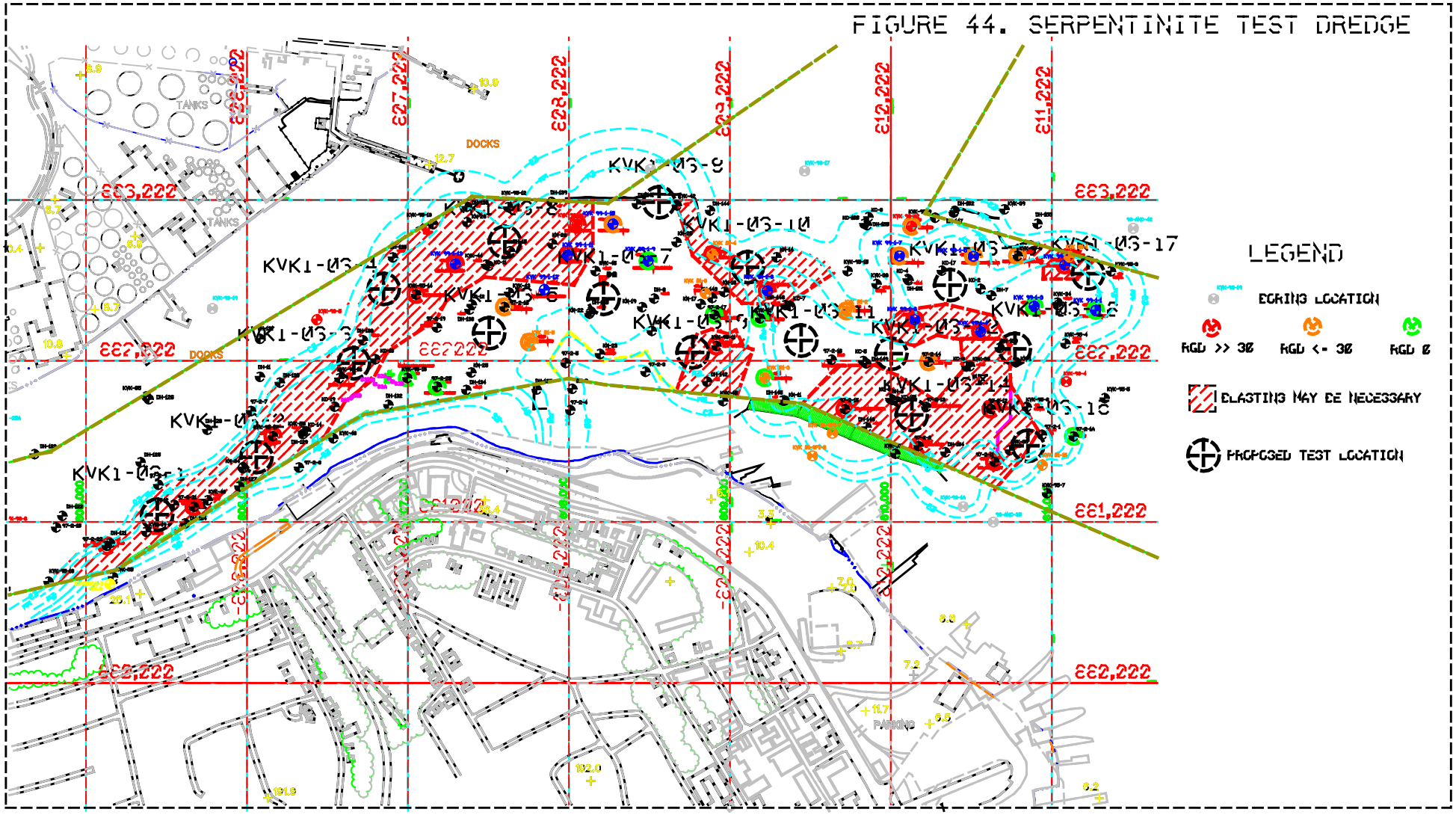


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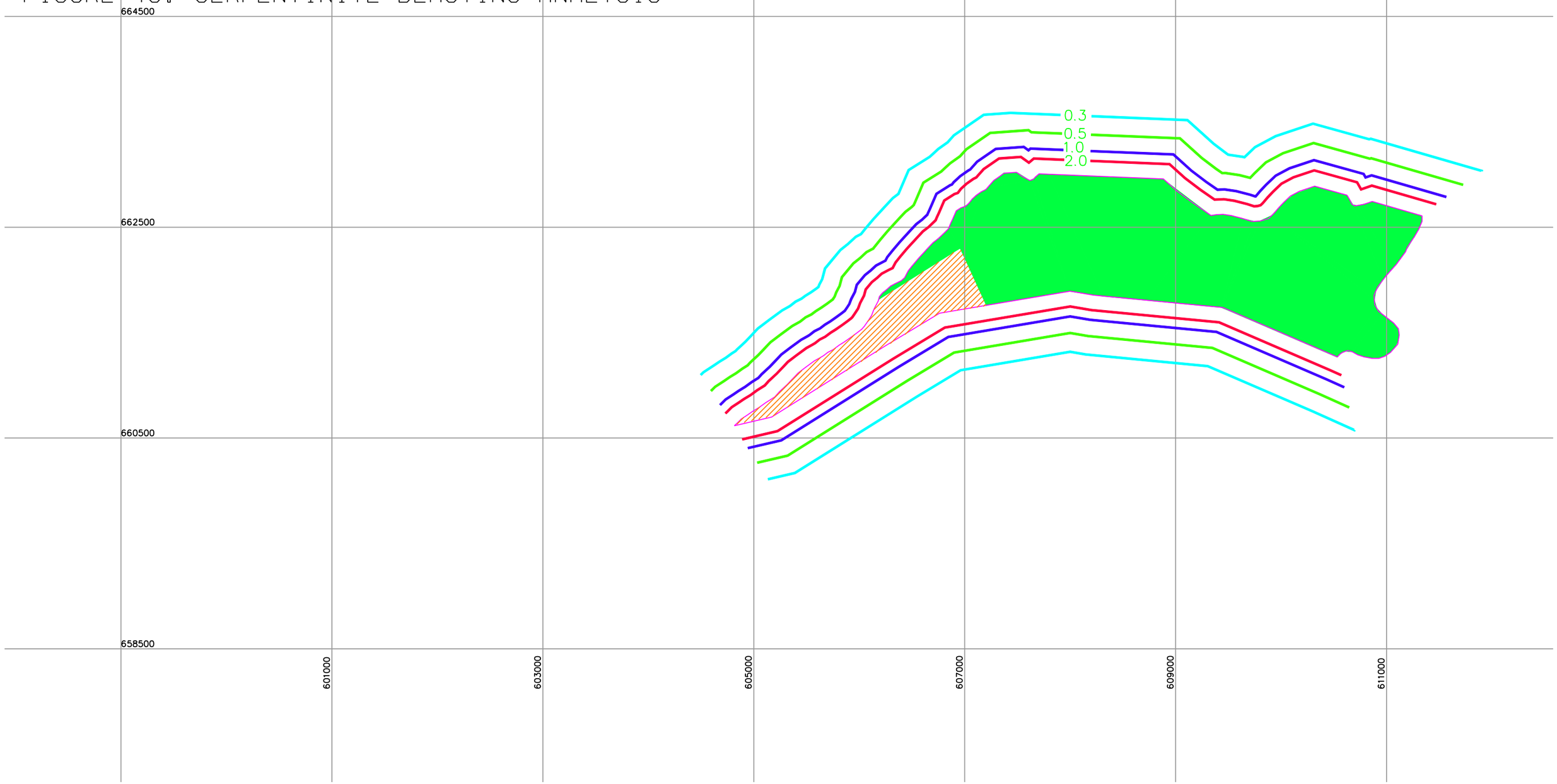
FIGURE 45. SERPENTINITE BLASTING ANALYSIS



LEGEND:

0.5 — CONTOURS OF ESTIMATED PEAK PARTICLE VELOCITY FOR PRODUCTION BLASTING PATTERN AT EDGE OF NAVIGATION CHANNEL

ESTIMATED AREA OF TYPE I BLASTING

ESTIMATED AREA OF TYPE II BLASTING IN SOUTHERN AND/OR EASTERN HALF OF NAVIGATION CHANNEL

NOTE:

NO BLAST ZONES ARE SHOWN ON FIGURE 4–12

0 500 1000 2000

SCALE (FEET)

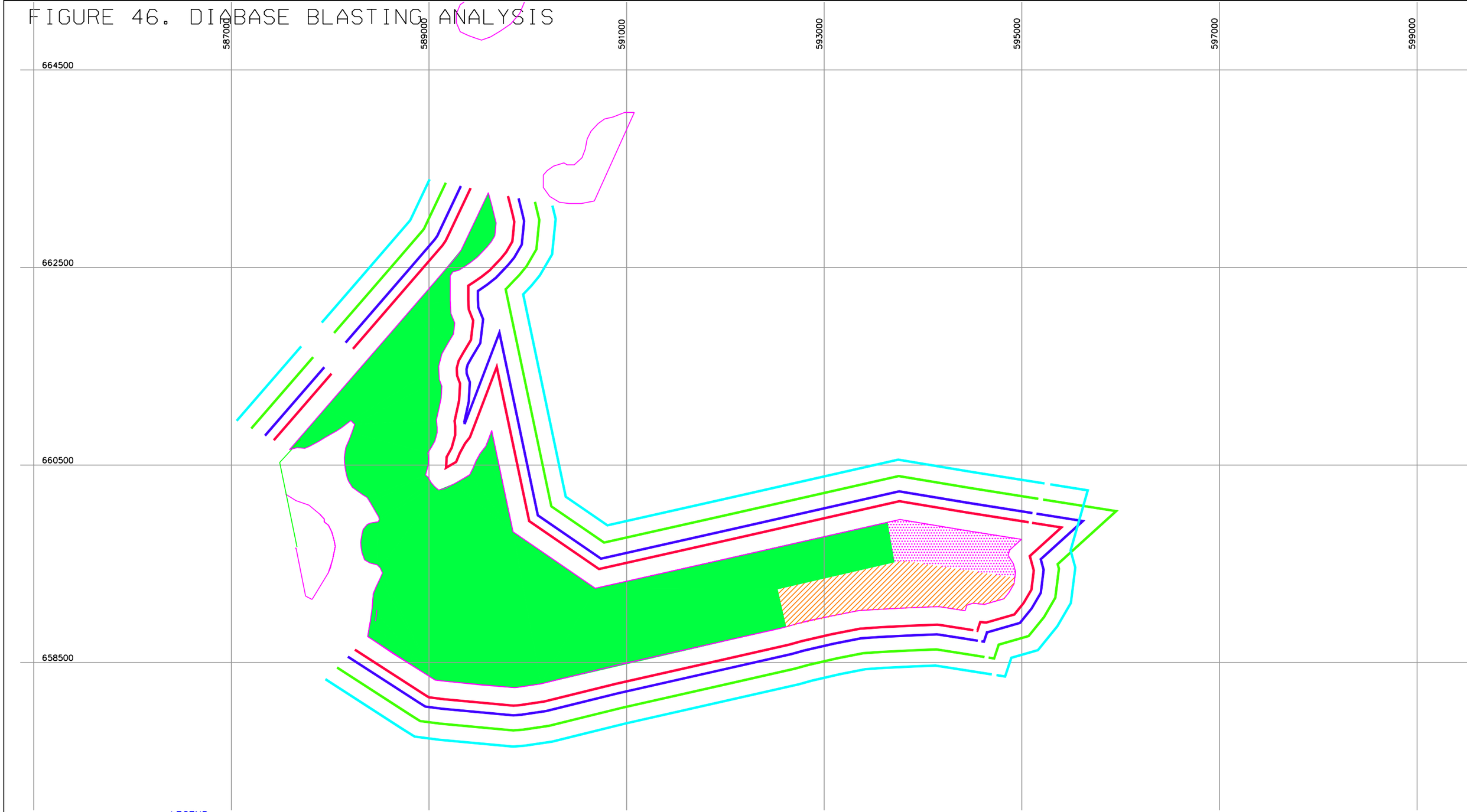
SUMMARY OF BLASTING PLAN
INCREASE IN DEPTH 47–52 FEET
KILL VAN KULL
SERPENTINITE AREA

URS
WAYNE, NEW JERSEY

DR. BY	FWD	SCALE	AS SHOWN	DWG. NO.	83602003	PROJ. NO.	19683602
CK'D. BY	AMH	DATE	JAN 22, 2003	FIG. NO.	3		

83602003.dwg 11/03/2003 07:19:33 PM

FIGURE 46. DIABASE BLASTING ANALYSIS



LEGEND:

0.5 — CONTOURS OF ESTIMATED PEAK PARTICLE VELOCITY FOR PRODUCTION BLASTING PATTERN AT EDGE OF NAVIGATION CHANNEL

ESTIMATED AREA OF TYPE I BLASTING

ESTIMATED AREA OF TYPE II BLASTING IN SOUTHERN AND/OR EASTERN HALF OF NAVIGATION CHANNEL

ESTIMATED AREA OF TYPE II BLASTING IN NORTHERN AND/OR WESTERN HALF OF NAVIGATION CHANNEL

NOTE:

NO BLAST ZONES ARE SHOWN ON FIGURE 4-12

0 500 1000 2000

SCALE (FEET)

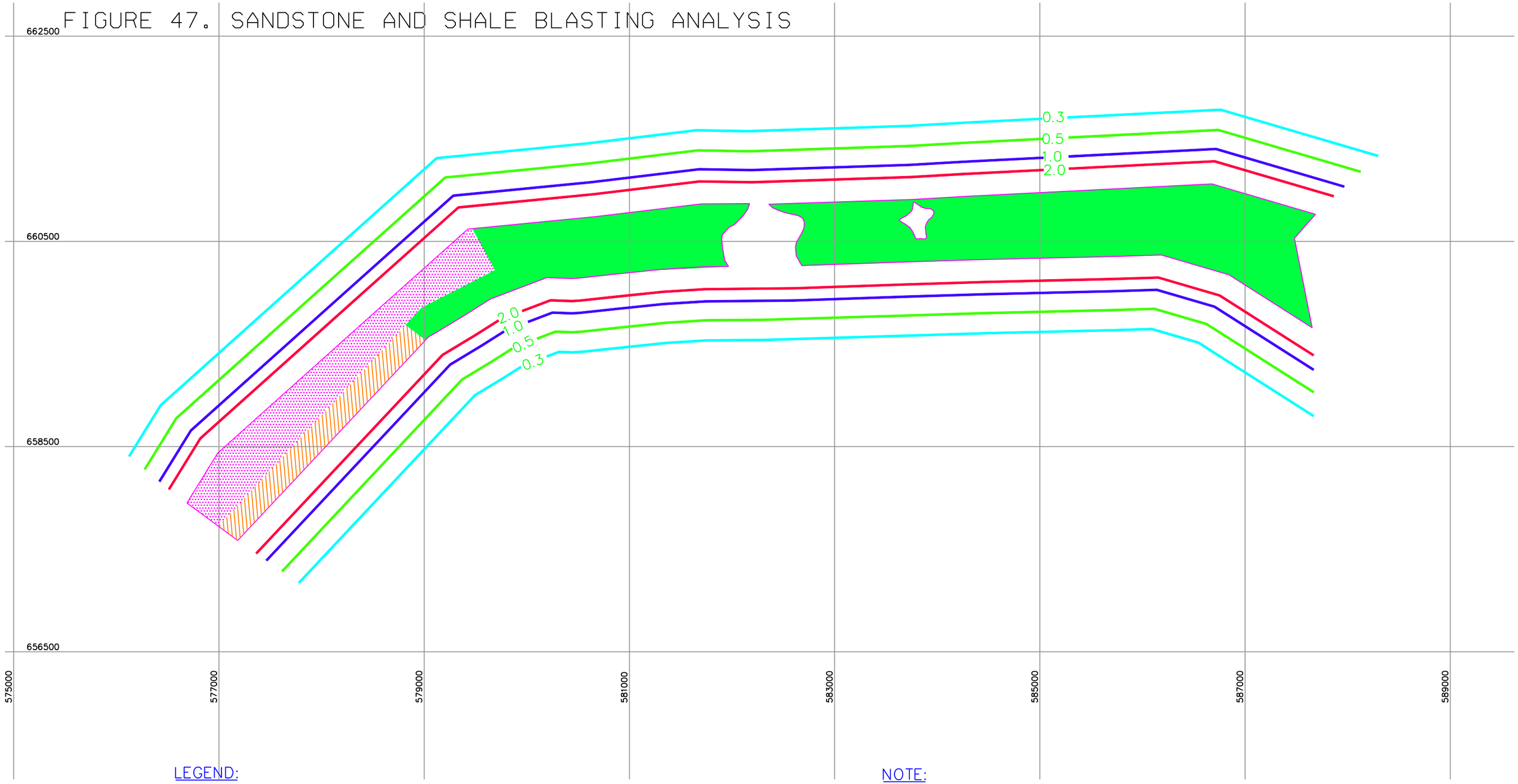
SUMMARY OF BLASTING PLAN
INCREASE IN DEPTH 47-52 FEET
DIABASE AREA
KILL VAN KULL

URS
WAYNE, NEW JERSEY

DR. BY	FWD	SCALE	AS SHOWN	DWG. NO. 83602005	PROJ. NO. 19683602
CK'D. BY	AMH	DATE	JAN 22, 2003	FIG. NO.	4

83602005.dwg 11/03/2003 07:20:28 PM

FIGURE 47. SANDSTONE AND SHALE BLASTING ANALYSIS



LEGEND:

0.5 — CONTOURS OF ESTIMATED PEAK PARTICLE VELOCITY FOR PRODUCTION BLASTING PATTERN AT EDGE OF NAVIGATION CHANNEL

ESTIMATED AREA OF TYPE I BLASTING

ESTIMATED AREA OF TYPE II BLASTING IN SOUTHERN AND/OR EASTERN HALF OF NAVIGATION CHANNEL

ESTIMATED AREA OF TYPE II BLASTING IN NORTHERN AND/OR WESTERN HALF OF NAVIGATION CHANNEL

NOTE:

NO BLAST ZONES ARE SHOWN ON FIGURE 4–12

0 500 1000 2000

SCALE (FEET)

SUMMARY OF BLASTING PLAN
INCREASE IN DEPTH 42–52 FEET
ARTHUR KILL

URS
WAYNE, NEW JERSEY

DR. BY	FWD	SCALE	AS SHOWN	DWG. NO.	83602004	PROJ. NO.	19683602
CK'D. BY	AMH	DATE	JAN 22, 2003	FIG. NO.	5		

83602004.dwg 11/03/2003 07:21:19 PM

Figure 49

ARTHUR KILL CHANNEL

Profile Line #1

NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
2	Gray Silt and Sand	96	Cohesion: 96.0 Friction angle: 26	Piezometric Line no. 1
3	Red-brown Silty Clay	127	Cohesion: 500.0 Friction angle: 15	Piezometric Line no. 1
4	Red Brown Till (Sand and Gravel)	125	Cohesion: 300.0 Friction angle: 35	Piezometric Line no. 1
5	Red Shale and Sandstone	155	Cohesion: 5000.0 Friction angle: 40	Piezometric Line no. 1

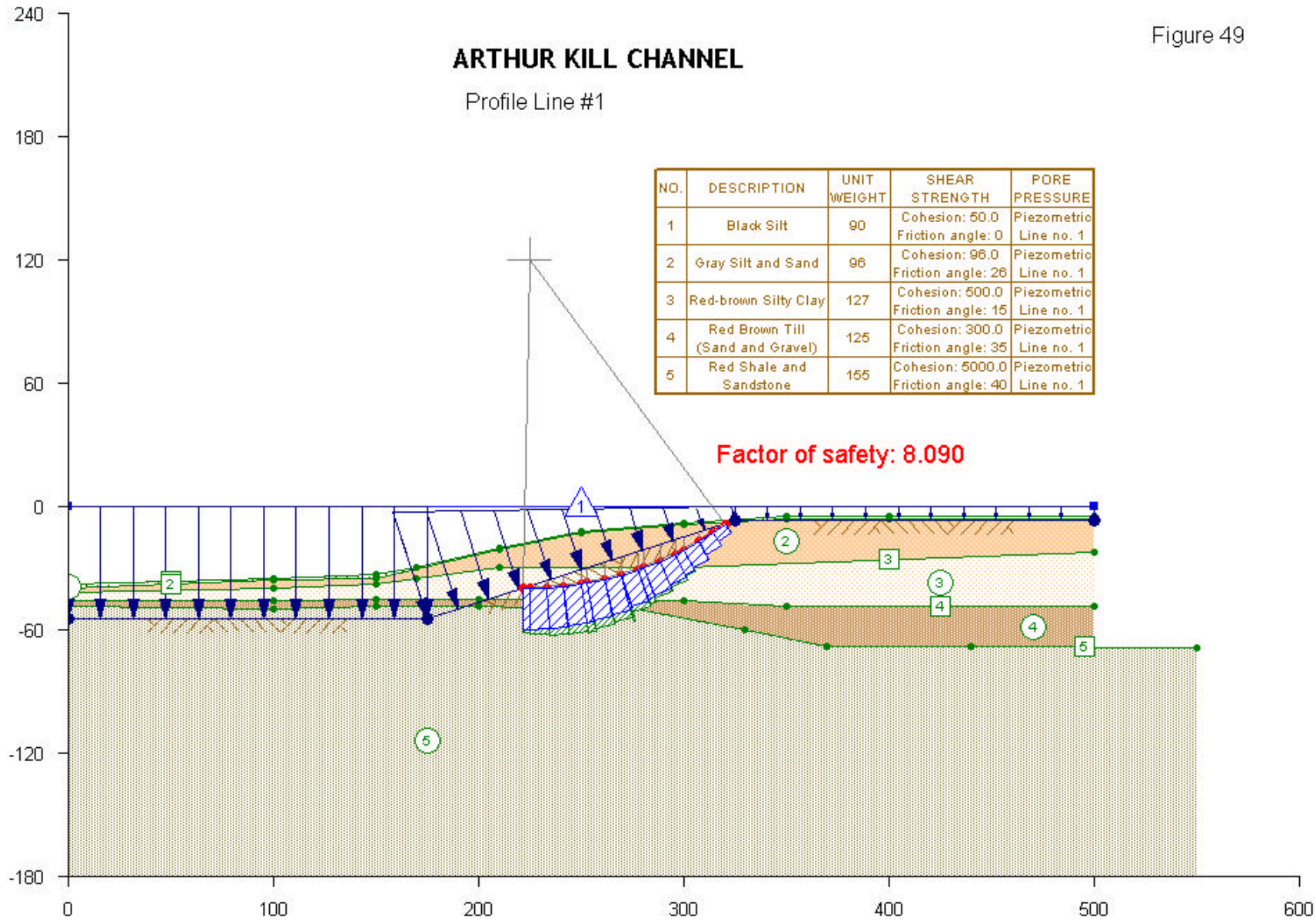
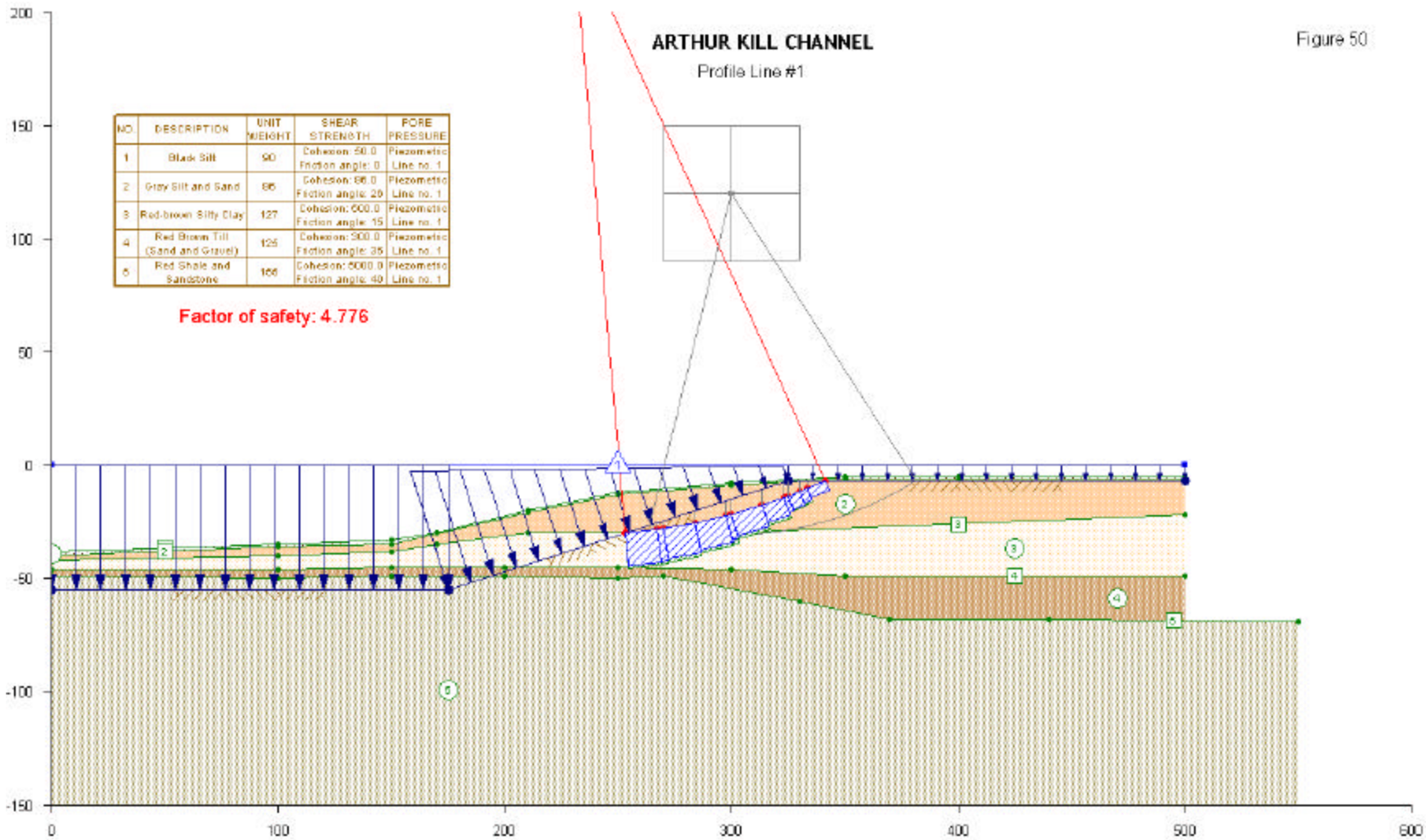


Figure 50



NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
2	Gray Silt and Sand	95	Cohesion: 95.0 Friction angle: 25	Piezometric Line no. 1
3	Red-brown Silty Clay	127	Cohesion: 600.0 Friction angle: 15	Piezometric Line no. 1
4	Red Brown Till (Sand and Gravel)	125	Cohesion: 500.0 Friction angle: 35	Piezometric Line no. 1
5	Red Shale and Sandstone	166	Cohesion: 5000.0 Friction angle: 40	Piezometric Line no. 1

Figure 51

ARTHUR KILL CHANNEL

Profile Line #4

NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
2	Gray Silt and Sand	96	Cohesion: 96.0 Friction angle: 26	Piezometric Line no. 1
3	Brown Sand with peat layer	115	Cohesion: 50.0 Friction angle: 31	Piezometric Line no. 1
4	Red Brown Till (Sand and Gravel)	125	Cohesion: 300.0 Friction angle: 35	Piezometric Line no. 1
5	Red Shale and Sandstone	155	Cohesion: 5000.0 Friction angle: 40	Piezometric Line no. 1

Factor of safety: 5.896

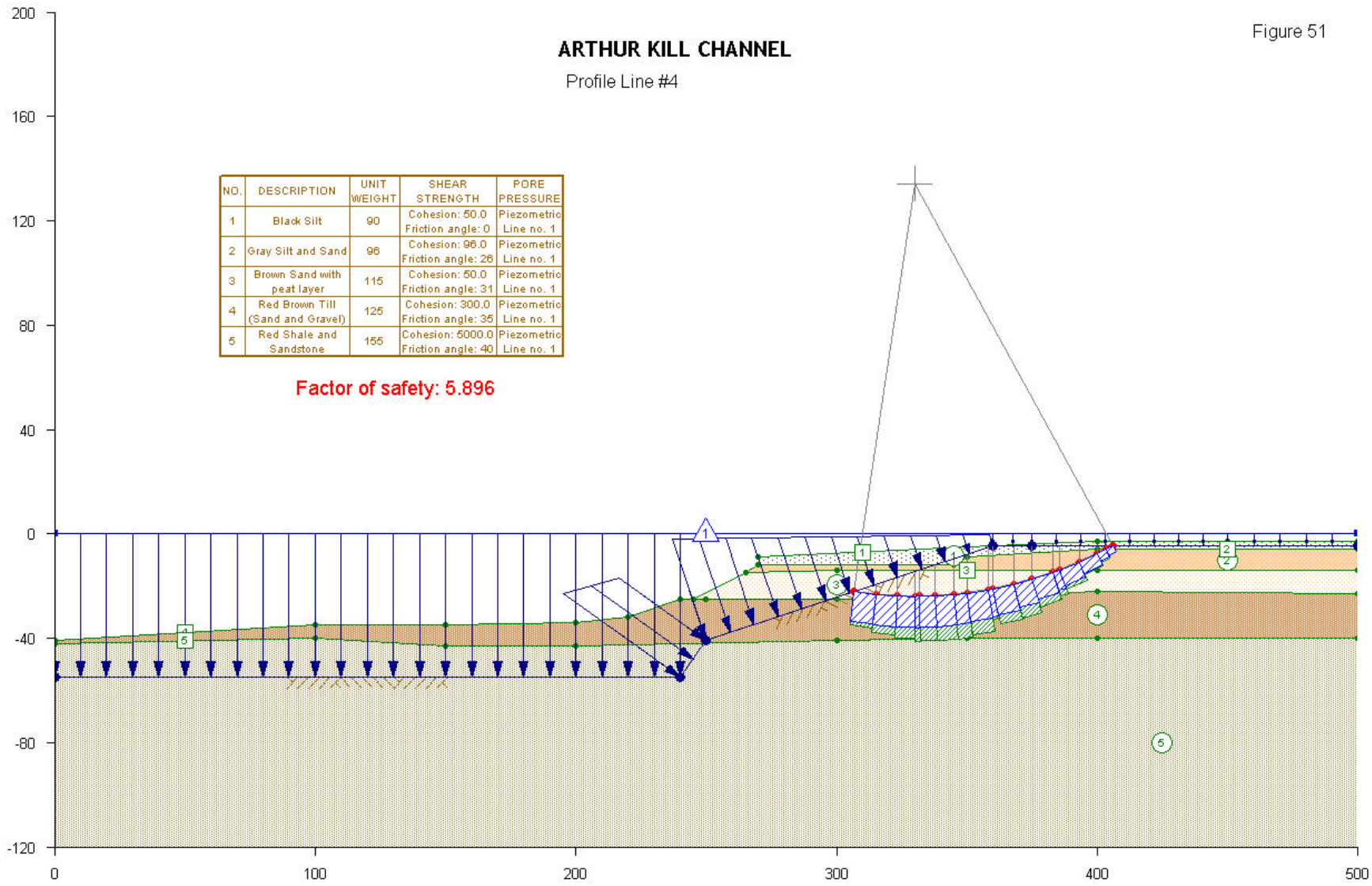


Figure 52

ARTHUR KILL CHANNEL

Profile Line #4

NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
2	Gray Silt and Sand	96	Cohesion: 96.0 Friction angle: 26	Piezometric Line no. 1
3	Brown Sand with peat layer	115	Cohesion: 50.0 Friction angle: 31	Piezometric Line no. 1
4	Red Brown Till (Sand and Gravel)	125	Cohesion: 300.0 Friction angle: 35	Piezometric Line no. 1
5	Red Shale and Sandstone	155	Cohesion: 5000.0 Friction angle: 0	Piezometric Line no. 1

Factor of safety: 5.895

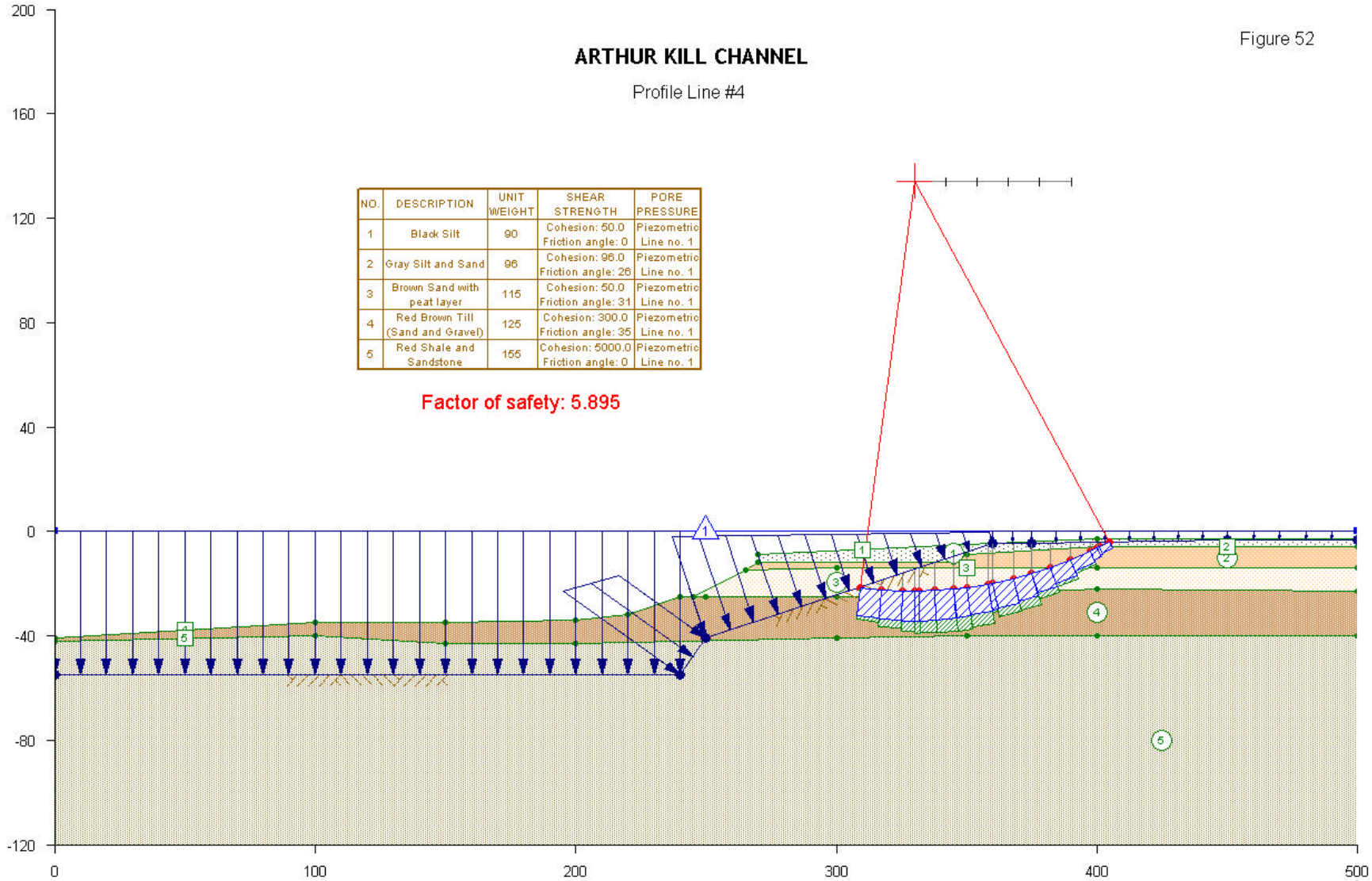


Figure 53

ARTHUR KILL CHANNEL

Profile Line #4

NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Black Silt	90	Cohesion: 200.0 Friction angle: 0	Piezometric Line no. 1
2	Gray Silt and Sand	100	Cohesion: 0.0 Friction angle: 31	Piezometric Line no. 1
3	Brown Sand with peat layer	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
4	Red Brown Till (Sand and Gravel)	125	Cohesion: 500.0 Friction angle: 0	Piezometric Line no. 1
5	Red Shale and Sandstone	155	Cohesion: 5000.0 Friction angle: 0	Piezometric Line no. 1

Factor of safety: 1.366

Side force Inclination: 0.13 degrees

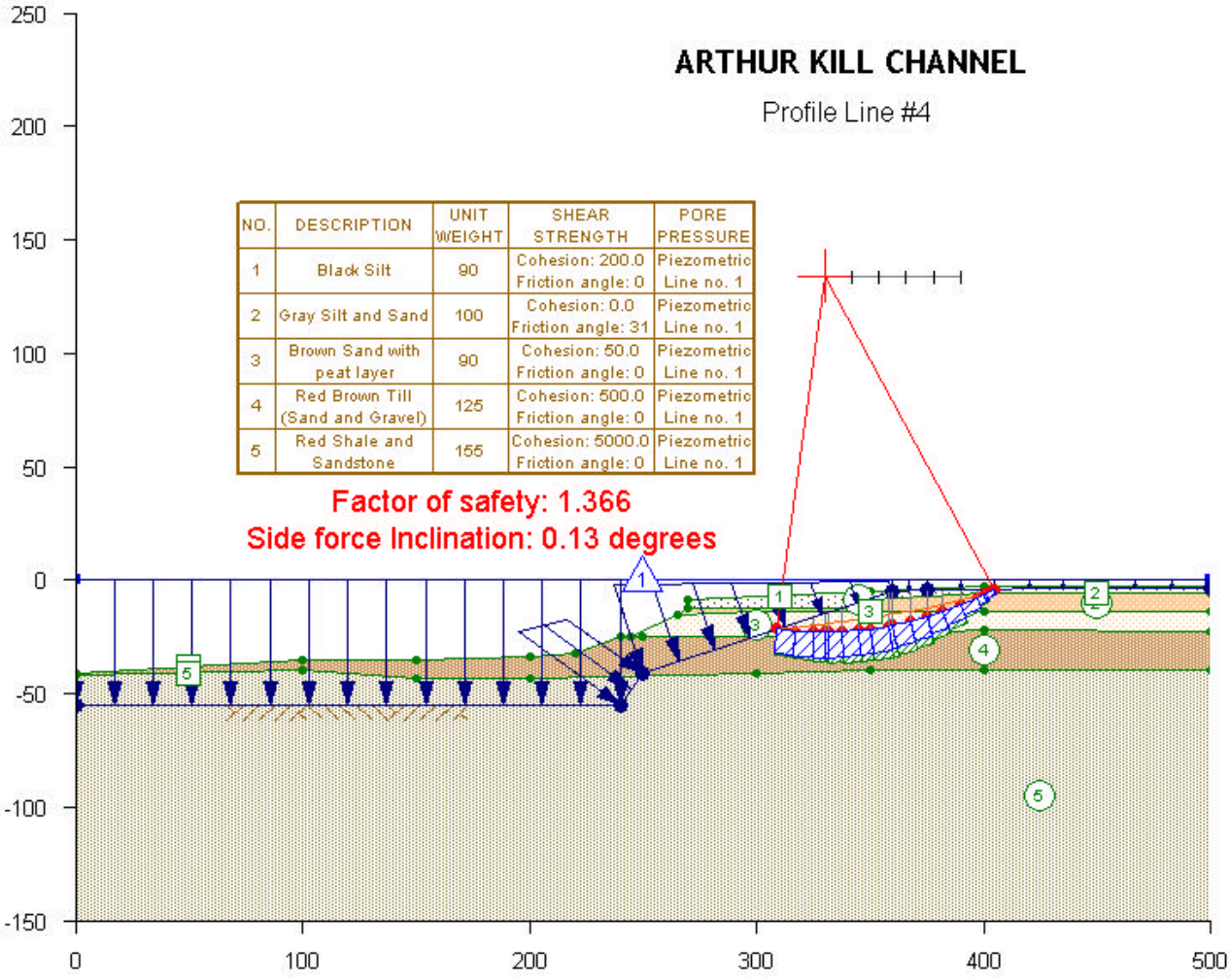
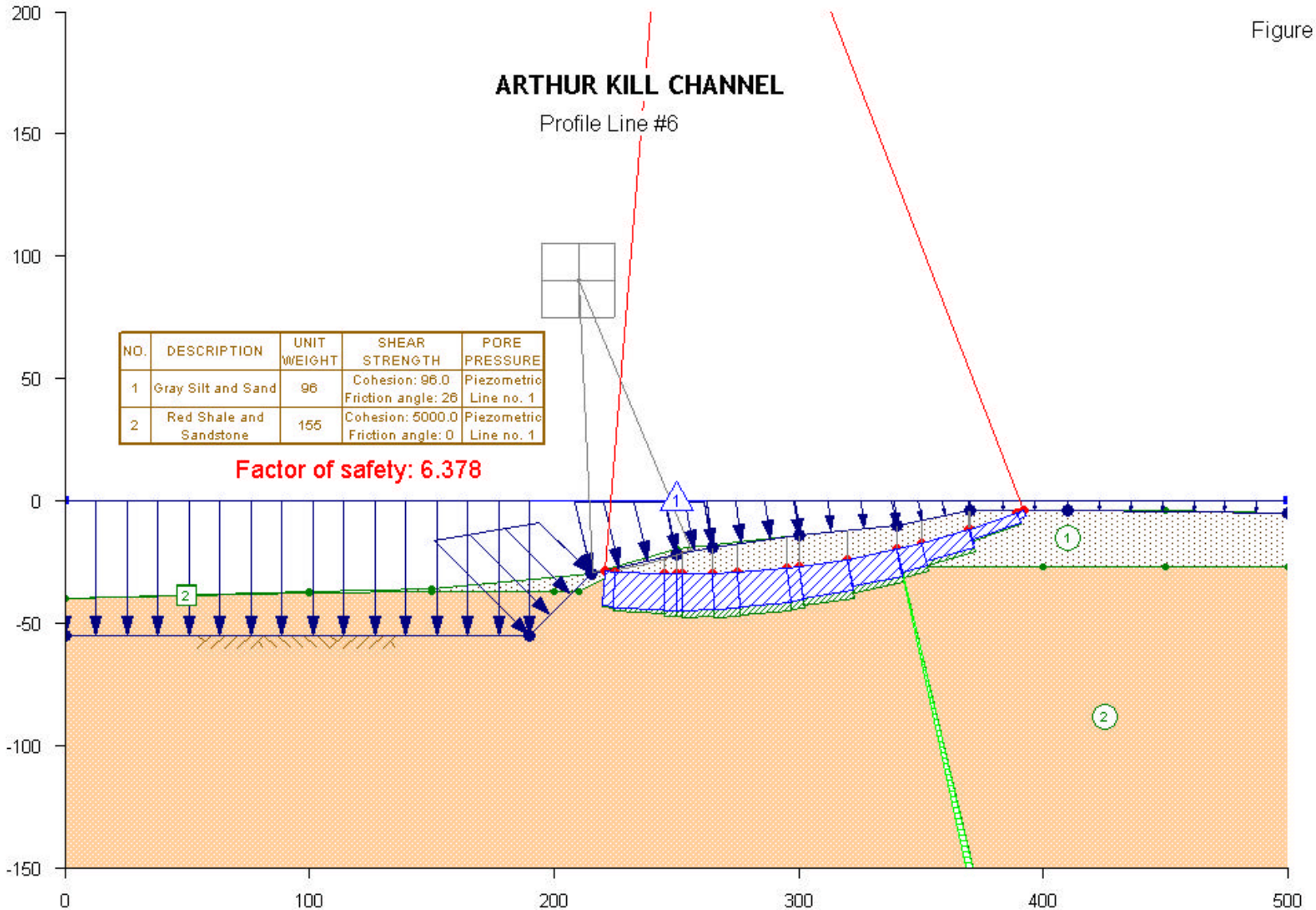
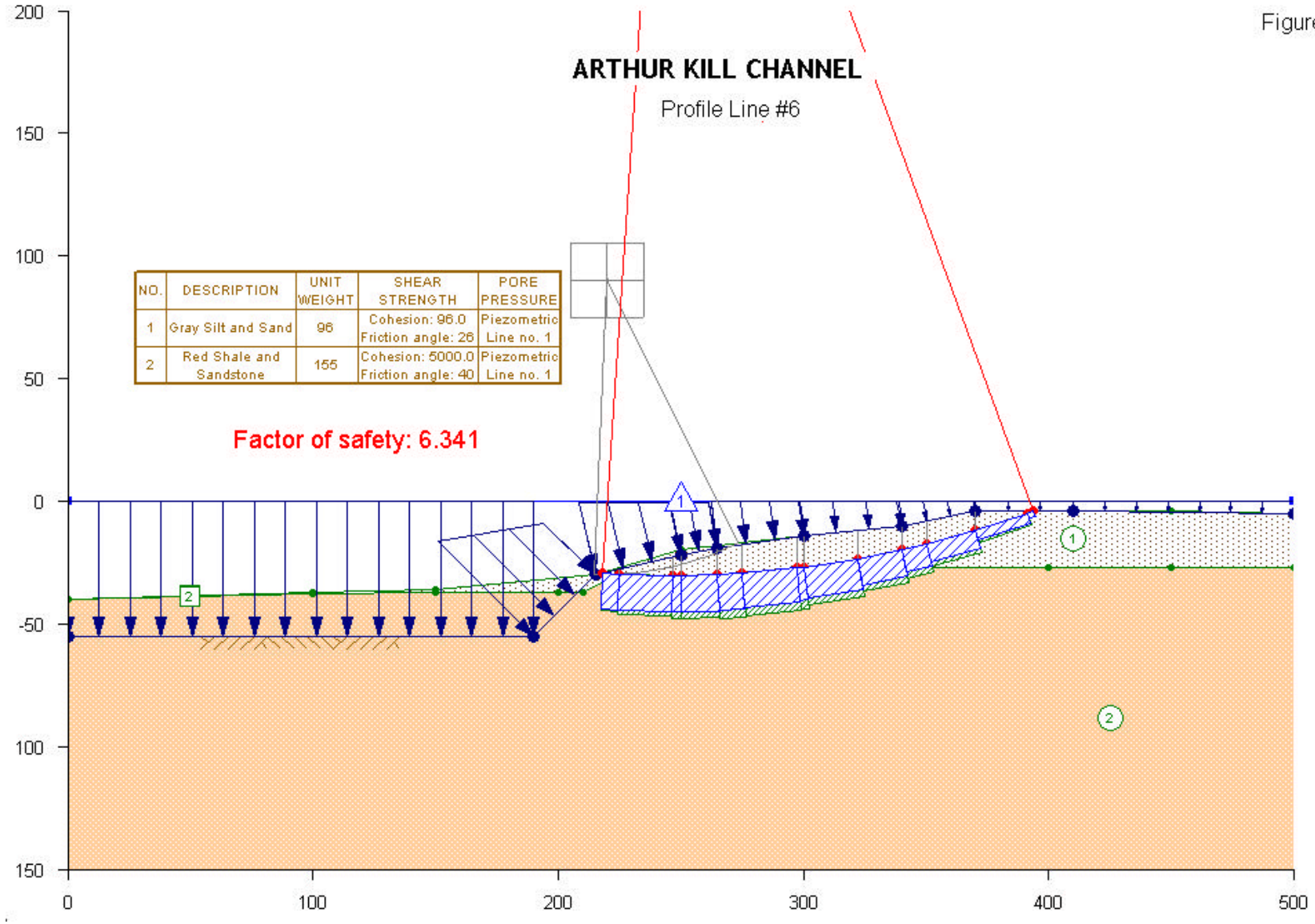


Figure 54



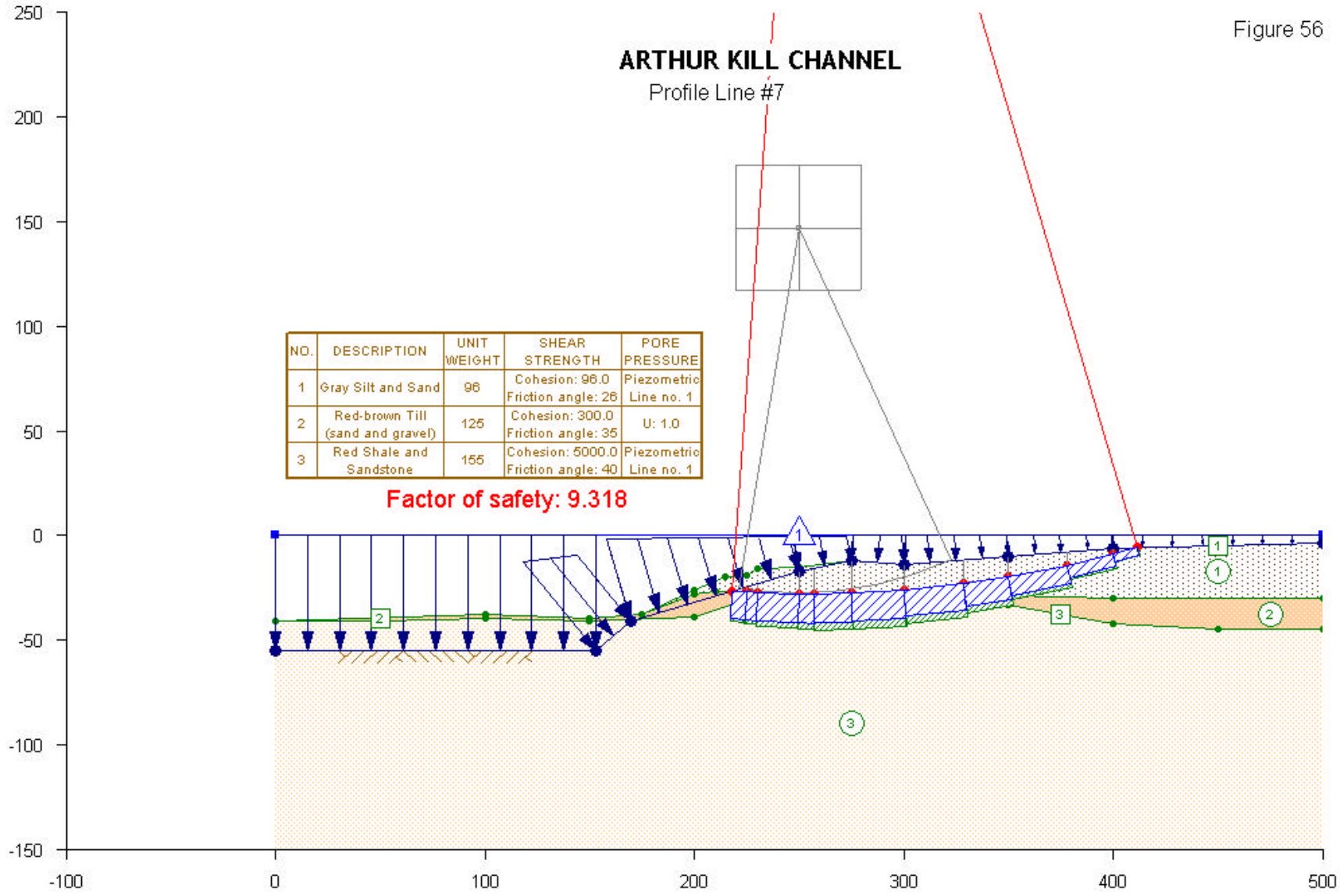
NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Gray Silt and Sand	96	Cohesion: 96.0 Friction angle: 26	Piezometric Line no. 1
2	Red Shale and Sandstone	155	Cohesion: 5000.0 Friction angle: 0	Piezometric Line no. 1

Figure 55



NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Gray Silt and Sand	96	Cohesion: 96.0 Friction angle: 26	Piezometric Line no. 1
2	Red Shale and Sandstone	155	Cohesion: 5000.0 Friction angle: 40	Piezometric Line no. 1

Figure 56



NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Gray Silt and Sand	96	Cohesion: 96.0 Friction angle: 26	Piezometric Line no. 1
2	Red-brown Till (sand and gravel)	125	Cohesion: 300.0 Friction angle: 35	U: 1.0
3	Red Shale and Sandstone	155	Cohesion: 5000.0 Friction angle: 40	Piezometric Line no. 1

Figure 57

ARTHUR KILL CHANNEL

Profile Line #7

NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Gray Silt and Sand	96	Cohesion: 96.0 Friction angle: 0	Piezometric Line no. 1
2	Red-brown Till (sand and gravel)	125	Cohesion: 300.0 Friction angle: 35	Piezometric Line no. 1
3	Red Shale and Sandstone	155	Cohesion: 5000.0 Friction angle: 0	Piezometric Line no. 1

Factor of safety: 1.468

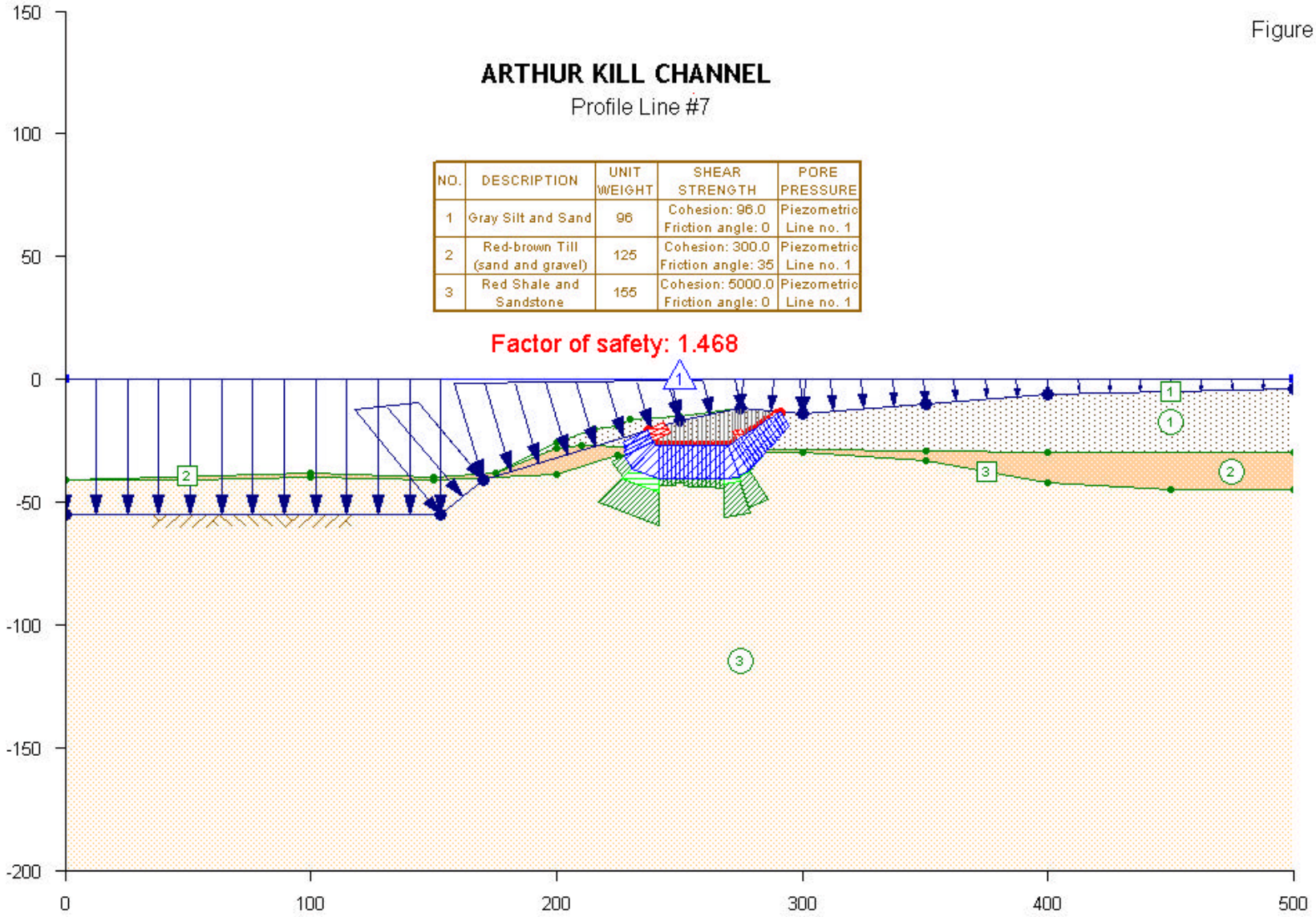


Figure 58

ARTHUR KILL CHANNEL

Profile Line #21

NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Gray Silt	100	Cohesion: 100.0 Friction angle: 0	Piezometric Line no. 1
2	Gray Silt and Sand	100	Cohesion: 50.0 Friction angle: 25	Piezometric Line no. 1
3	Boulders and Till	125	Cohesion: 50.0 Friction angle: 40	Piezometric Line no. 1
4	Basalt	165	Cohesion: 5000.0 Friction angle: 32	Piezometric Line no. 1

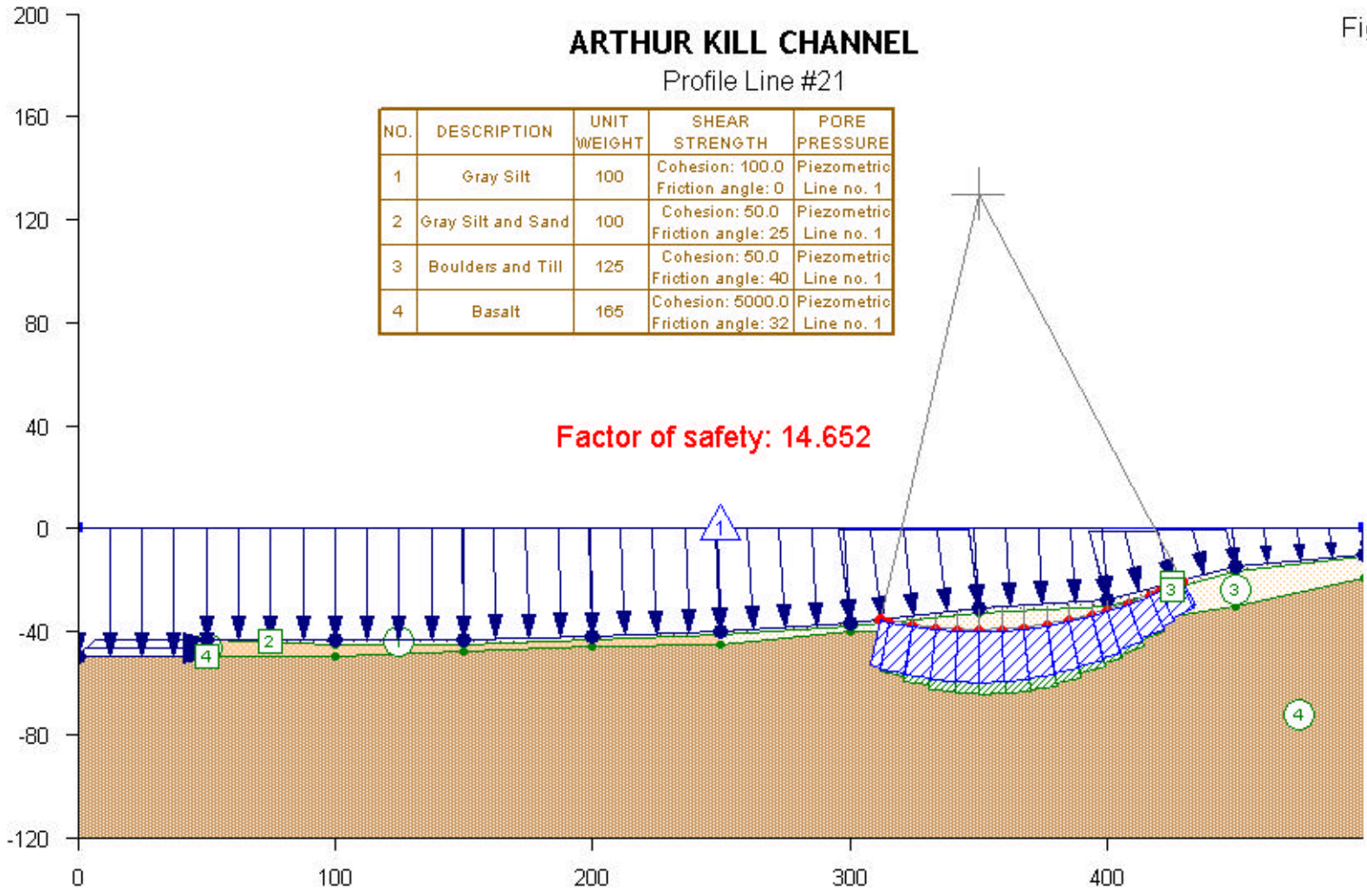


Figure 59

KILL VAN KULL CHANNEL Profile Line #21

NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Gray Silt	90	Cohesion: 100.0 Friction angle: 11	Piezometric Line no. 1
2	Gray Silt and Sand	96	Cohesion: 96.0 Friction angle: 26	Piezometric Line no. 1
3	Boulders and Till	130	Cohesion: 50.0 Friction angle: 40	Piezometric Line no. 1
4	Basalt	165	Cohesion: 5000.0 Friction angle: 32	Piezometric Line no. 1

Factor of safety: 5.854

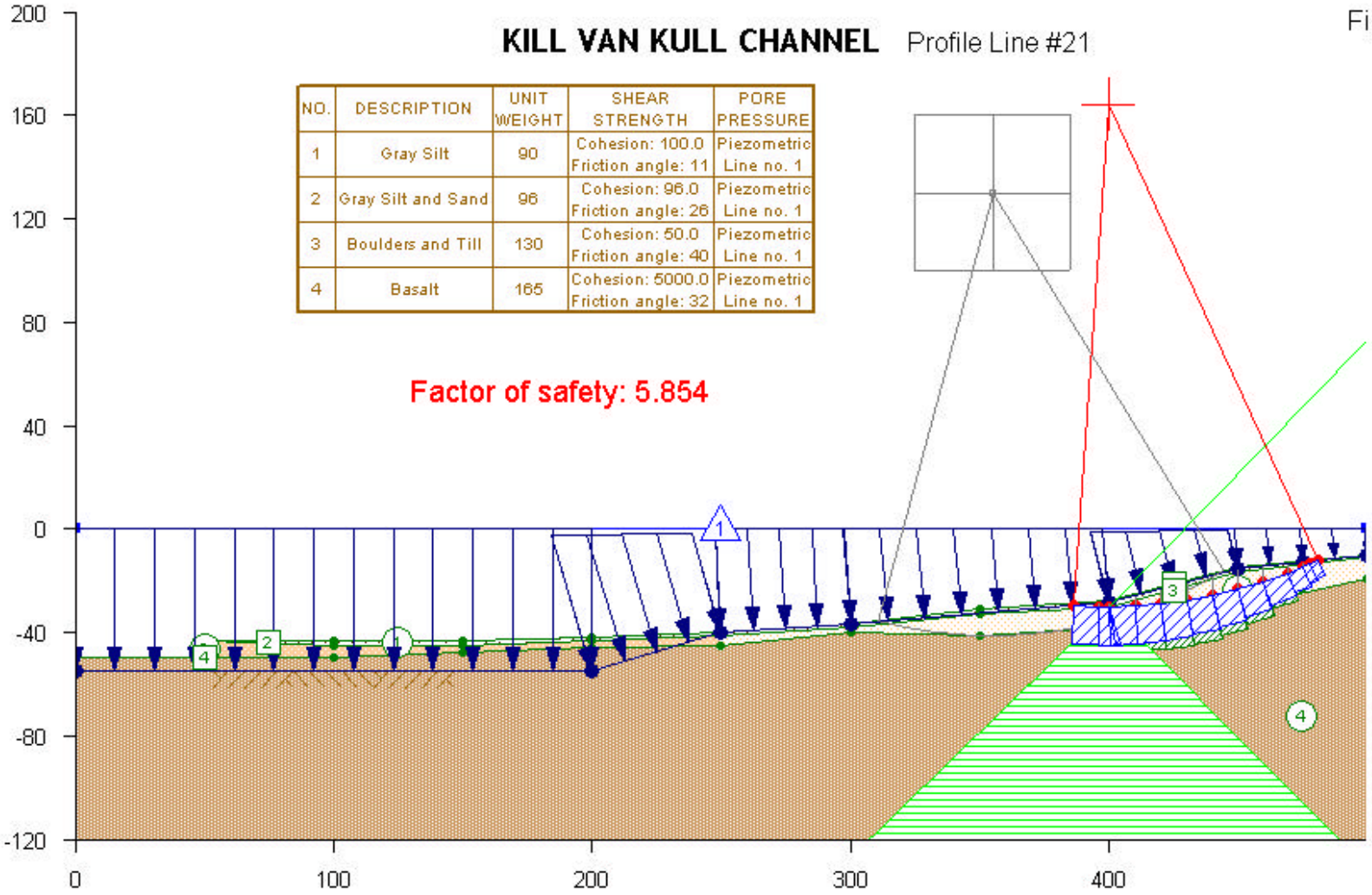


Figure 60

KILL VAN KULL CHANNEL

Profile Line #21

NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Gray Silt	90	Cohesion: 100.0 Friction angle: 11	Piezometric Line no. 1
2	Gray Silt and Sand	96	Cohesion: 96.0 Friction angle: 11	Piezometric Line no. 1
3	Boulders and Till	130	Cohesion: 50.0 Friction angle: 40	Piezometric Line no. 1
4	Basalt	165	Cohesion: 5000.0 Friction angle: 40	Piezometric Line no. 1

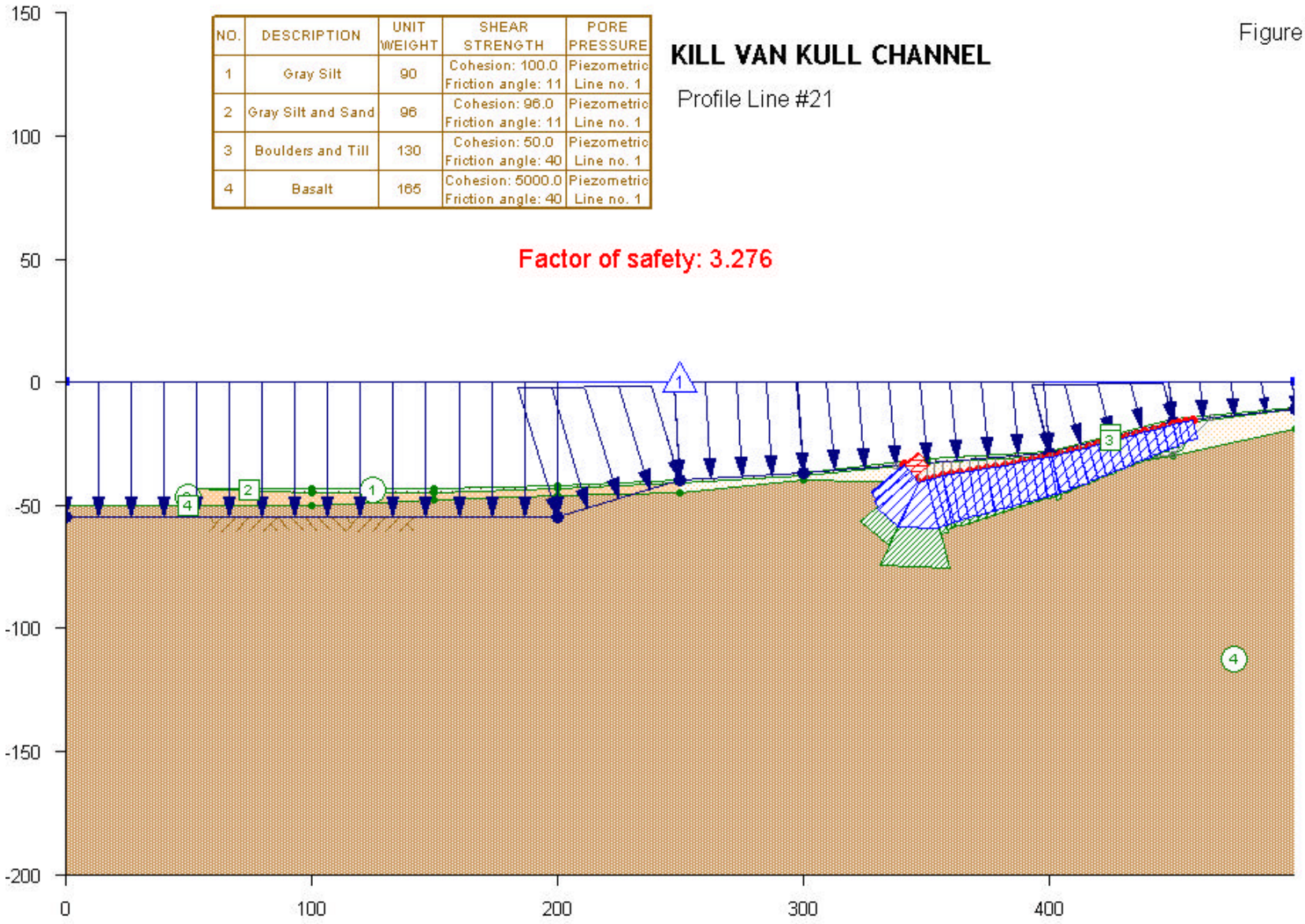


Figure 61

KILL VAN KULL CHANNEL

Profile Line #21

NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Gray Silt	90	Cohesion: 100.0 Friction angle: 11	Piezometric Line no. 1
2	Gray Silt and Sand	100	Cohesion: 100.0 Friction angle: 32	Piezometric Line no. 1
3	Boulders and Till	130	Cohesion: 50.0 Friction angle: 40	Piezometric Line no. 1
4	Basalt	165	Cohesion: 5000.0 Friction angle: 45	Piezometric Line no. 1

Factor of safety: 5.819

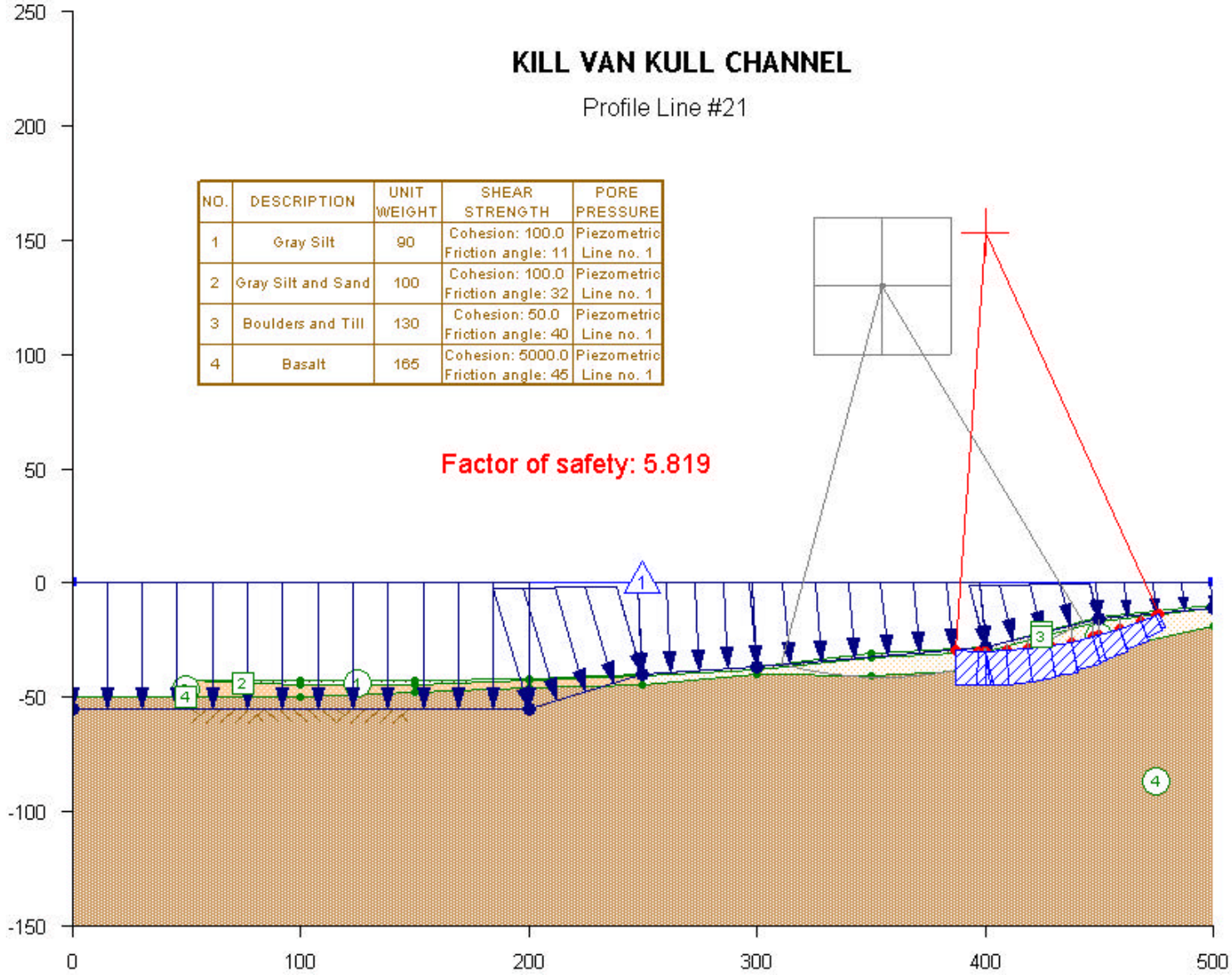


Figure 62

KILL VAN KULL CHANNEL

Profile Line #21

NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Gray Silt	90	Cohesion: 100.0 Friction angle: 11	Piezometric Line no. 1
2	Gray Silt and Sand	96	Cohesion: 96.0 Friction angle: 26	Piezometric Line no. 1
3	Boulders and Till	130	Cohesion: 50.0 Friction angle: 40	Piezometric Line no. 1
4	Basalt	165	Cohesion: 5000.0 Friction angle: 32	Piezometric Line no. 1

Factor of safety: 15.165

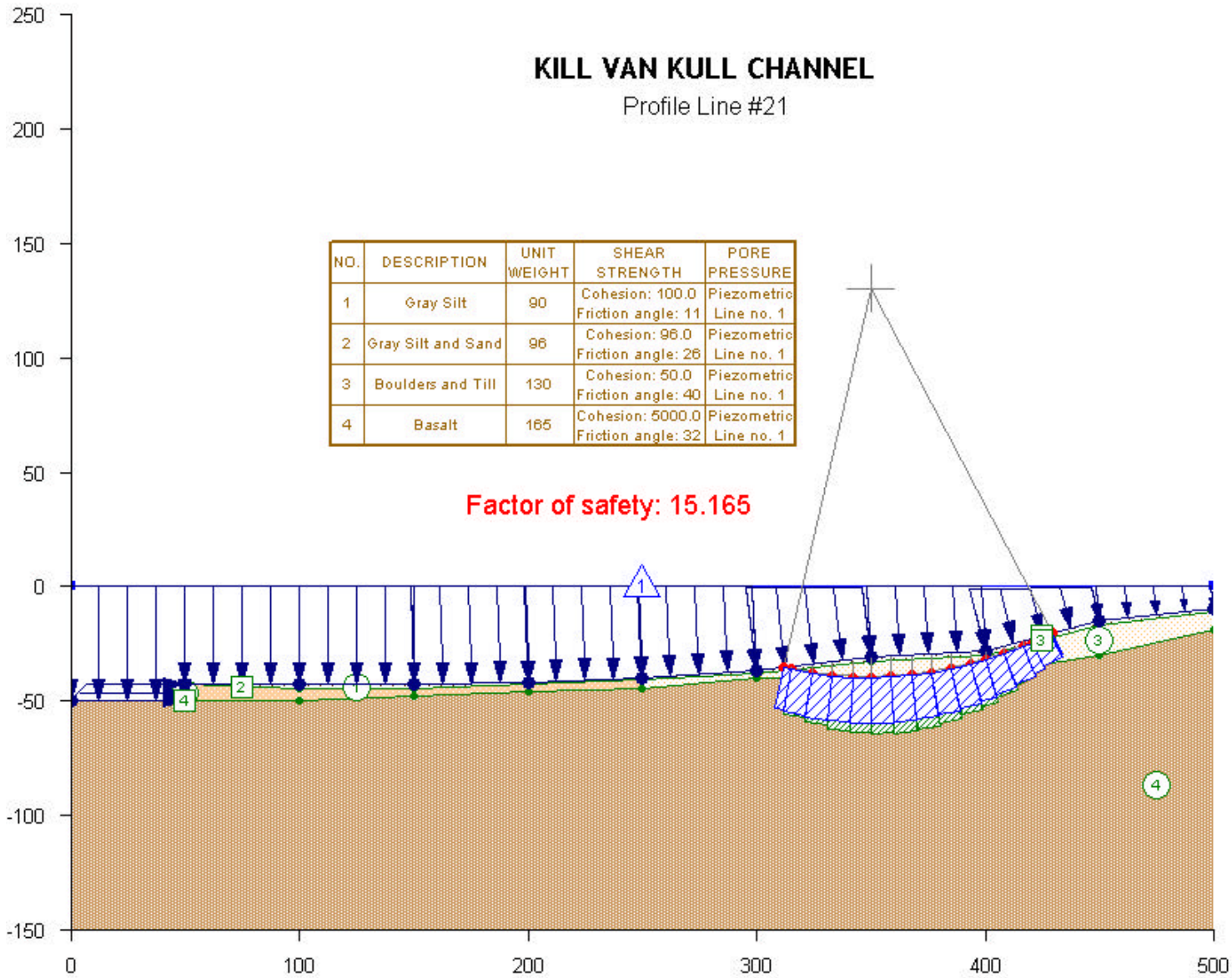


Figure 63

KILL VAN KULL CHANNEL

Profile Line #22

NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Brown Sand and Fine Gravel	125	Cohesion: 0.0 Friction angle: 34	Piezometric Line no. 1
2	Red Brown to Brown Till	125	Cohesion: 200.0 Friction angle: 35	Piezometric Line no. 1

Factor of safety: 7.597

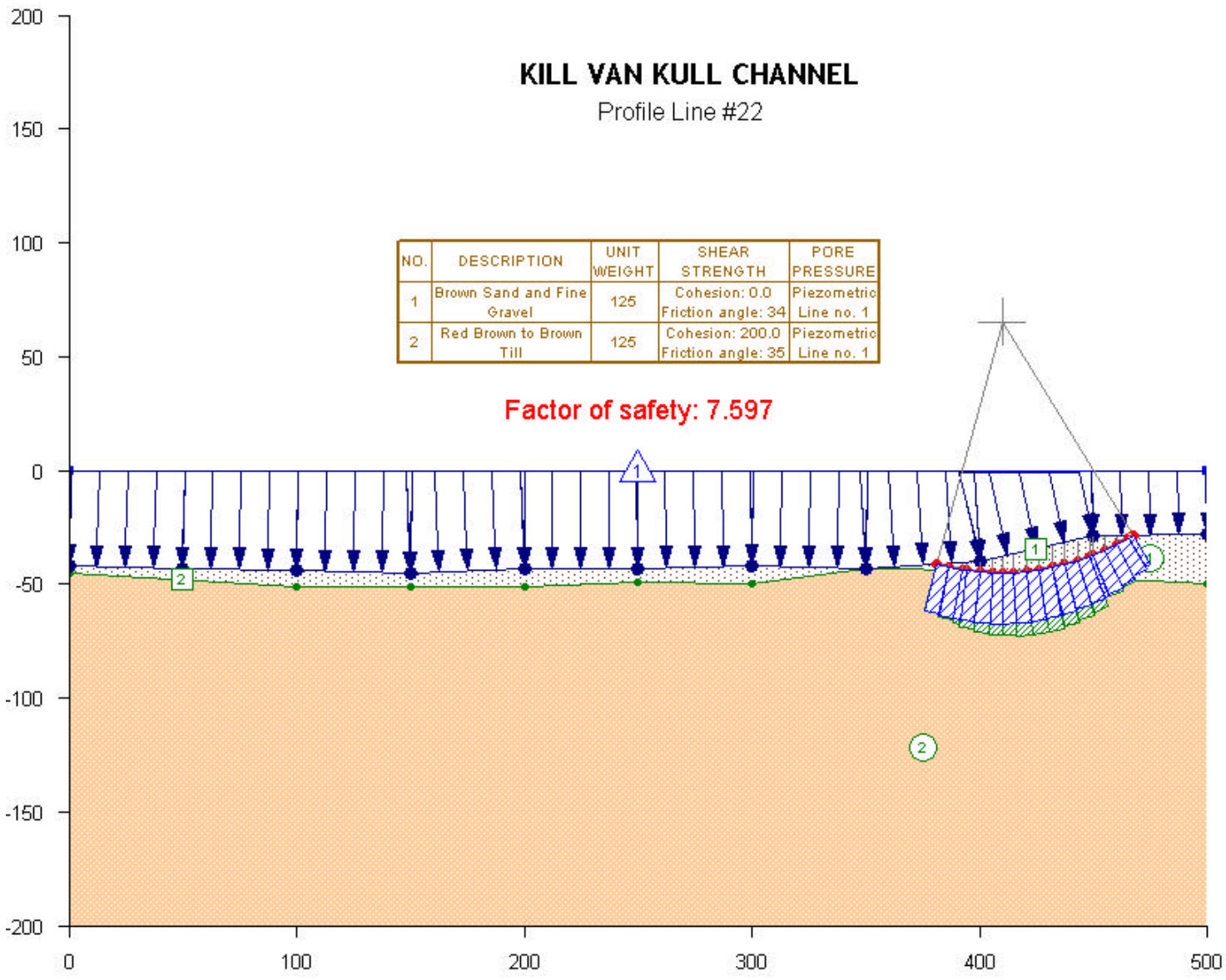
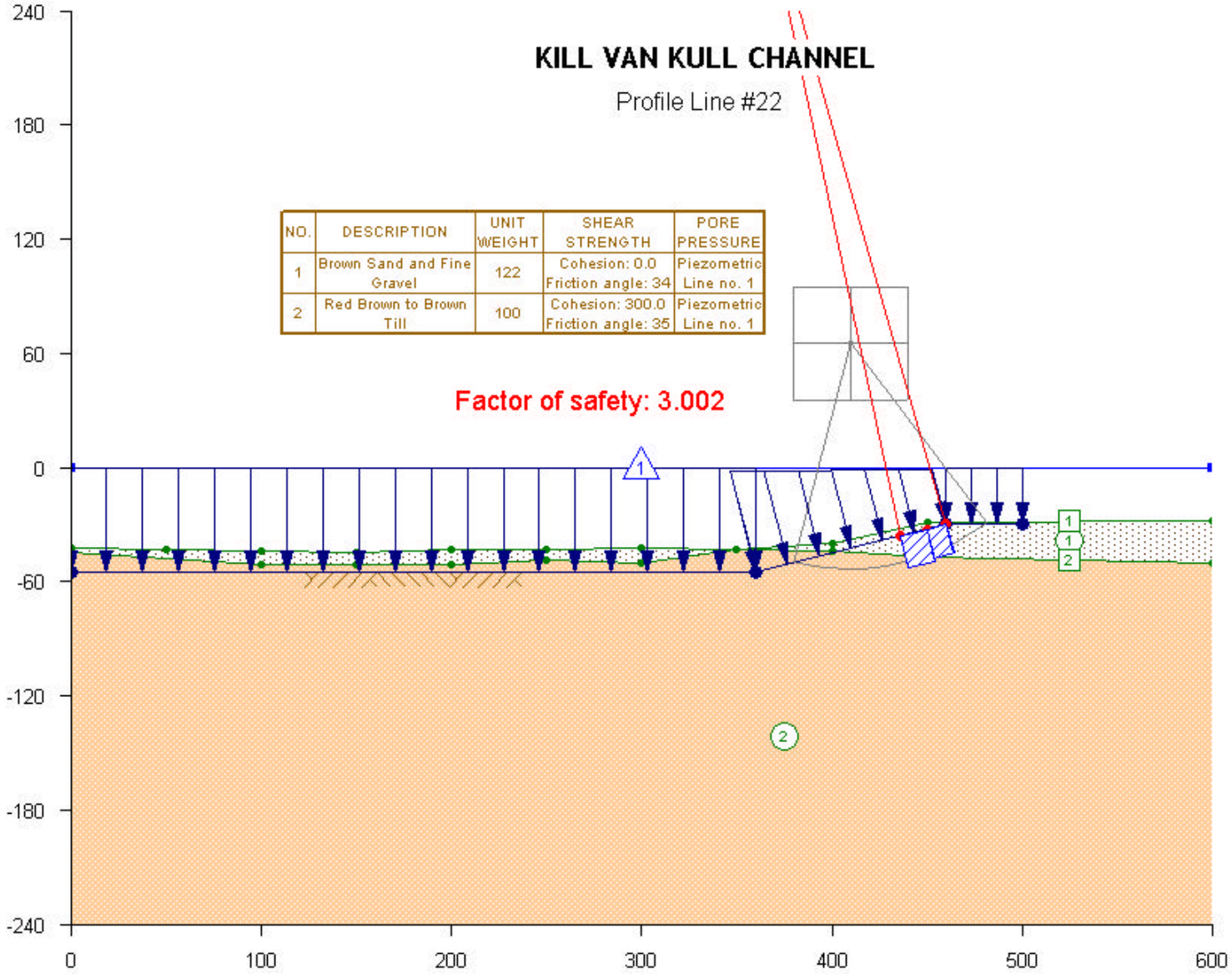


Figure 64



NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Brown Sand and Fine Gravel	122	Cohesion: 0.0 Friction angle: 34	Piezometric Line no. 1
2	Red Brown to Brown Till	100	Cohesion: 300.0 Friction angle: 35	Piezometric Line no. 1

Figure 65

KILL VAN KULL CHANNEL

Profile Line #22

NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Brown Sand and Fine Gravel	122	Cohesion: 0.0 Friction angle: 34	Piezometric Line no. 1
2	Red Brown to Brown Till	125	Cohesion: 300.0 Friction angle: 35	Piezometric Line no. 1

Factor of safety: 2.806

Side force Inclination: 1.44 degrees

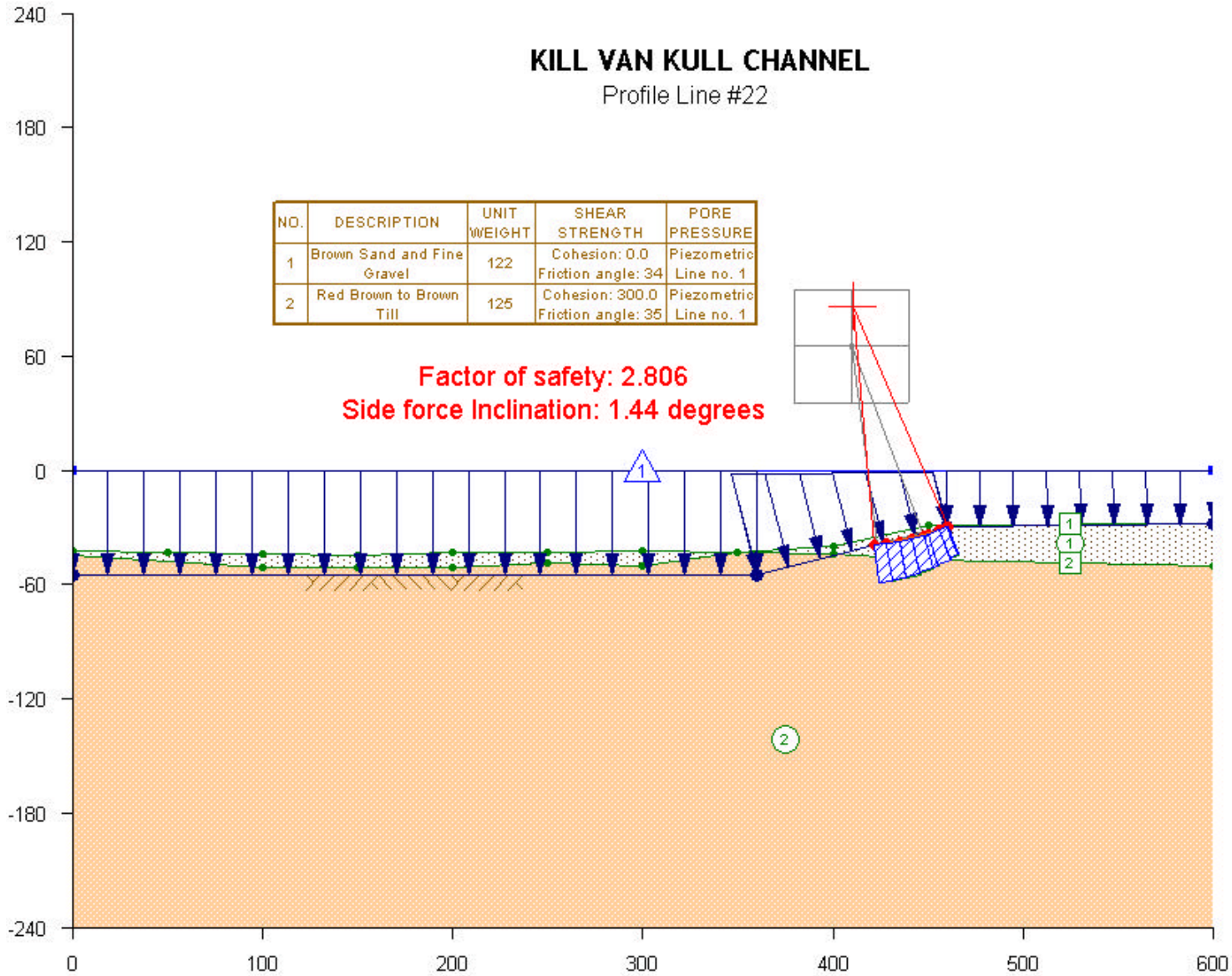


Figure 66

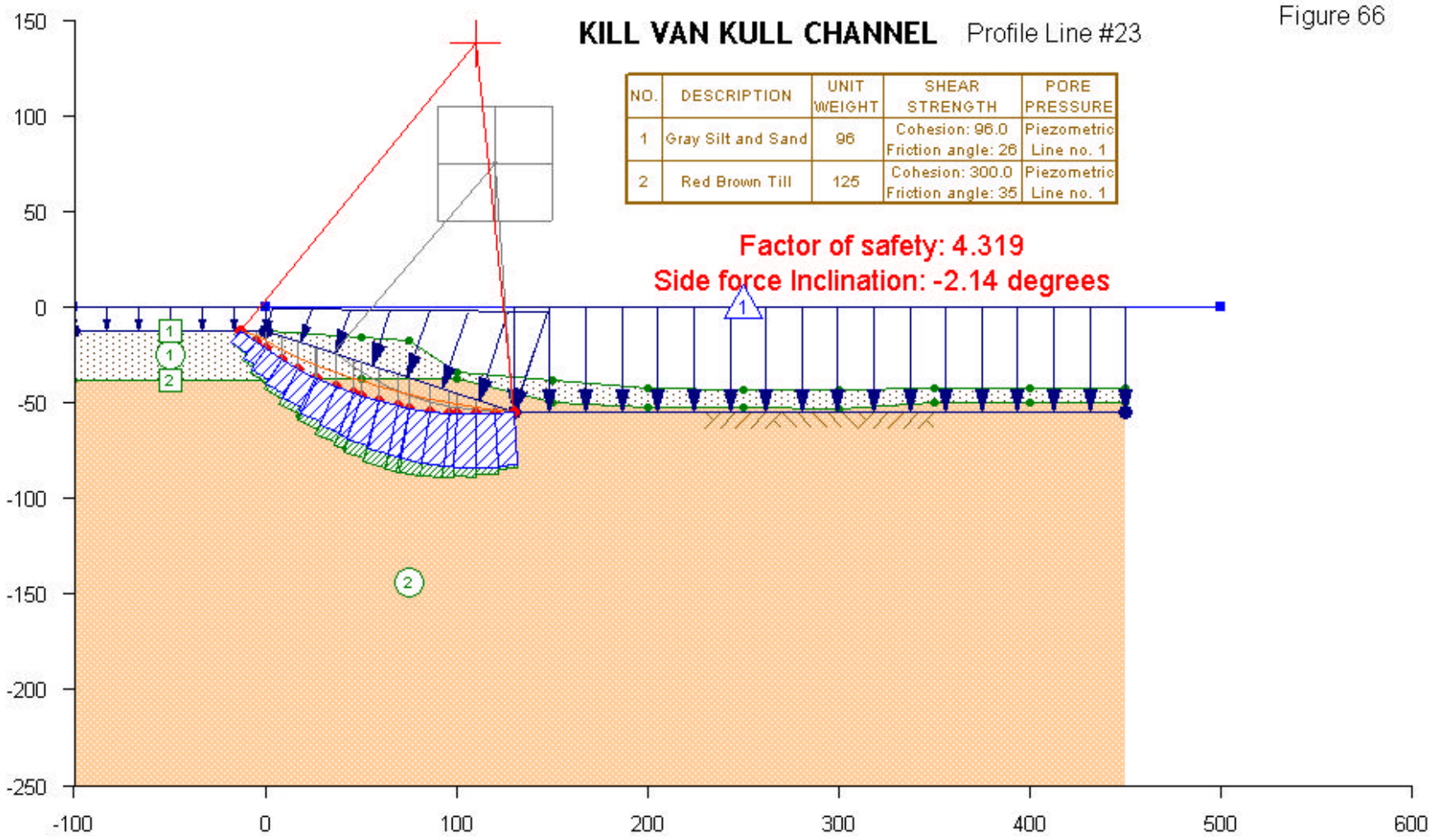

KILL VAN KULL CHANNEL
Profile Line #23
NO. | DESCRIPTION | UNIT WEIGHT | SHEAR STRENGTH | PORE PRESSURE
1 | Gray Silt and Sand | 96 | Cohesion: 96.0 Friction angle: 26 | Piezometric Line no. 1
2 | Red Brown Till | 125 | Cohesion: 300.0 Friction angle: 35 | Piezometric Line no. 1
Factor of safety: 4.319
Side force Inclination: -2.14 degrees
150
100
50
0
-50
-100
-150
-200
-250
-100
0
100
200
300
400
500
600

Figure 67

KILL VAN KULL CHANNEL

Profile Line #23

NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Gray Silt and Sand	96	Cohesion: 96.0 Friction angle: 26	Piezometric Line no. 1
2	Red Brown Till	125	Cohesion: 300.0 Friction angle: 35	Piezometric Line no. 1

Factor of safety: 5.107

Side force Inclination: -1.21 degrees

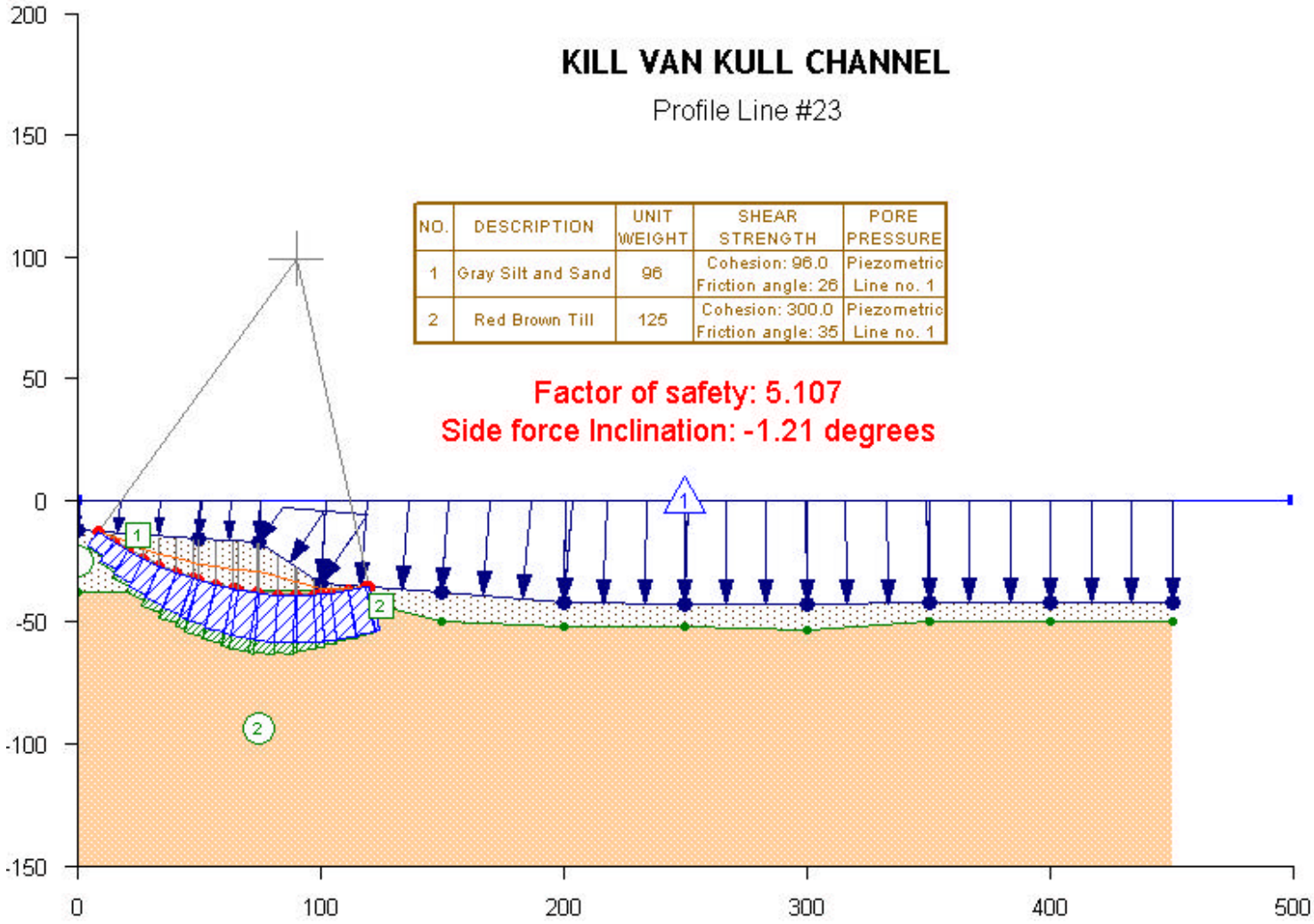


Figure 68

KILL VAN KULL CHANNEL

Profile Line #23

NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Gray Silt and Sand	96	Cohesion: 96.0 Friction angle: 26	Piezometric Line no. 1
2	Red Brown Till	125	Cohesion: 300.0 Friction angle: 35	Piezometric Line no. 1

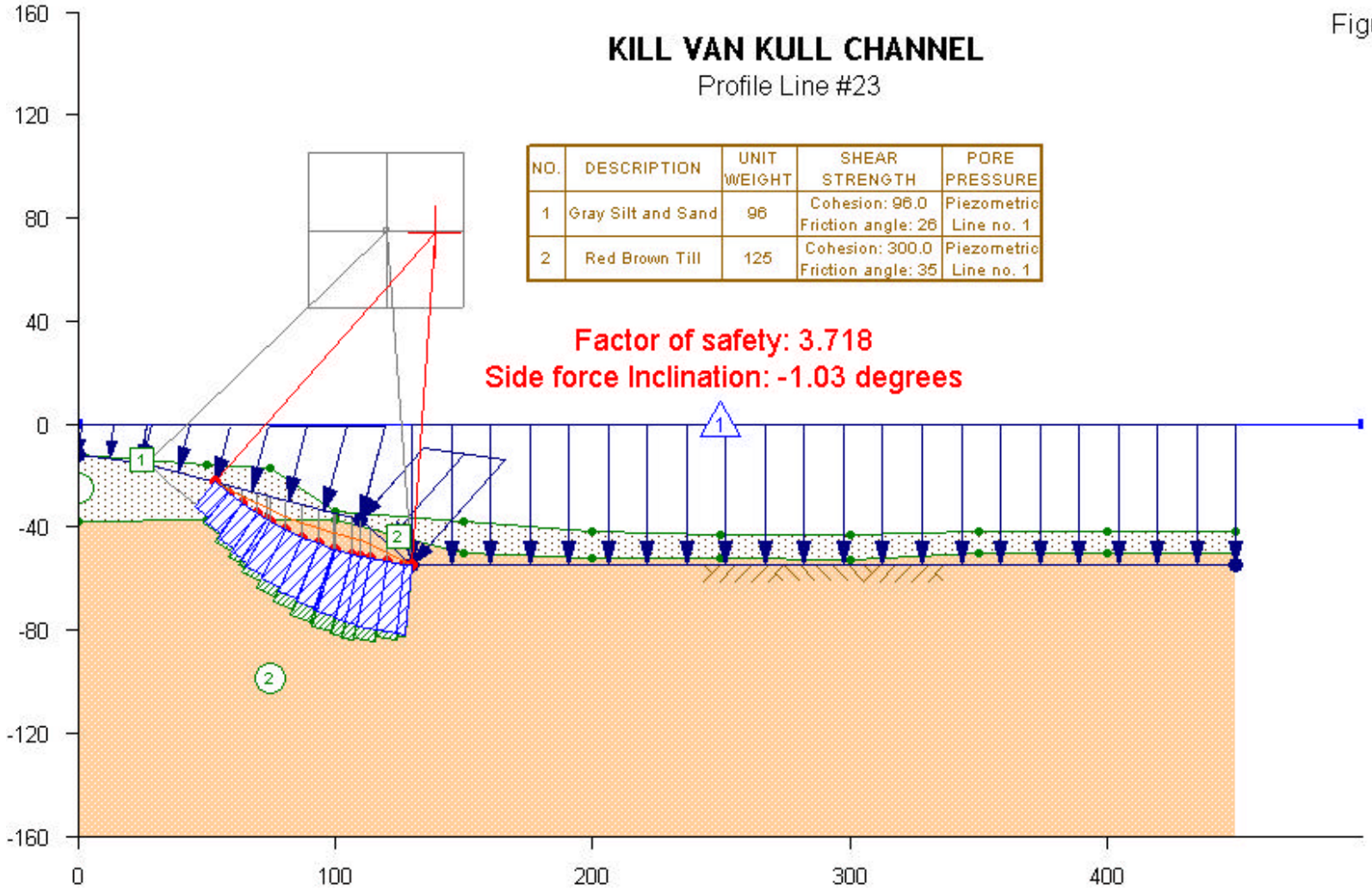


Figure 69

KILL VAN KULL CHANNEL

Profile Line #23

NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Gray Silt and Sand	96	Cohesion: 96.0 Friction angle: 26	Piezometric Line no. 1
2	Red Brown Till	125	Cohesion: 300.0 Friction angle: 35	Piezometric Line no. 1

Factor of safety: 5.062

Side force Inclination: -0.59 degrees

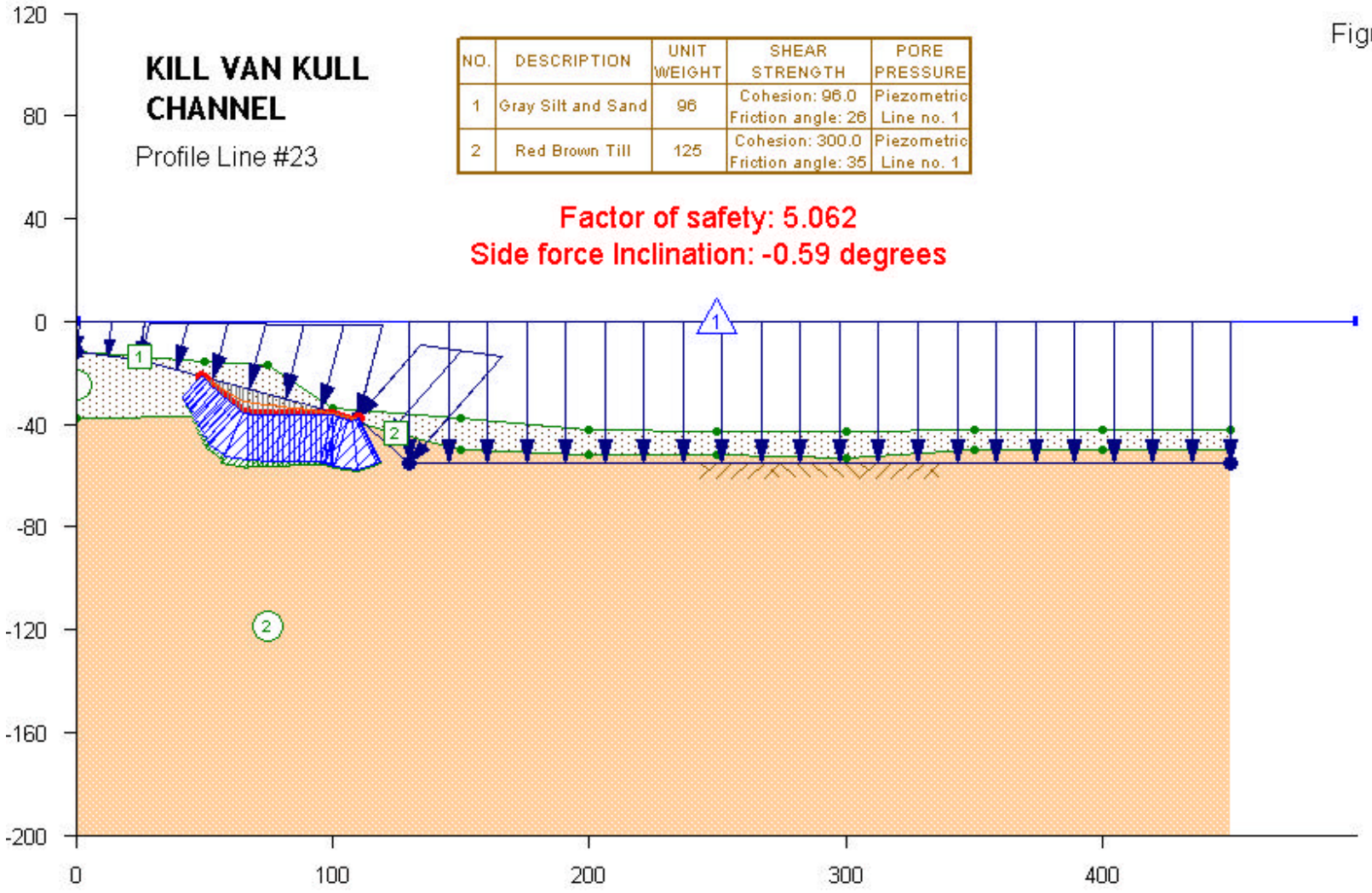
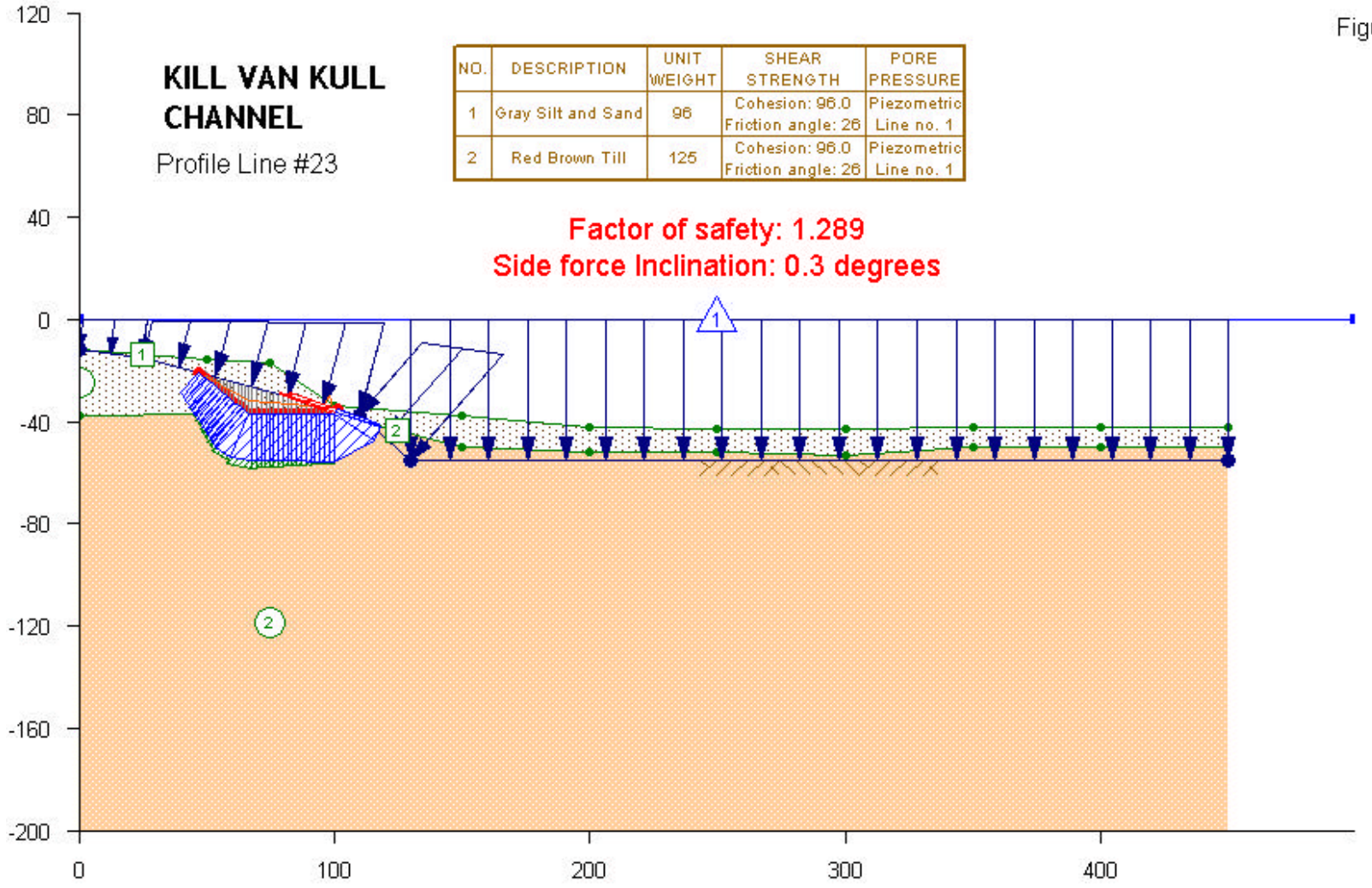
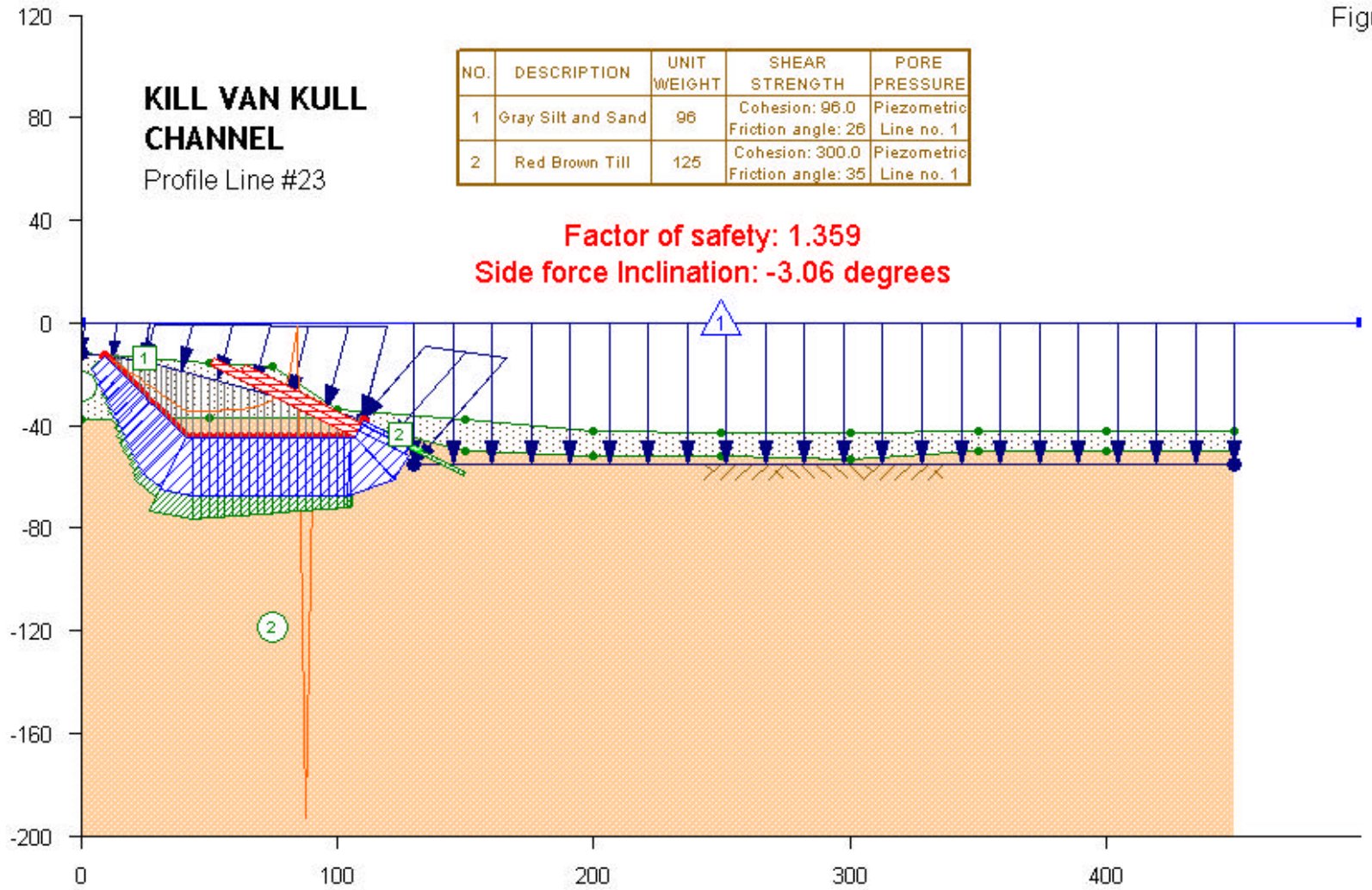


Figure 70



NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Gray Silt and Sand	96	Cohesion: 96.0 Friction angle: 26	Piezometric Line no. 1
2	Red Brown Till	125	Cohesion: 96.0 Friction angle: 26	Piezometric Line no. 1

Figure 71



NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Gray Silt and Sand	96	Cohesion: 96.0 Friction angle: 26	Piezometric Line no. 1
2	Red Brown Till	125	Cohesion: 300.0 Friction angle: 35	Piezometric Line no. 1

Figure 72

KILL VAN KULL CHANNEL

Profile Line #24

NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Gray Silt and Sand	96	Cohesion: 96.0 Friction angle: 26	Piezometric Line no. 1
4	Red Shale and Sandstone	155	Cohesion: 3000.0 Friction angle: 0	Piezometric Line no. 1
2	Brown Sands	120	Cohesion: 0.0 Friction angle: 32	Piezometric Line no. 1
3	Red-brown Till (Sand and Gravel)	125	Cohesion: 300.0 Friction angle: 35	Piezometric Line no. 1

Factor of safety: 3.630

Side force Inclination: -2.39 degrees

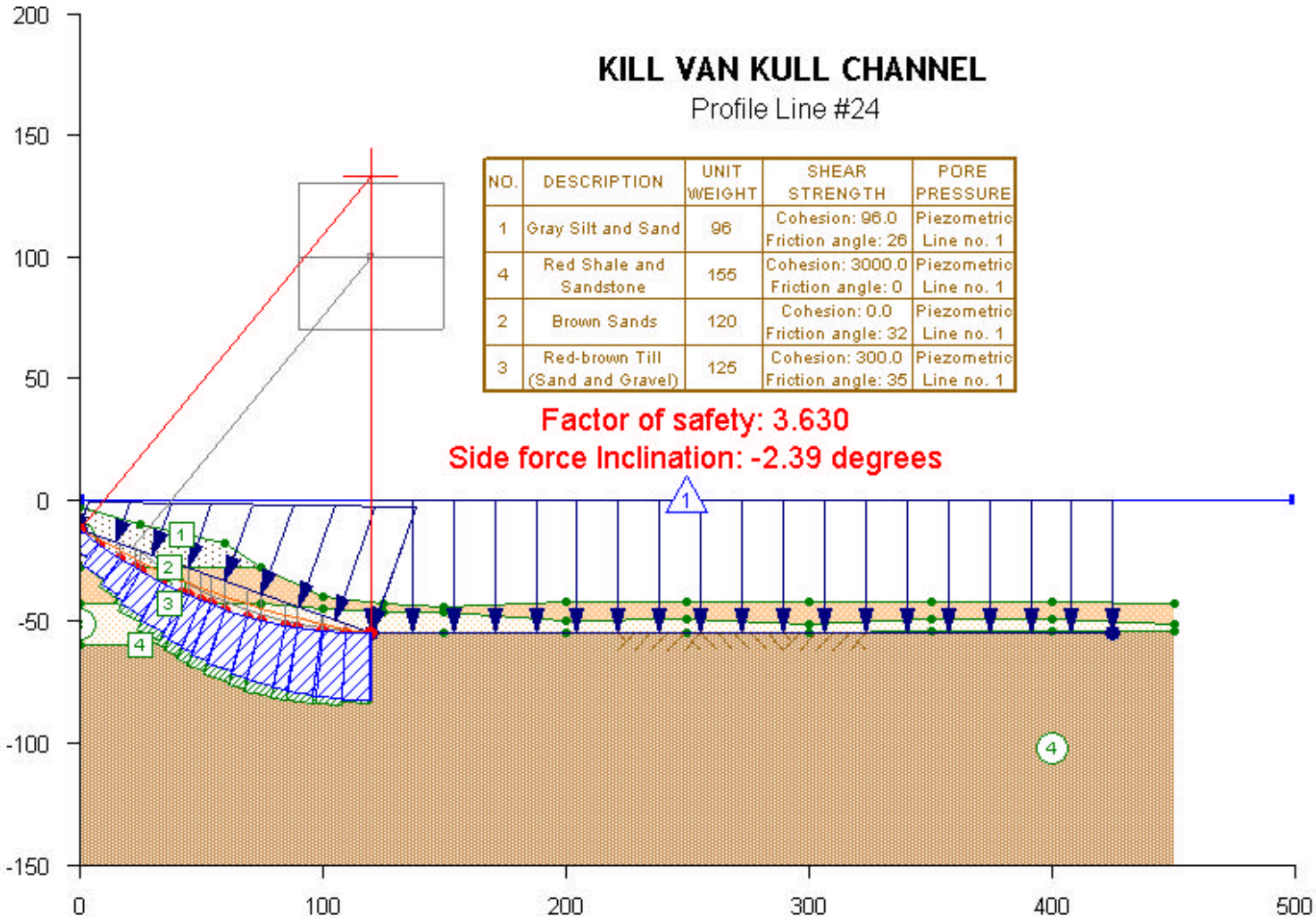


Figure 73

KILL VAN KULL CHANNEL

Profile Line #24

NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Gray Silt and Sand	100	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
4	Red Shale and Sandstone	155	Cohesion: 5000.0 Friction angle: 0	Piezometric Line no. 1
2	Brown Sands	110	Cohesion: 0.0 Friction angle: 32	Piezometric Line no. 1
3	Red-brown Till (Sand and Gravel)	125	Cohesion: 0.0 Friction angle: 32	Piezometric Line no. 1

Factor of safety: 3.631

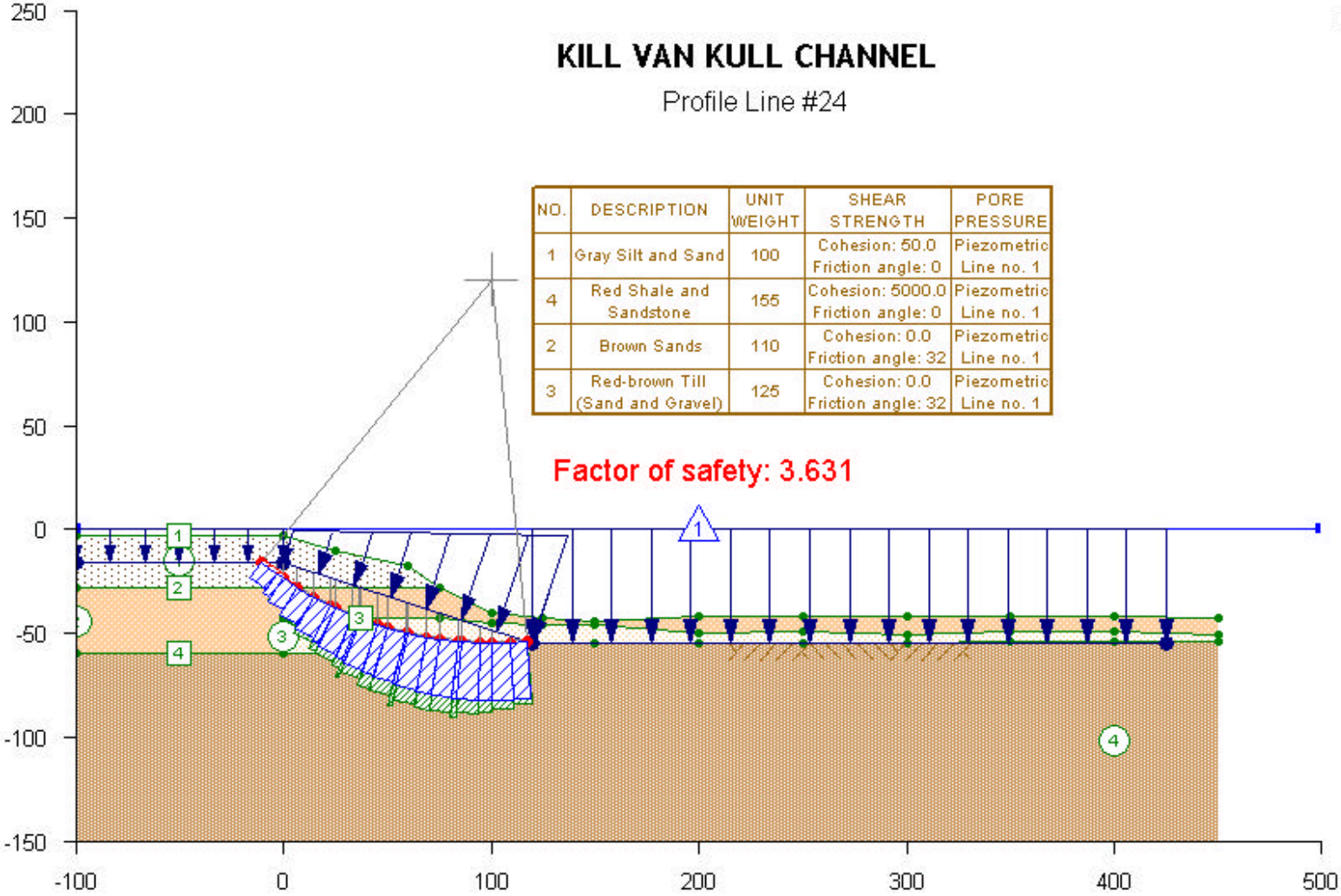


Figure 74

KILL VAN KULL CHANNEL

Profile Line #24

NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Gray Silt and Sand	96	Cohesion: 96.0 Friction angle: 0	Piezometric Line no. 1
4	Red Shale and Sandstone	155	Cohesion: 3000.0 Friction angle: 0	Piezometric Line no. 1
2	Brown Sands	120	Cohesion: 0.0 Friction angle: 32	Piezometric Line no. 1
3	Red-brown Till (Sand and Gravel)	125	Cohesion: 300.0 Friction angle: 35	Piezometric Line no. 1

Factor of safety: 2.207

Side force Inclination: -1.13 degrees

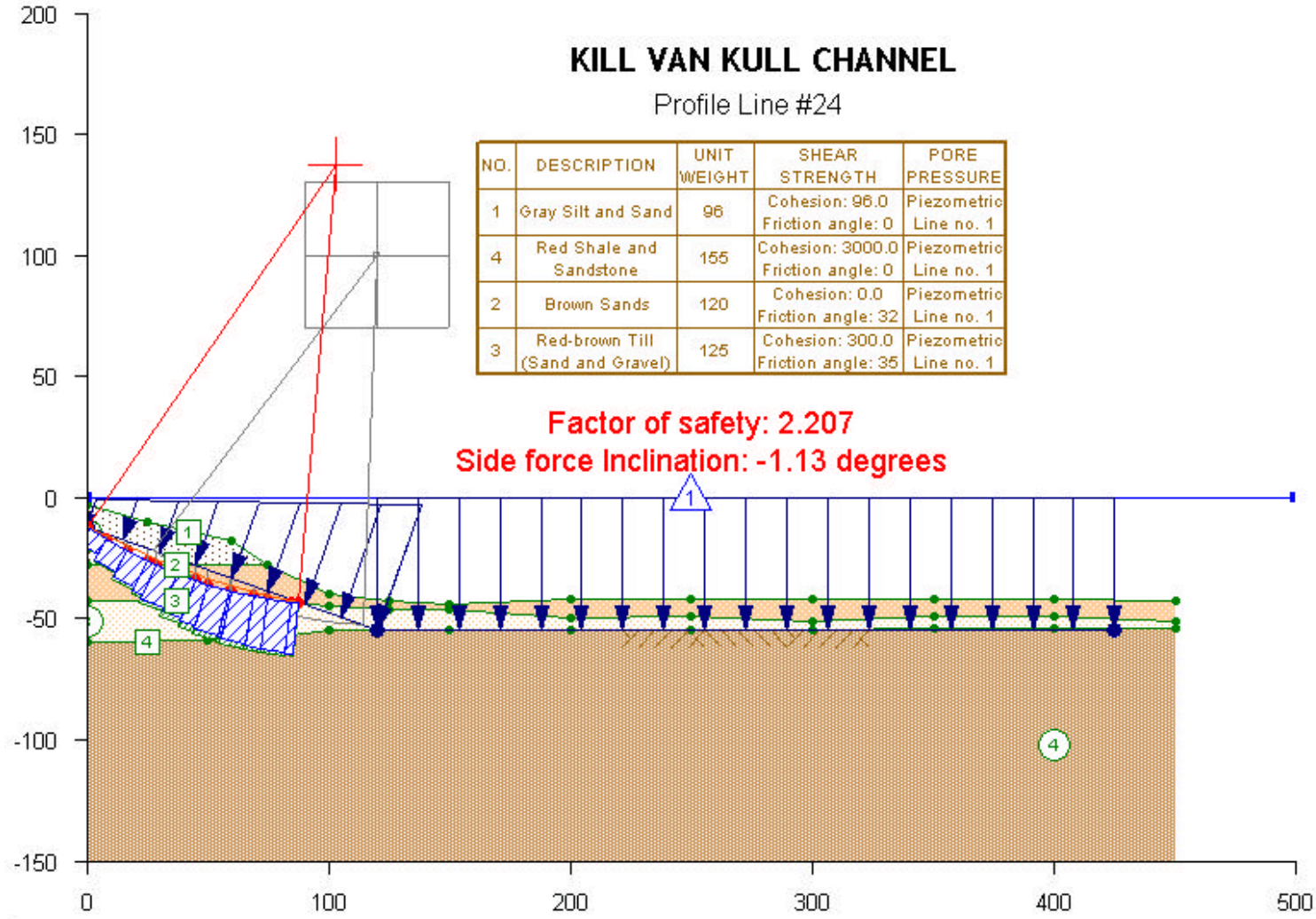


Figure 75

KILL VAN KULL CHANNEL

Profile Line #26

NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Gray Silt and Sand	96	Cohesion: 96.0 Friction angle: 26	Piezometric Line no. 1
4	Red Shale and Sandstone	155	Cohesion: 3000.0 Friction angle: 0	Piezometric Line no. 1
2	Brown Sands	120	Cohesion: 0.0 Friction angle: 32	Piezometric Line no. 1
3	Red-brown Till (Sand and Gravel)	125	Cohesion: 300.0 Friction angle: 35	Piezometric Line no. 1

Factor of safety: 3.630

Side force Inclination: -2.39 degrees

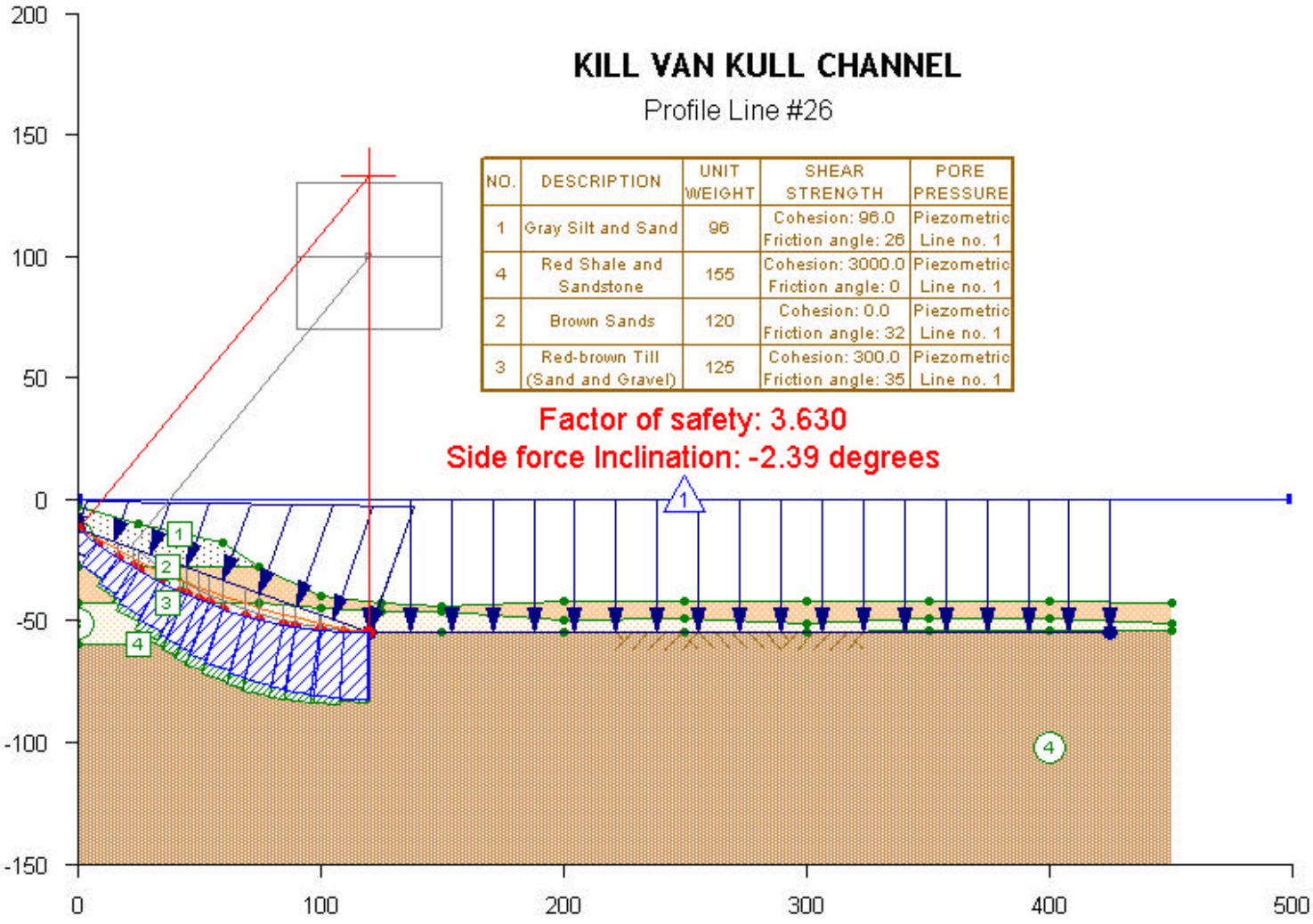
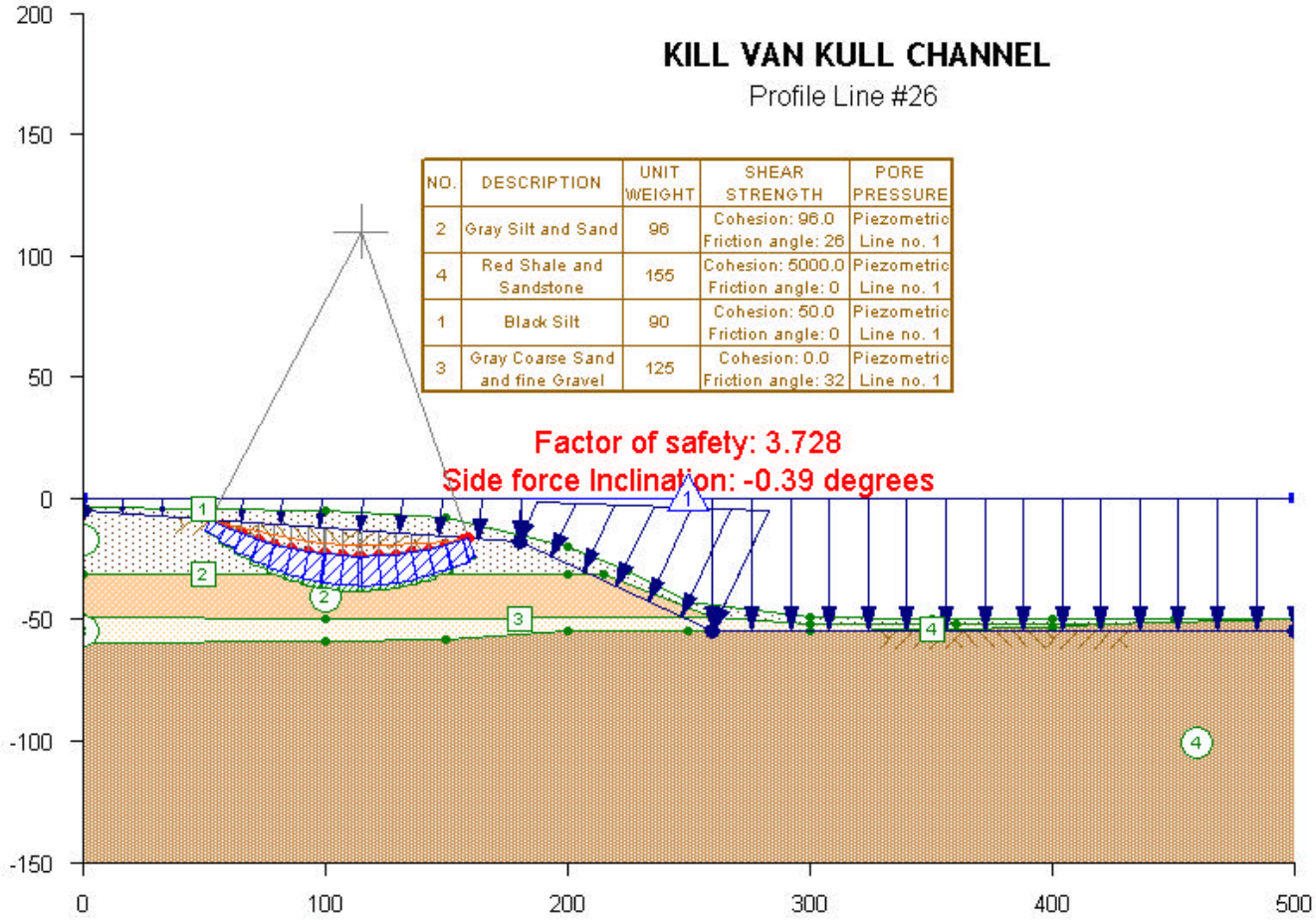


Figure 76

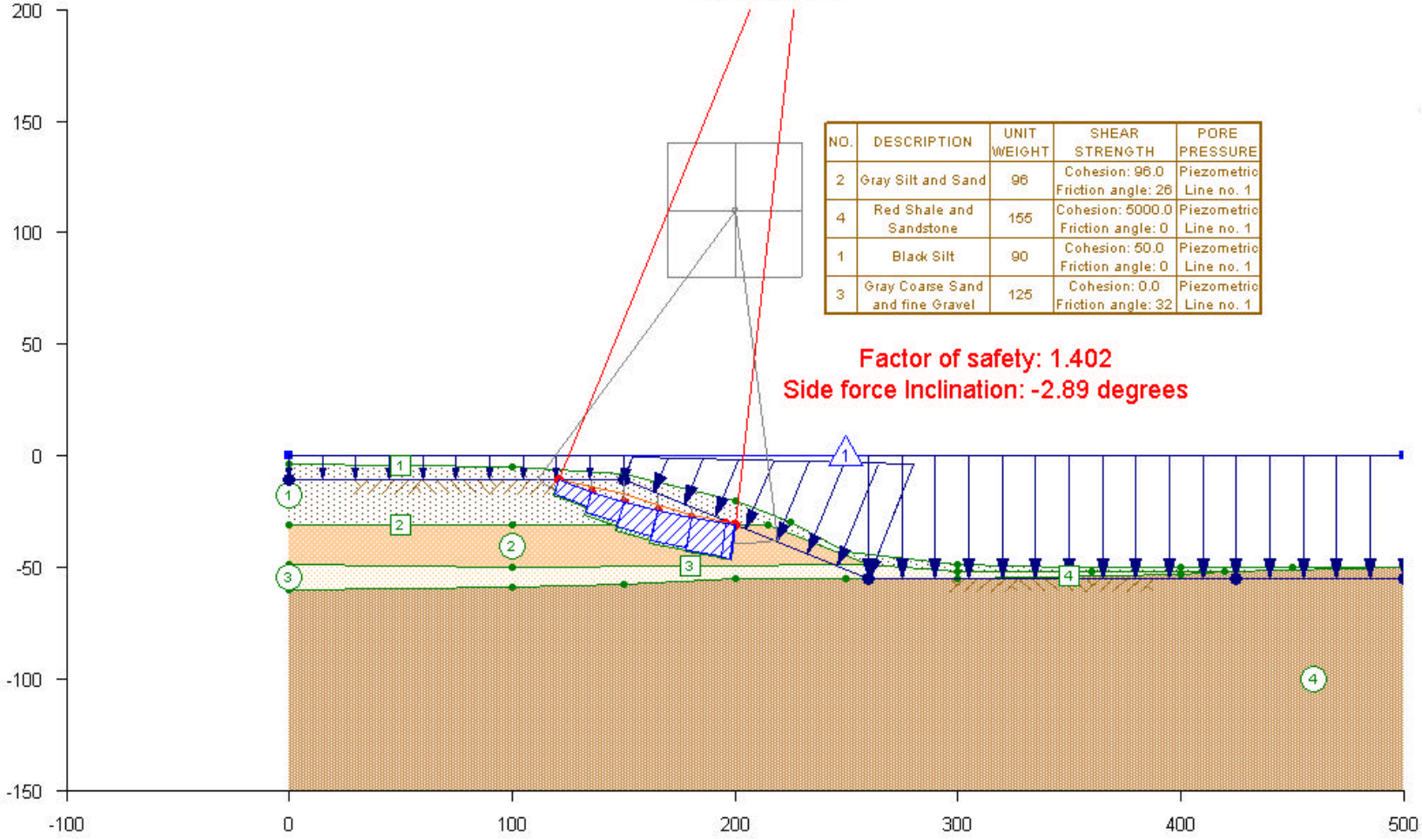


NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
2	Gray Silt and Sand	96	Cohesion: 96.0 Friction angle: 26	Piezometric Line no. 1
4	Red Shale and Sandstone	155	Cohesion: 5000.0 Friction angle: 0	Piezometric Line no. 1
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
3	Gray Coarse Sand and fine Gravel	125	Cohesion: 0.0 Friction angle: 32	Piezometric Line no. 1

Figure 77

KILL VAN KULL CHANNEL

Profile Line #26



NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
2	Gray Silt and Sand	96	Cohesion: 96.0 Friction angle: 26	Piezometric Line no. 1
4	Red Shale and Sandstone	155	Cohesion: 5000.0 Friction angle: 0	Piezometric Line no. 1
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
3	Gray Coarse Sand and fine Gravel	125	Cohesion: 0.0 Friction angle: 32	Piezometric Line no. 1

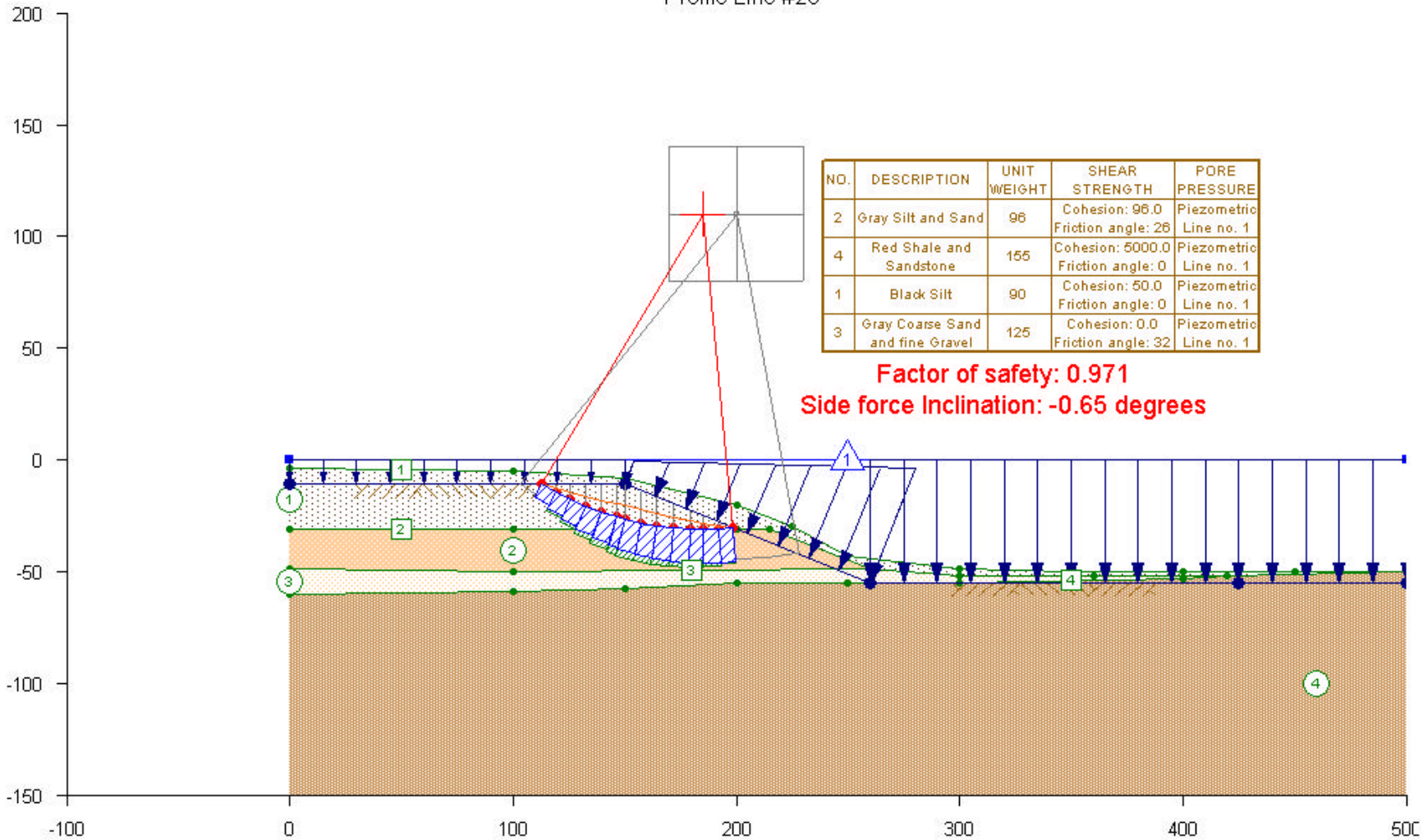
Factor of safety: 1.402

Side force Inclination: -2.89 degrees

Figure 78

KILL VAN KULL CHANNEL

Profile Line #26

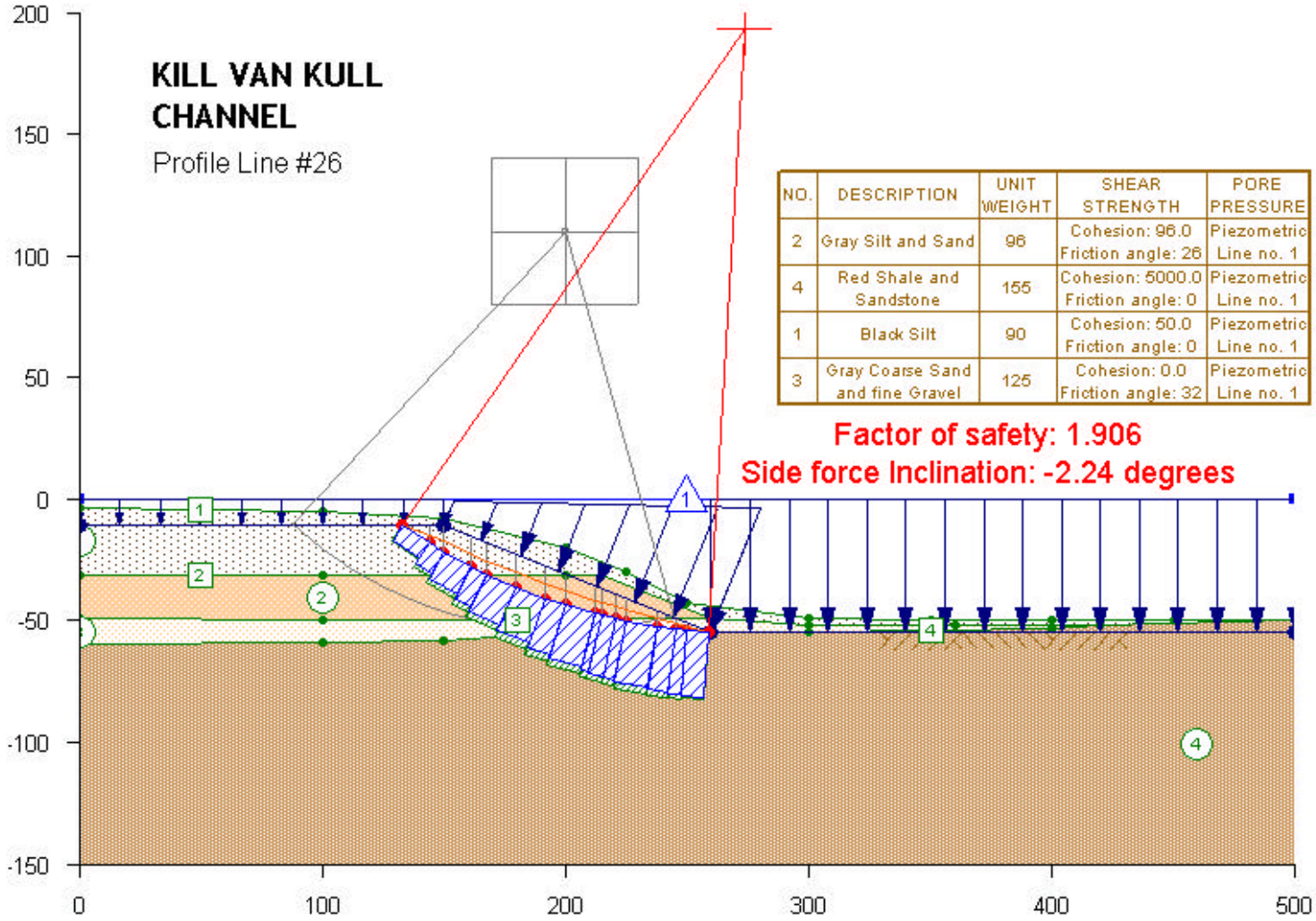


NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
2	Gray Silt and Sand	96	Cohesion: 96.0 Friction angle: 26	Piezometric Line no. 1
4	Red Shale and Sandstone	155	Cohesion: 5000.0 Friction angle: 0	Piezometric Line no. 1
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
3	Gray Coarse Sand and fine Gravel	125	Cohesion: 0.0 Friction angle: 32	Piezometric Line no. 1

Factor of safety: 0.971

Side force Inclination: -0.65 degrees

Figure 79

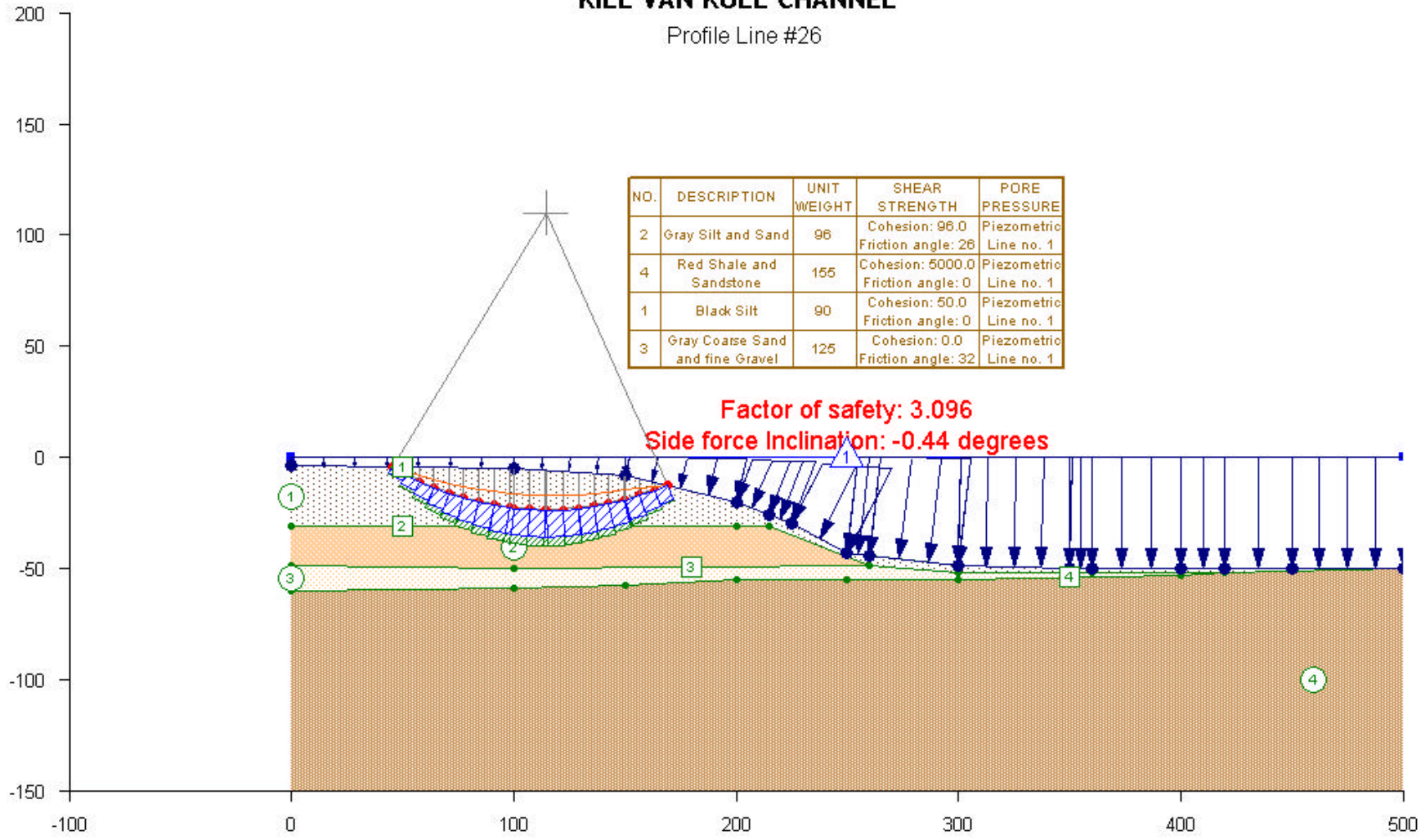


NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
2	Gray Silt and Sand	96	Cohesion: 96.0 Friction angle: 26	Piezometric Line no. 1
4	Red Shale and Sandstone	155	Cohesion: 5000.0 Friction angle: 0	Piezometric Line no. 1
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
3	Gray Coarse Sand and fine Gravel	125	Cohesion: 0.0 Friction angle: 32	Piezometric Line no. 1

Figure 80

KILL VAN KULL CHANNEL

Profile Line #26



NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
2	Gray Silt and Sand	96	Cohesion: 96.0 Friction angle: 26	Piezometric Line no. 1
4	Red Shale and Sandstone	155	Cohesion: 5000.0 Friction angle: 0	Piezometric Line no. 1
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
3	Gray Coarse Sand and fine Gravel	125	Cohesion: 0.0 Friction angle: 32	Piezometric Line no. 1

Figure 81

KILL VAN KULL CHANNEL

Profile Line #26

NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
2	Gray Silt and Sand	96	Cohesion: 96.0 Friction angle: 26	Piezometric Line no. 1
4	Red Shale and Sandstone	155	Cohesion: 5000.0 Friction angle: 0	Piezometric Line no. 1
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
3	Gray Coarse Sand and fine Gravel	125	Cohesion: 0.0 Friction angle: 32	Piezometric Line no. 1

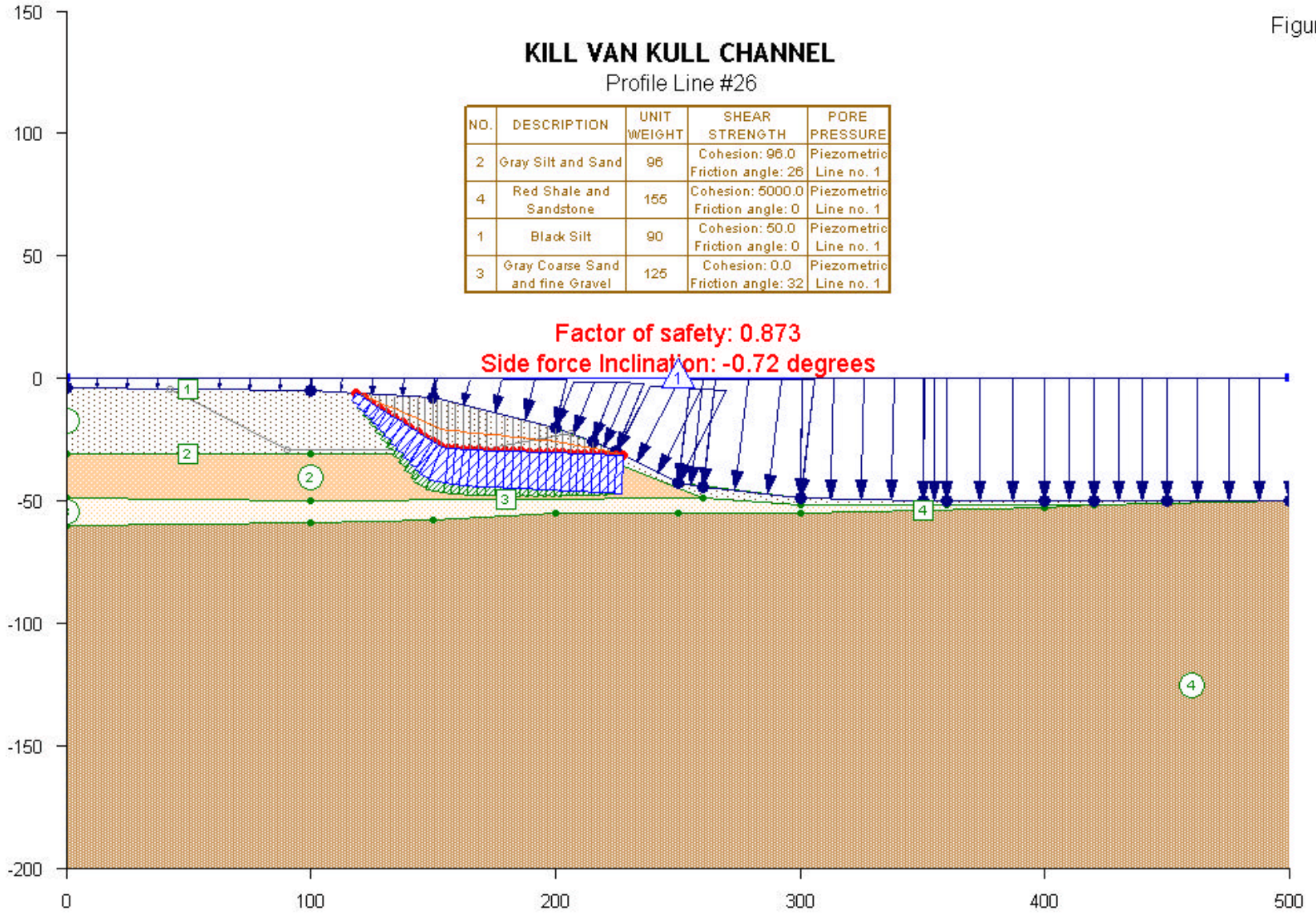
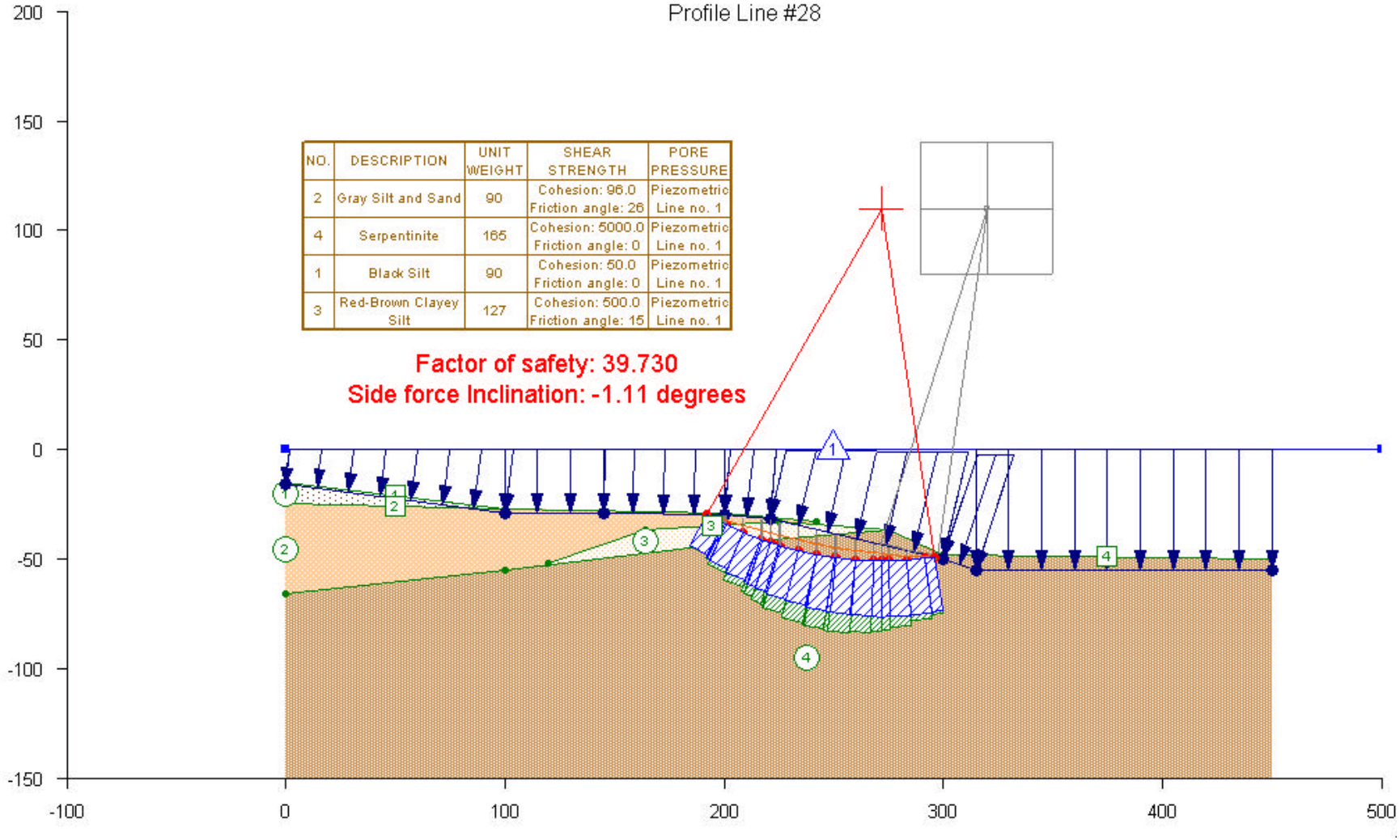


Figure 82

KILL VAN KULL CHANNEL

Profile Line #28

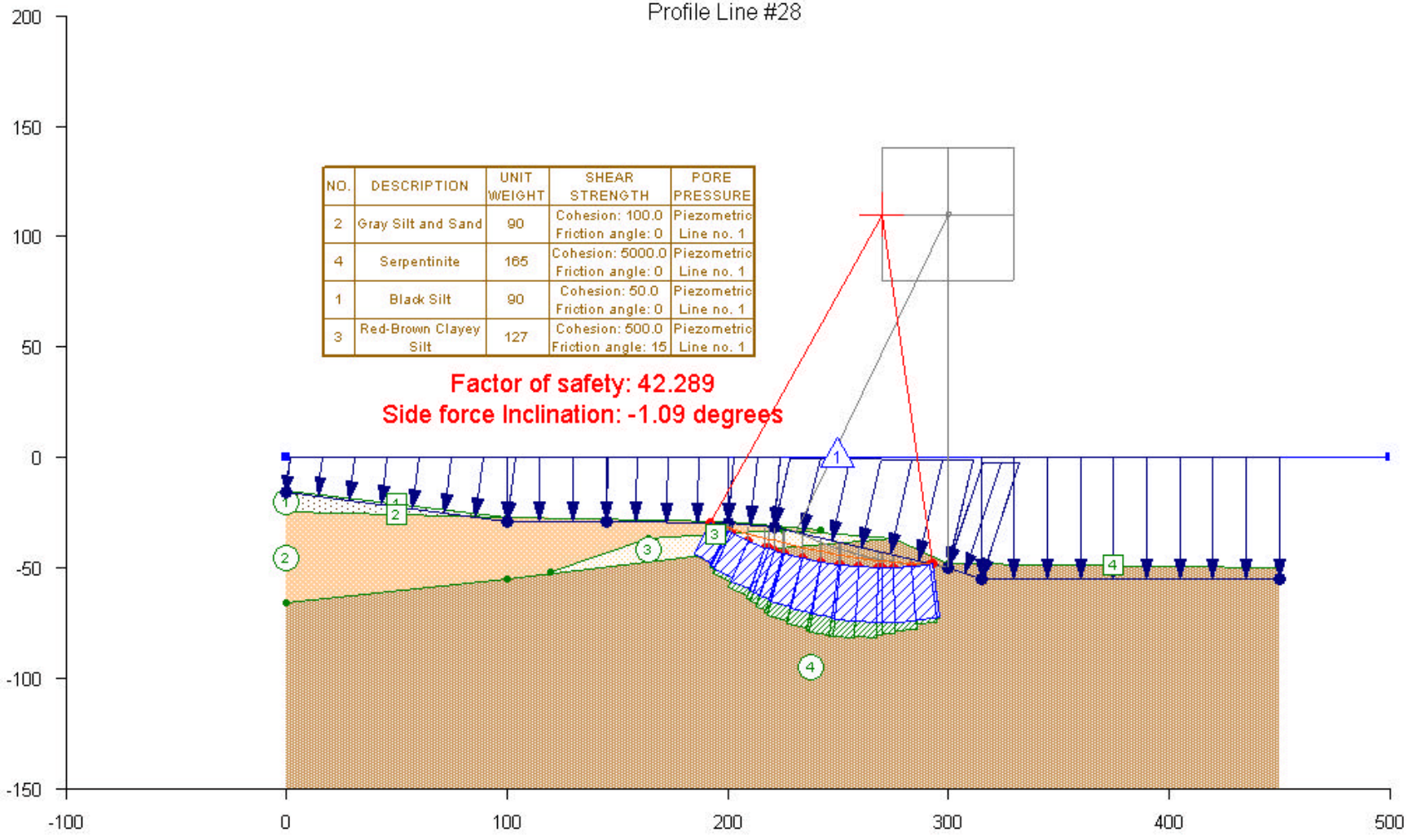


NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
2	Gray Silt and Sand	90	Cohesion: 96.0 Friction angle: 26	Piezometric Line no. 1
4	Serpentinite	165	Cohesion: 5000.0 Friction angle: 0	Piezometric Line no. 1
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
3	Red-Brown Clayey Silt	127	Cohesion: 500.0 Friction angle: 15	Piezometric Line no. 1

Figure 83

KILL VAN KULL CHANNEL

Profile Line #28

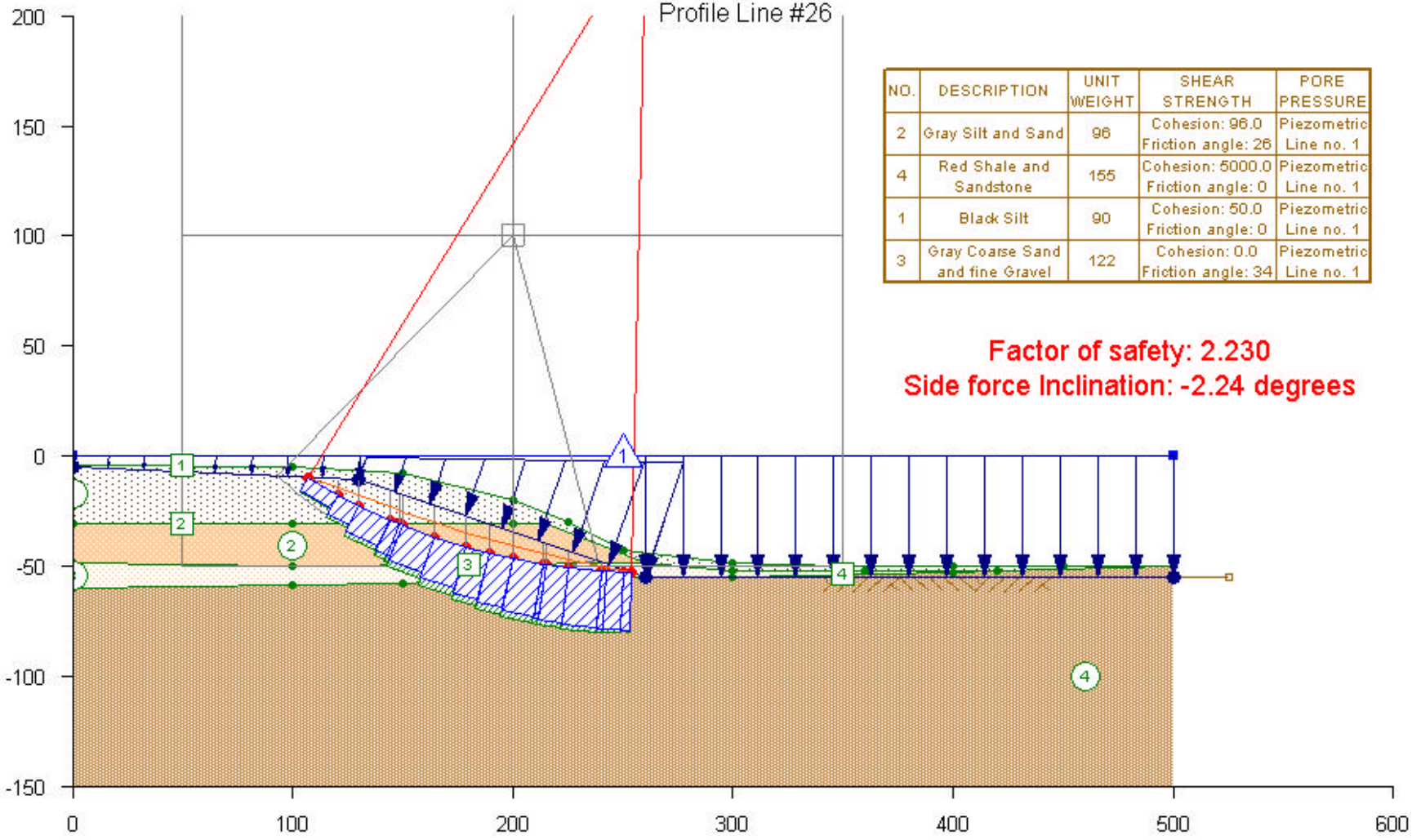


NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
2	Gray Silt and Sand	90	Cohesion: 100.0 Friction angle: 0	Piezometric Line no. 1
4	Serpentinite	165	Cohesion: 5000.0 Friction angle: 0	Piezometric Line no. 1
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
3	Red-Brown Clayey Silt	127	Cohesion: 500.0 Friction angle: 15	Piezometric Line no. 1

Figure 84

KILL VAN KULL CHANNEL

Profile Line #26



NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
2	Gray Silt and Sand	96	Cohesion: 96.0 Friction angle: 26	Piezometric Line no. 1
4	Red Shale and Sandstone	155	Cohesion: 5000.0 Friction angle: 0	Piezometric Line no. 1
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
3	Gray Coarse Sand and fine Gravel	122	Cohesion: 0.0 Friction angle: 34	Piezometric Line no. 1

Factor of safety: 2.230

Side force Inclination: -2.24 degrees

Figure 85

KILL VAN KULL CHANNEL

Profile Line #27

NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
2	Gray Silt and Sand	96	Cohesion: 96.0 Friction angle: 26	Piezometric Line no. 1
4	Red Shale and Sandstone	155	Cohesion: 5000.0 Friction angle: 0	Piezometric Line no. 1
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
3	Red Brown Till	125	Cohesion: 300.0 Friction angle: 35	Piezometric Line no. 1

Factor of safety: 2.572

Side force Inclination: -0.75 degrees

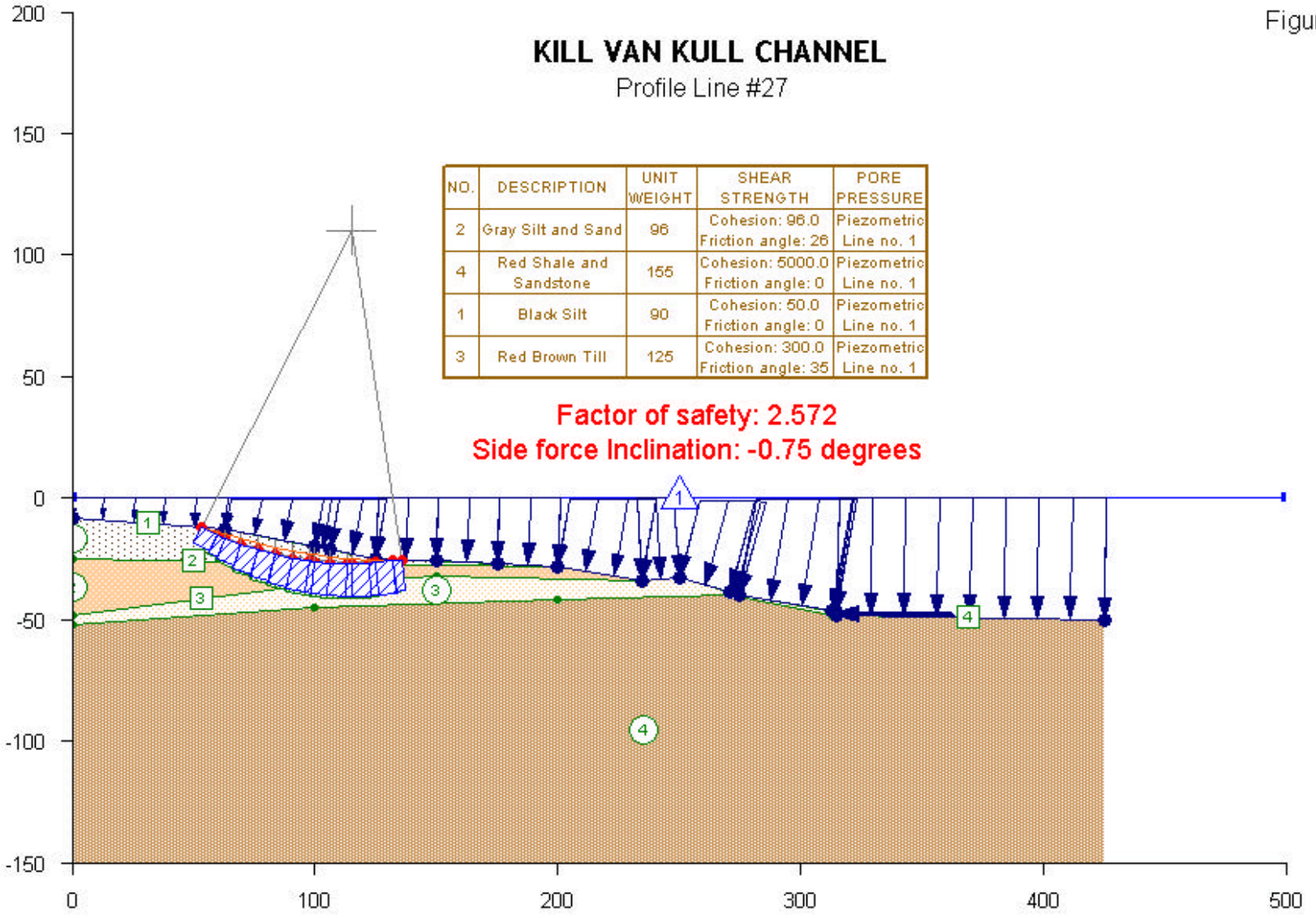


Figure 86

KILL VAN KULL CHANNEL

Profile Line #27

NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
2	Gray Silt and Sand	96	Cohesion: 96.0 Friction angle: 26	Piezometric Line no. 1
4	Red Shale and Sandstone	155	Cohesion: 5000.0 Friction angle: 0	Piezometric Line no. 1
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
3	Red Brown Till	125	Cohesion: 300.0 Friction angle: 35	Piezometric Line no. 1

Factor of safety: 20.696

Side force Inclination: 0.39 degrees

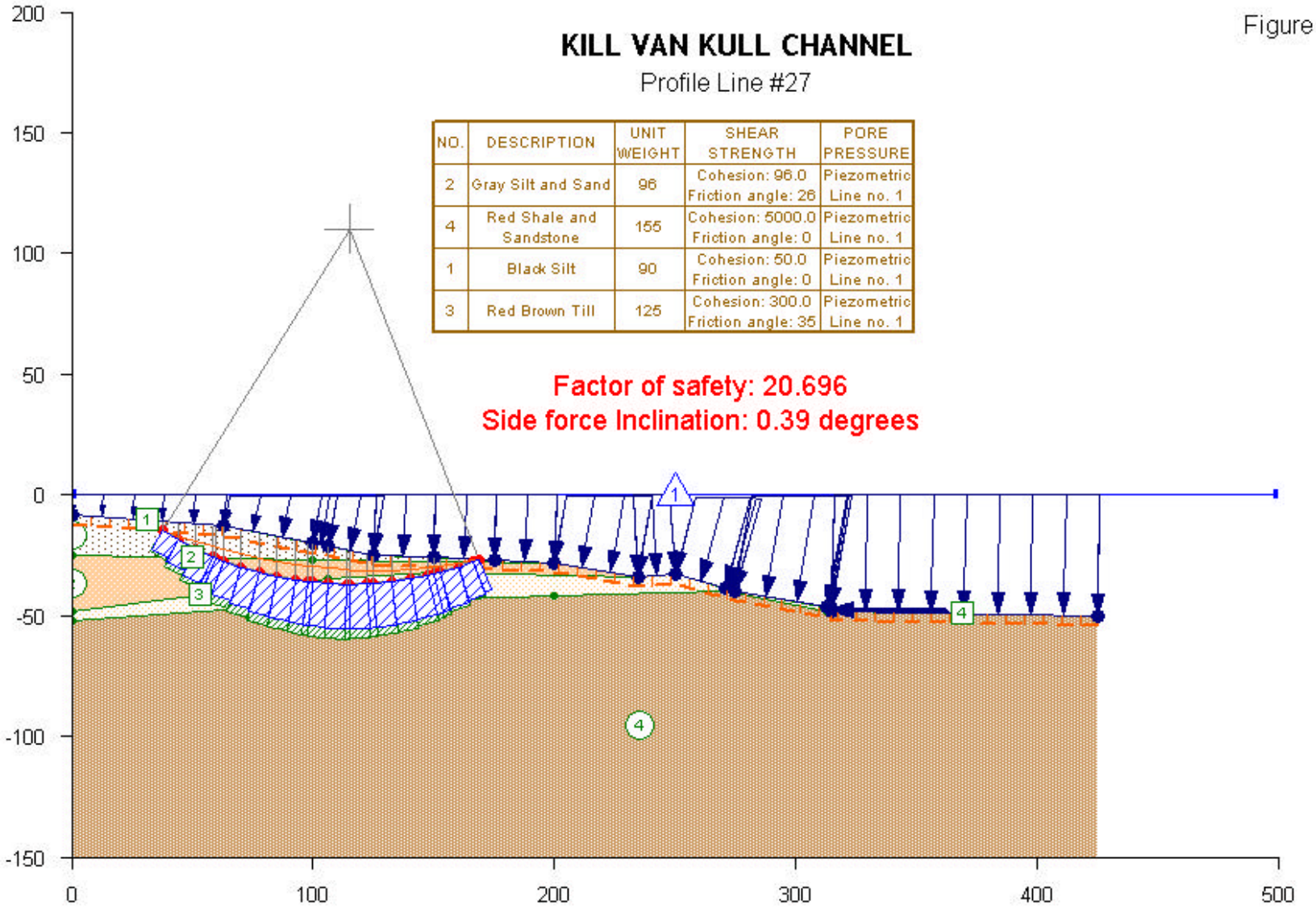


Figure 87

KILL VAN KULL CHANNEL

Profile Line #27

NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
2	Gray Silt and Sand	96	Cohesion: 96.0 Friction angle: 26	Piezometric Line no. 1
4	Red Shale and Sandstone	155	Cohesion: 5000.0 Friction angle: 0	Piezometric Line no. 1
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
3	Red Brown Till	125	Cohesion: 300.0 Friction angle: 35	Piezometric Line no. 1

Factor of safety: 64.010

Side force Inclination: 0.37 degrees

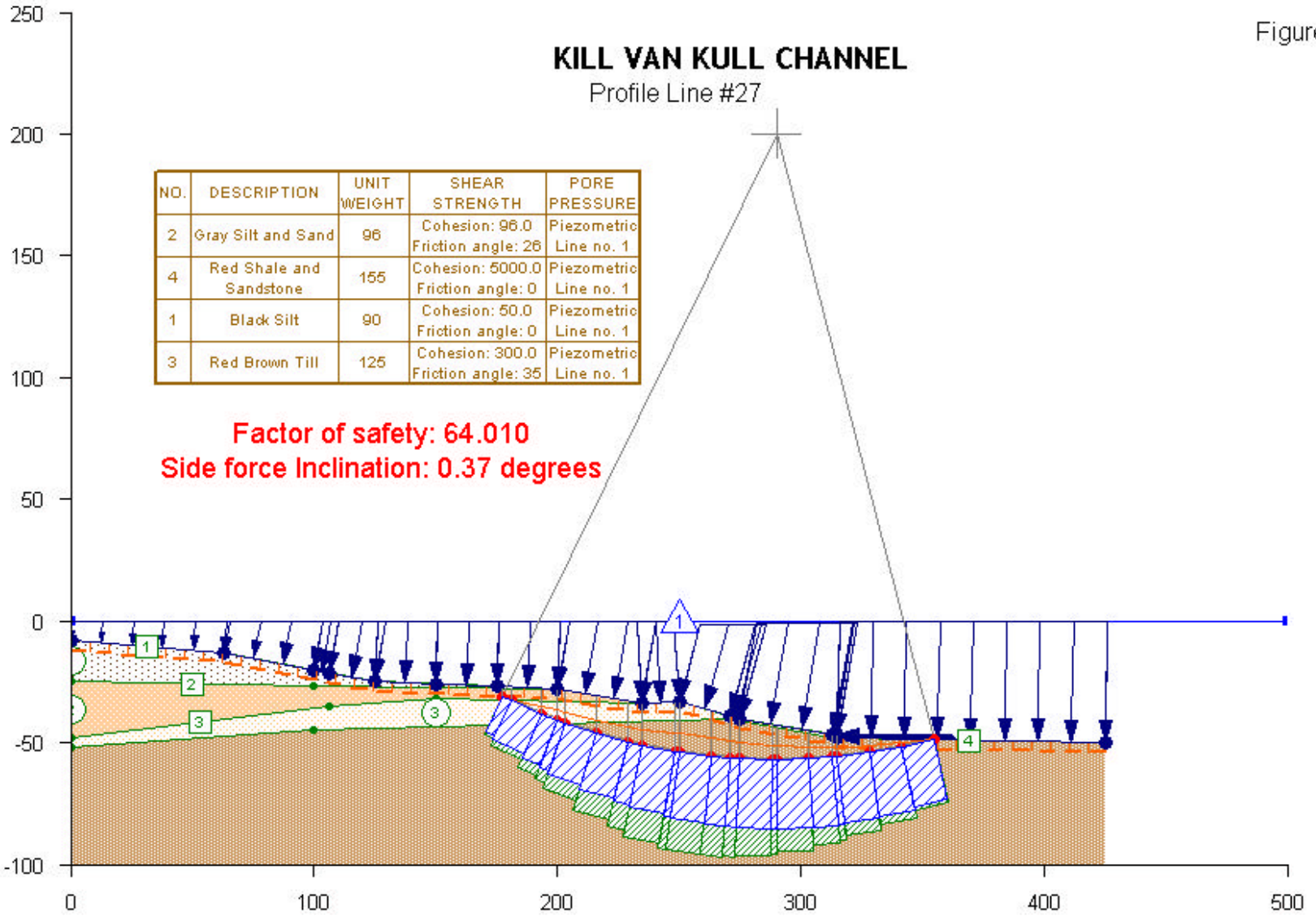


Figure 88

NEWARK BAY

Profile Line #14

NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	GRAY AND BLACK SILT	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
2	PLEISTOCENE CLAY	115	Cohesion: 500.0 Friction angle: 0	Piezometric Line no. 1
3	PLEISTOCENE SAND AND GRAVEL	125	Cohesion: 0.0 Friction angle: 33	Piezometric Line no. 1
4	TRIASSIC SANDSTONE AND BASALT	165	Cohesion: 4000.0 Friction angle: 45	Piezometric Line no. 1

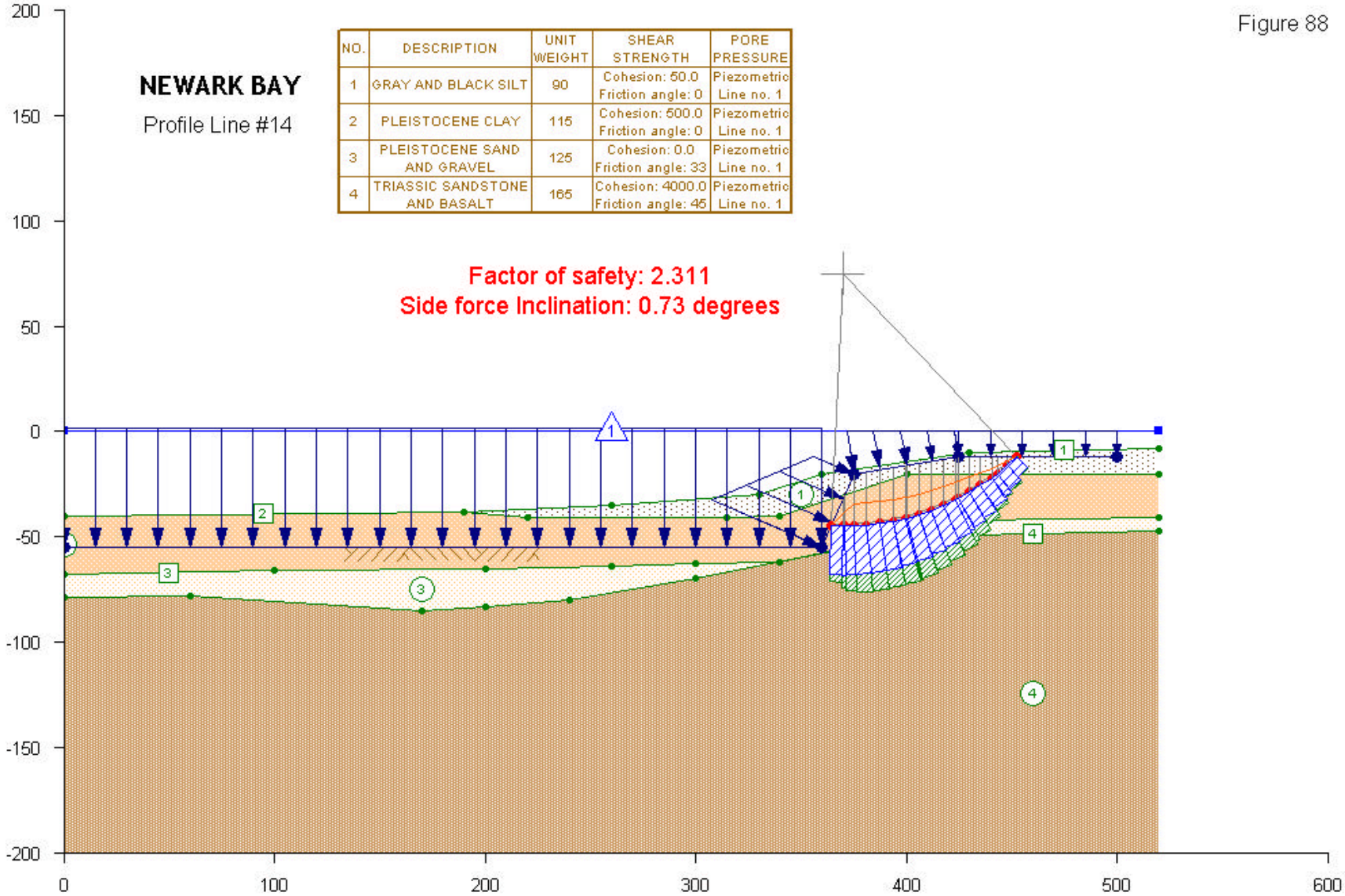


Figure 89

NEWARK BAY Profile Line #14

NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	GRAY AND BLACK SILT	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
2	PLEISTOCENE CLAY	115	Cohesion: 500.0 Friction angle: 0	Piezometric Line no. 1
3	PLEISTOCENE SAND AND GRAVEL	125	Cohesion: 0.0 Friction angle: 33	Piezometric Line no. 1
4	TRIASSIC SANDSTONE AND BASALT	125	Cohesion: 4000.0 Friction angle: 45	Piezometric Line no. 1

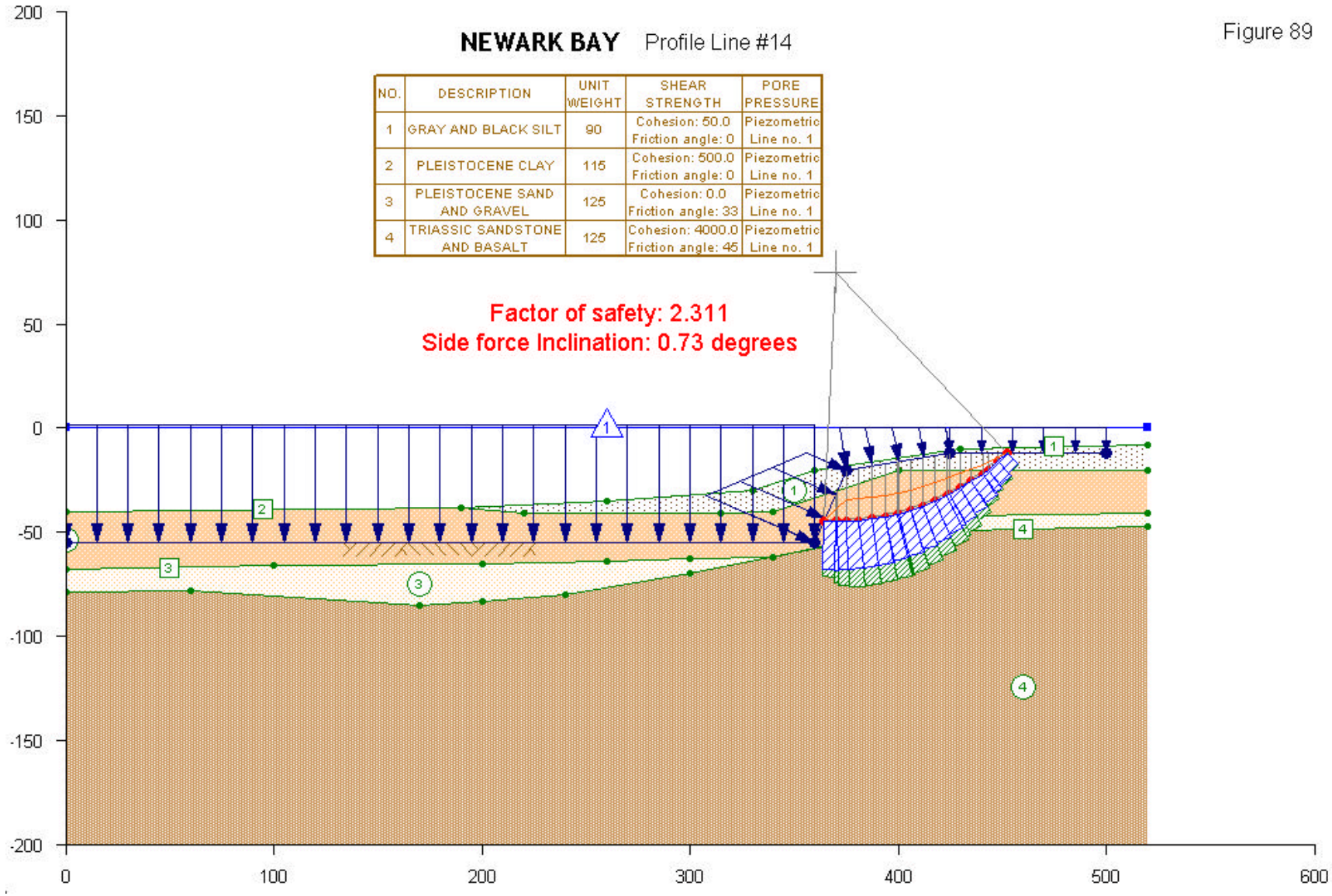


Figure 90

NEWARK BAY

Profile Line #14

NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	GRAY AND BLACK SILT	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
2	PLEISTOCENE CLAY	115	Cohesion: 500.0 Friction angle: 0	Piezometric Line no. 1
3	PLEISTOCENE SAND AND GRAVEL	125	Cohesion: 0.0 Friction angle: 33	Piezometric Line no. 1
4	TRIASSIC SANDSTONE AND BASALT	125	Cohesion: 4000.0 Friction angle: 45	Piezometric Line no. 1

Factor of safety: 2.006
Side force Inclination: 0.49 degrees

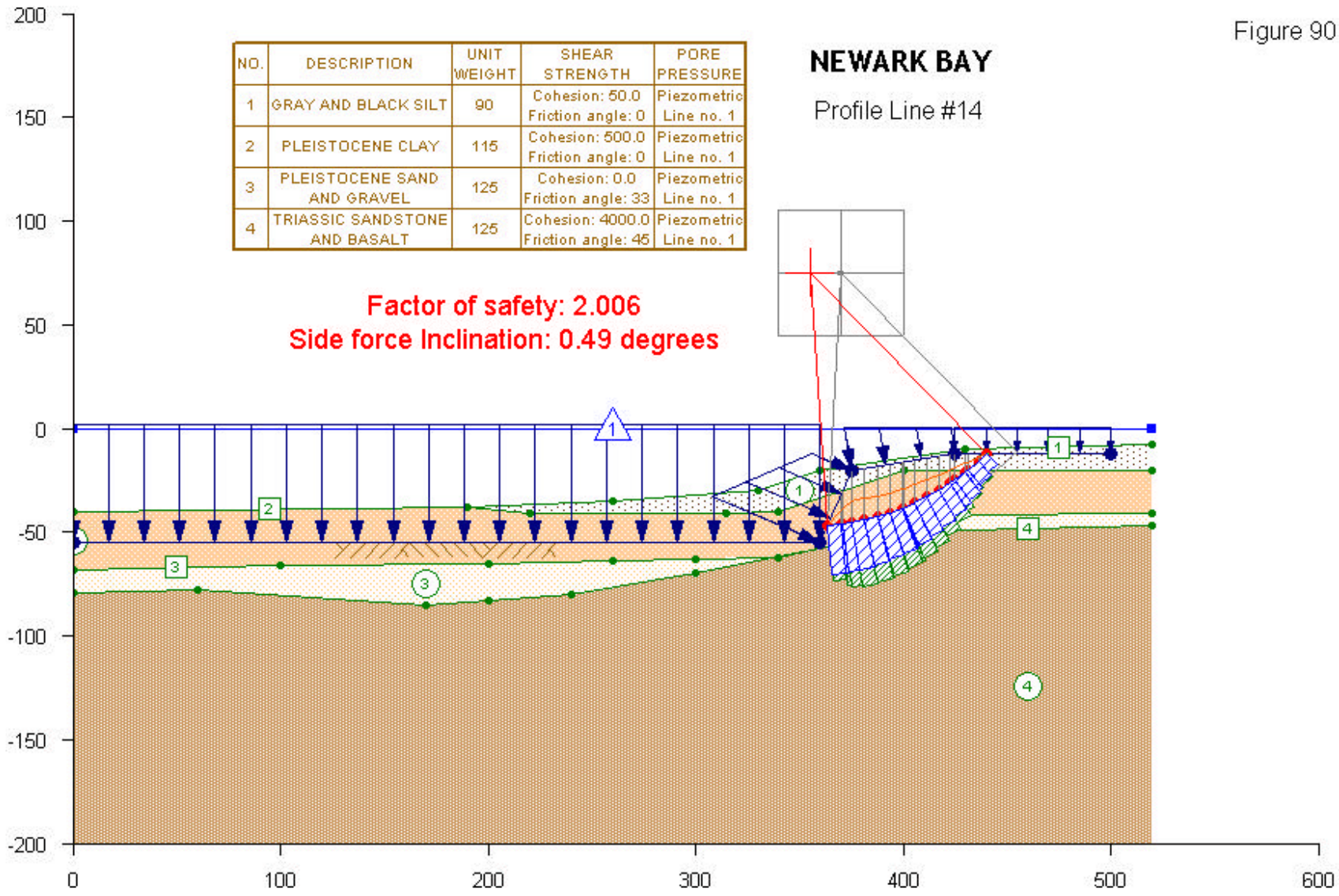


Figure 91

NEWARK BAY

Profile Line #16

NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Gray Silt and Sand	96	Cohesion: 96.0 Friction angle: 26	Piezometric Line no. 1
2	Red-Brown Clayey Silt	125	Cohesion: 500.0 Friction angle: 15	Piezometric Line no. 1
3	Triassic Gray Sandstone	155	Cohesion: 3000.0 Friction angle: 40	Piezometric Line no. 1

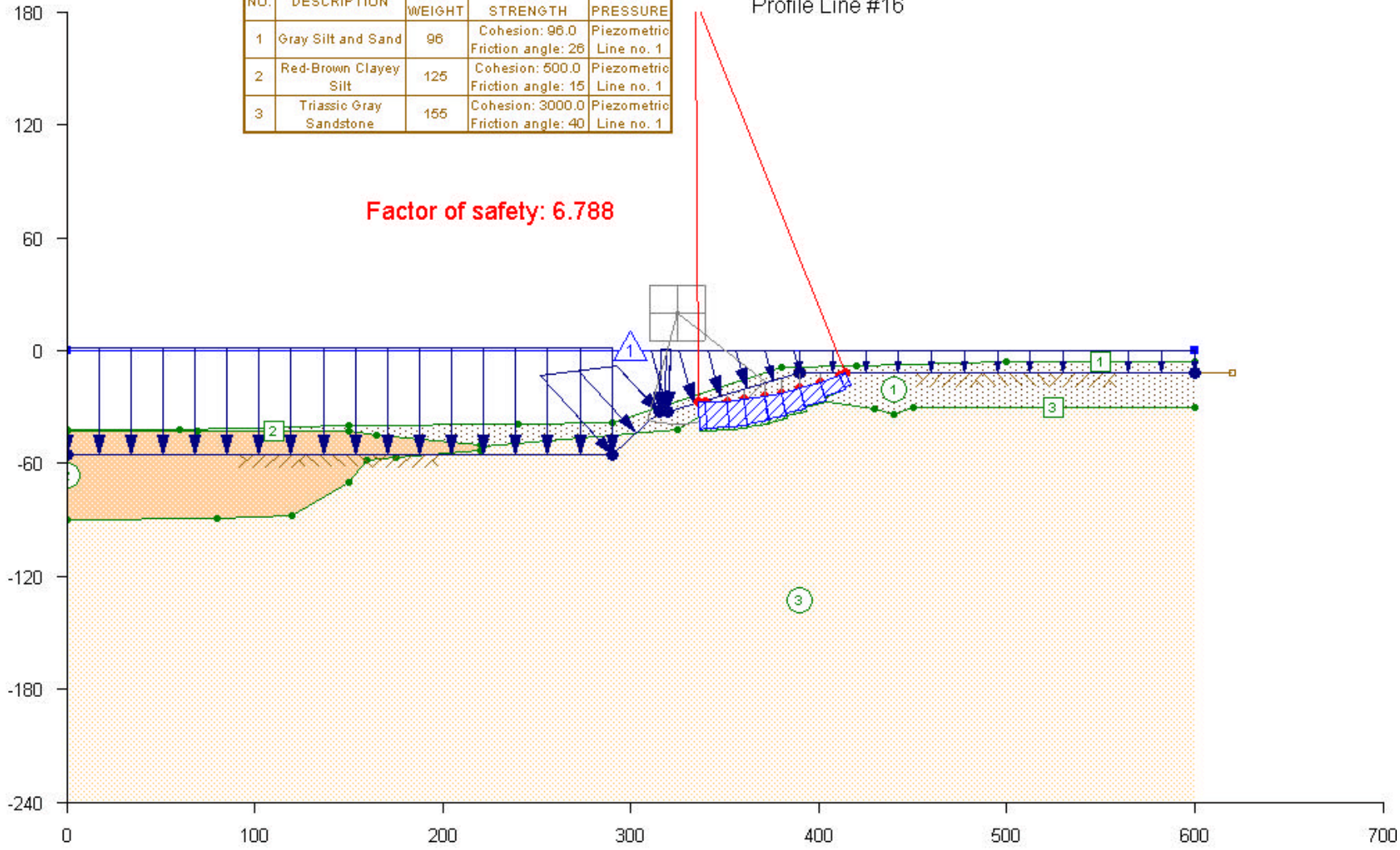


Figure 92

NEWARK BAY Profile Line #17

NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
2	Holocene Gray Silt	100	Cohesion: 100.0 Friction angle: 11	Piezometric Line no. 1
3	Red Clay	125	Cohesion: 500.0 Friction angle: 15	Piezometric Line no. 1
4	Sandstone	155	Cohesion: 3000.0 Friction angle: 40	Piezometric Line no. 1

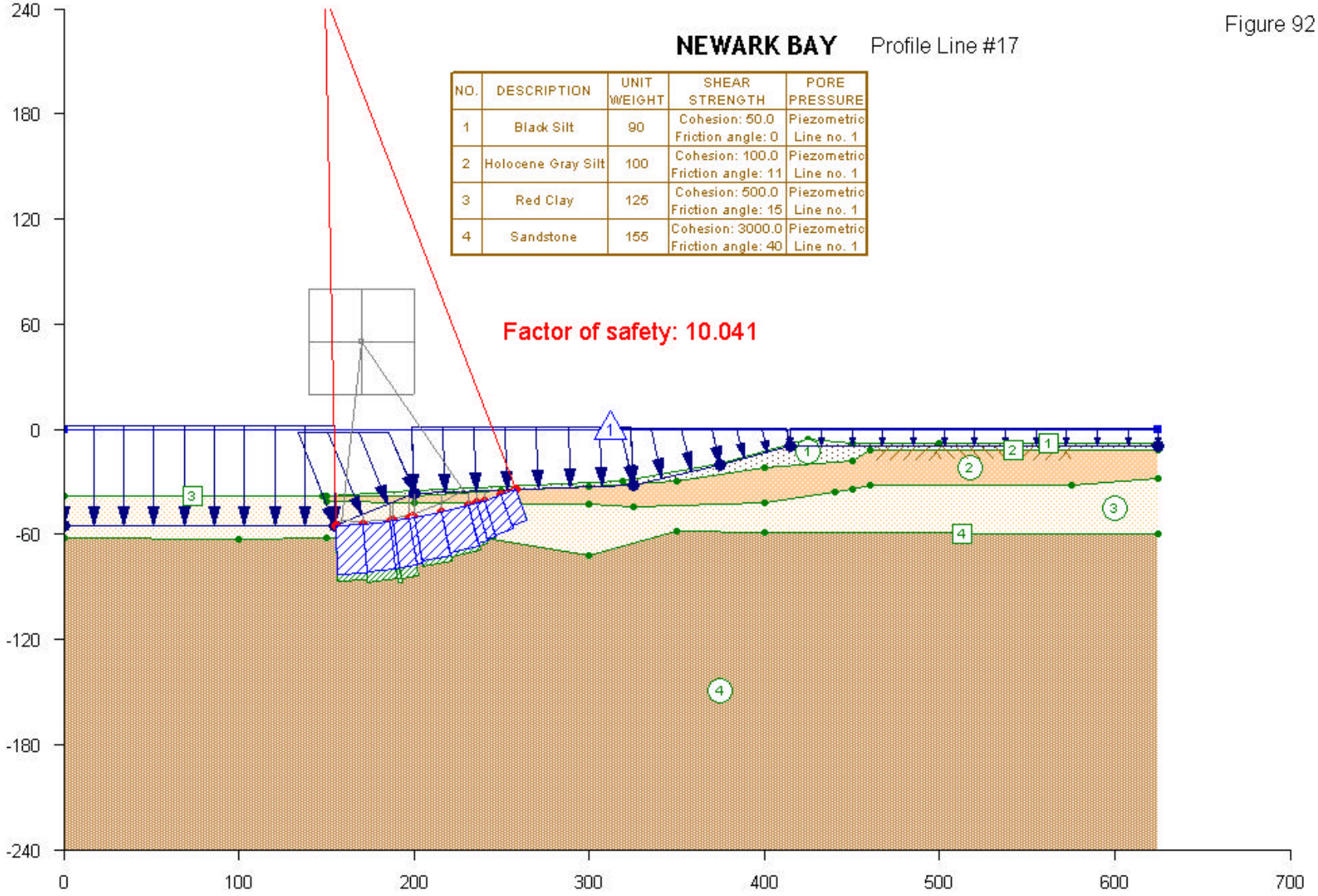


Figure 93

PORT ELIZABETH

Profile Line #9

NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	GRAY SILT AND SAND	96	Cohesion: 96.0 Friction angle: 26	Piezometric Line no. 1
2	PLEISTOCENE RED-BROWN CLAYEY SILT	127	Cohesion: 500.0 Friction angle: 15	Piezometric Line no. 1
3	TRIASSIC SANDSTONE AND SILTSTONE	155	Cohesion: 3000.0 Friction angle: 40	Piezometric Line no. 1

Factor of safety: 4.143

Side force Inclination: 77.58 degrees

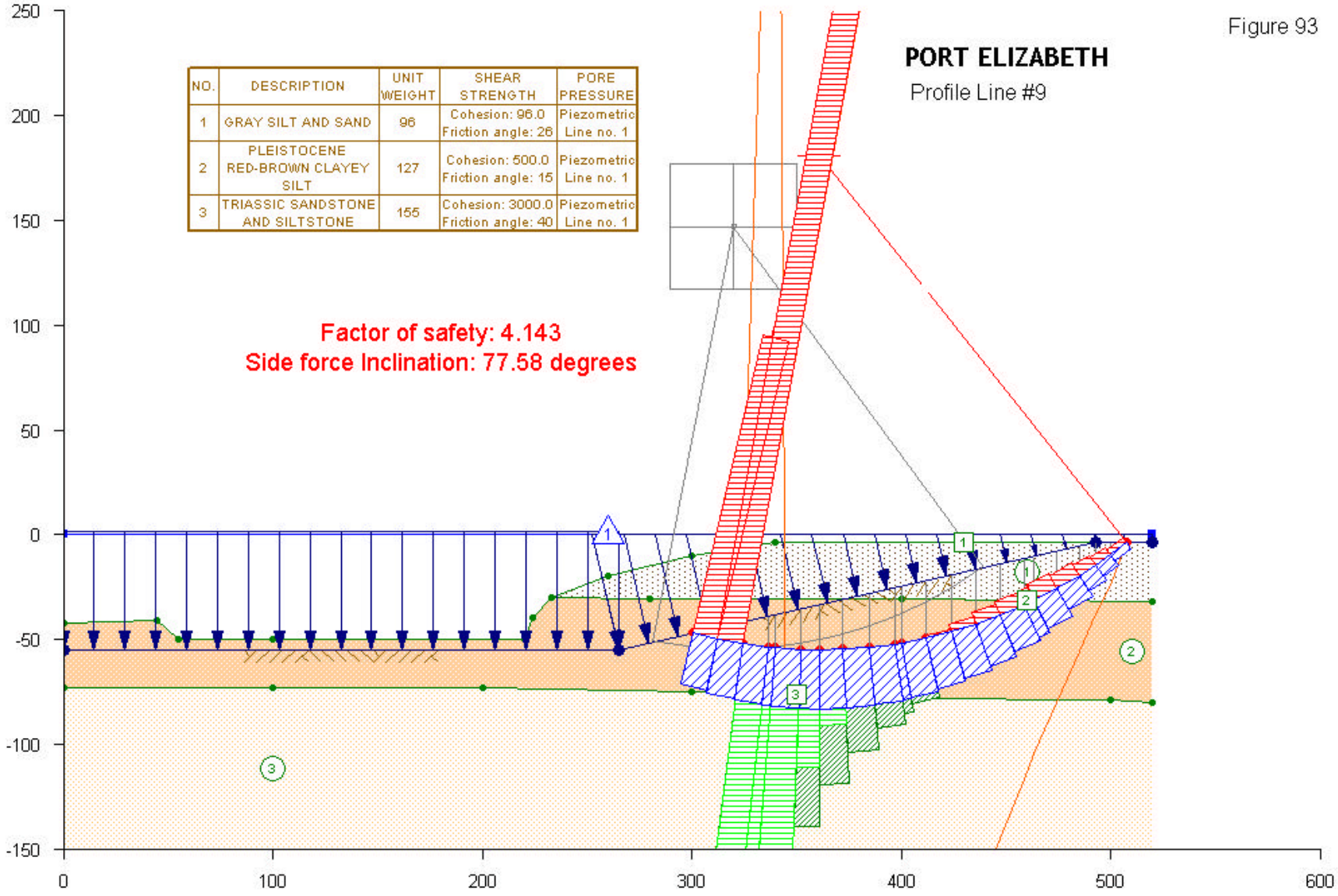


Figure 94

PORT ELIZABETH Profile Line #10

NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Holocene Gray to Brown Silt and Sand	96	Cohesion: 96.0 Friction angle: 26	Piezometric Line no. 1
2	Pleistocene Red-Brown Clayey Silt (Varved)	127	Cohesion: 500.0 Friction angle: 15	Piezometric Line no. 1
3	Triassic Sandstone and Siltstone	155	Cohesion: 3000.0 Friction angle: 40	Piezometric Line no. 1

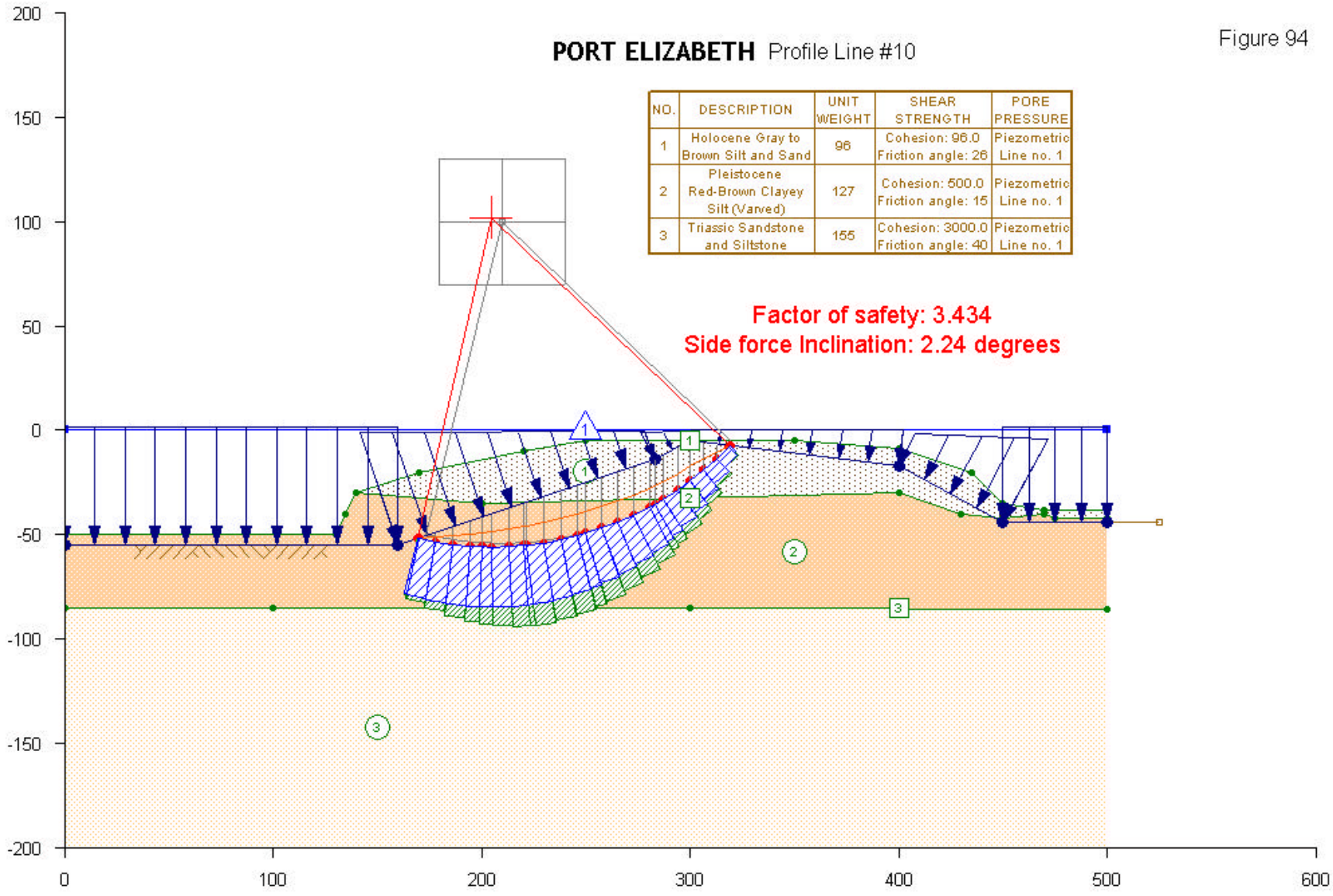
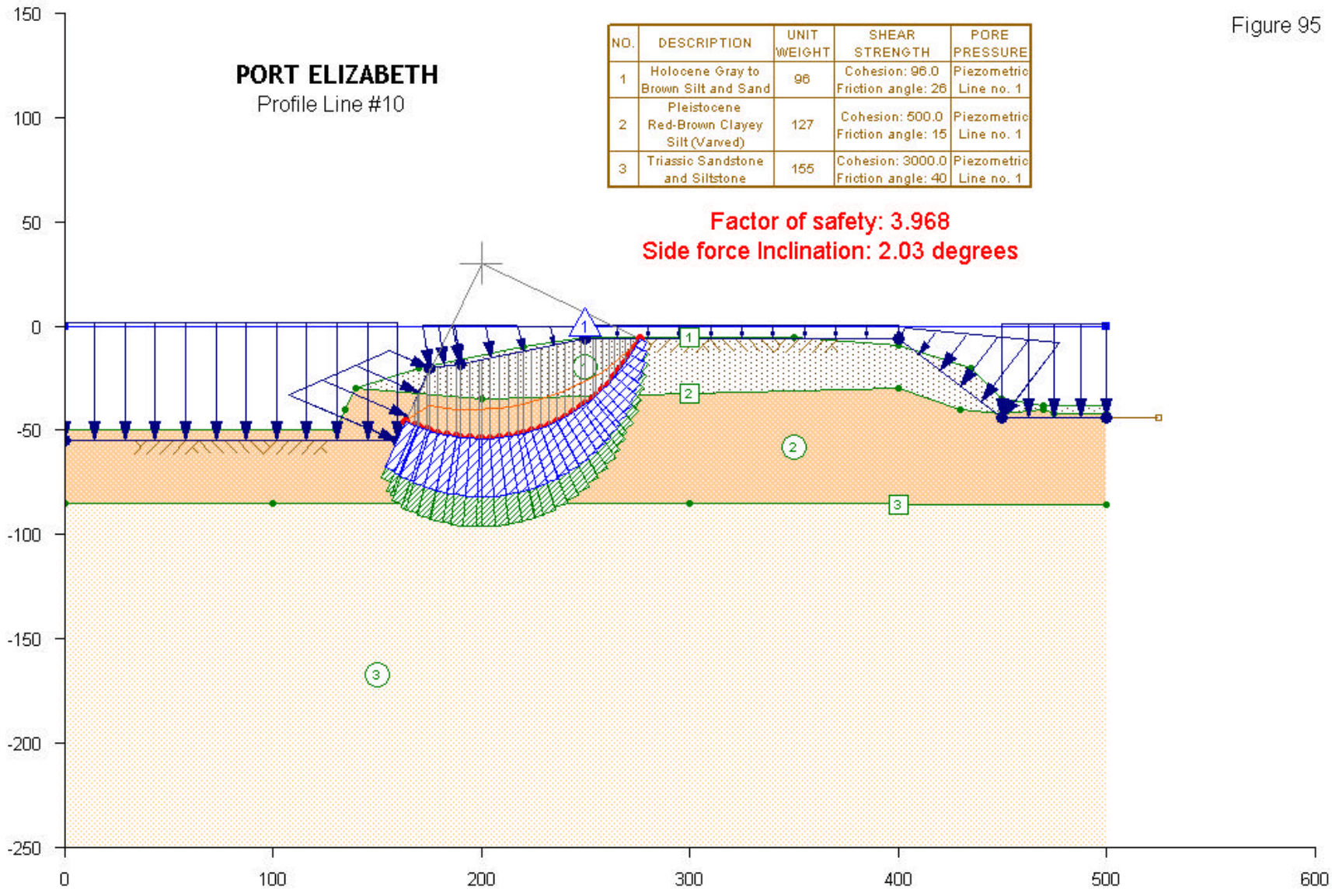
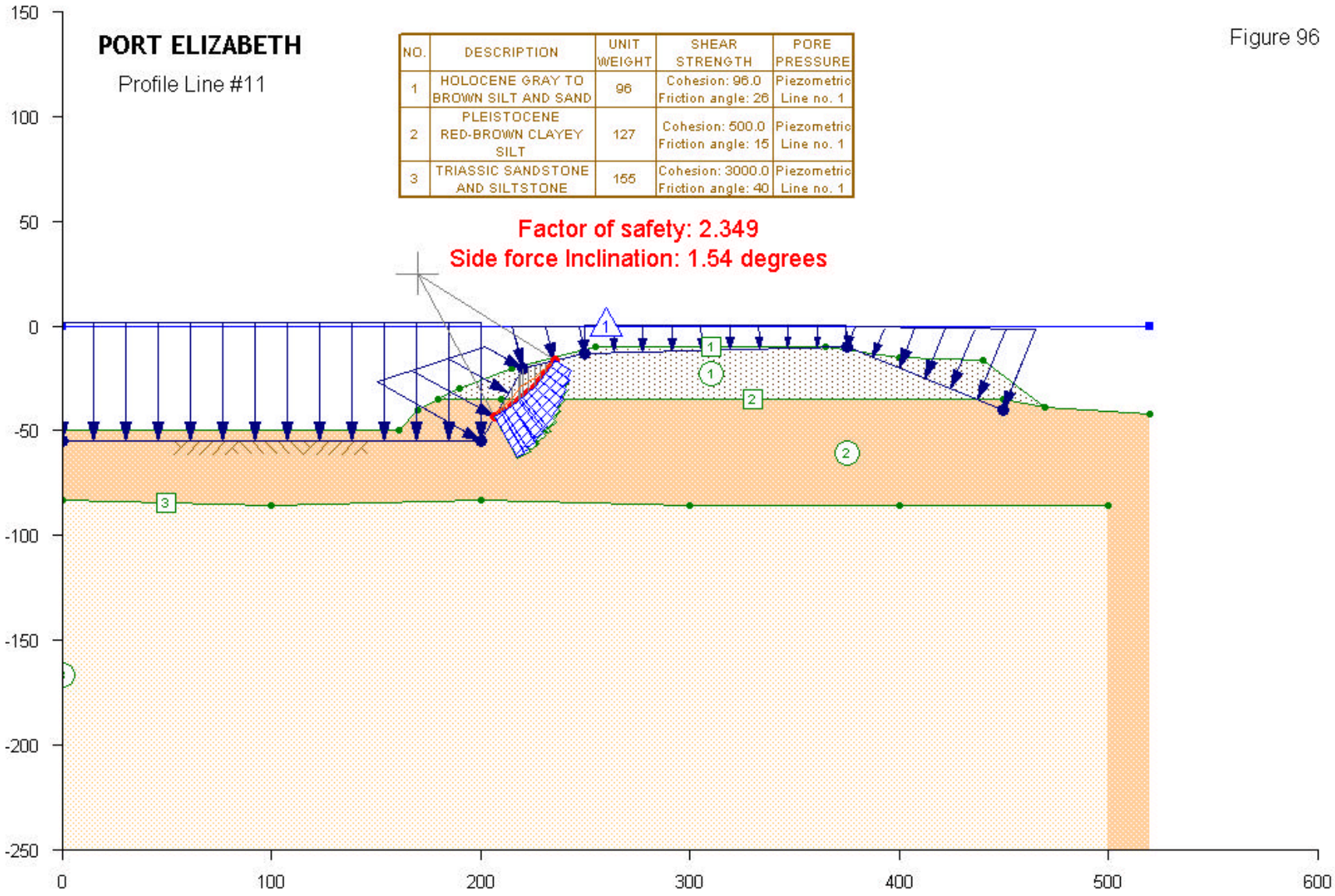


Figure 95



NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Holocene Gray to Brown Silt and Sand	96	Cohesion: 96.0 Friction angle: 26	Piezometric Line no. 1
2	Pleistocene Red-Brown Clayey Silt (Varved)	127	Cohesion: 500.0 Friction angle: 15	Piezometric Line no. 1
3	Triassic Sandstone and Siltstone	155	Cohesion: 3000.0 Friction angle: 40	Piezometric Line no. 1

Figure 96



NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	HOLOCENE GRAY TO BROWN SILT AND SAND	96	Cohesion: 96.0 Friction angle: 26	Piezometric Line no. 1
2	PLEISTOCENE RED-BROWN CLAYEY SILT	127	Cohesion: 500.0 Friction angle: 15	Piezometric Line no. 1
3	TRIASSIC SANDSTONE AND SILTSTONE	155	Cohesion: 3000.0 Friction angle: 40	Piezometric Line no. 1

Figure 97

NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	HOLOCENE GRAY TO BROWN SILT AND SAND	115	Cohesion: 100.0 Friction angle: 32	Piezometric Line no. 1
2	PLEISTOCENE RED-BROWN CLAYEY SILT	110	Cohesion: 500.0 Friction angle: 25	Piezometric Line no. 1
3	TRIASSIC SANDSTONE AND SILTSTONE	155	Cohesion: 3000.0 Friction angle: 40	Piezometric Line no. 1

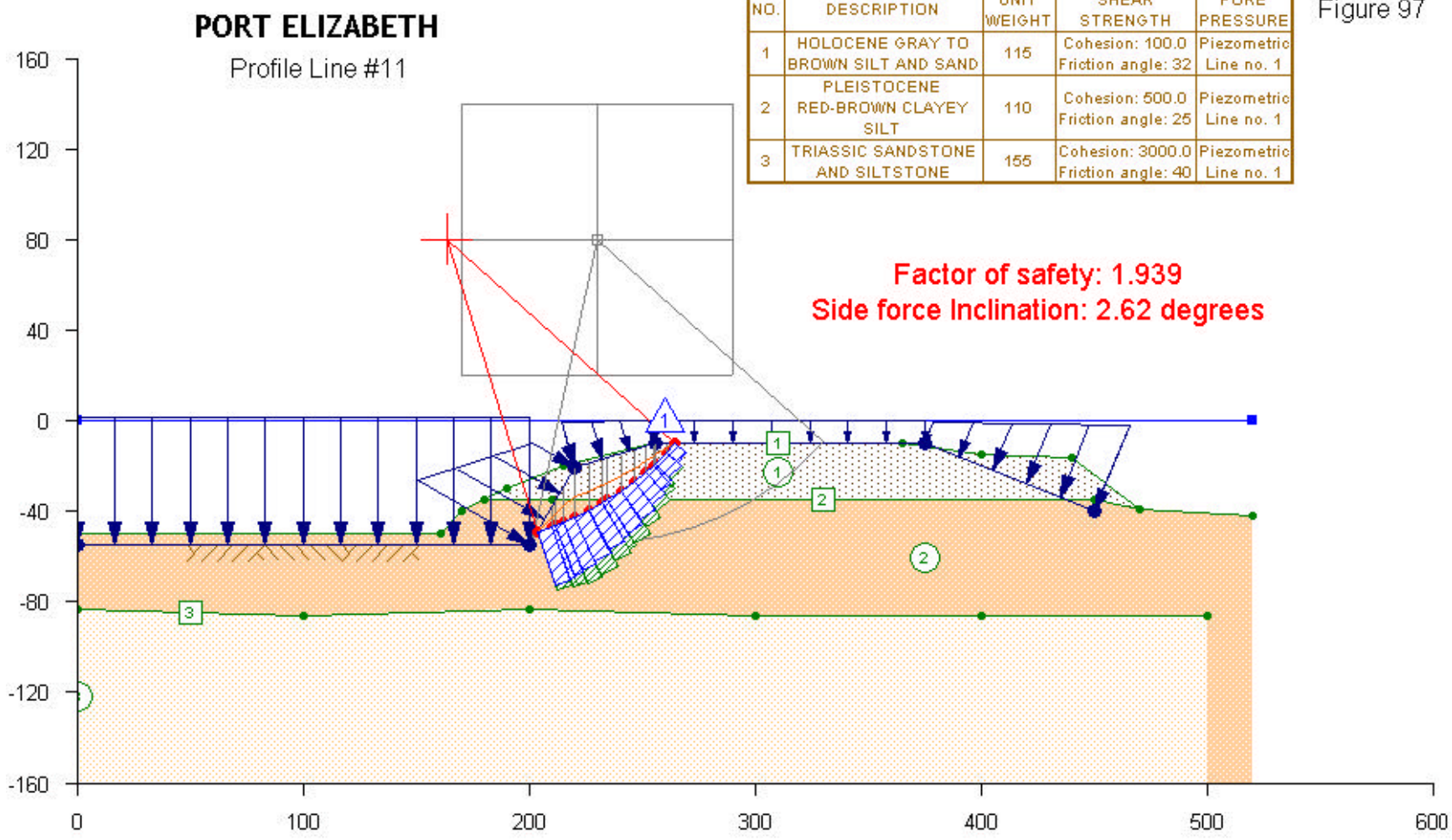
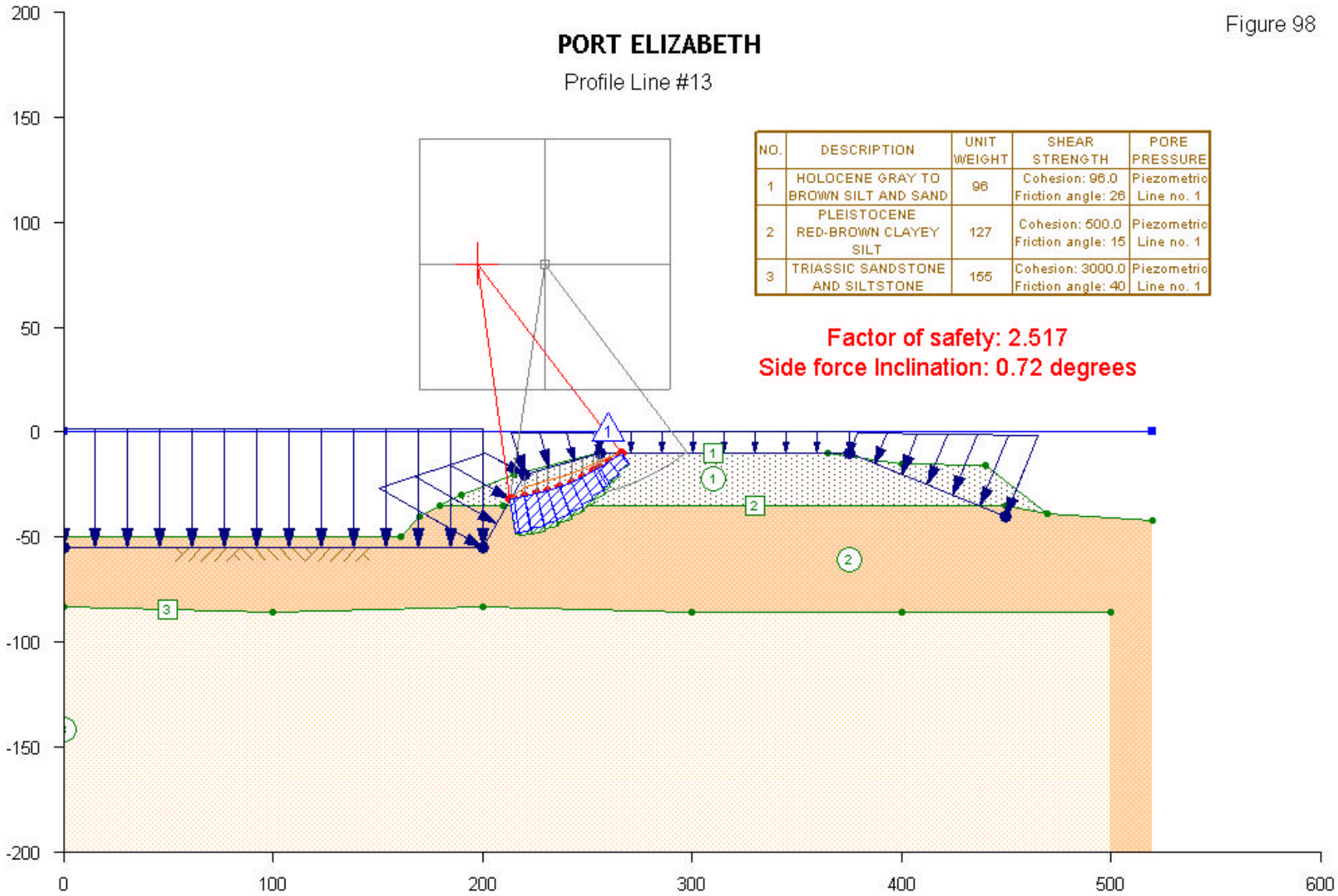


Figure 98

PORT ELIZABETH

Profile Line #13



NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	HOLOCENE GRAY TO BROWN SILT AND SAND	96	Cohesion: 96.0 Friction angle: 26	Piezometric Line no. 1
2	PLEISTOCENE RED-BROWN CLAYEY SILT	127	Cohesion: 500.0 Friction angle: 15	Piezometric Line no. 1
3	TRIASSIC SANDSTONE AND SILTSTONE	155	Cohesion: 3000.0 Friction angle: 40	Piezometric Line no. 1

Factor of safety: 2.517

Side force Inclination: 0.72 degrees

Figure 99

PORT ELIZABETH

Profile Line #13

NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
2	Gray To Brown Silt and Sand	96	Cohesion: 96.0 Friction angle: 26	Piezometric Line no. 1
3	Varved Silt and Clay	127	Cohesion: 500.0 Friction angle: 15	Piezometric Line no. 1

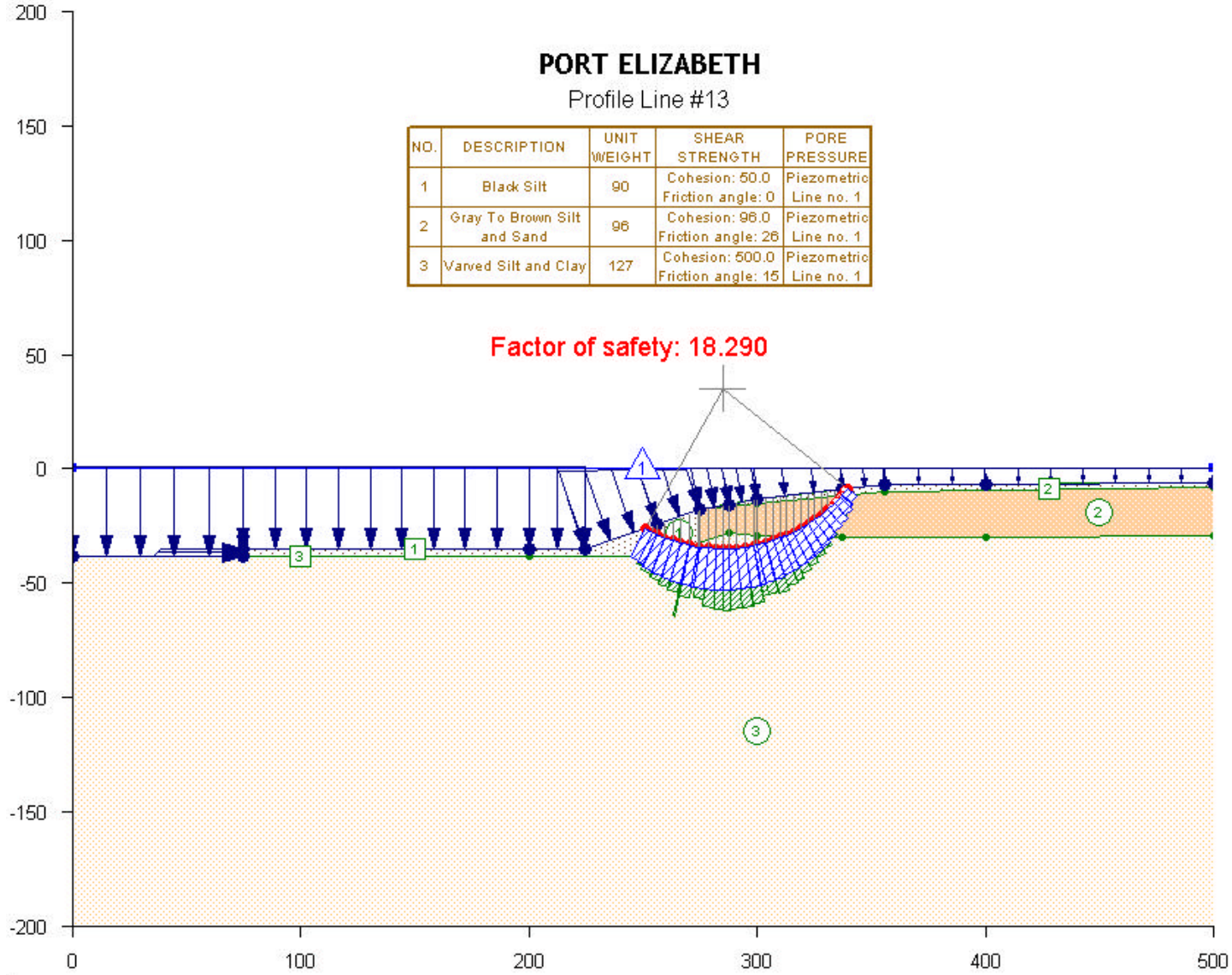


Figure 100

PORT ELIZABETH

Profile Line #13

NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
2	Gray To Brown Silt and Sand	96	Cohesion: 96.0 Friction angle: 26	Piezometric Line no. 1
3	Varved Silt and Clay	125	Cohesion: 500.0 Friction angle: 15	Piezometric Line no. 1

Factor of safety: 2.767

Side force Inclination: 1.02 degrees

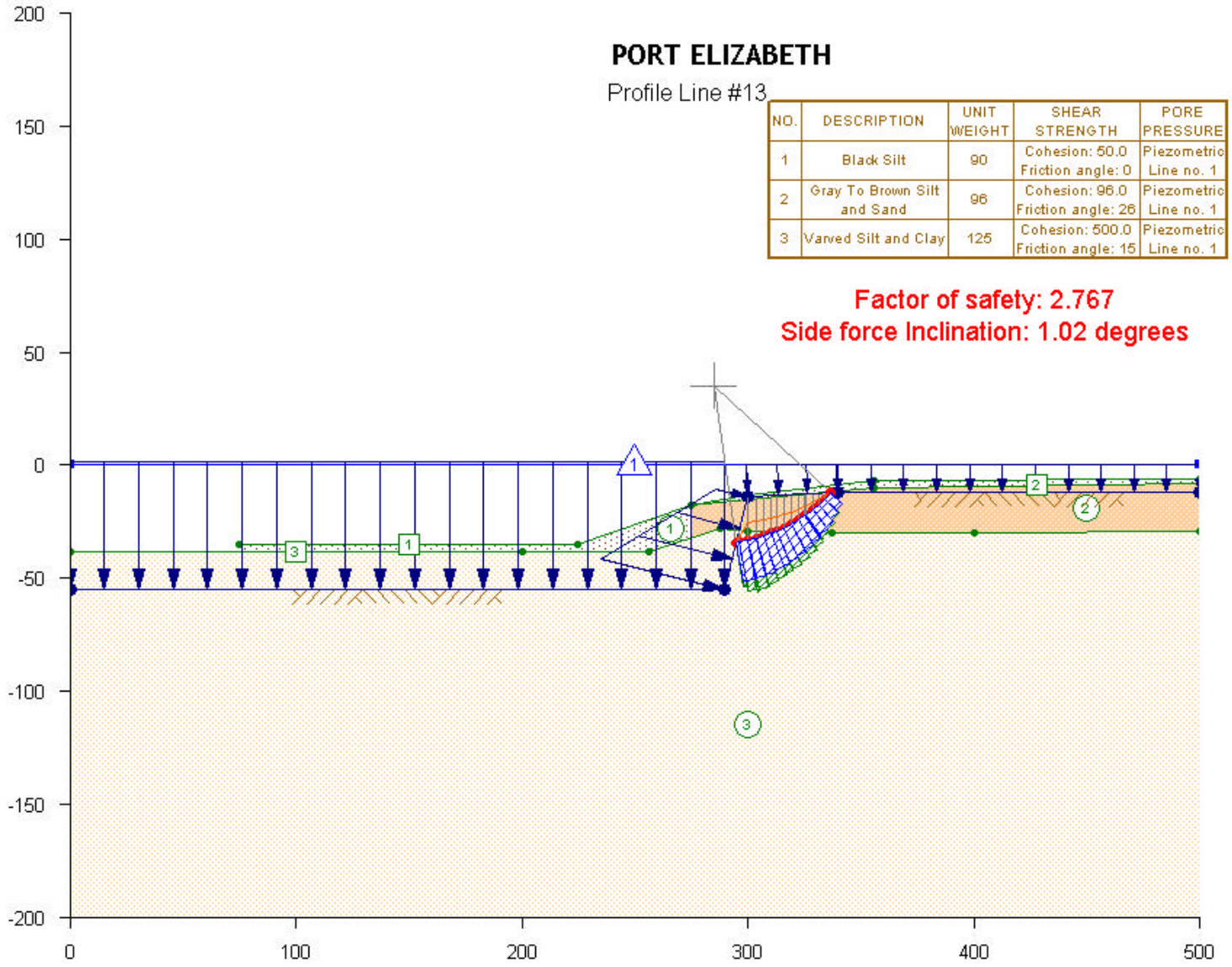


Figure 101

PORT ELIZABETH Profile Line #14

NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
2	Gray To Brown Silt and Sand	96	Cohesion: 96.0 Friction angle: 26	None
3	Varved Silt and Clay	127	Cohesion: 500.0 Friction angle: 15	Piezometric Line no. 1

Factor of safety: 2.116

Side force Inclination: -2.87 degrees

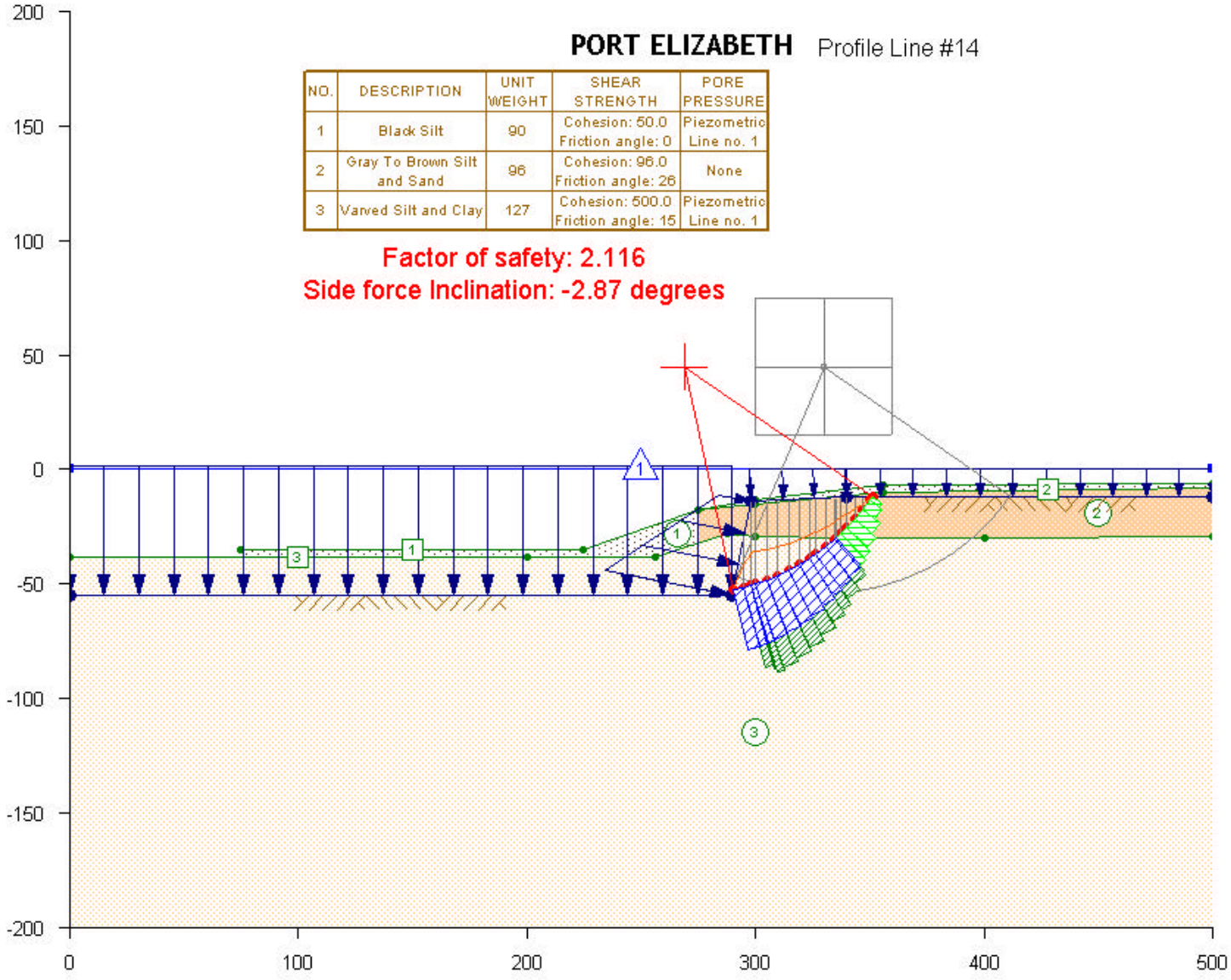


Figure 102

SOUTH ELIZABETH CHANNEL

Profile Line #8

NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
2	Red Silt and Sand	110	Cohesion: 100.0 Friction angle: 32	Piezometric Line no. 1
3	Red Brown Clayey and Silt	115	Cohesion: 500.0 Friction angle: 20	Piezometric Line no. 1
4	Red Brown Till	125	Cohesion: 500.0 Friction angle: 35	Piezometric Line no. 1
5	Triassic Sandstone	155	Cohesion: 5000.0 Friction angle: 40	Piezometric Line no. 1

Factor of safety: 7.484

Side force Inclination: -1.46 degrees

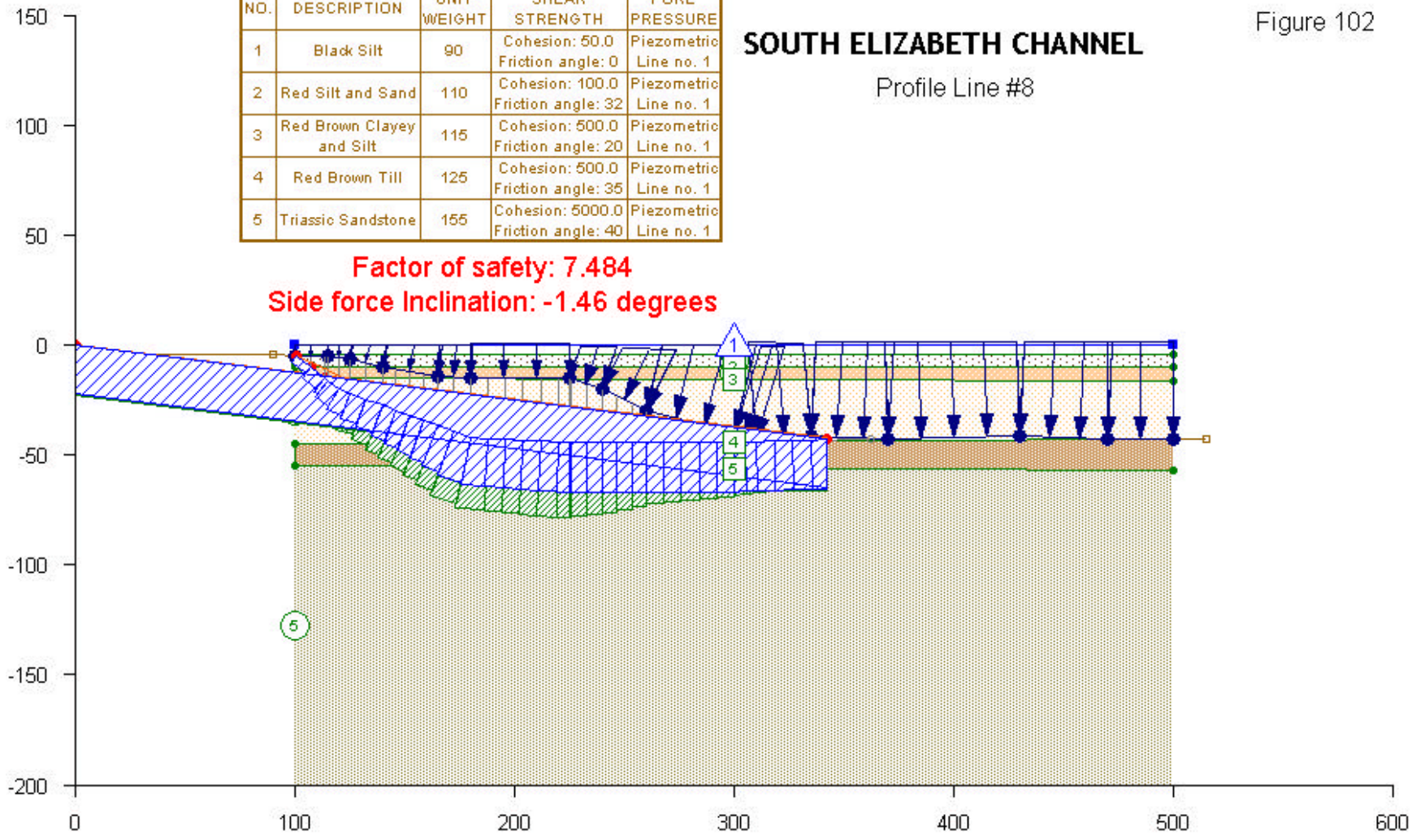


Figure 103

SOUTH ELIZABETH CHANNEL

Profile Line #8

NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
2	Red Silt and Sand	110	Cohesion: 100.0 Friction angle: 32	Piezometric Line no. 1
3	Red Brown Clayey and Silt	115	Cohesion: 500.0 Friction angle: 20	Piezometric Line no. 1
4	Red Brown Till	125	Cohesion: 500.0 Friction angle: 35	Piezometric Line no. 1
5	Triassic Sandstone	155	Cohesion: 5000.0 Friction angle: 40	Piezometric Line no. 1

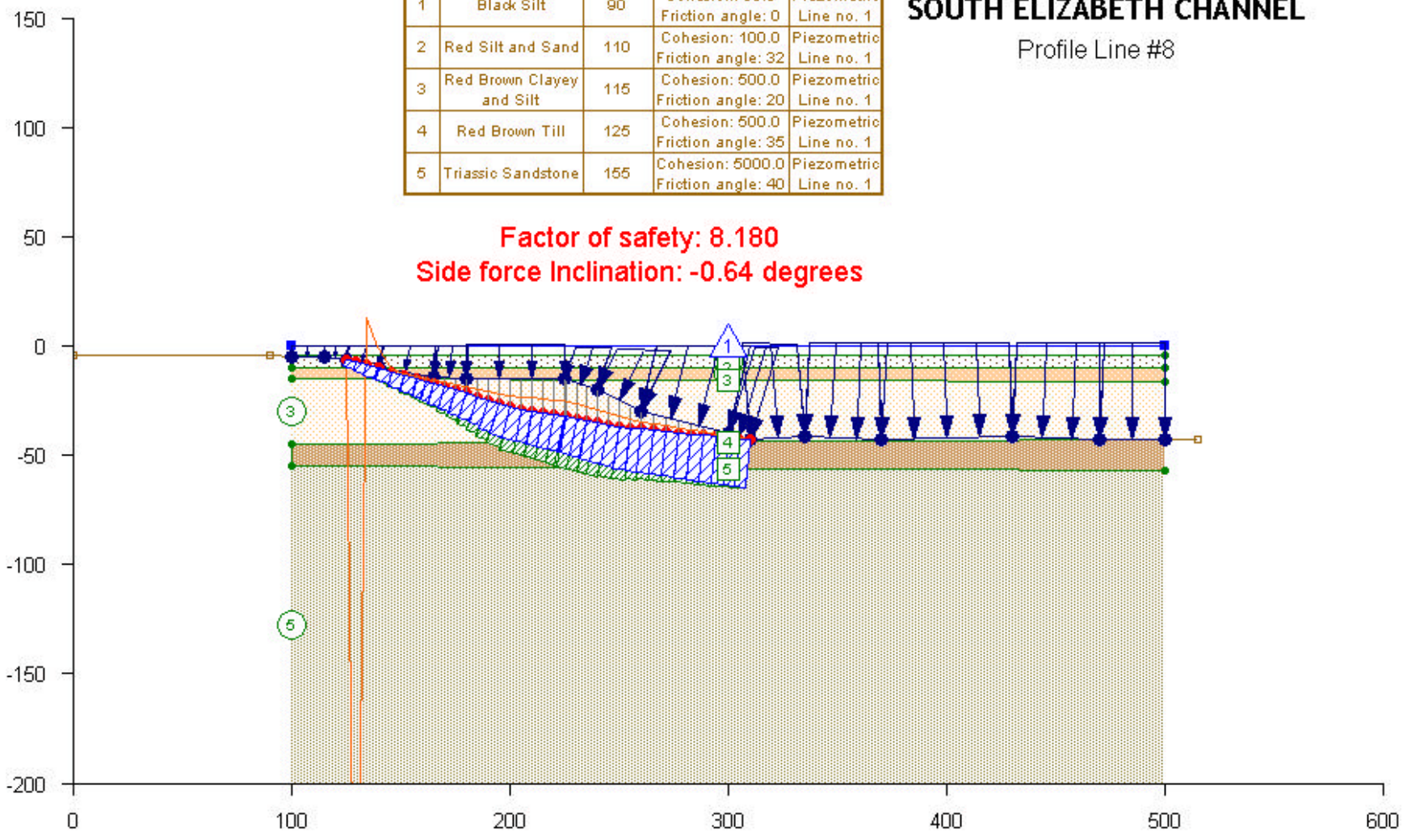


Figure 104

NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
2	Red Silt and Sand	110	Cohesion: 100.0 Friction angle: 32	Piezometric Line no. 1
3	Red Brown Clayey and Silt	115	Cohesion: 500.0 Friction angle: 20	Piezometric Line no. 1
4	Red Brown Till	125	Cohesion: 500.0 Friction angle: 35	Piezometric Line no. 1
5	Triassic Sandstone	155	Cohesion: 5000.0 Friction angle: 40	Piezometric Line no. 1

SOUTH ELIZABETH CHANNEL

Profile Line #8

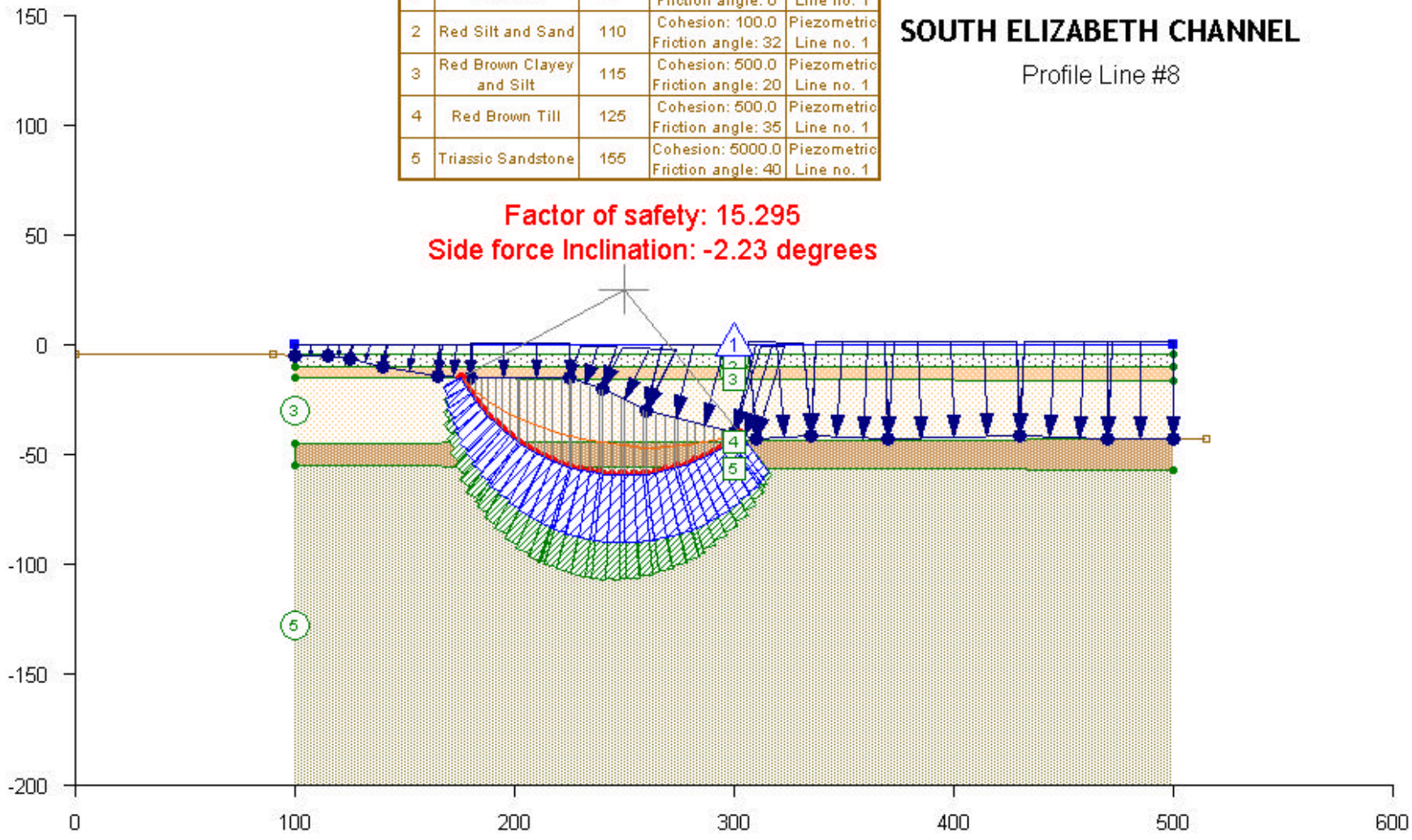
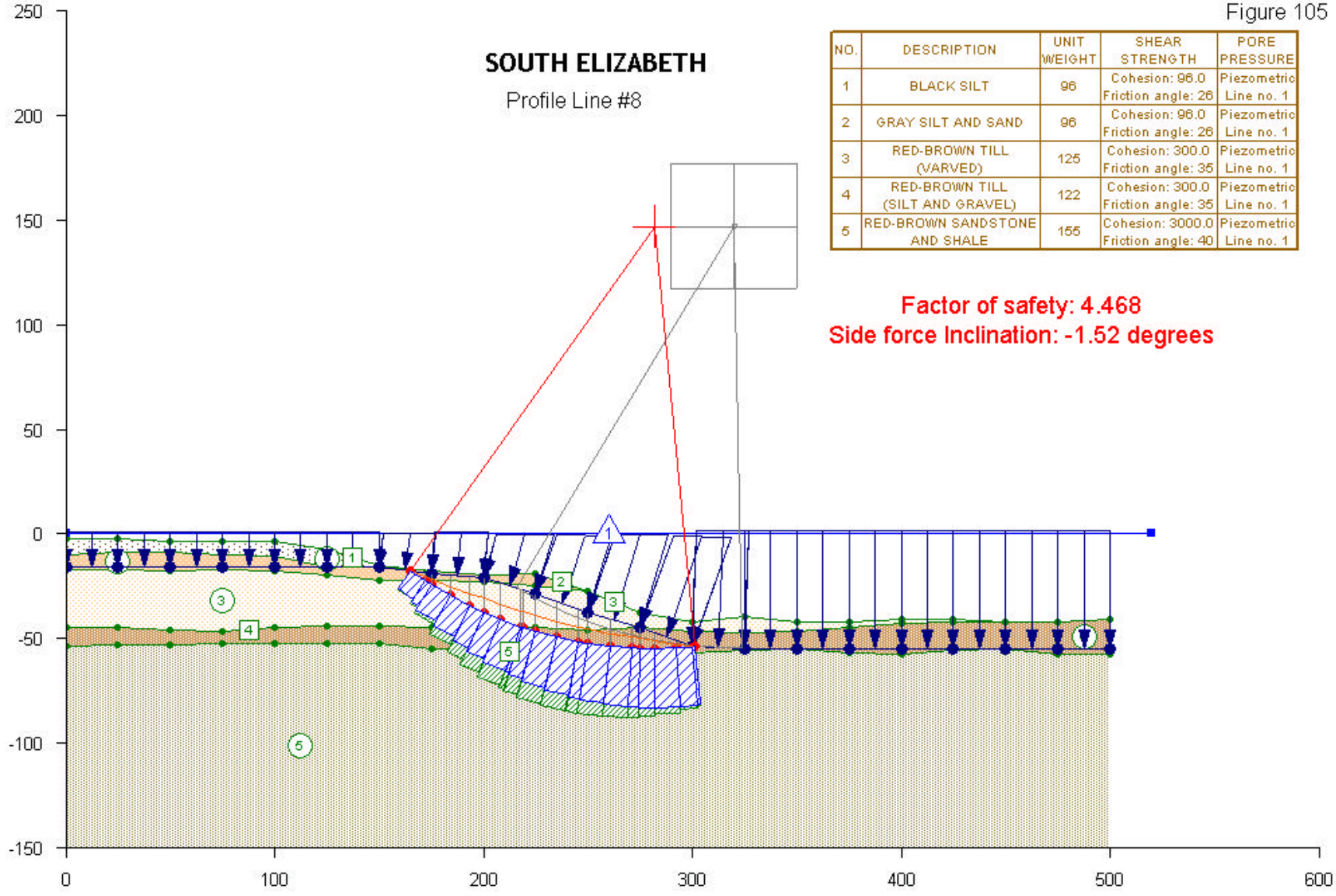
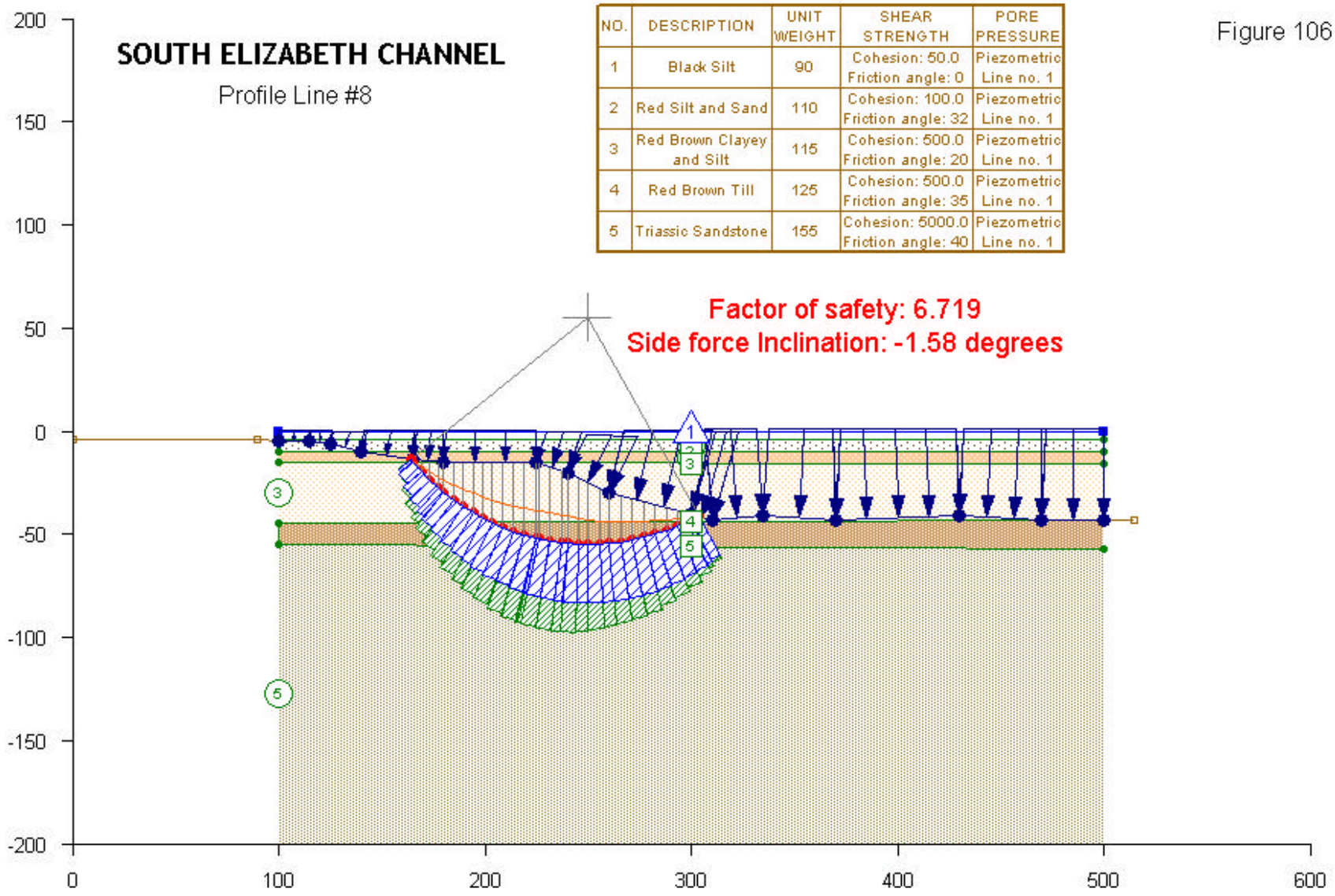


Figure 105



NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	BLACK SILT	96	Cohesion: 96.0 Friction angle: 26	Piezometric Line no. 1
2	GRAY SILT AND SAND	96	Cohesion: 96.0 Friction angle: 26	Piezometric Line no. 1
3	RED-BROWN TILL (VARVED)	125	Cohesion: 300.0 Friction angle: 35	Piezometric Line no. 1
4	RED-BROWN TILL (SILT AND GRAVEL)	122	Cohesion: 300.0 Friction angle: 35	Piezometric Line no. 1
5	RED-BROWN SANDSTONE AND SHALE	155	Cohesion: 3000.0 Friction angle: 40	Piezometric Line no. 1

Figure 106



NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
2	Red Silt and Sand	110	Cohesion: 100.0 Friction angle: 32	Piezometric Line no. 1
3	Red Brown Clayey and Silt	115	Cohesion: 500.0 Friction angle: 20	Piezometric Line no. 1
4	Red Brown Till	125	Cohesion: 500.0 Friction angle: 35	Piezometric Line no. 1
5	Triassic Sandstone	155	Cohesion: 5000.0 Friction angle: 40	Piezometric Line no. 1

Figure 107

TEXACO, PIER 9
NEWARK BAY Profile Line #21

NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
2	Red-brown Silty CLAY	127	Cohesion: 500.0 Friction angle: 15	Piezometric Line no. 1
3	Red-brown, Sand and Gravel	122	Cohesion: 0.0 Friction angle: 35	Piezometric Line no. 1
4	Basalt	165	Cohesion: 5000.0 Friction angle: 45	Piezometric Line no. 1

Factor of safety: 3.747

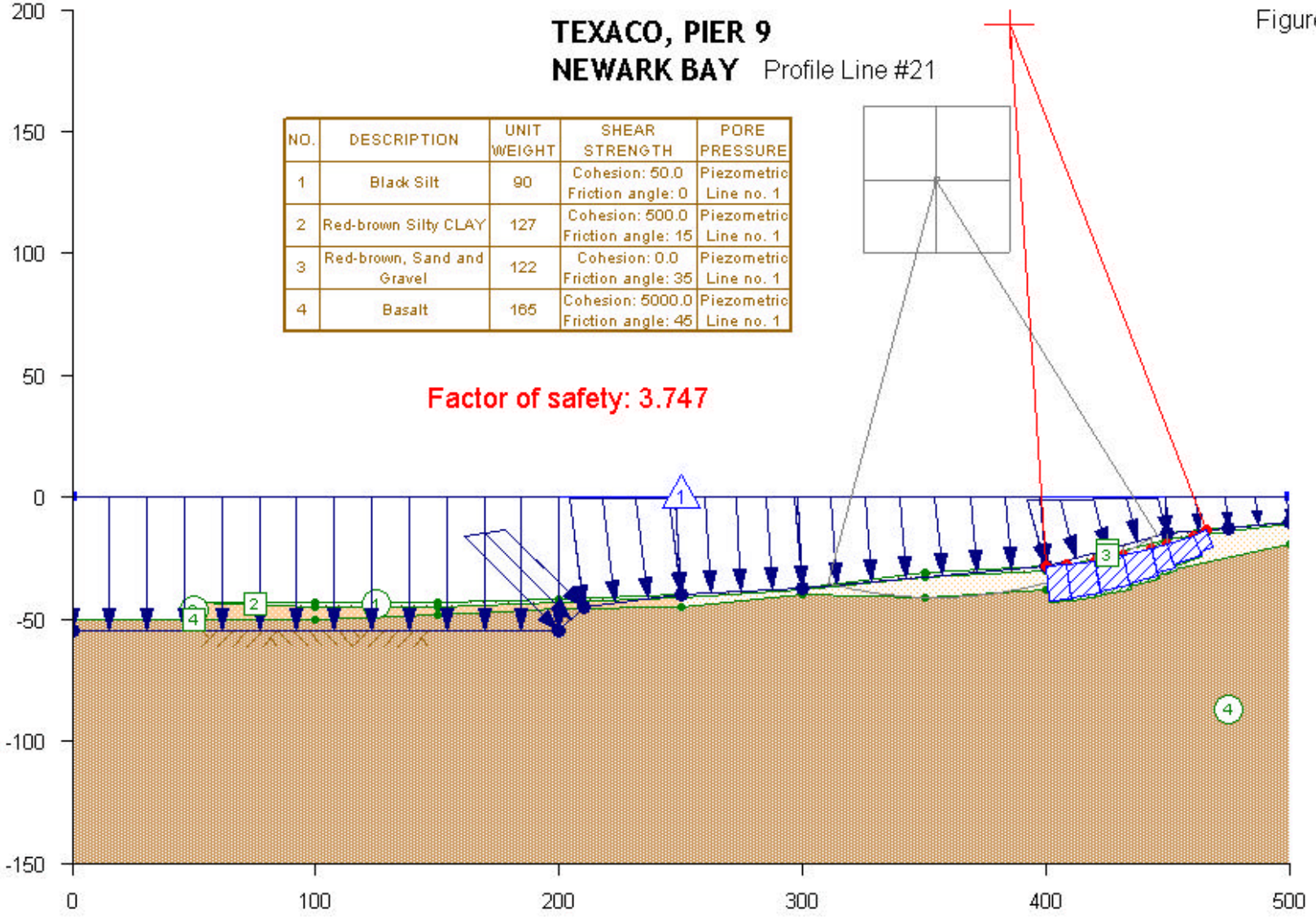


Figure 108

TEXACO, PIER 9
NEWARK BAY

Profile Line #21

NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
2	Red-brown Silty CLAY	127	Cohesion: 500.0 Friction angle: 15	Piezometric Line no. 1
3	Red-brown, Sand and Gravel	122	Cohesion: 0.0 Friction angle: 35	Piezometric Line no. 1
4	Basalt	165	Cohesion: 5000.0 Friction angle: 45	Piezometric Line no. 1

Factor of safety: 3.747

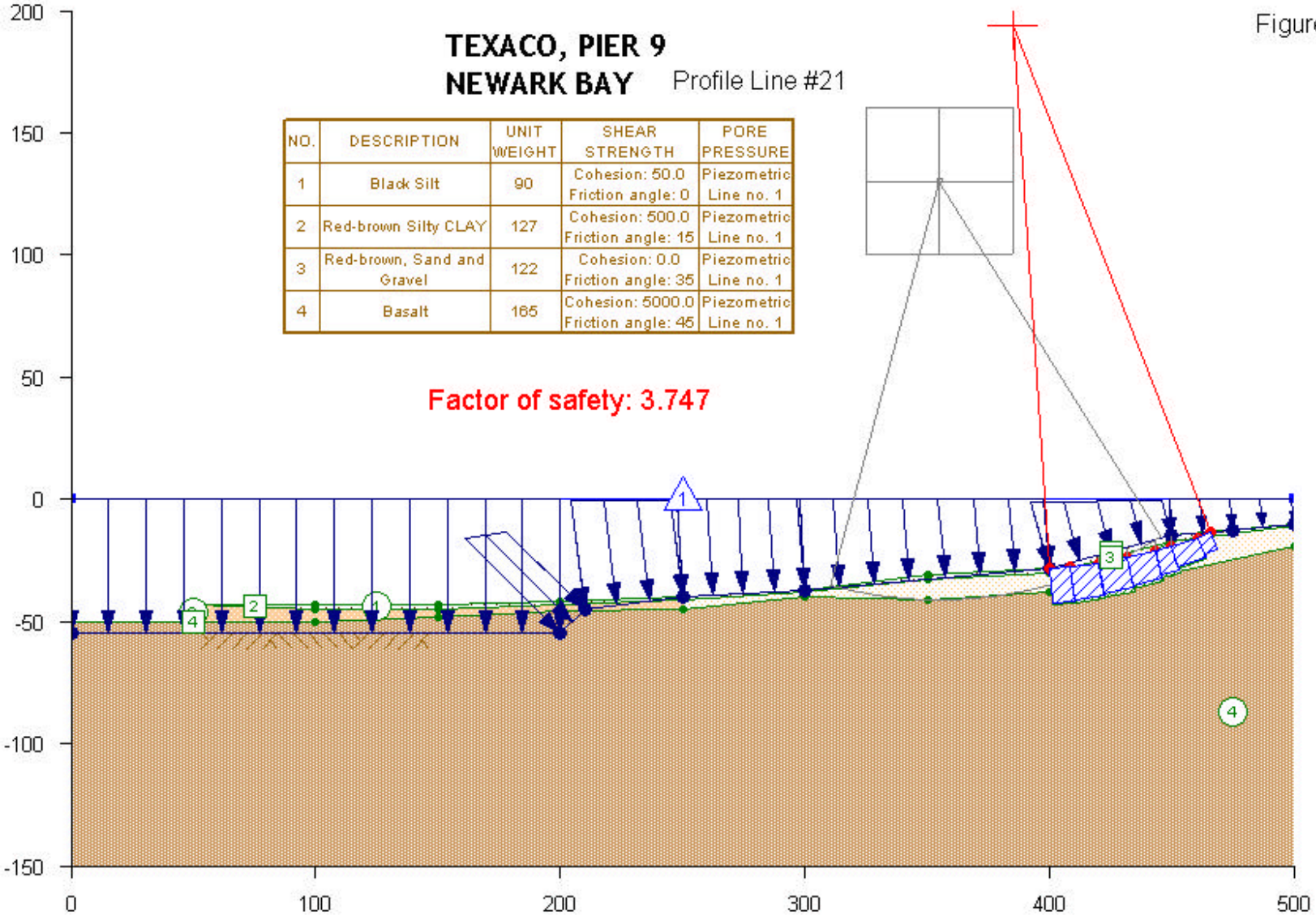


Figure 109

TEXACO, PIER 9
NEWARK BAY

Profile Line #21

NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
2	Red-brown Silty CLAY	127	Cohesion: 500.0 Friction angle: 15	Piezometric Line no. 1
3	Red-brown, Sand and Gravel	122	Cohesion: 0.0 Friction angle: 35	Piezometric Line no. 1
4	Basalt	165	Cohesion: 5000.0 Friction angle: 45	Piezometric Line no. 1

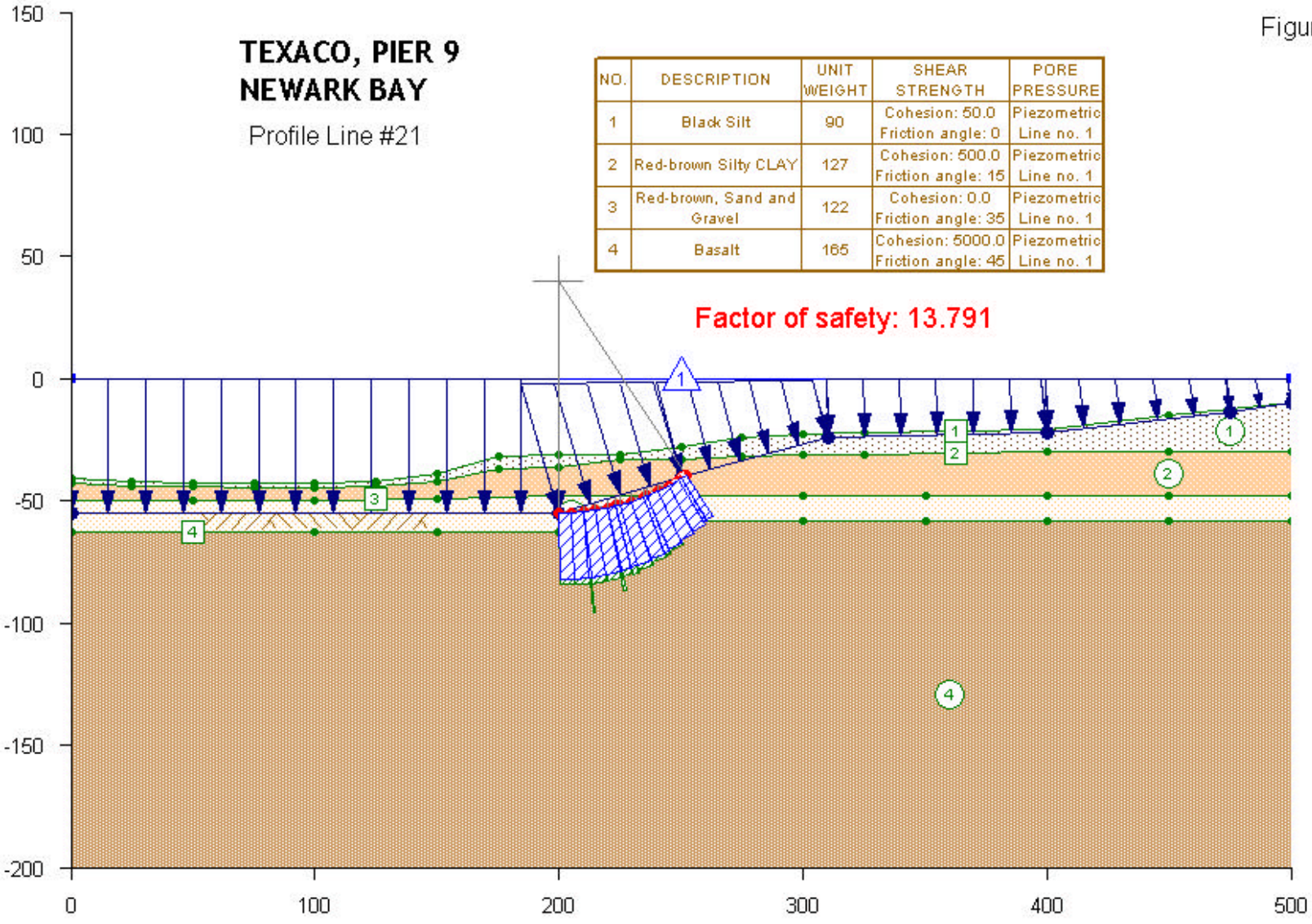
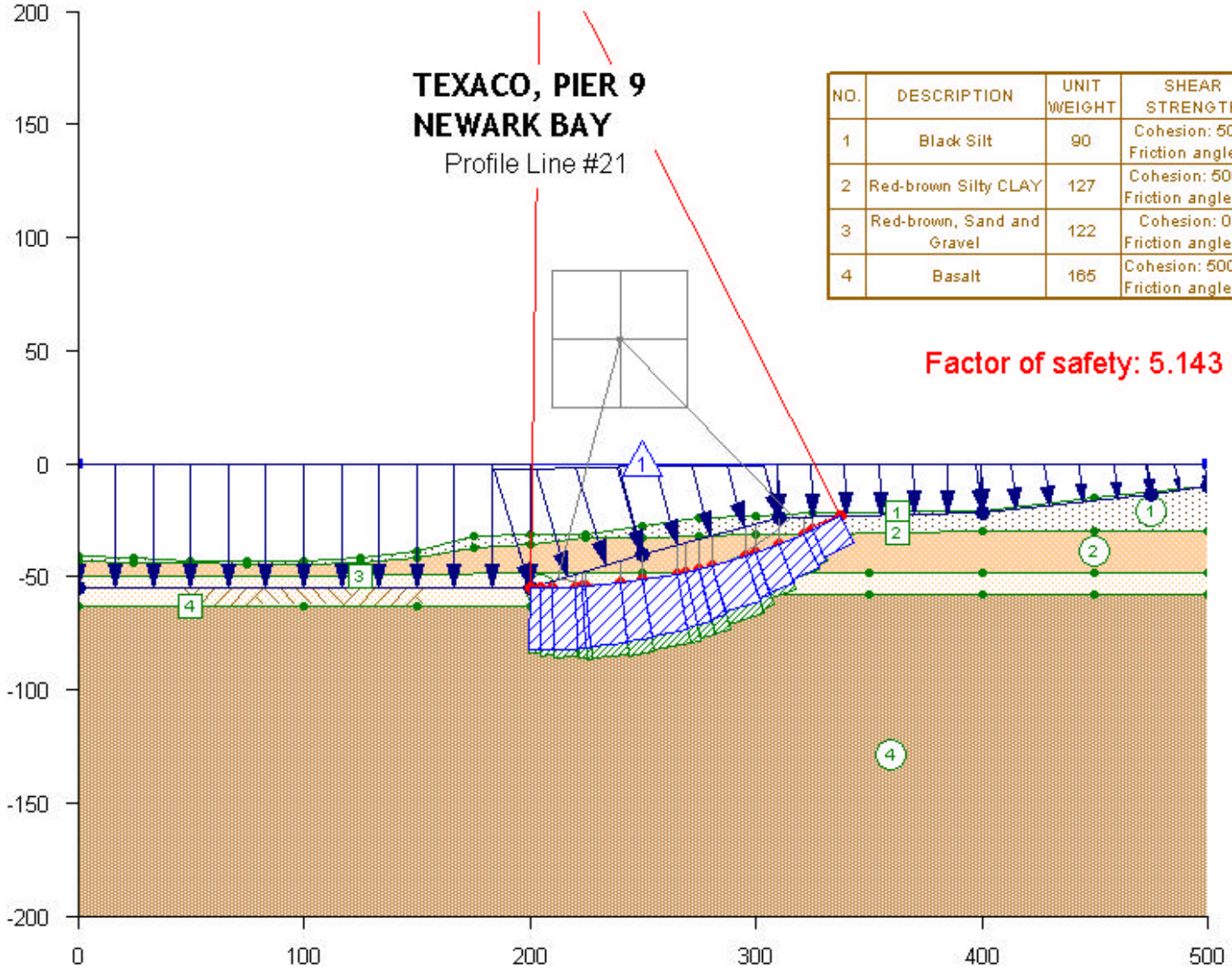
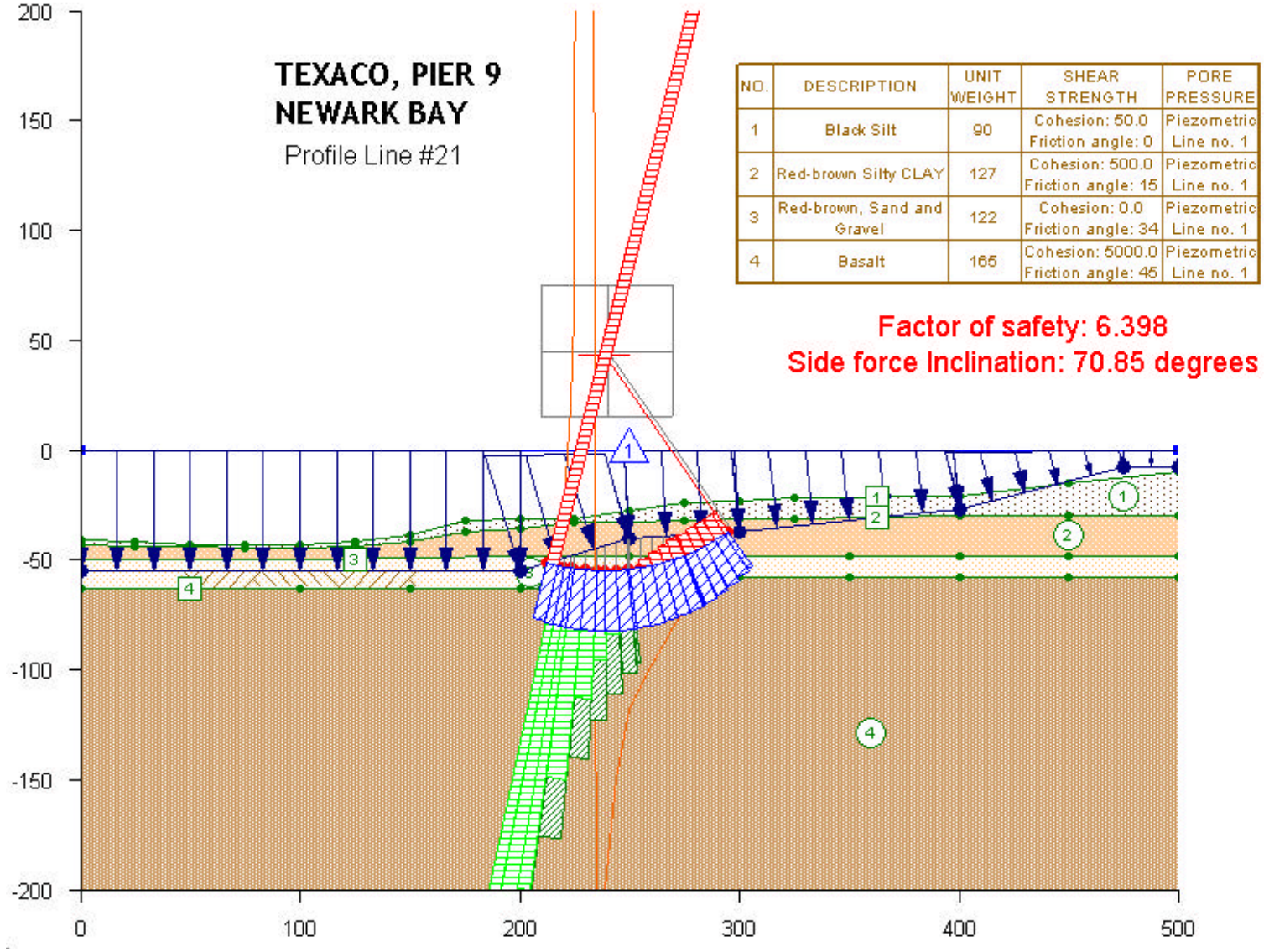


Figure 110



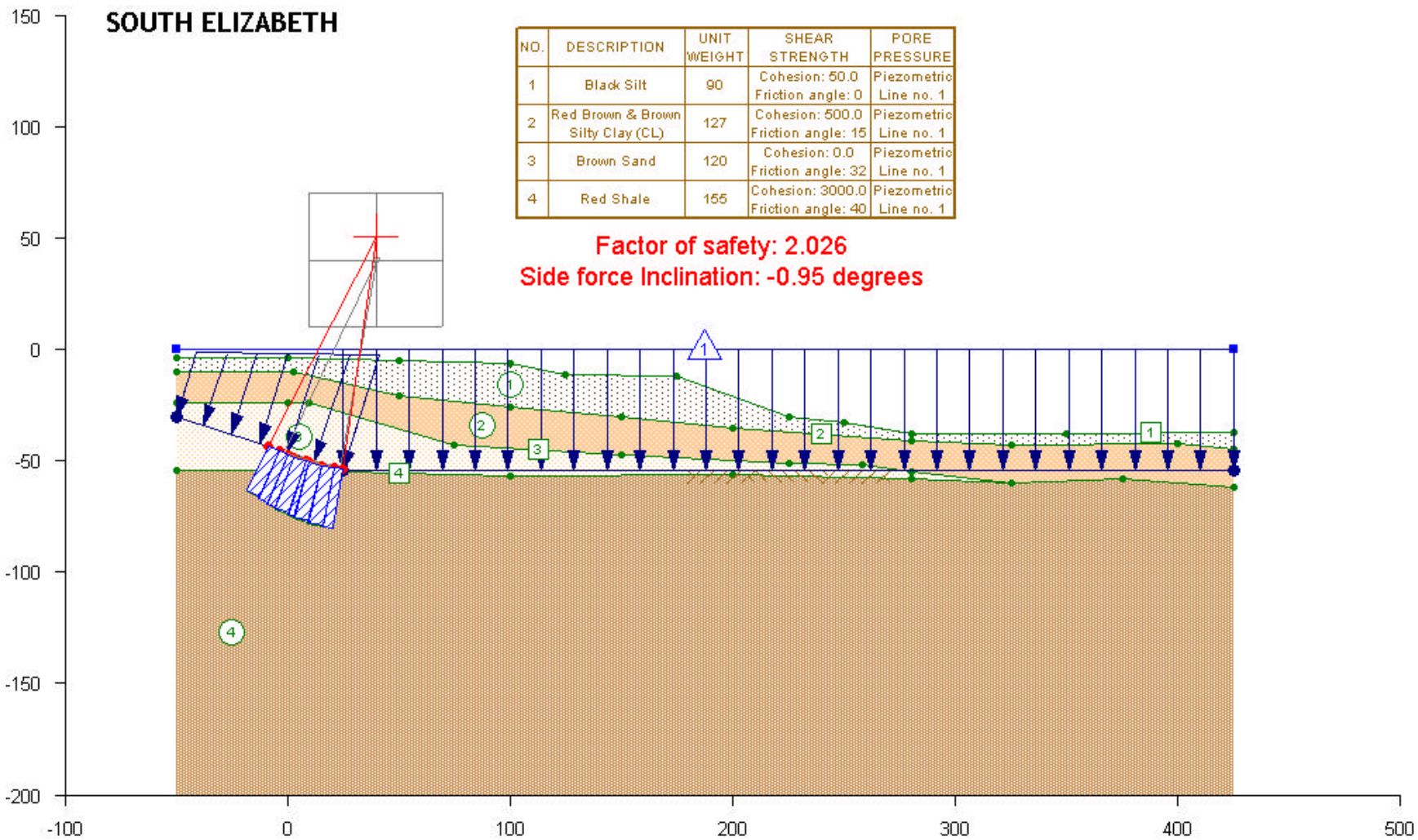
NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
2	Red-brown Silty CLAY	127	Cohesion: 500.0 Friction angle: 15	Piezometric Line no. 1
3	Red-brown, Sand and Gravel	122	Cohesion: 0.0 Friction angle: 35	Piezometric Line no. 1
4	Basalt	165	Cohesion: 5000.0 Friction angle: 45	Piezometric Line no. 1

Figure 111



NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
2	Red-brown Silty CLAY	127	Cohesion: 500.0 Friction angle: 15	Piezometric Line no. 1
3	Red-brown, Sand and Gravel	122	Cohesion: 0.0 Friction angle: 34	Piezometric Line no. 1
4	Basalt	165	Cohesion: 5000.0 Friction angle: 45	Piezometric Line no. 1

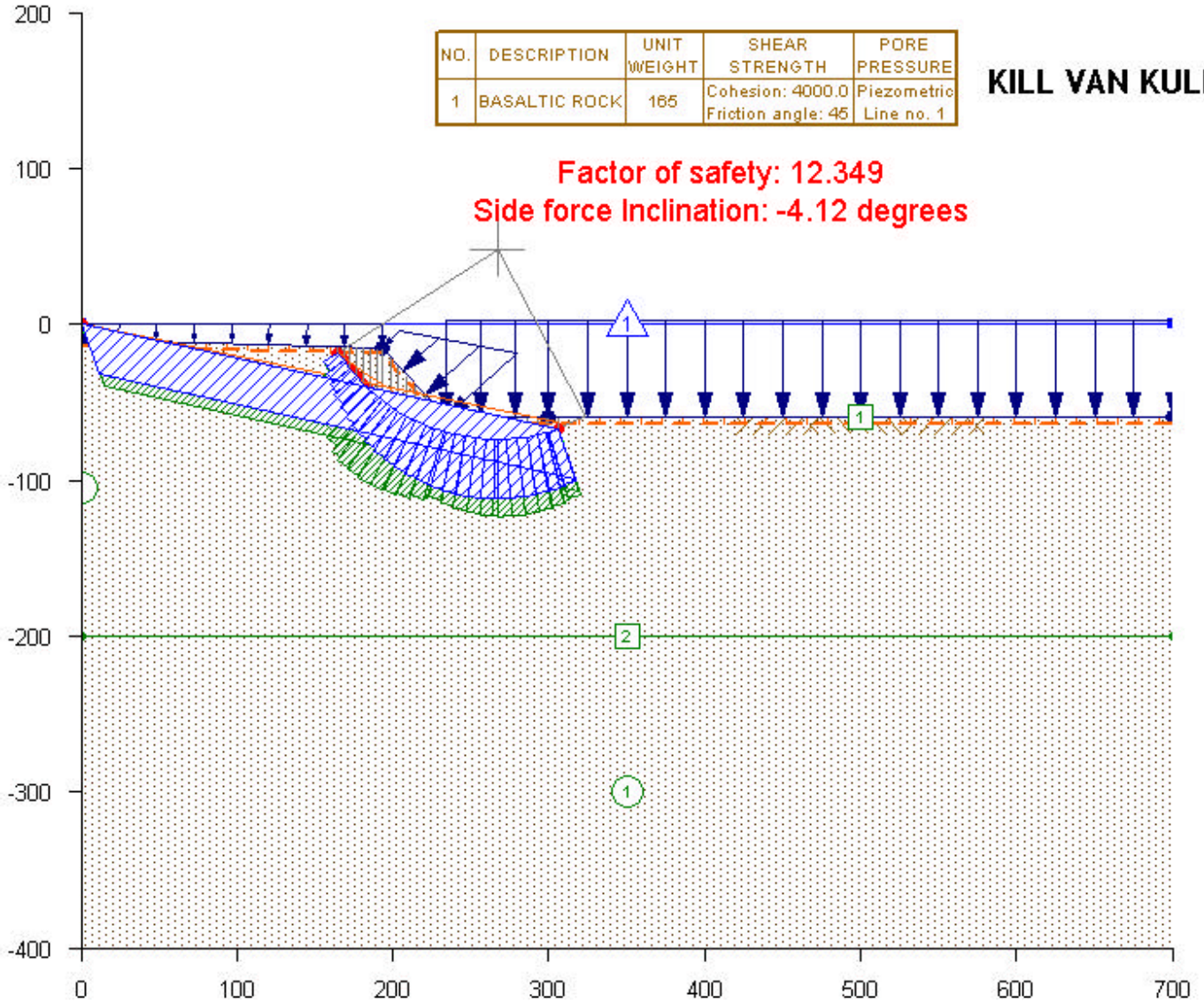
Figure 112



NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
2	Red Brown & Brown Silty Clay (CL)	127	Cohesion: 500.0 Friction angle: 15	Piezometric Line no. 1
3	Brown Sand	120	Cohesion: 0.0 Friction angle: 32	Piezometric Line no. 1
4	Red Shale	155	Cohesion: 3000.0 Friction angle: 40	Piezometric Line no. 1

Figure 113

KILL VAN KULL CHANNEL



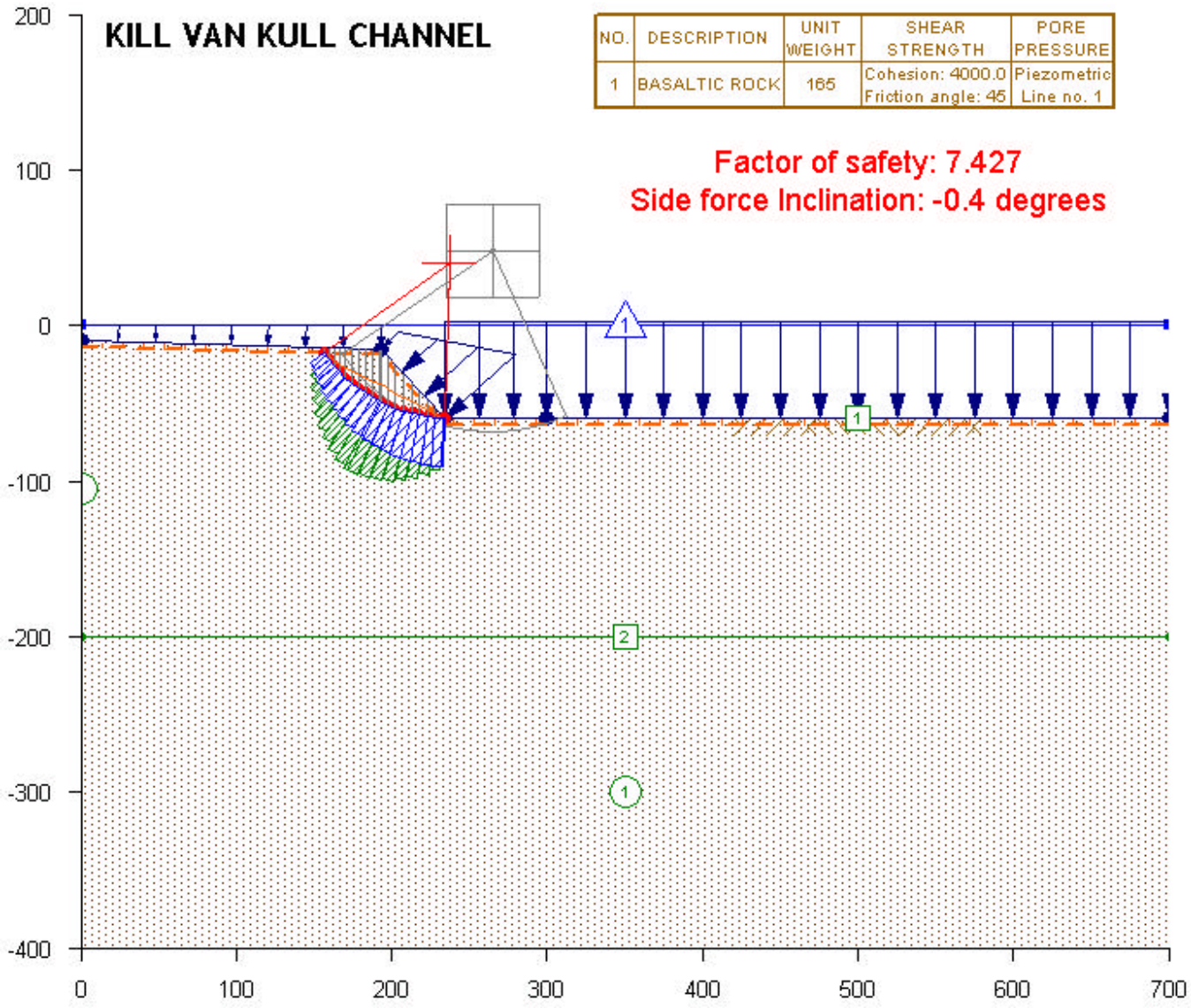

KILL VAN KULL CHANNEL
NO. | DESCRIPTION | UNIT WEIGHT | SHEAR STRENGTH | PORE PRESSURE
1 | BASALTIC ROCK | 165 | Cohesion: 4000.0 Friction angle: 45 | Piezometric Line no. 1
Factor of safety: 7.427
Side force Inclination: -0.4 degrees
200
100
0
-100
-200
-300
-400
0
100
200
300
400
500
600
700
1
1
2
1

Figure 114

Figure 115

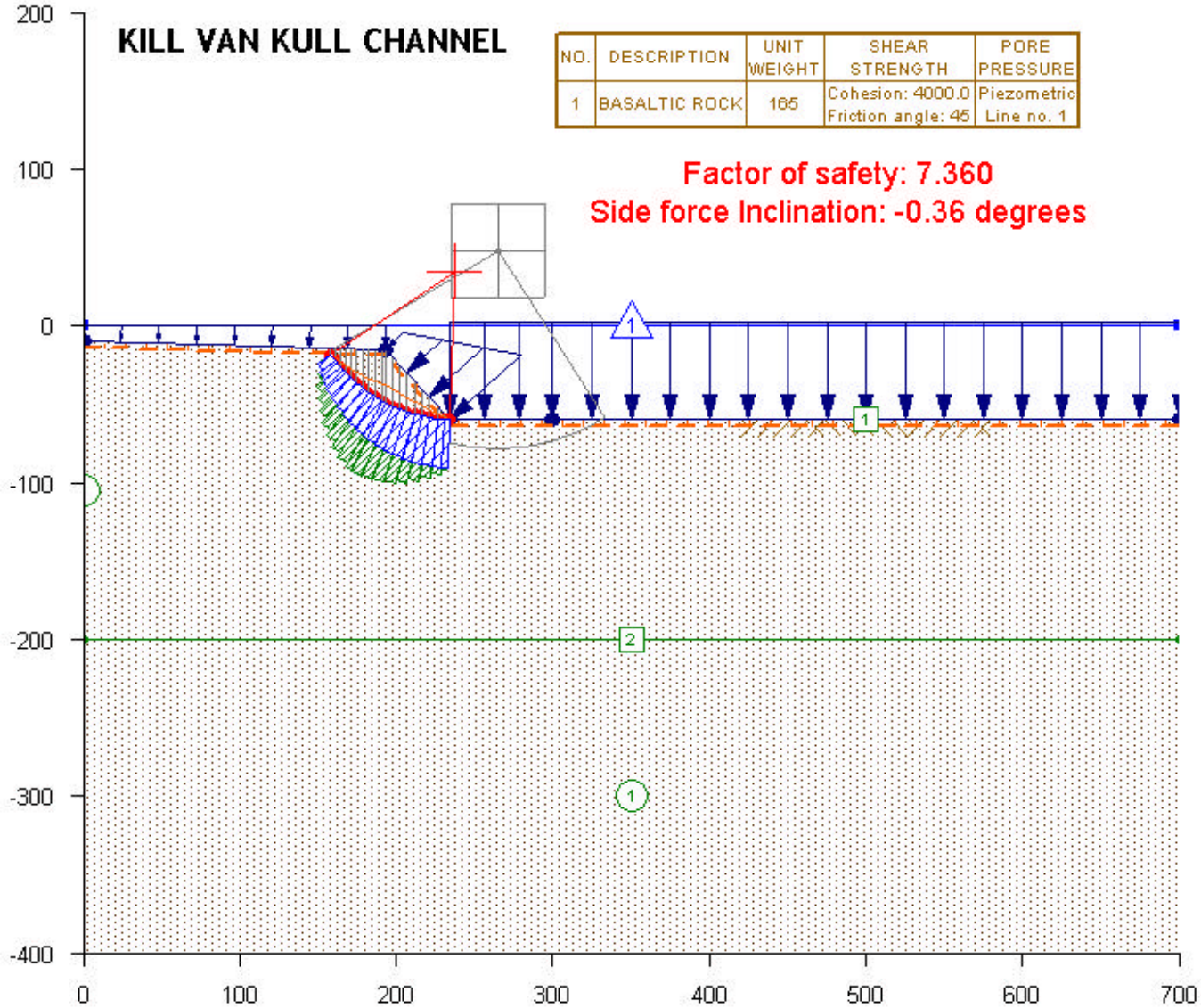

KILL VAN KULL CHANNEL
NO. | DESCRIPTION | UNIT WEIGHT | SHEAR STRENGTH | PORE PRESSURE
1 | BASALTIC ROCK | 165 | Cohesion: 4000.0 Friction angle: 45 | Piezometric Line no. 1
Factor of safety: 7.360
Side force Inclination: -0.36 degrees
200
100
0
-100
-200
-300
-400
0
100
200
300
400
500
600
700
1
1
2
1

Figure 116

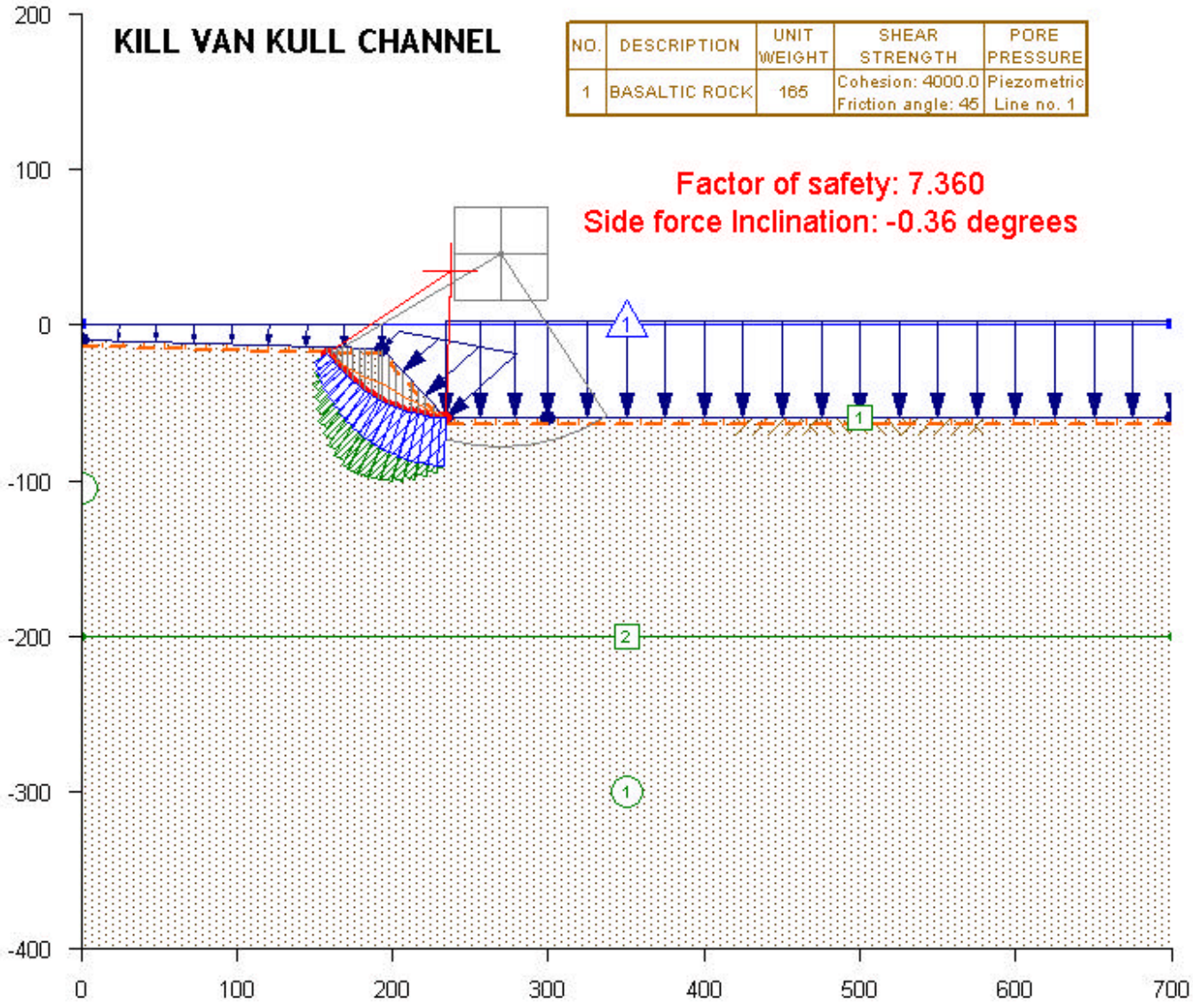

KILL VAN KULL CHANNEL
NO. | DESCRIPTION | UNIT WEIGHT | SHEAR STRENGTH | PORE PRESSURE
1 | BASALTIC ROCK | 165 | Cohesion: 4000.0 Friction angle: 45 | Piezometric Line no. 1
Factor of safety: 7.360
Side force Inclination: -0.36 degrees
200
100
0
-100
-200
-300
-400
0
100
200
300
400
500
600
700
1
1
2
1

Figure 117

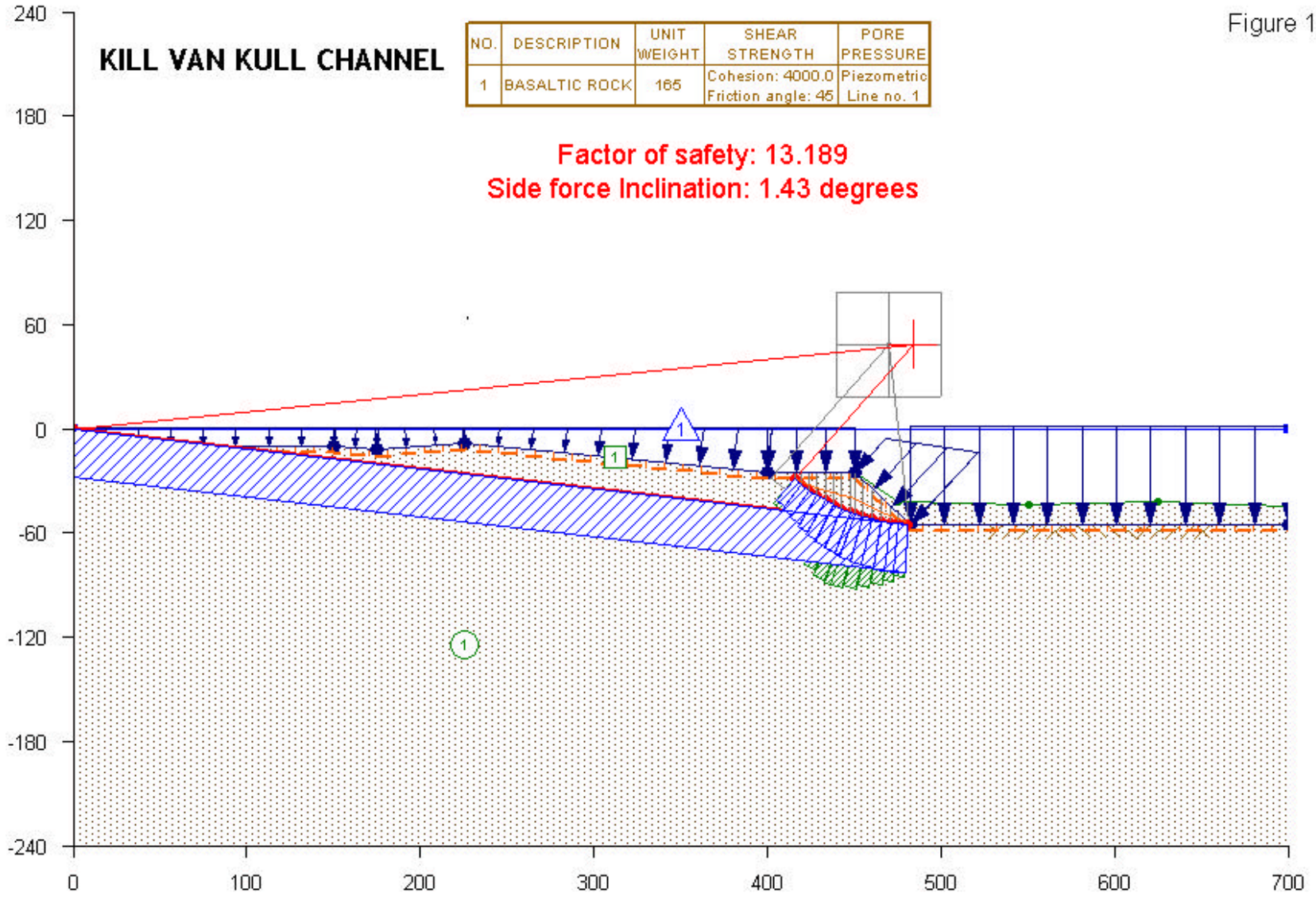
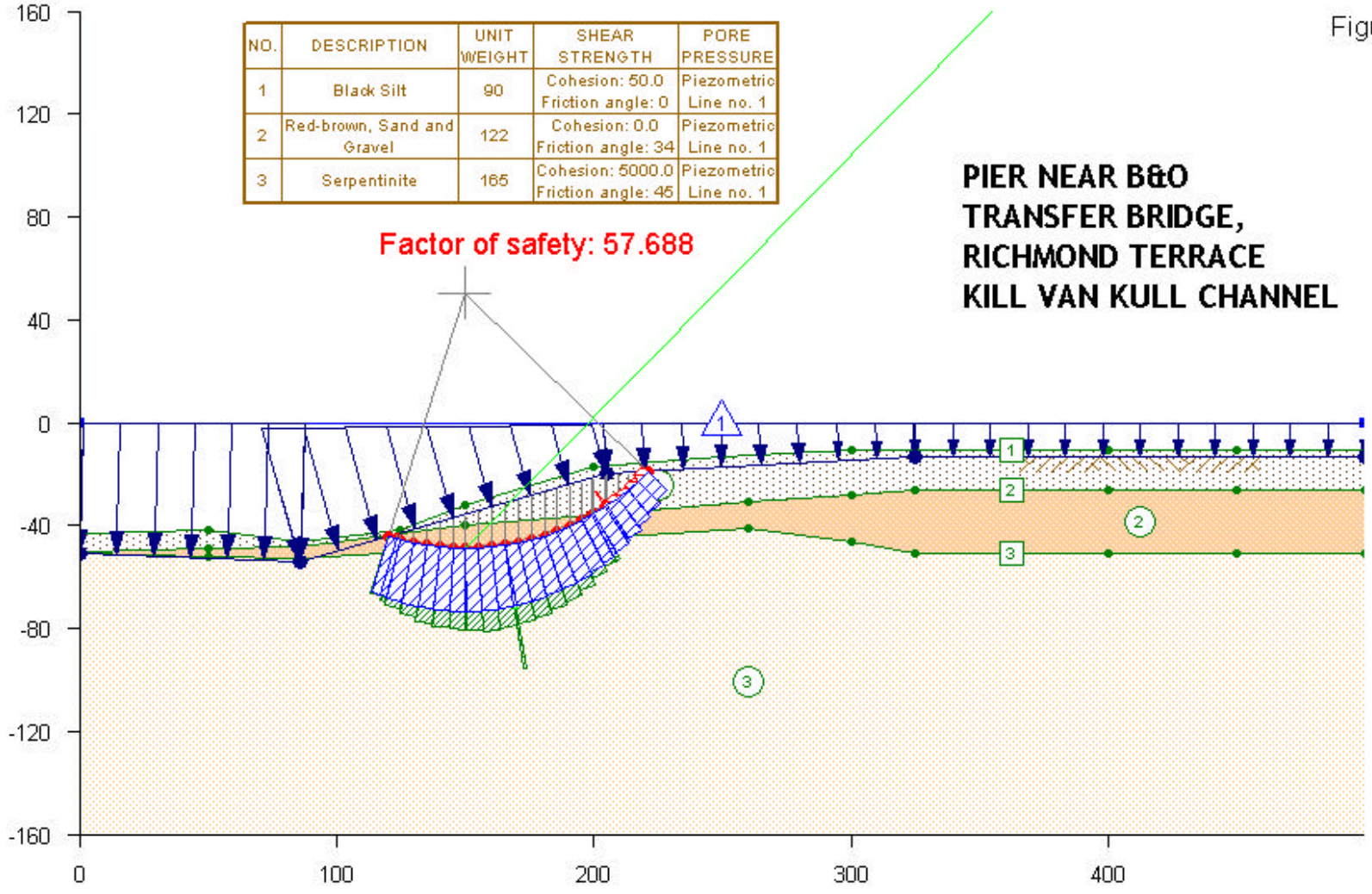
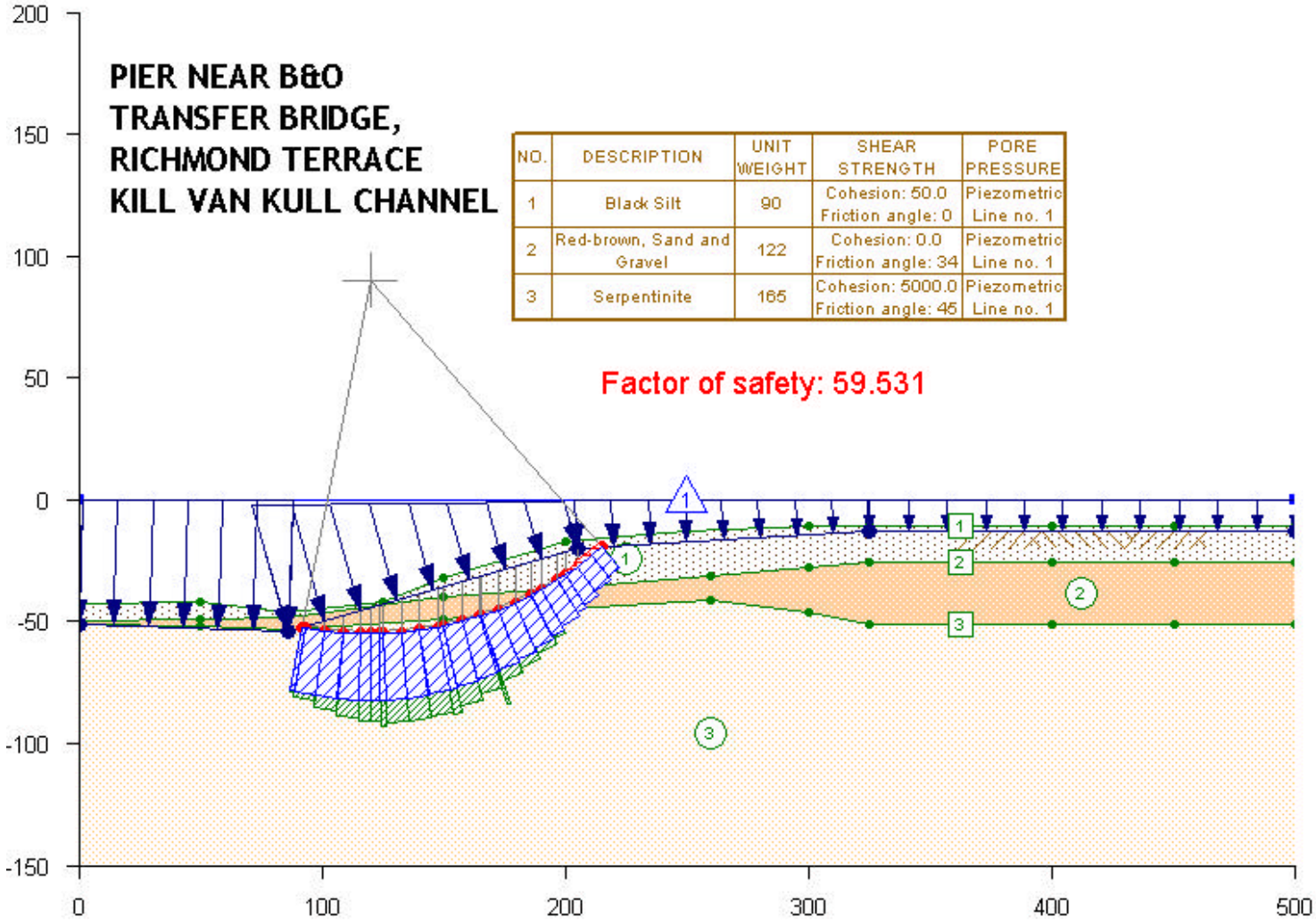

KILL VAN KULL CHANNEL
NO. | DESCRIPTION | UNIT WEIGHT | SHEAR STRENGTH | PORE PRESSURE
1 | BASALTIC ROCK | 165 | Cohesion: 4000.0 Friction angle: 45 | Piezometric Line no. 1
Factor of safety: 13.189
Side force Inclination: 1.43 degrees
240
180
120
60
0
-60
-120
-180
-240
0
100
200
300
400
500
600
700
1
1
1

Figure 118



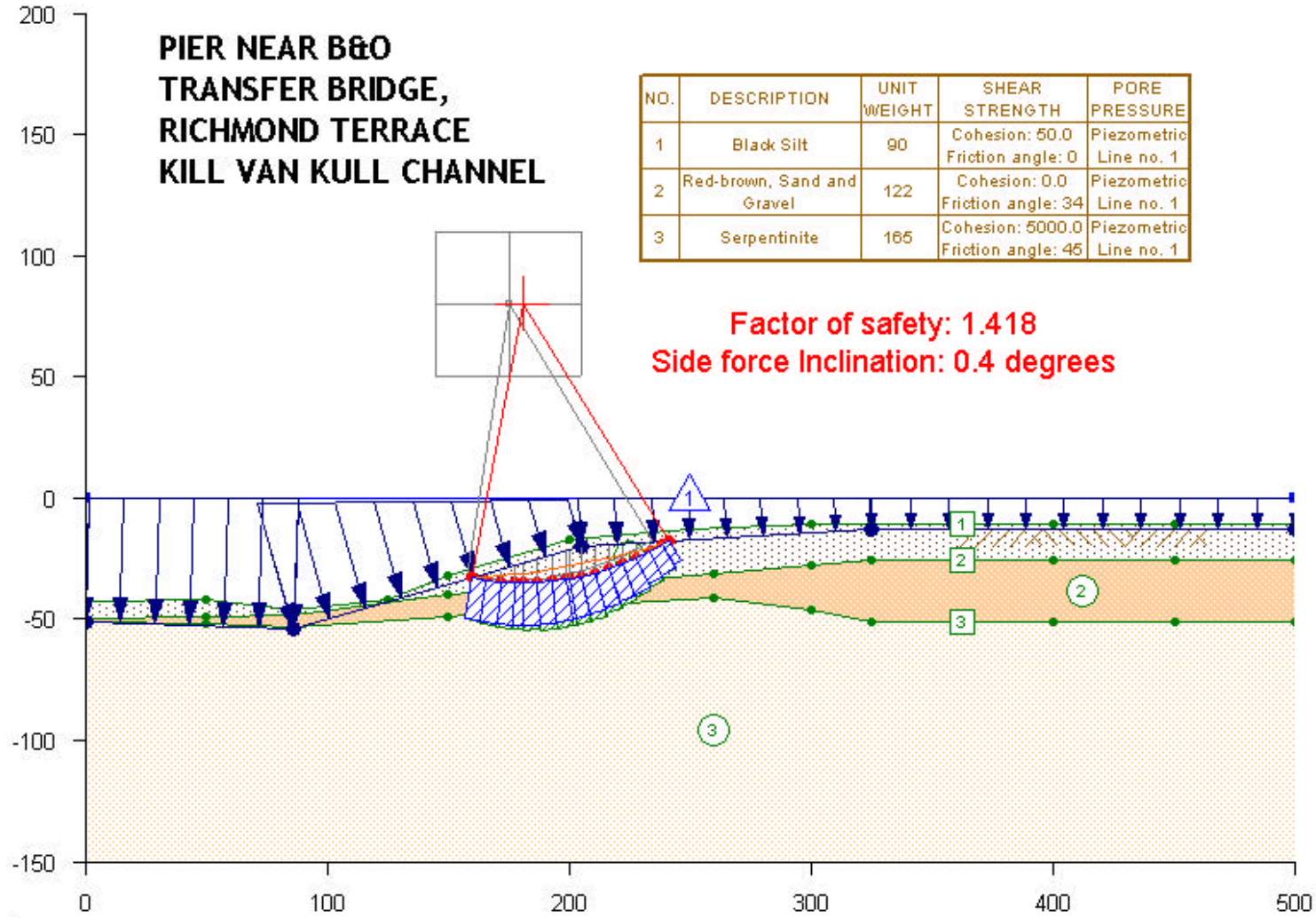
NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
2	Red-brown, Sand and Gravel	122	Cohesion: 0.0 Friction angle: 34	Piezometric Line no. 1
3	Serpentinite	165	Cohesion: 5000.0 Friction angle: 45	Piezometric Line no. 1

Figure 119



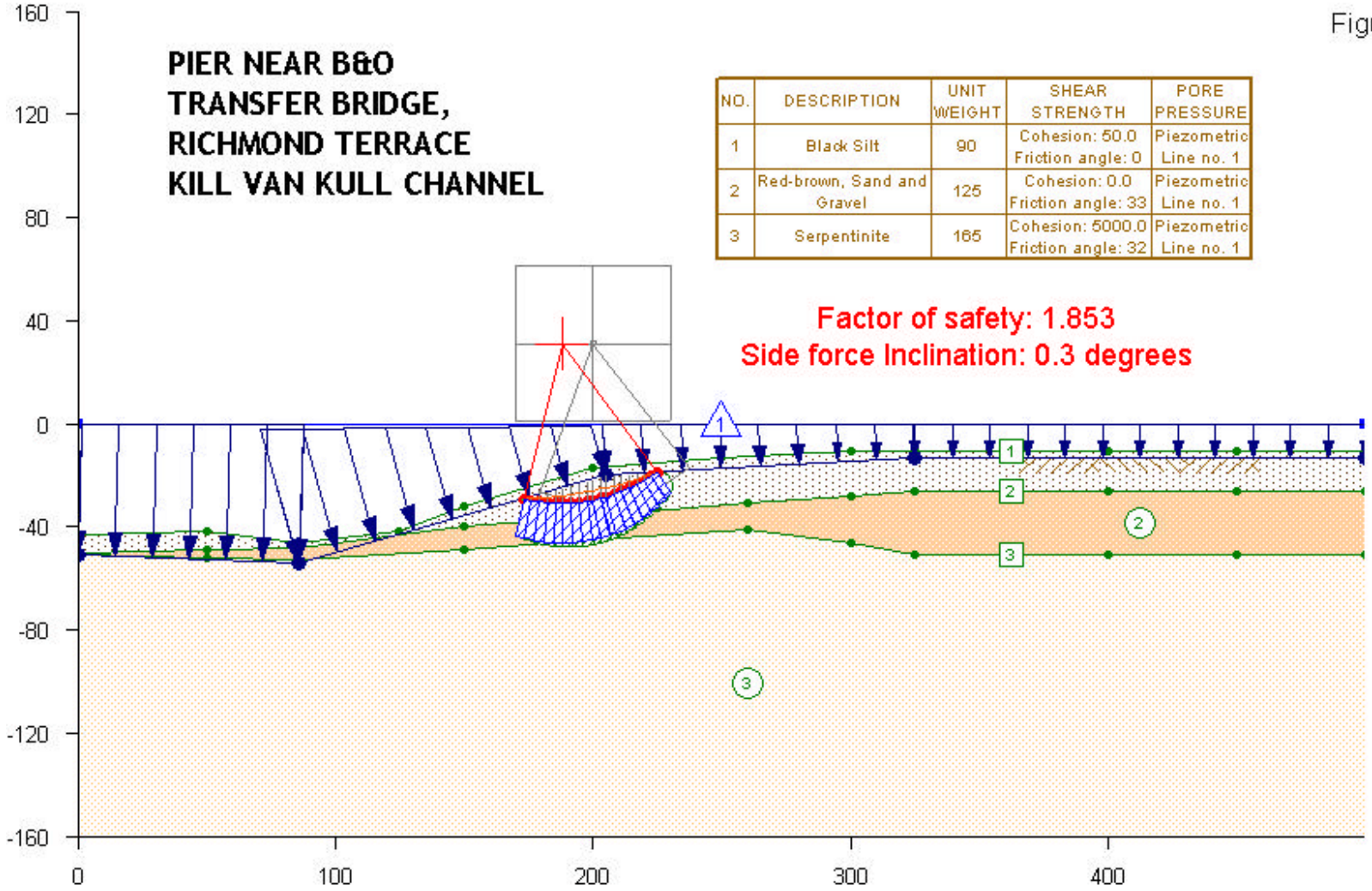
NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
2	Red-brown, Sand and Gravel	122	Cohesion: 0.0 Friction angle: 34	Piezometric Line no. 1
3	Serpentinite	165	Cohesion: 5000.0 Friction angle: 45	Piezometric Line no. 1

Figure 120



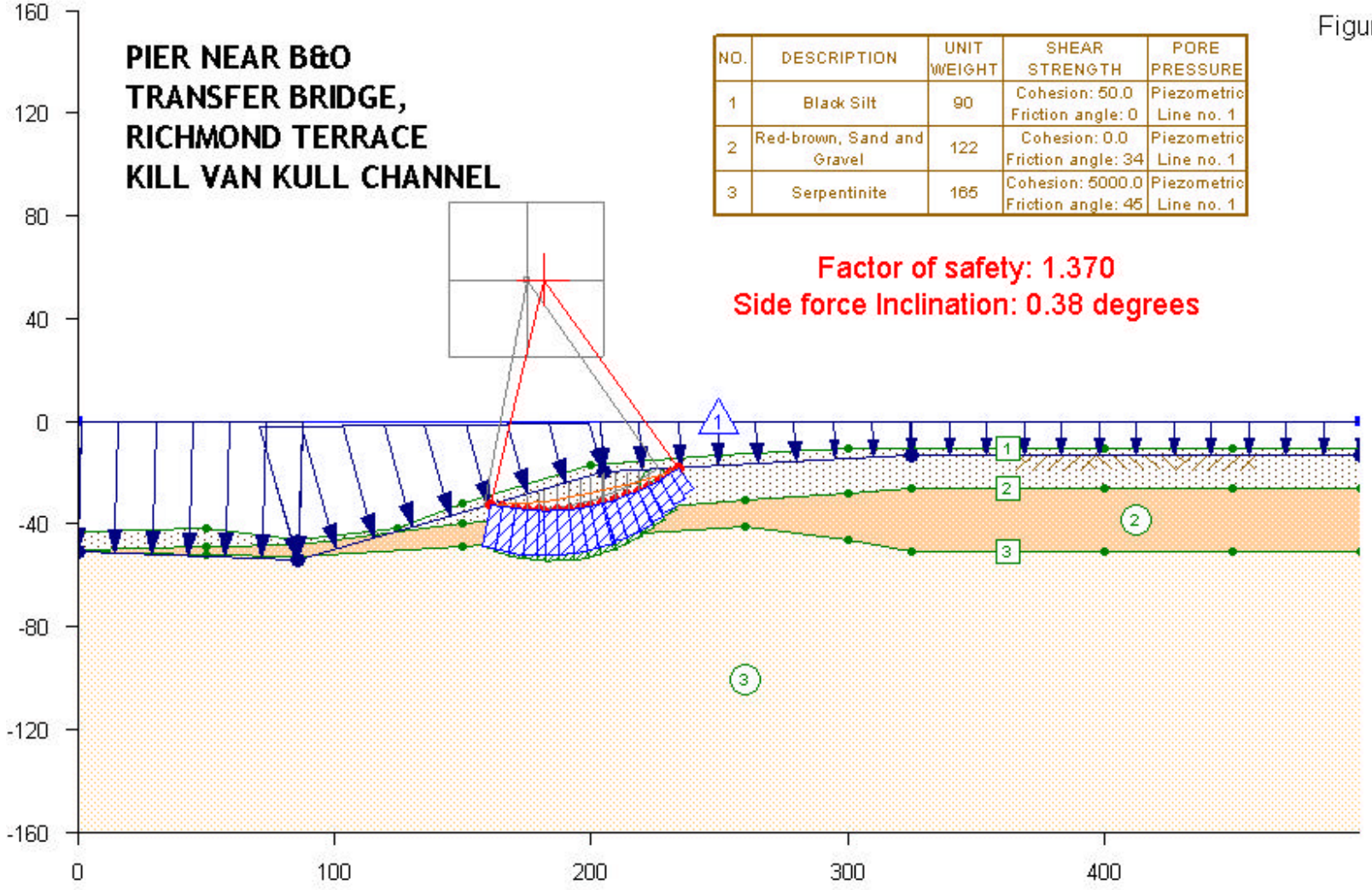
NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
2	Red-brown, Sand and Gravel	122	Cohesion: 0.0 Friction angle: 34	Piezometric Line no. 1
3	Serpentinite	165	Cohesion: 5000.0 Friction angle: 45	Piezometric Line no. 1

Figure 121



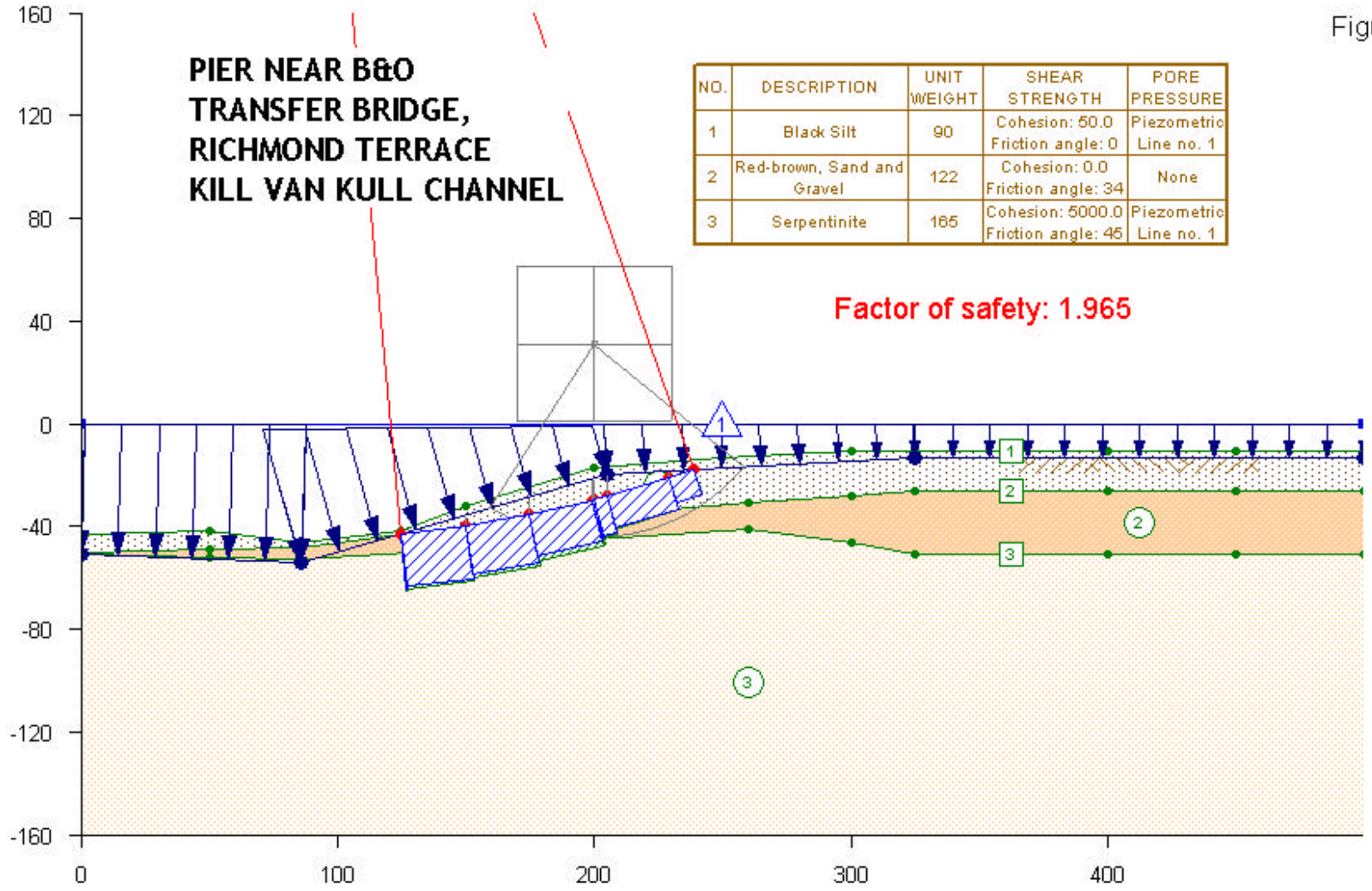
NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
2	Red-brown, Sand and Gravel	125	Cohesion: 0.0 Friction angle: 33	Piezometric Line no. 1
3	Serpentinite	165	Cohesion: 5000.0 Friction angle: 32	Piezometric Line no. 1

Figure 122



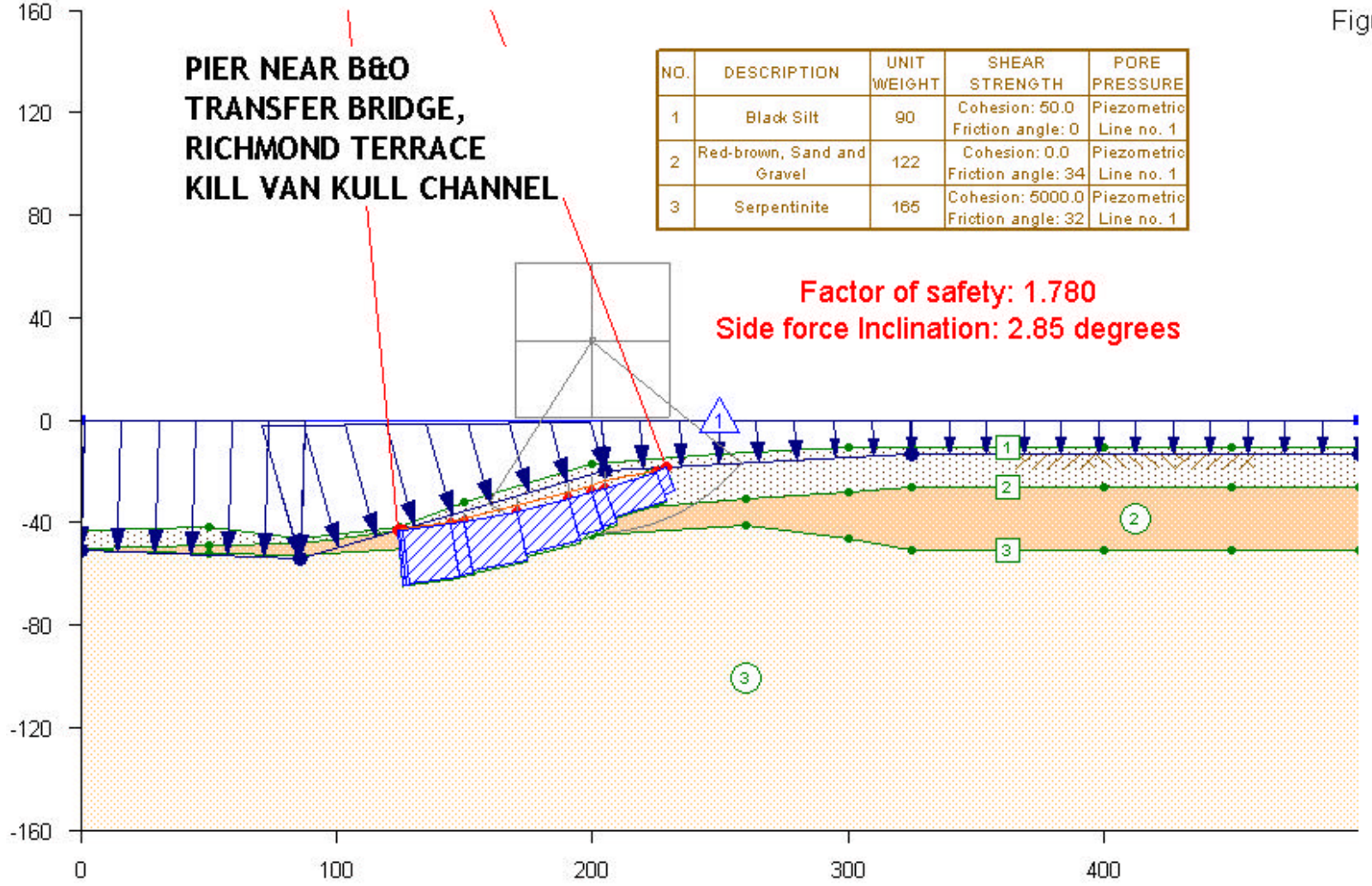
NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
2	Red-brown, Sand and Gravel	122	Cohesion: 0.0 Friction angle: 34	Piezometric Line no. 1
3	Serpentinite	165	Cohesion: 5000.0 Friction angle: 45	Piezometric Line no. 1

Figure 123



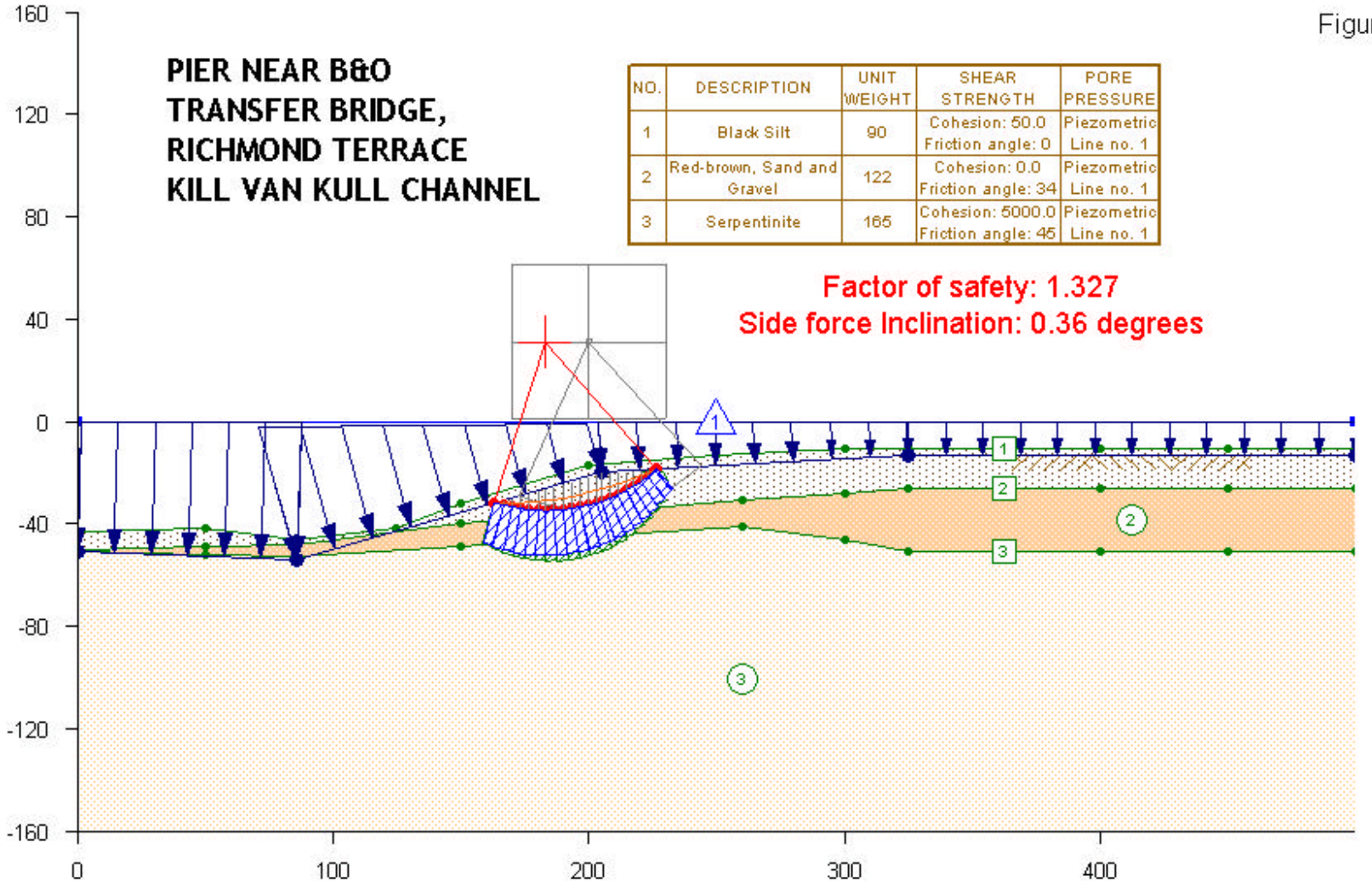
NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
2	Red-brown, Sand and Gravel	122	Cohesion: 0.0 Friction angle: 34	None
3	Serpentinite	165	Cohesion: 5000.0 Friction angle: 45	Piezometric Line no. 1

Figure 124



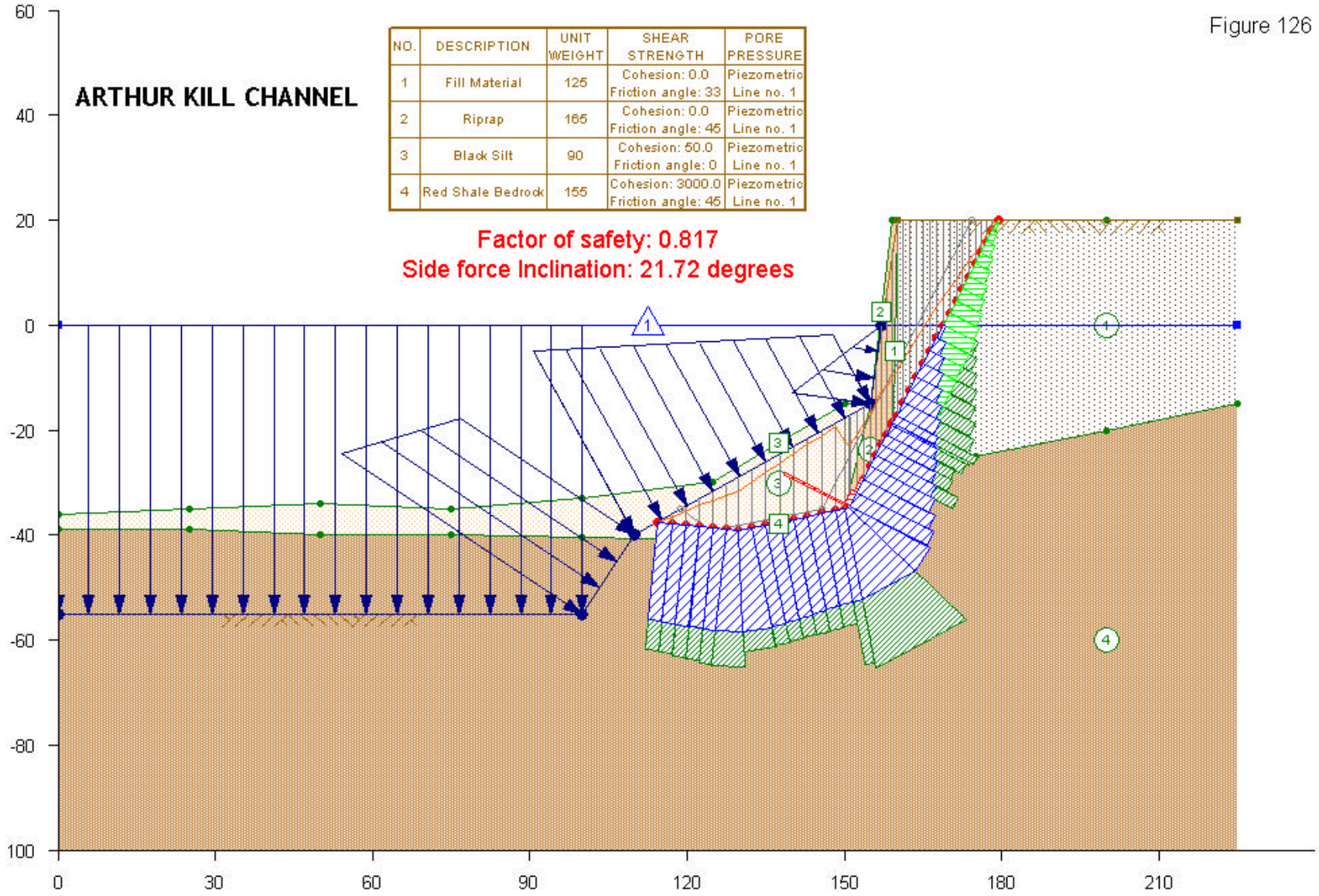
NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
2	Red-brown, Sand and Gravel	122	Cohesion: 0.0 Friction angle: 34	Piezometric Line no. 1
3	Serpentinite	165	Cohesion: 5000.0 Friction angle: 32	Piezometric Line no. 1

Figure 125



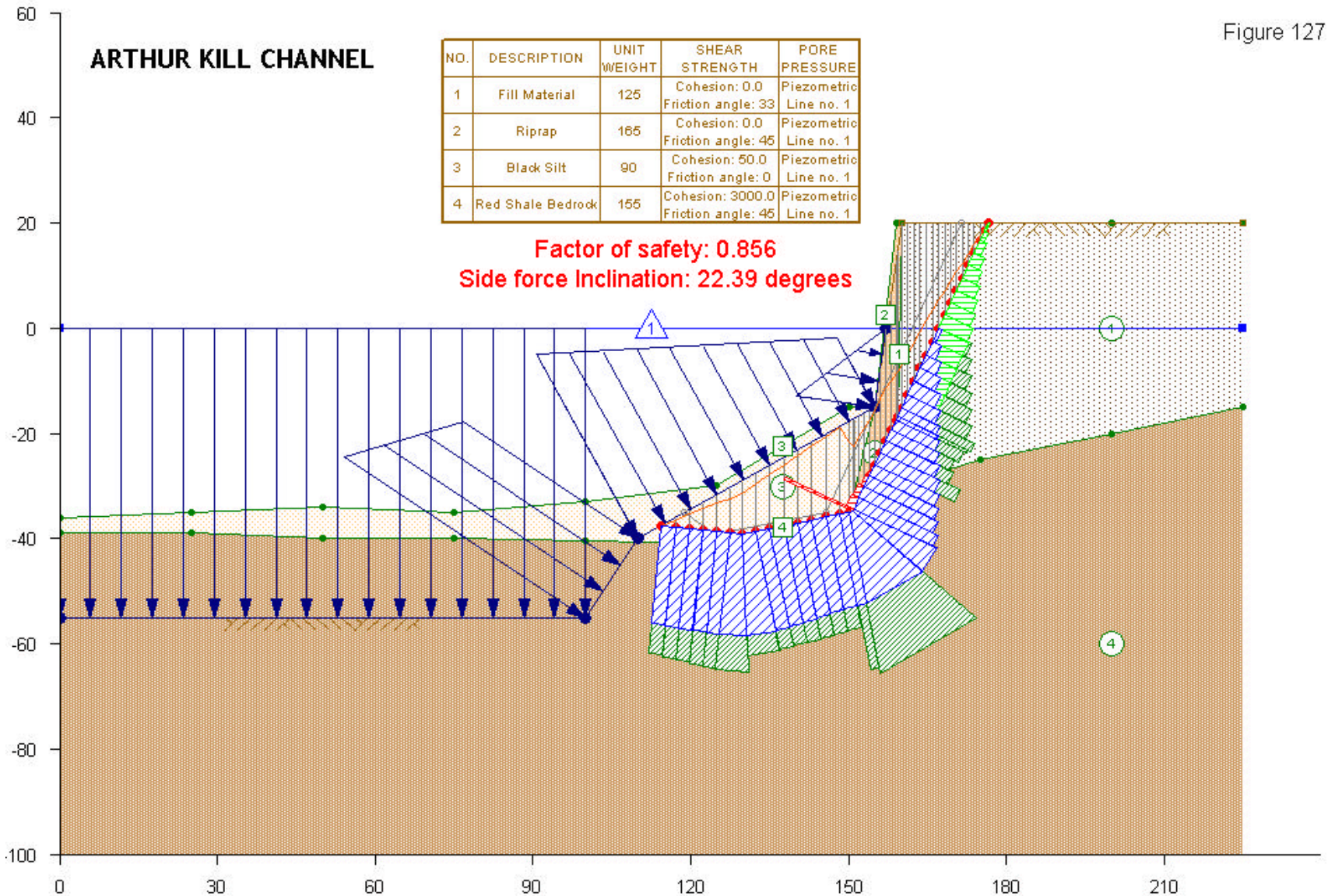
NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
2	Red-brown, Sand and Gravel	122	Cohesion: 0.0 Friction angle: 34	Piezometric Line no. 1
3	Serpentinite	165	Cohesion: 5000.0 Friction angle: 45	Piezometric Line no. 1

Figure 126



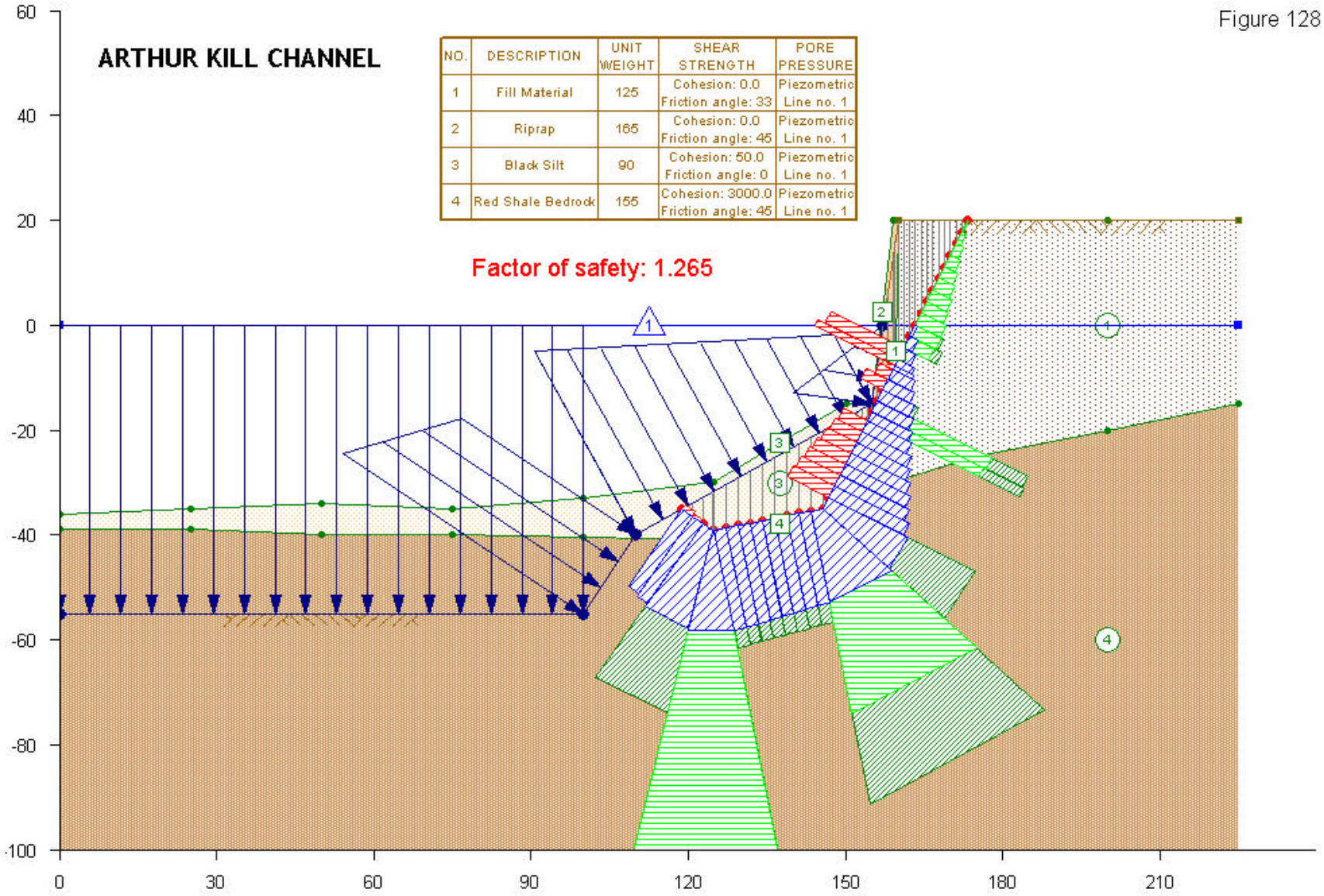
NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Fill Material	125	Cohesion: 0.0 Friction angle: 33	Piezometric Line no. 1
2	Riprap	165	Cohesion: 0.0 Friction angle: 45	Piezometric Line no. 1
3	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
4	Red Shale Bedrock	155	Cohesion: 3000.0 Friction angle: 45	Piezometric Line no. 1

Figure 127



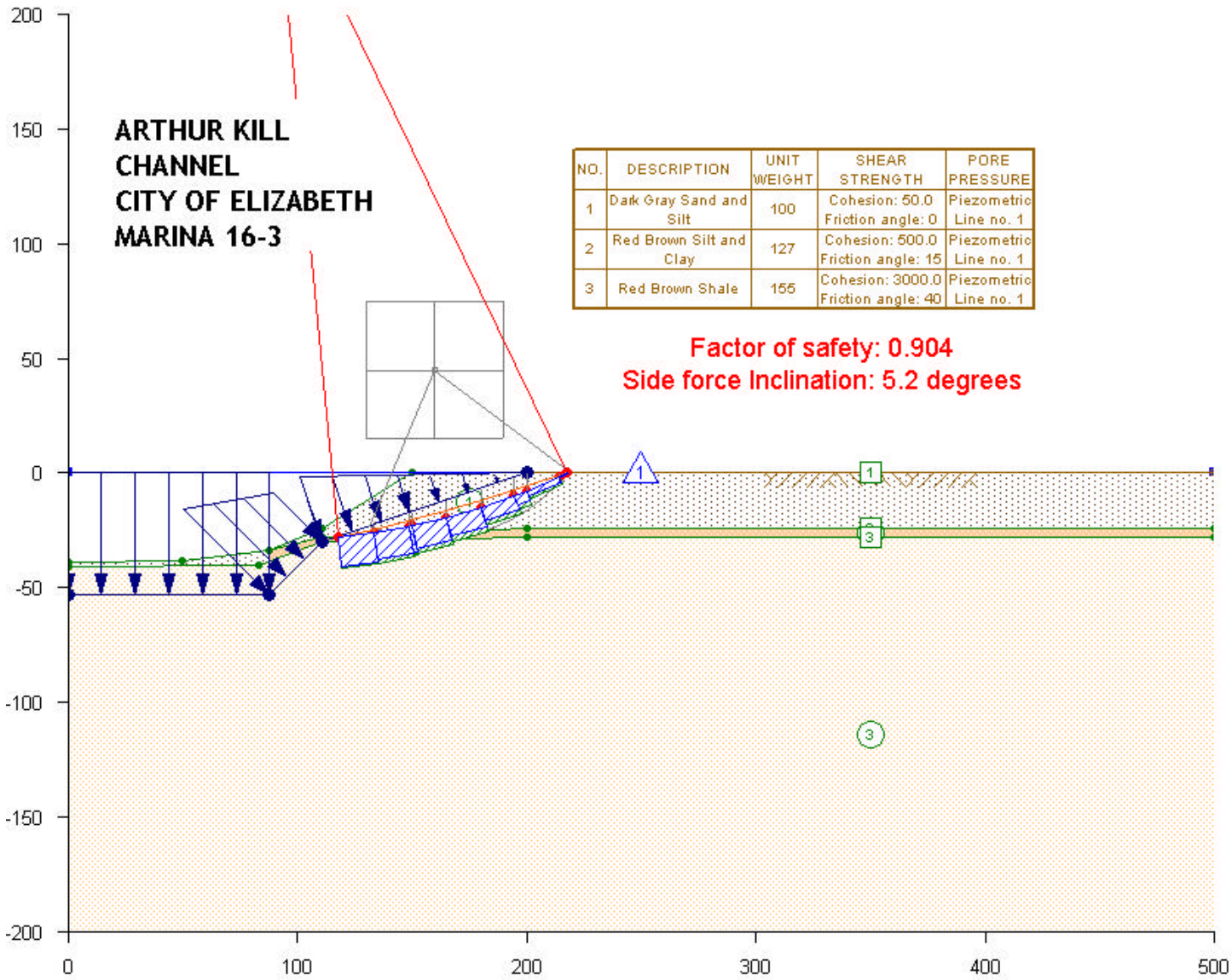
NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Fill Material	125	Cohesion: 0.0 Friction angle: 33	Piezometric Line no. 1
2	Riprap	165	Cohesion: 0.0 Friction angle: 45	Piezometric Line no. 1
3	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
4	Red Shale Bedrock	155	Cohesion: 3000.0 Friction angle: 45	Piezometric Line no. 1

Figure 128



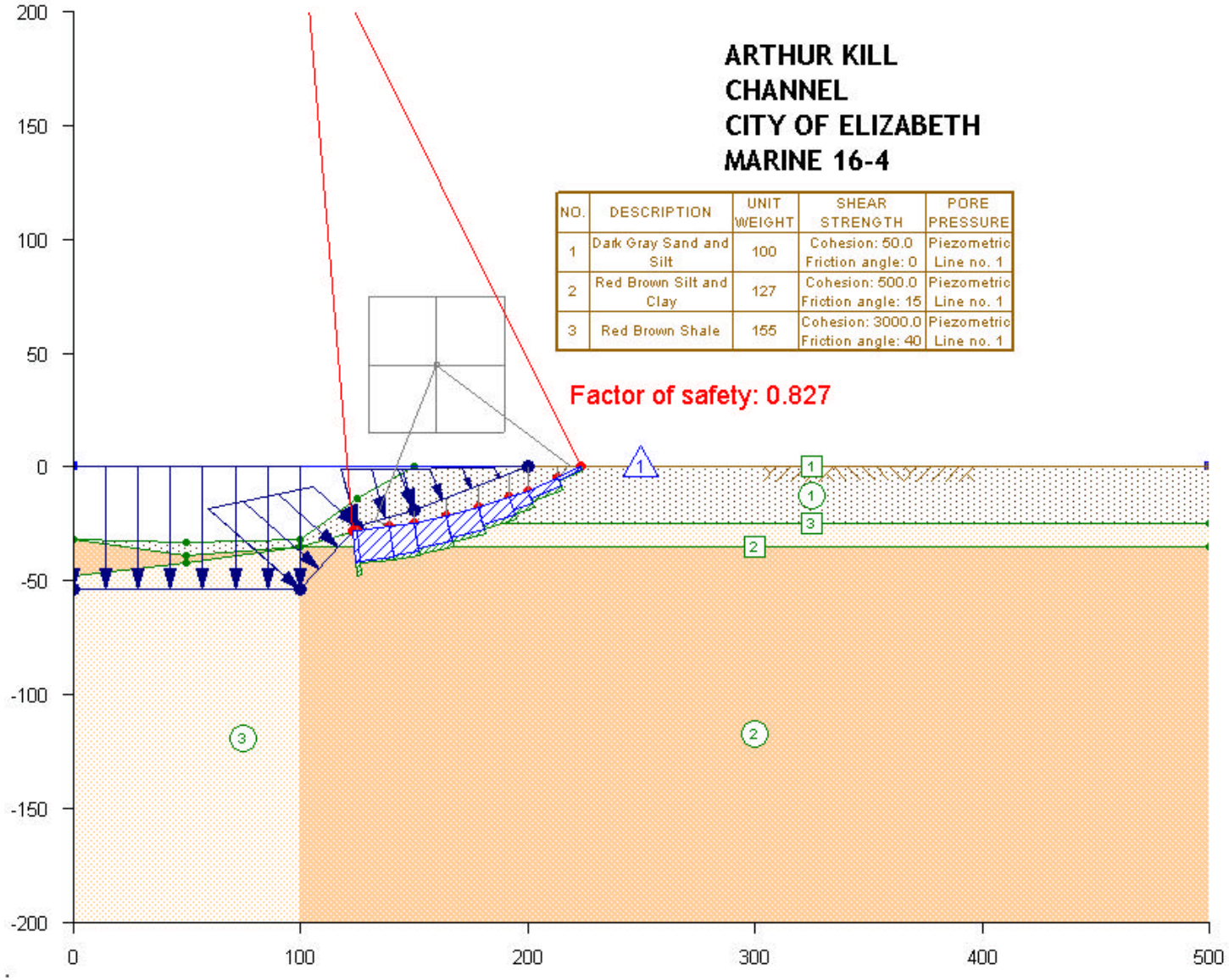
NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Fill Material	125	Cohesion: 0.0 Friction angle: 33	Piezometric Line no. 1
2	Riprap	165	Cohesion: 0.0 Friction angle: 45	Piezometric Line no. 1
3	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
4	Red Shale Bedrock	155	Cohesion: 3000.0 Friction angle: 45	Piezometric Line no. 1

Figure 129



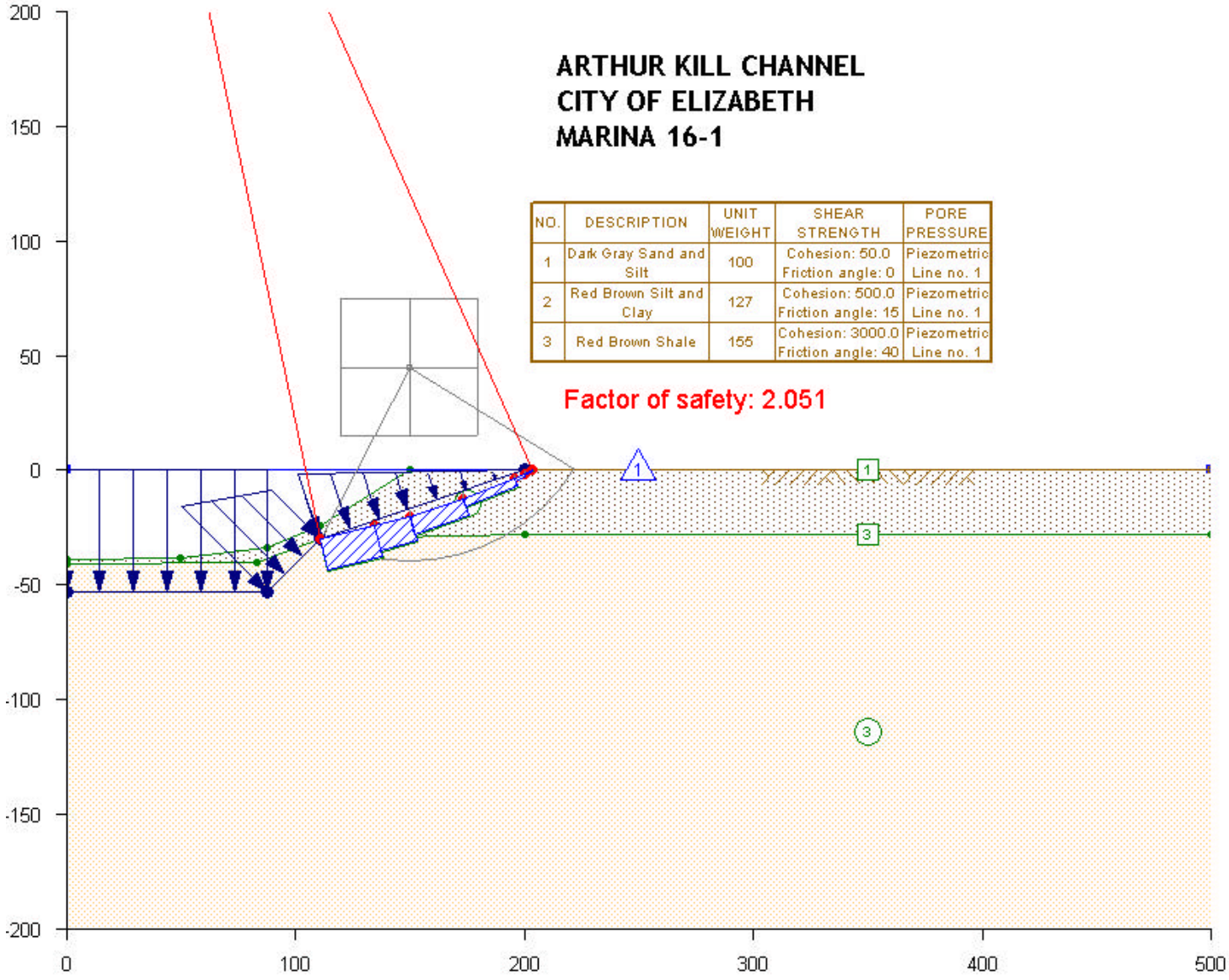
NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Dark Gray Sand and Silt	100	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
2	Red Brown Silt and Clay	127	Cohesion: 500.0 Friction angle: 15	Piezometric Line no. 1
3	Red Brown Shale	155	Cohesion: 3000.0 Friction angle: 40	Piezometric Line no. 1

Figure 130



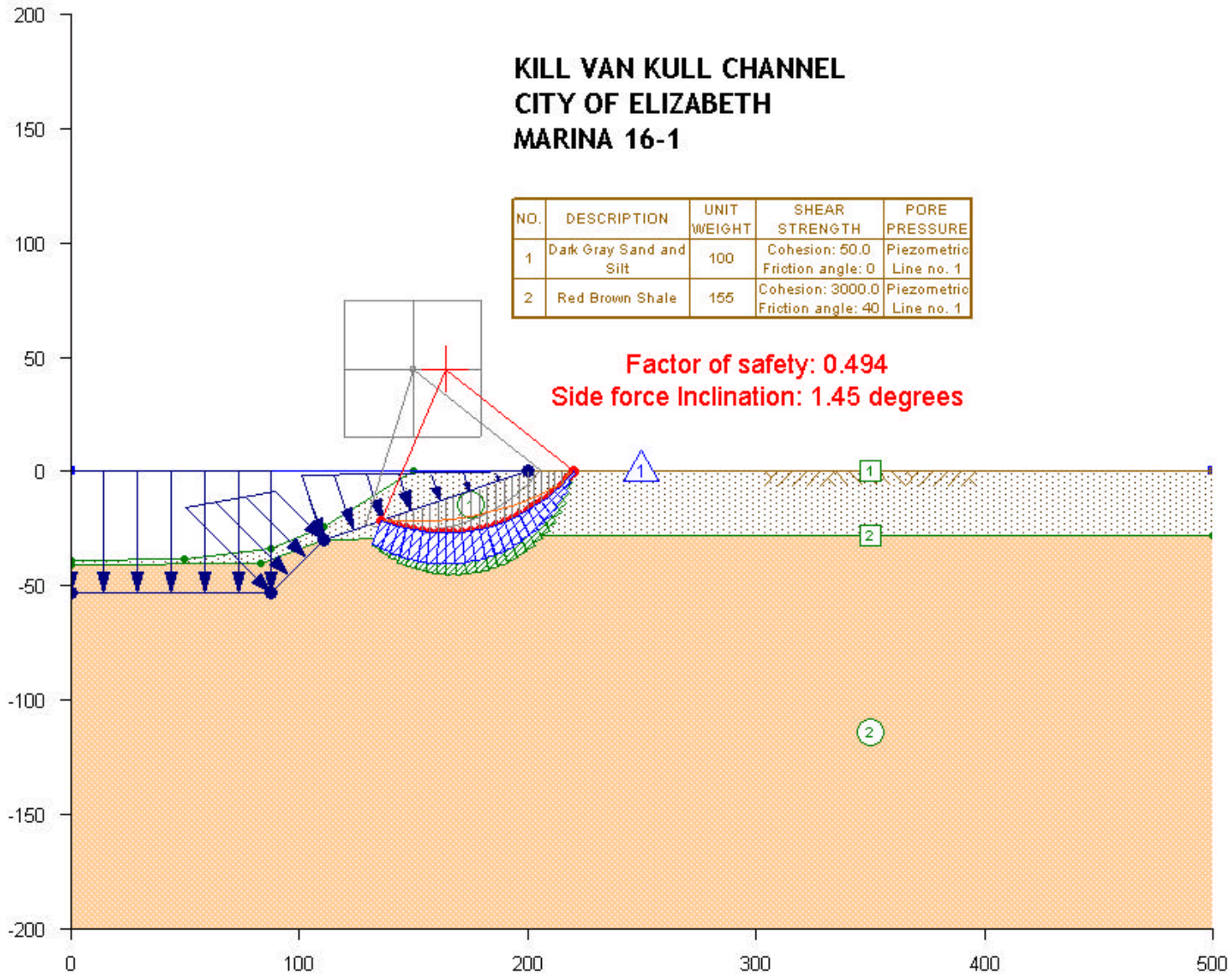
NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Dark Gray Sand and Silt	100	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
2	Red Brown Silt and Clay	127	Cohesion: 500.0 Friction angle: 15	Piezometric Line no. 1
3	Red Brown Shale	155	Cohesion: 3000.0 Friction angle: 40	Piezometric Line no. 1

Figure 131



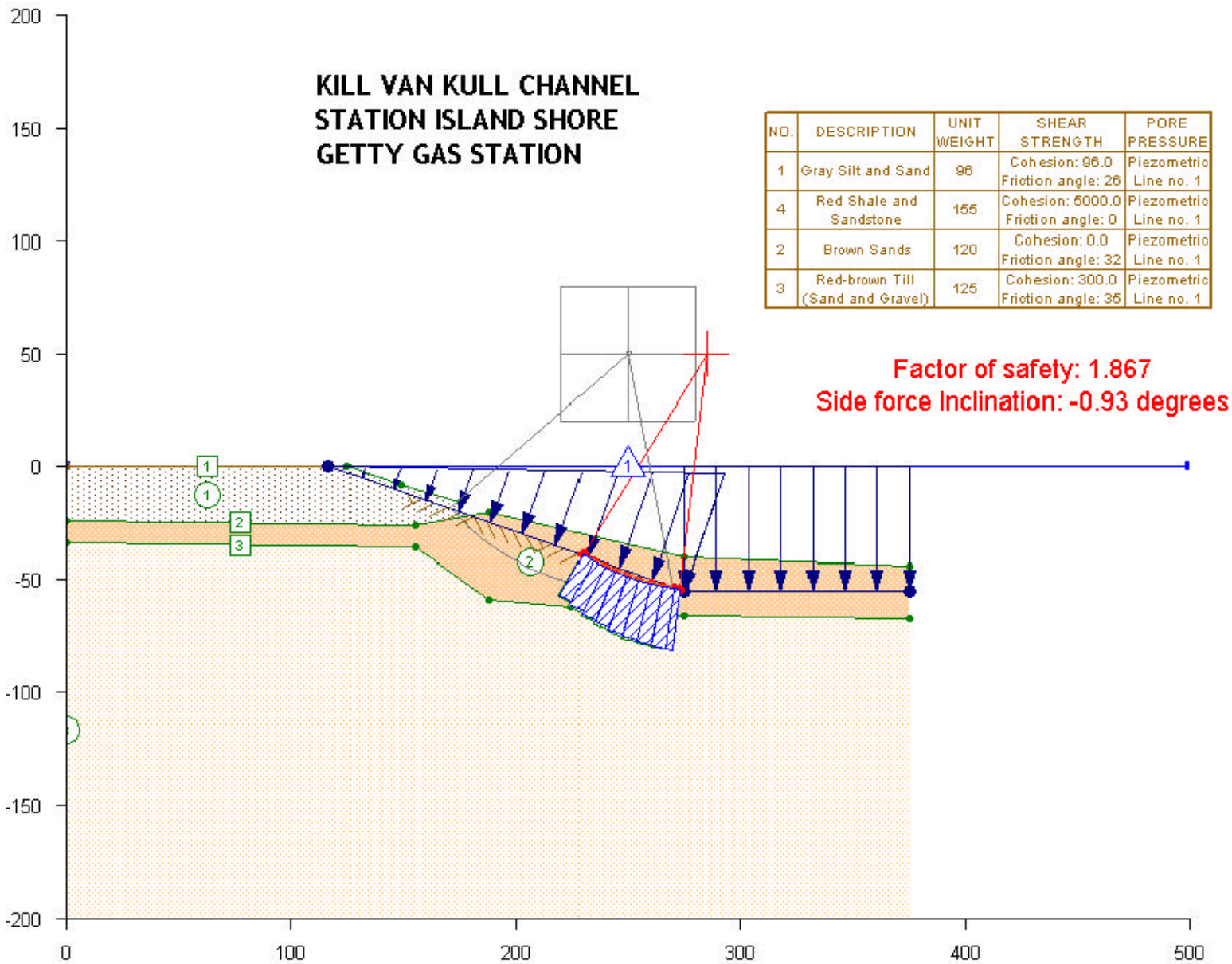
NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Dark Gray Sand and Silt	100	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
2	Red Brown Silt and Clay	127	Cohesion: 500.0 Friction angle: 15	Piezometric Line no. 1
3	Red Brown Shale	155	Cohesion: 3000.0 Friction angle: 40	Piezometric Line no. 1

Figure 132



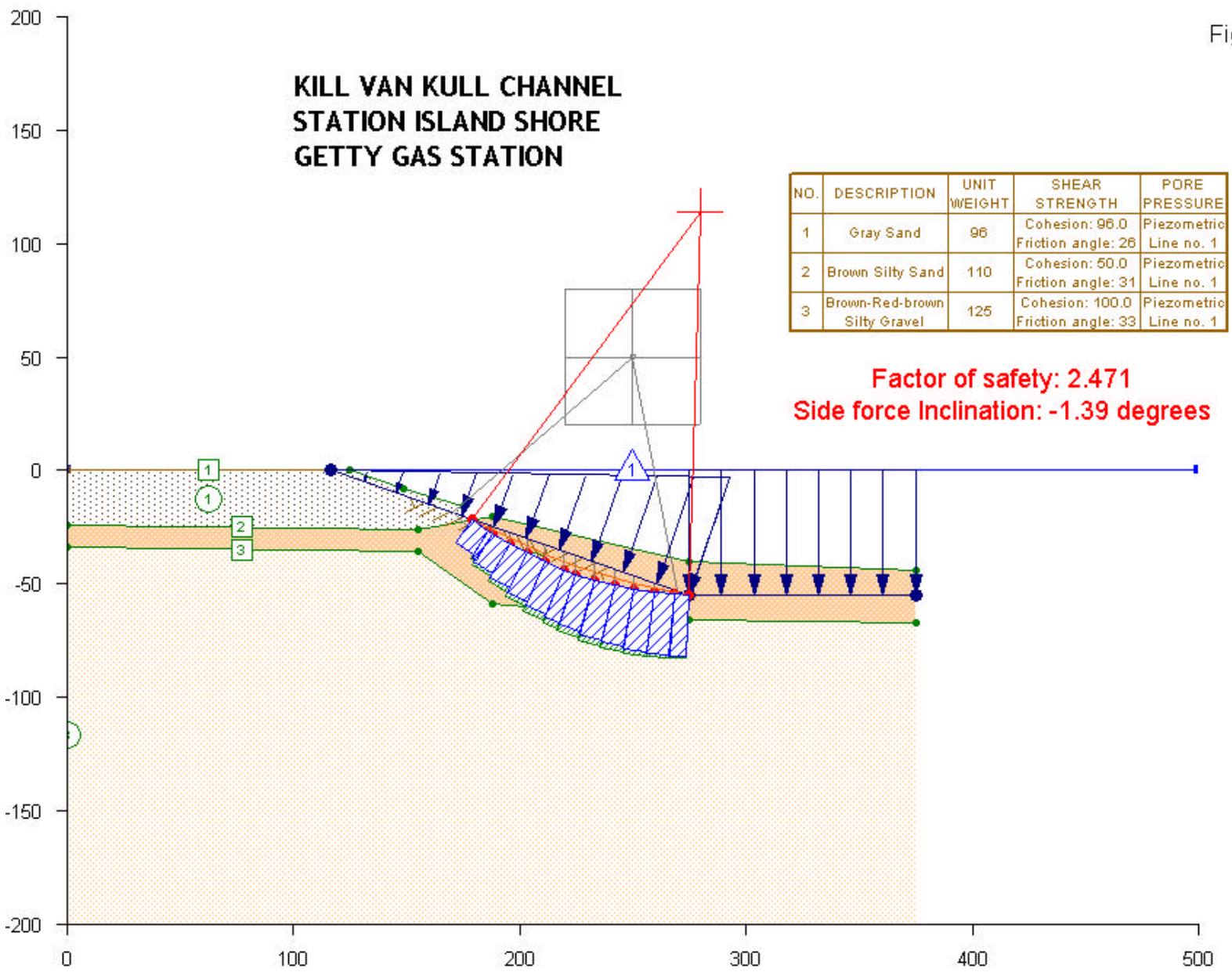
NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Dark Gray Sand and Silt	100	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
2	Red Brown Shale	155	Cohesion: 3000.0 Friction angle: 40	Piezometric Line no. 1

Figure 133



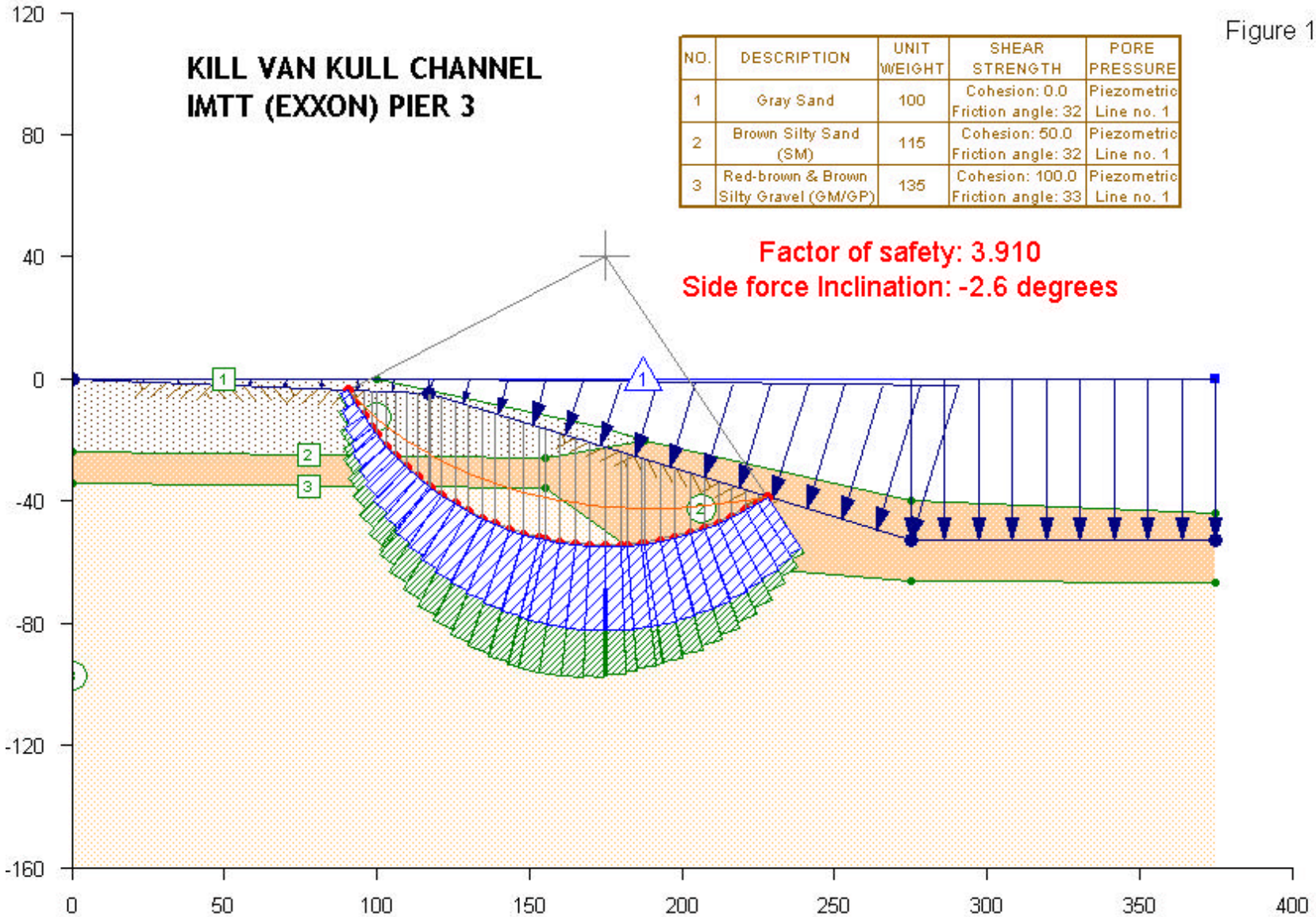
NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Gray Silt and Sand	96	Cohesion: 96.0 Friction angle: 26	Piezometric Line no. 1
4	Red Shale and Sandstone	155	Cohesion: 5000.0 Friction angle: 0	Piezometric Line no. 1
2	Brown Sands	120	Cohesion: 0.0 Friction angle: 32	Piezometric Line no. 1
3	Red-brown Till (Sand and Gravel)	125	Cohesion: 300.0 Friction angle: 35	Piezometric Line no. 1

Figure 134



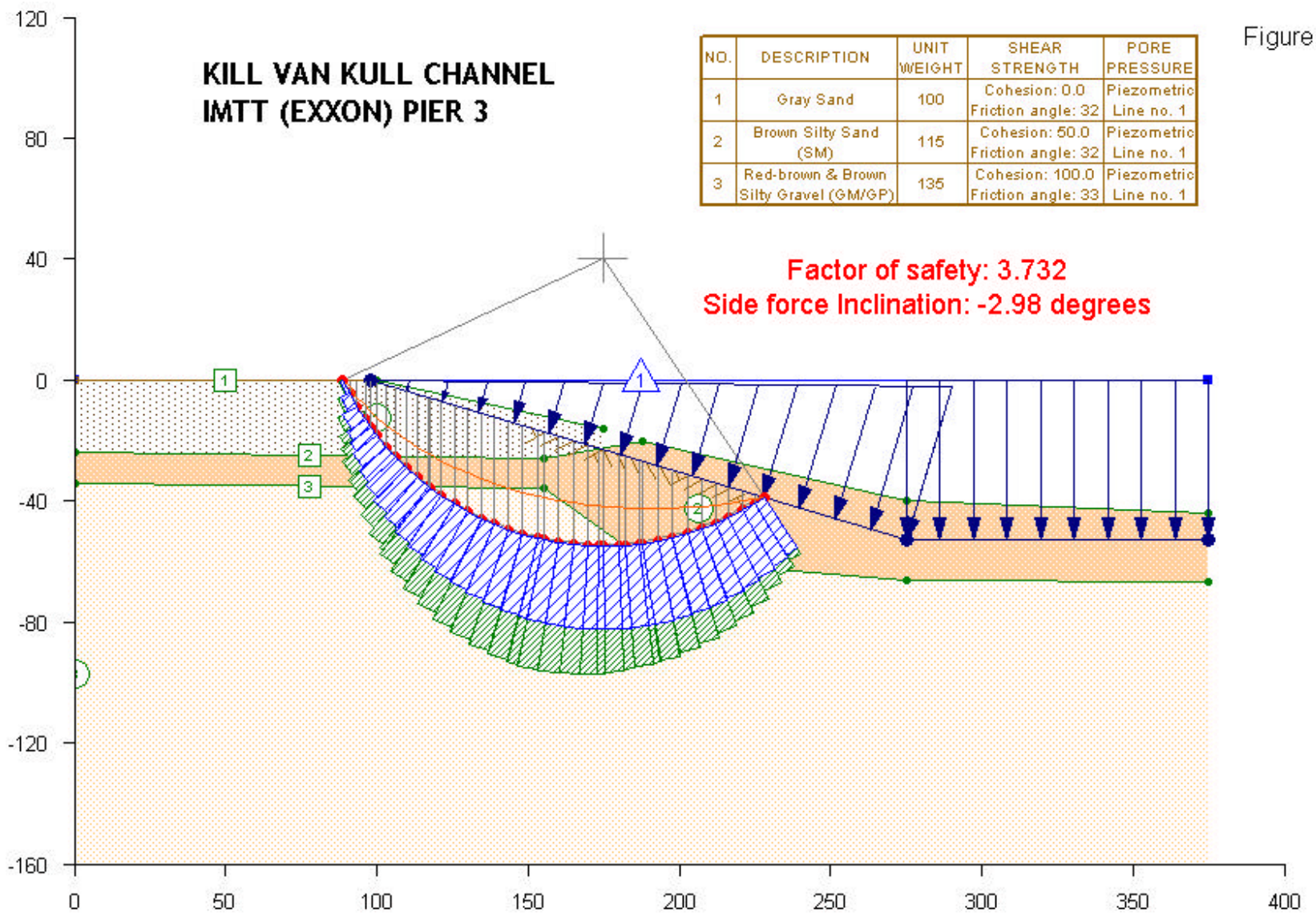
NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Gray Sand	96	Cohesion: 96.0 Friction angle: 26	Piezometric Line no. 1
2	Brown Silty Sand	110	Cohesion: 50.0 Friction angle: 31	Piezometric Line no. 1
3	Brown-Red-brown Silty Gravel	125	Cohesion: 100.0 Friction angle: 33	Piezometric Line no. 1

Figure 135



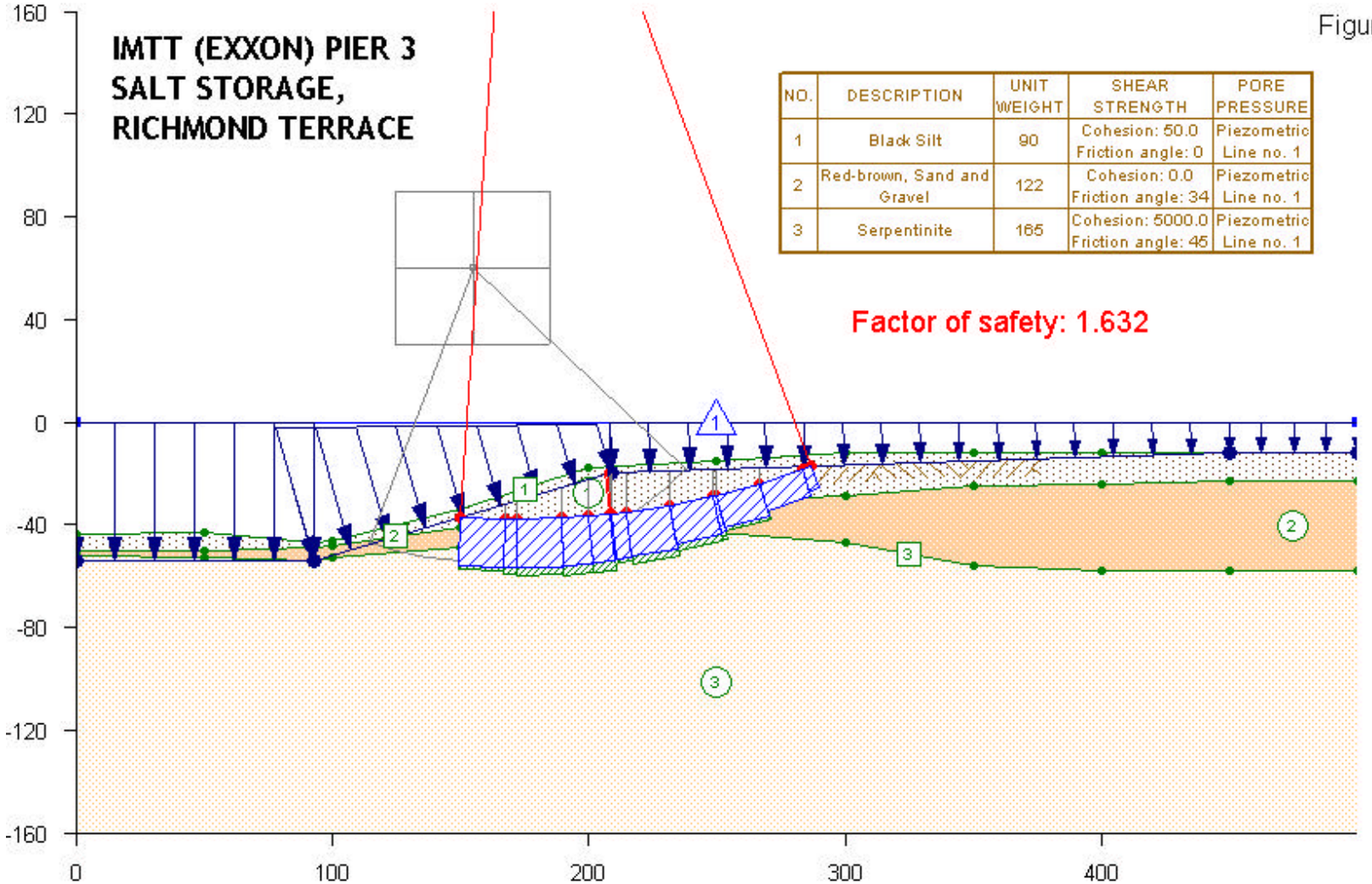
NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Gray Sand	100	Cohesion: 0.0 Friction angle: 32	Piezometric Line no. 1
2	Brown Silty Sand (SM)	115	Cohesion: 50.0 Friction angle: 32	Piezometric Line no. 1
3	Red-brown & Brown Silty Gravel (GM/GP)	135	Cohesion: 100.0 Friction angle: 33	Piezometric Line no. 1

Figure 136



NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Gray Sand	100	Cohesion: 0.0 Friction angle: 32	Piezometric Line no. 1
2	Brown Silty Sand (SM)	115	Cohesion: 50.0 Friction angle: 32	Piezometric Line no. 1
3	Red-brown & Brown Silty Gravel (GM/GP)	135	Cohesion: 100.0 Friction angle: 33	Piezometric Line no. 1

Figure 137



NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
2	Red-brown, Sand and Gravel	122	Cohesion: 0.0 Friction angle: 34	Piezometric Line no. 1
3	Serpentinite	165	Cohesion: 5000.0 Friction angle: 45	Piezometric Line no. 1

Figure 138

IMTT (EXXON) PIER 3 SALT STORAGE, RICHMOND TERRACE

NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
2	Red-brown, Sand and Gravel	122	Cohesion: 0.0 Friction angle: 34	Piezometric Line no. 1
3	Serpentinite	165	Cohesion: 5000.0 Friction angle: 45	Piezometric Line no. 1

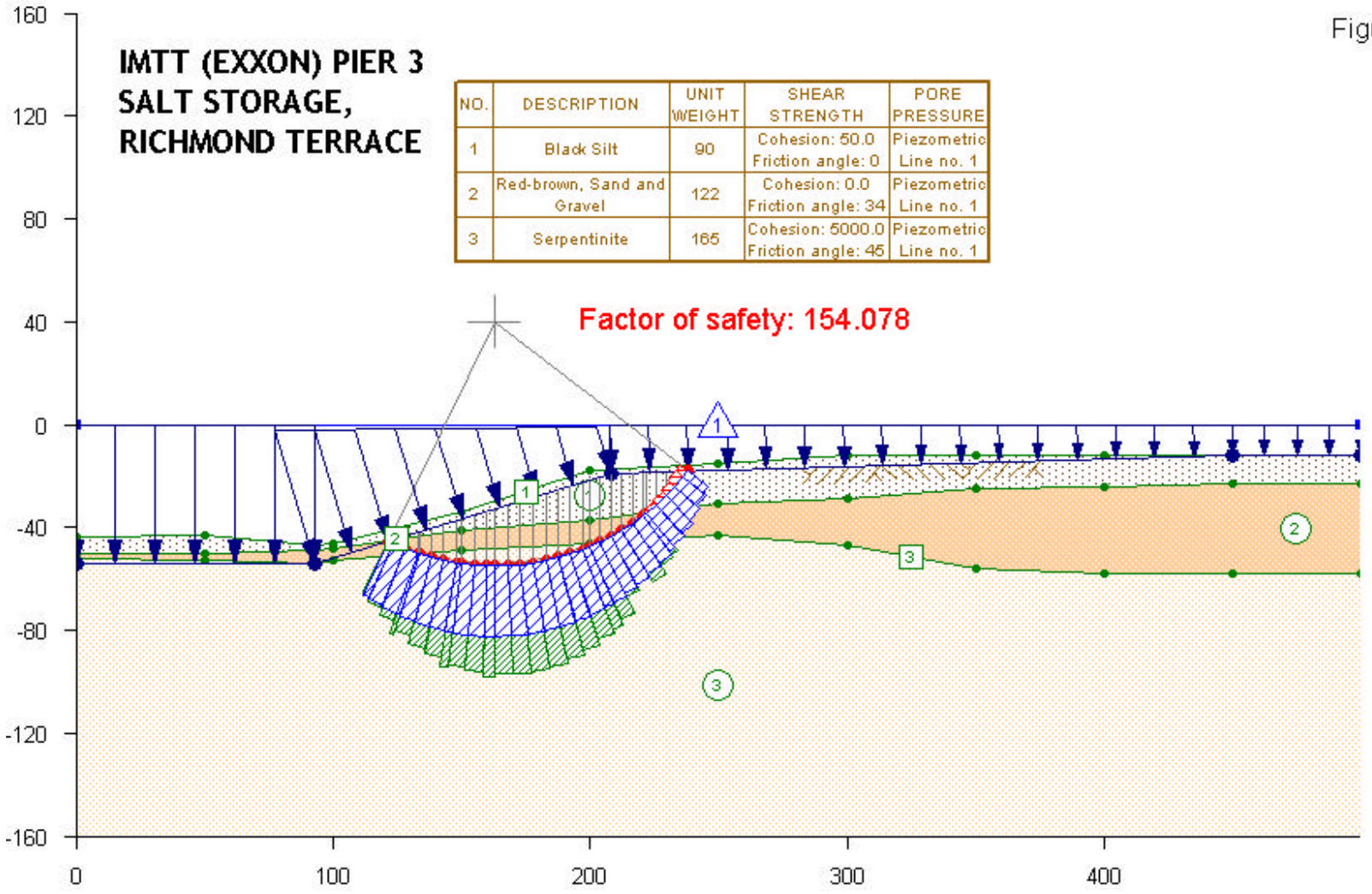


Figure 139

IMTT (EXXON) PIER 3 SALT STORAGE, RICHMOND TERRACE

NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
2	Red-brown, Sand and Gravel	122	Cohesion: 0.0 Friction angle: 34	Piezometric Line no. 1
3	Serpentinite	165	Cohesion: 5000.0 Friction angle: 45	Piezometric Line no. 1

Factor of safety: 1.545
Side force Inclination: 0.46 degrees

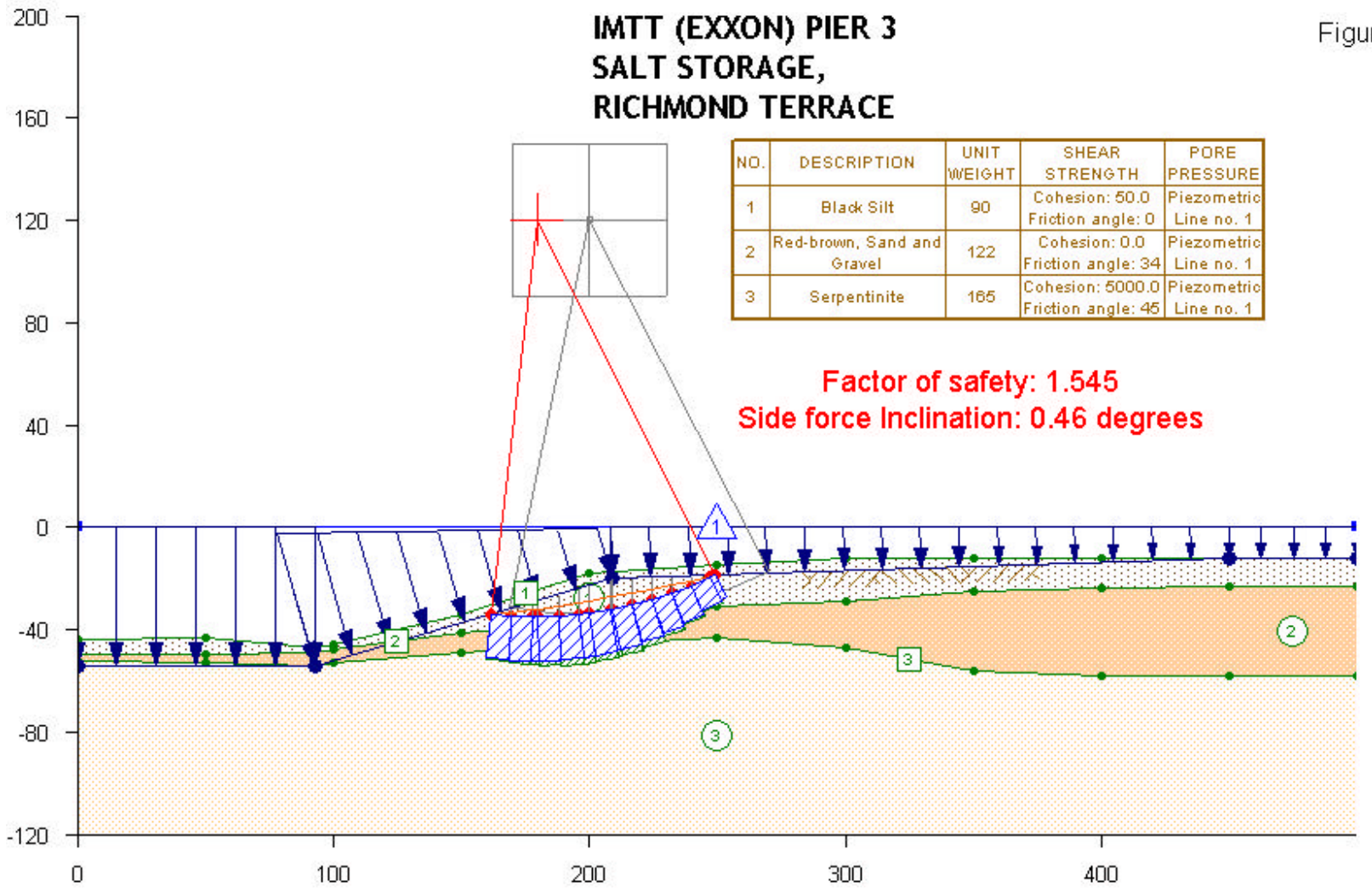
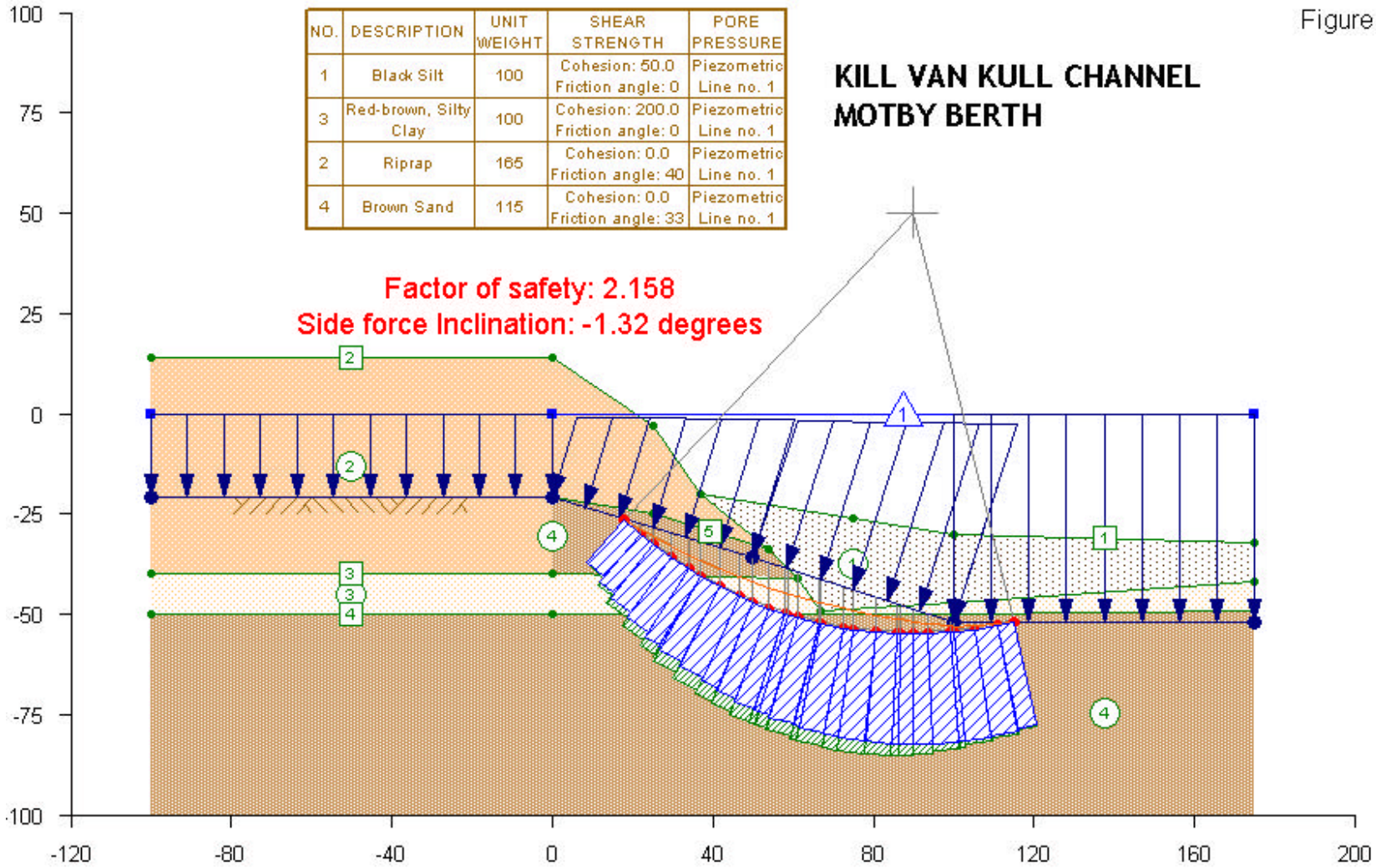


Figure 140

KILL VAN KULL CHANNEL
MOTBY BERTH

NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Black Silt	100	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
3	Red-brown, Silty Clay	100	Cohesion: 200.0 Friction angle: 0	Piezometric Line no. 1
2	Riprap	165	Cohesion: 0.0 Friction angle: 40	Piezometric Line no. 1
4	Brown Sand	115	Cohesion: 0.0 Friction angle: 33	Piezometric Line no. 1



KILL VAN KULL CHANNEL
MOTBY BERTH

Figure 141

NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
3	Red-brown, Silty Clay	127	Cohesion: 500.0 Friction angle: 15	Piezometric Line no. 1
2	Riprap	165	Cohesion: 0.0 Friction angle: 40	Piezometric Line no. 1
4	Brown Sand	122	Cohesion: 0.0 Friction angle: 33	Piezometric Line no. 1

Factor of safety: 2.492
Side force Inclination: -2.11 degrees

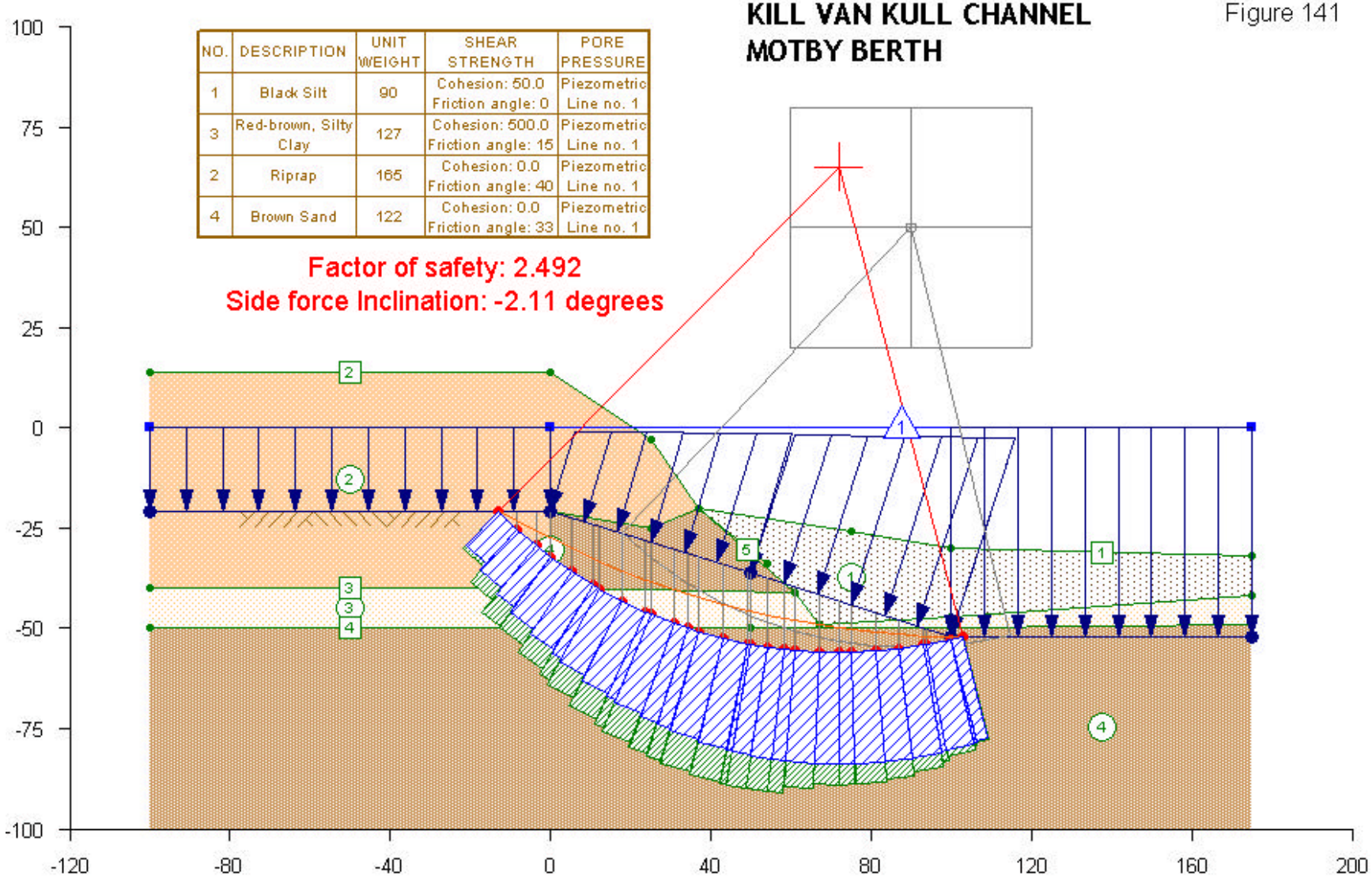
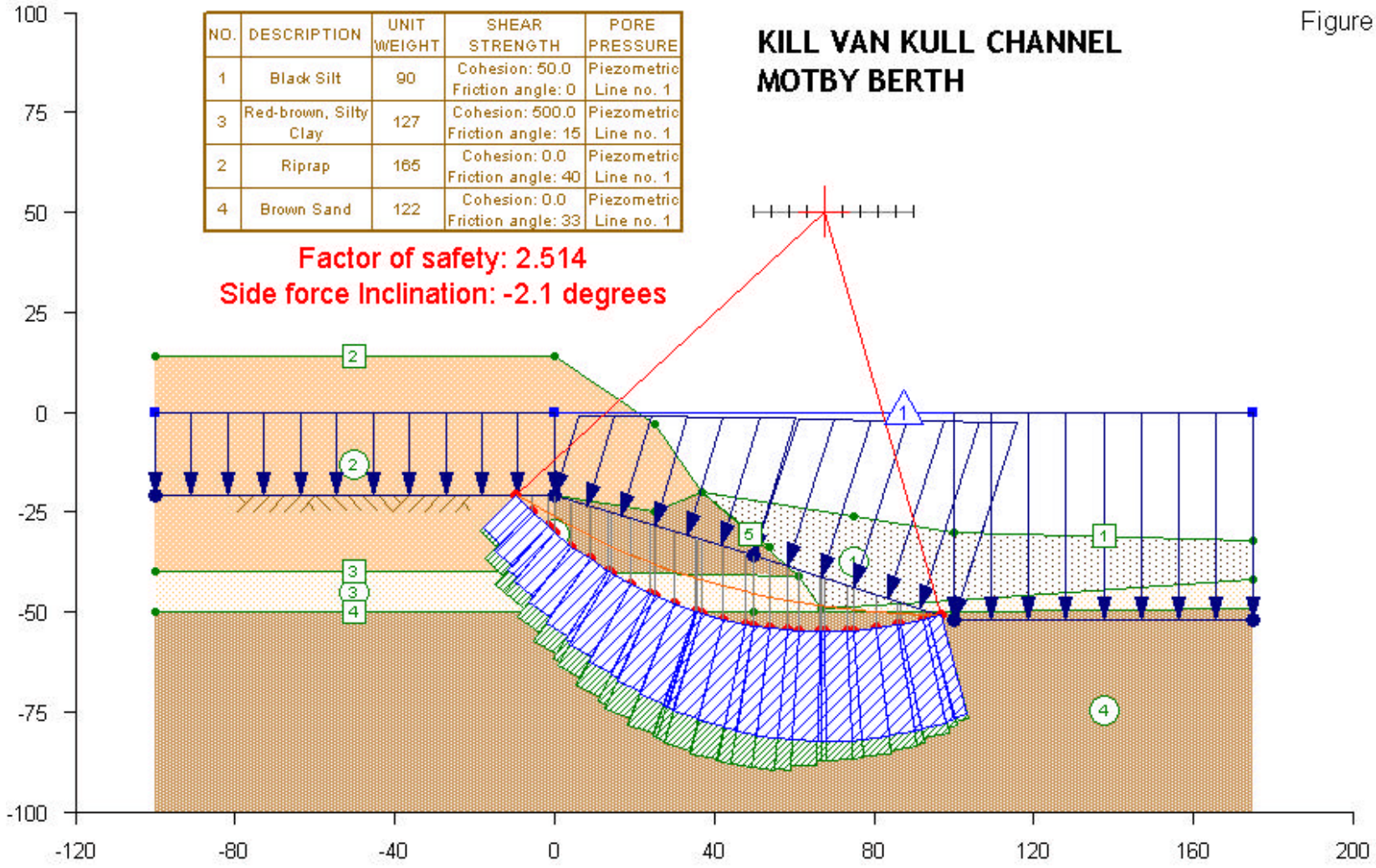


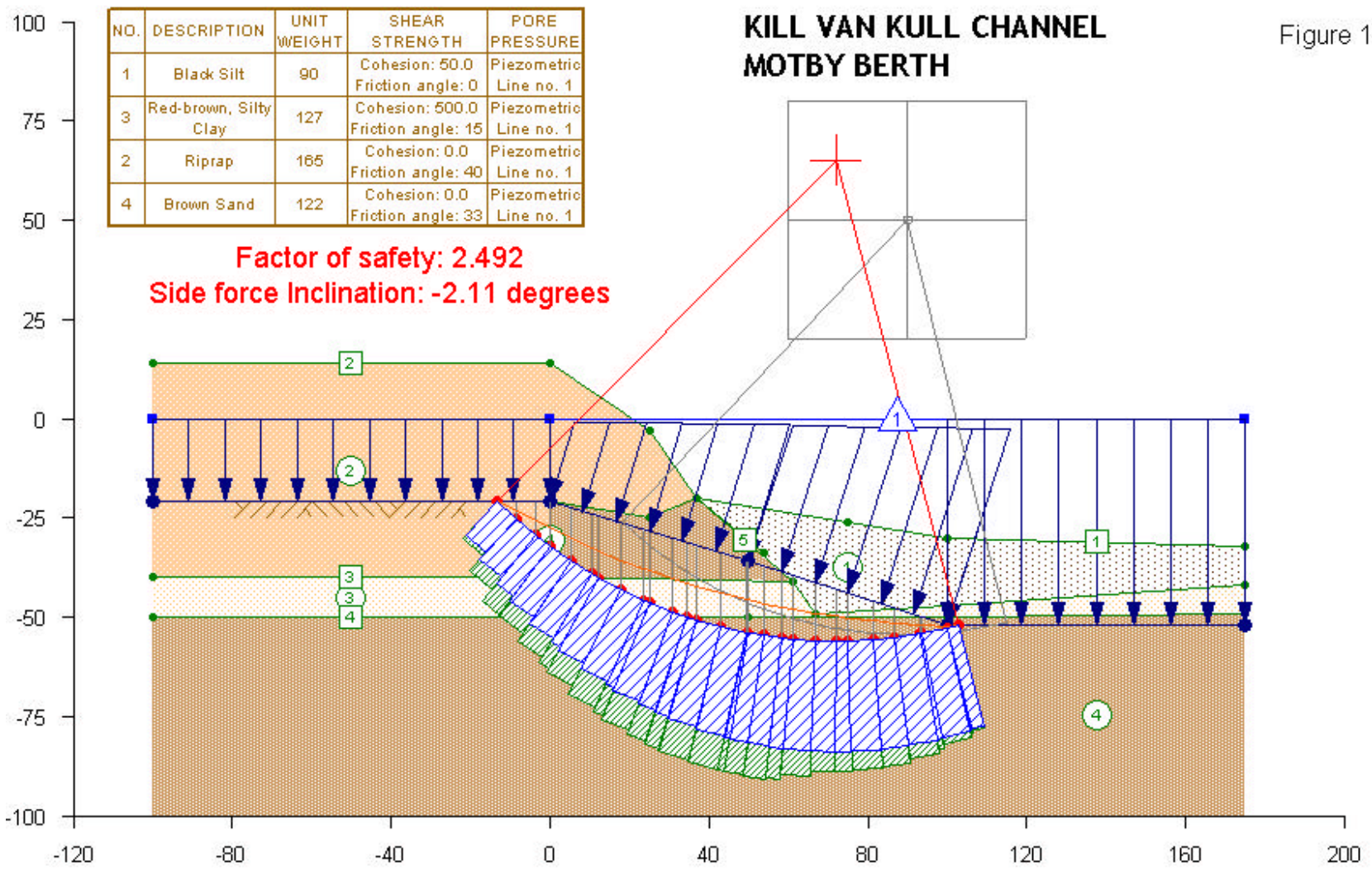
Figure 142

KILL VAN KULL CHANNEL
MOTBY BERTH

NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
3	Red-brown, Silty Clay	127	Cohesion: 500.0 Friction angle: 15	Piezometric Line no. 1
2	Riprap	165	Cohesion: 0.0 Friction angle: 40	Piezometric Line no. 1
4	Brown Sand	122	Cohesion: 0.0 Friction angle: 33	Piezometric Line no. 1

Factor of safety: 2.514
Side force Inclination: -2.1 degrees

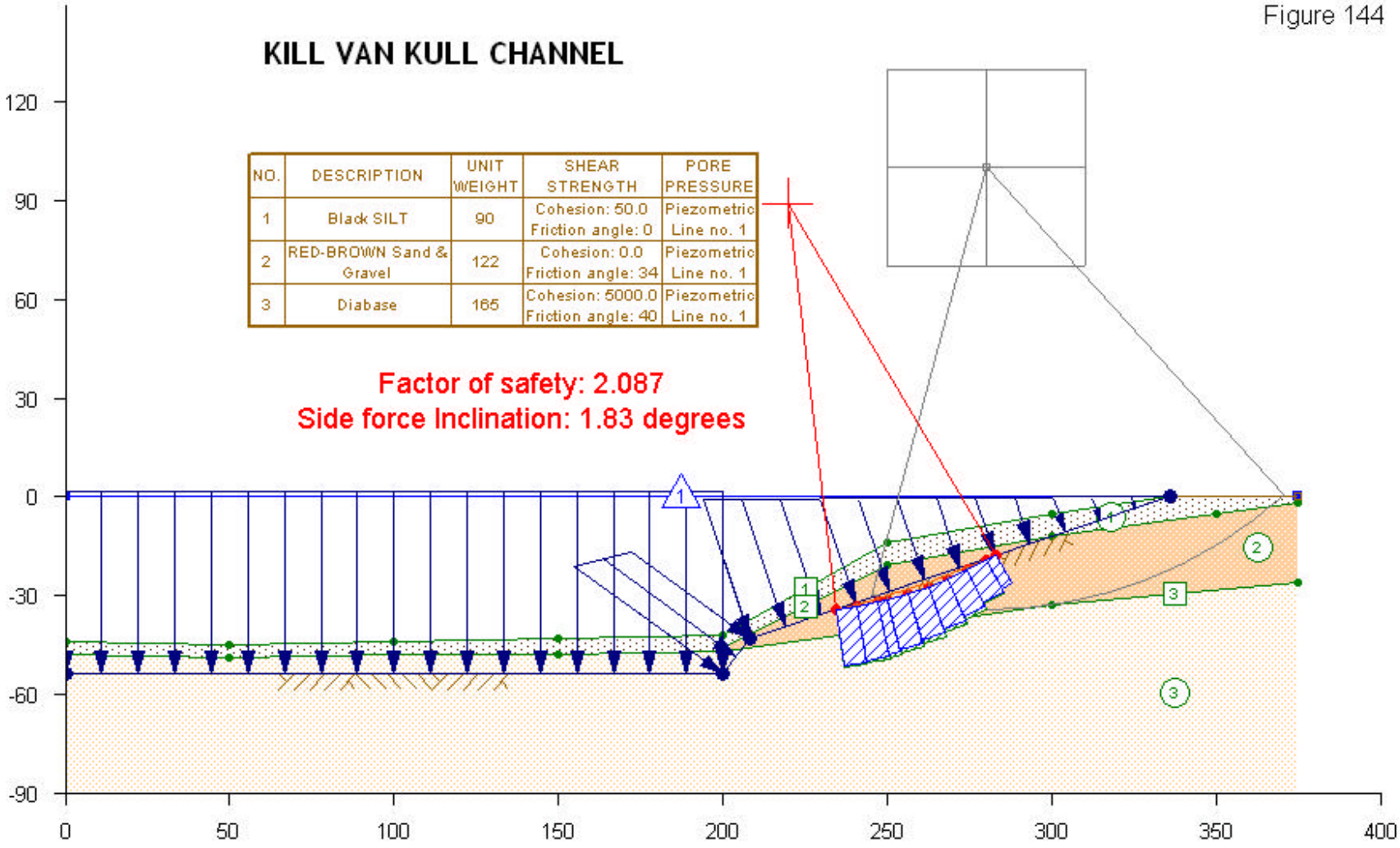




NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
3	Red-brown, Silty Clay	127	Cohesion: 500.0 Friction angle: 15	Piezometric Line no. 1
2	Riprap	165	Cohesion: 0.0 Friction angle: 40	Piezometric Line no. 1
4	Brown Sand	122	Cohesion: 0.0 Friction angle: 33	Piezometric Line no. 1

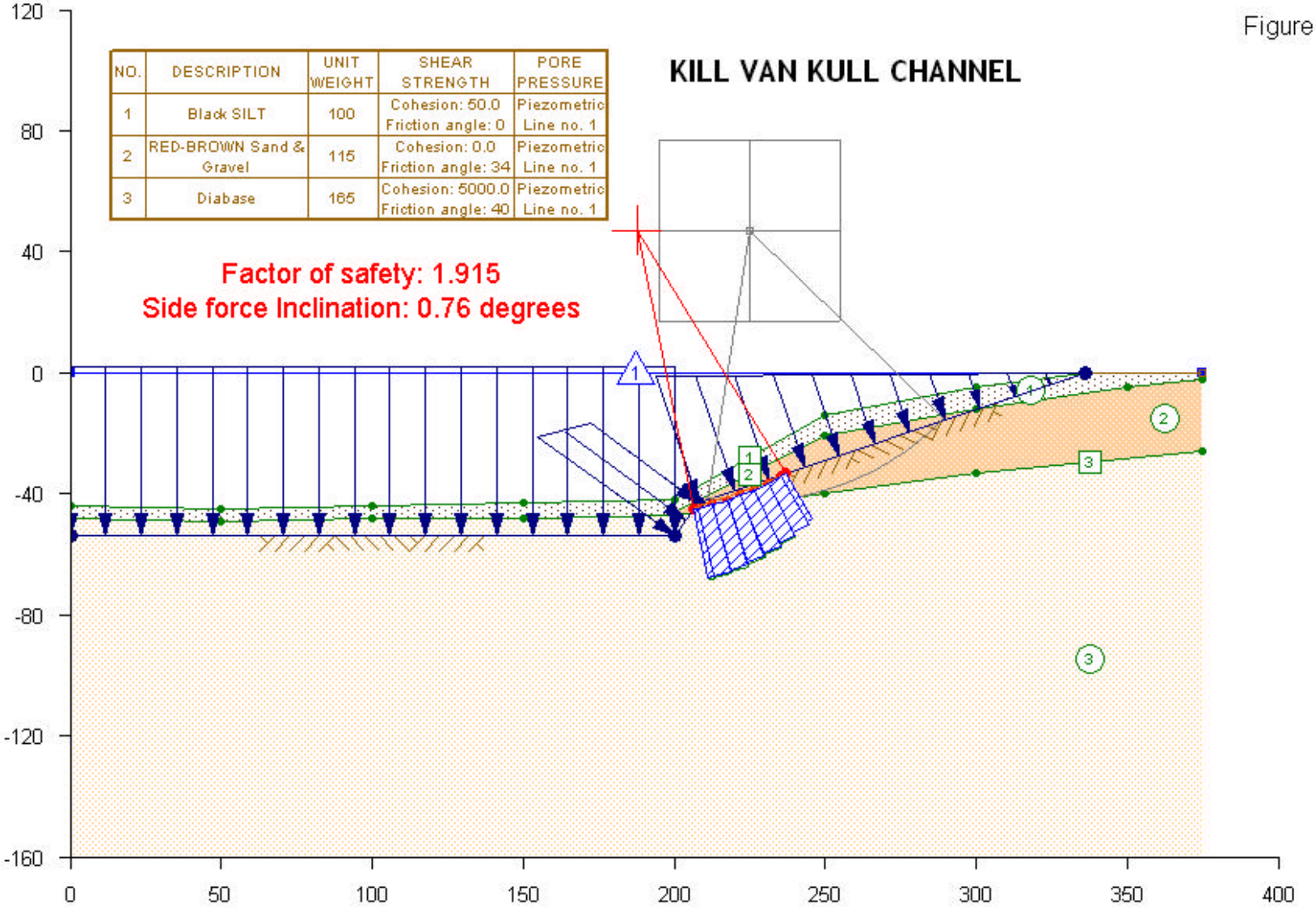
Figure 143

Figure 144



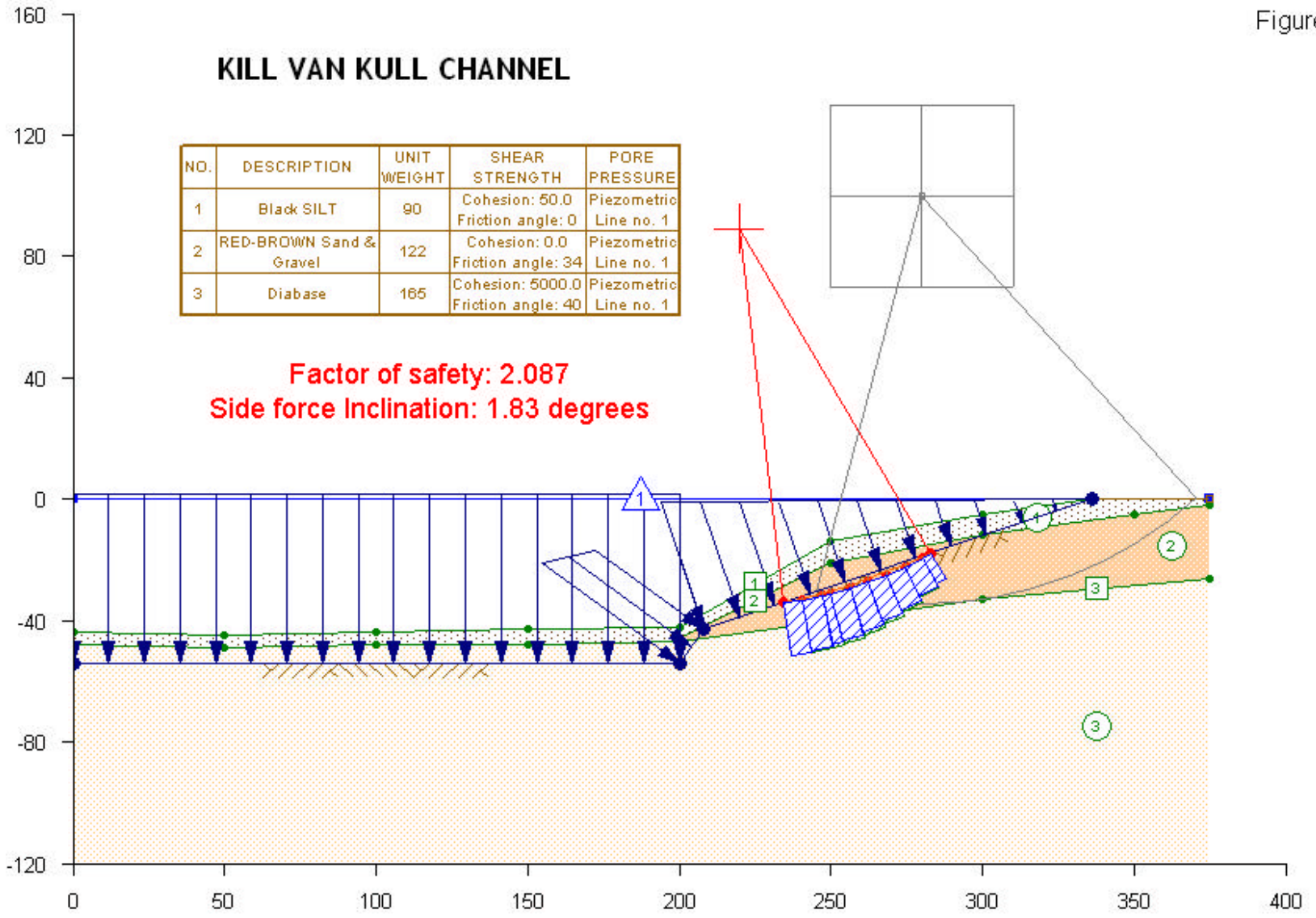
NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Black SILT	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
2	RED-BROWN Sand & Gravel	122	Cohesion: 0.0 Friction angle: 34	Piezometric Line no. 1
3	Diabase	165	Cohesion: 5000.0 Friction angle: 40	Piezometric Line no. 1

Figure 145



NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Black SILT	100	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
2	RED-BROWN Sand & Gravel	115	Cohesion: 0.0 Friction angle: 34	Piezometric Line no. 1
3	Diabase	165	Cohesion: 5000.0 Friction angle: 40	Piezometric Line no. 1

Figure 146



NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Black SILT	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
2	RED-BROWN Sand & Gravel	122	Cohesion: 0.0 Friction angle: 34	Piezometric Line no. 1
3	Diabase	165	Cohesion: 5000.0 Friction angle: 40	Piezometric Line no. 1

Figure 147

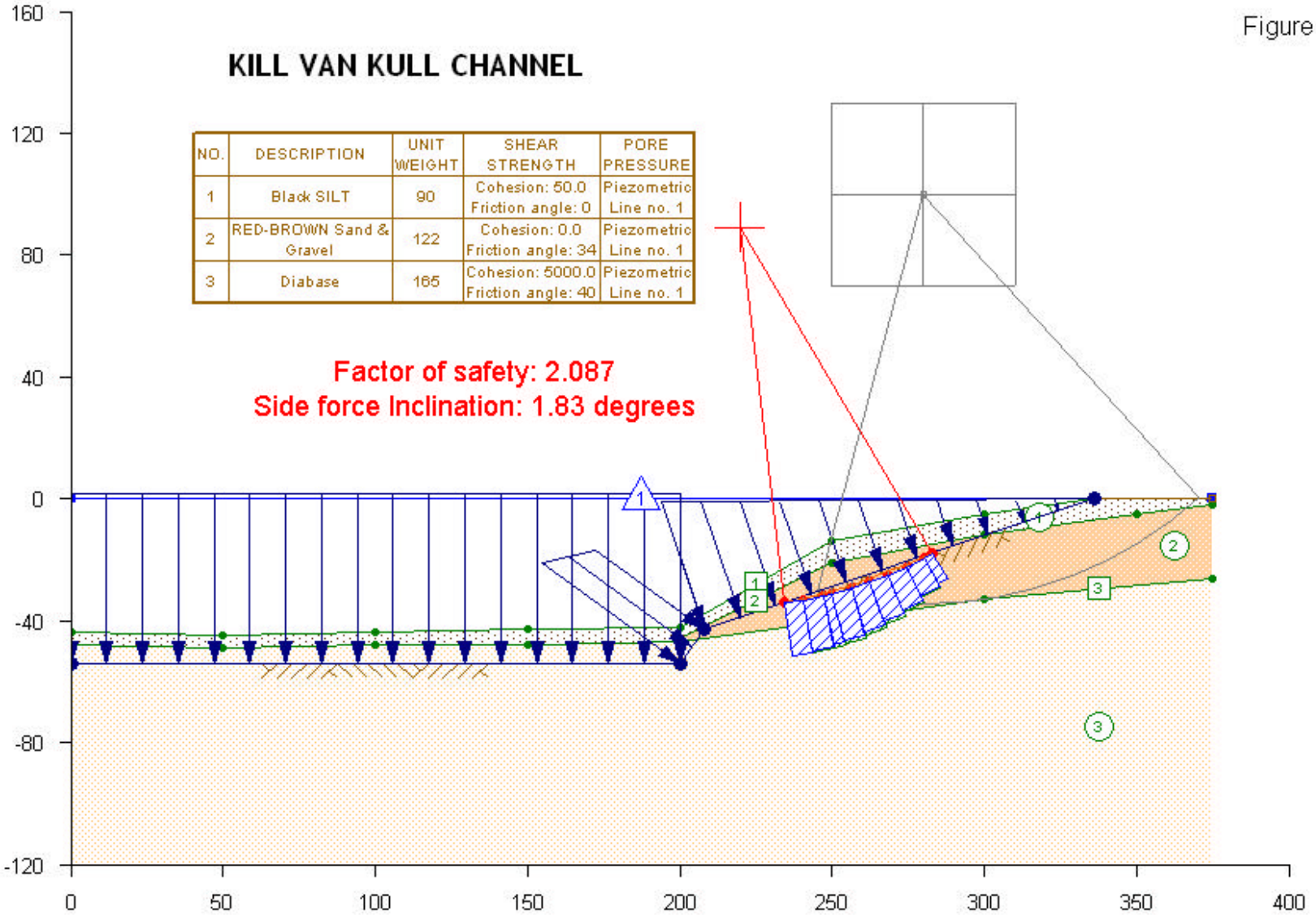
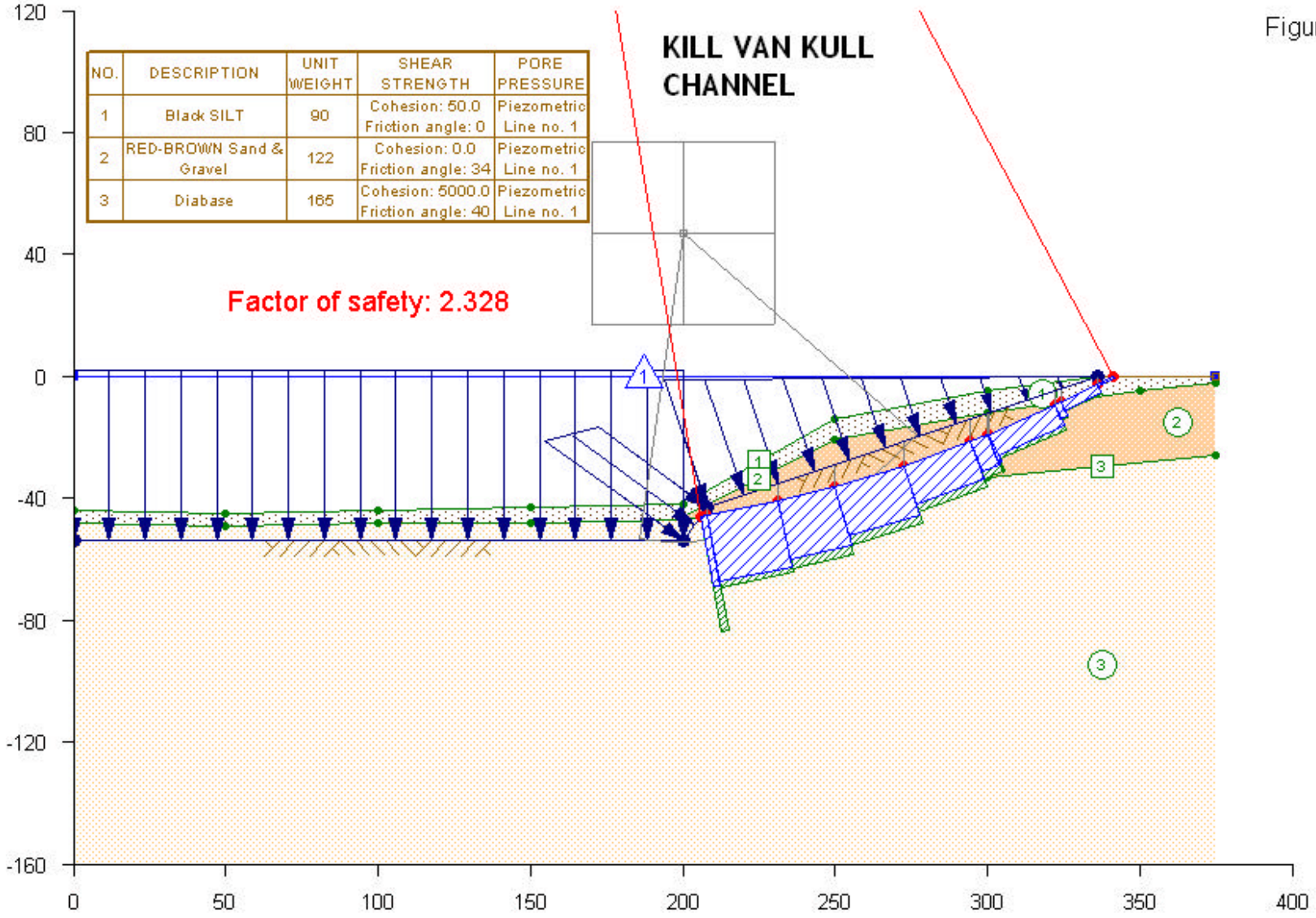
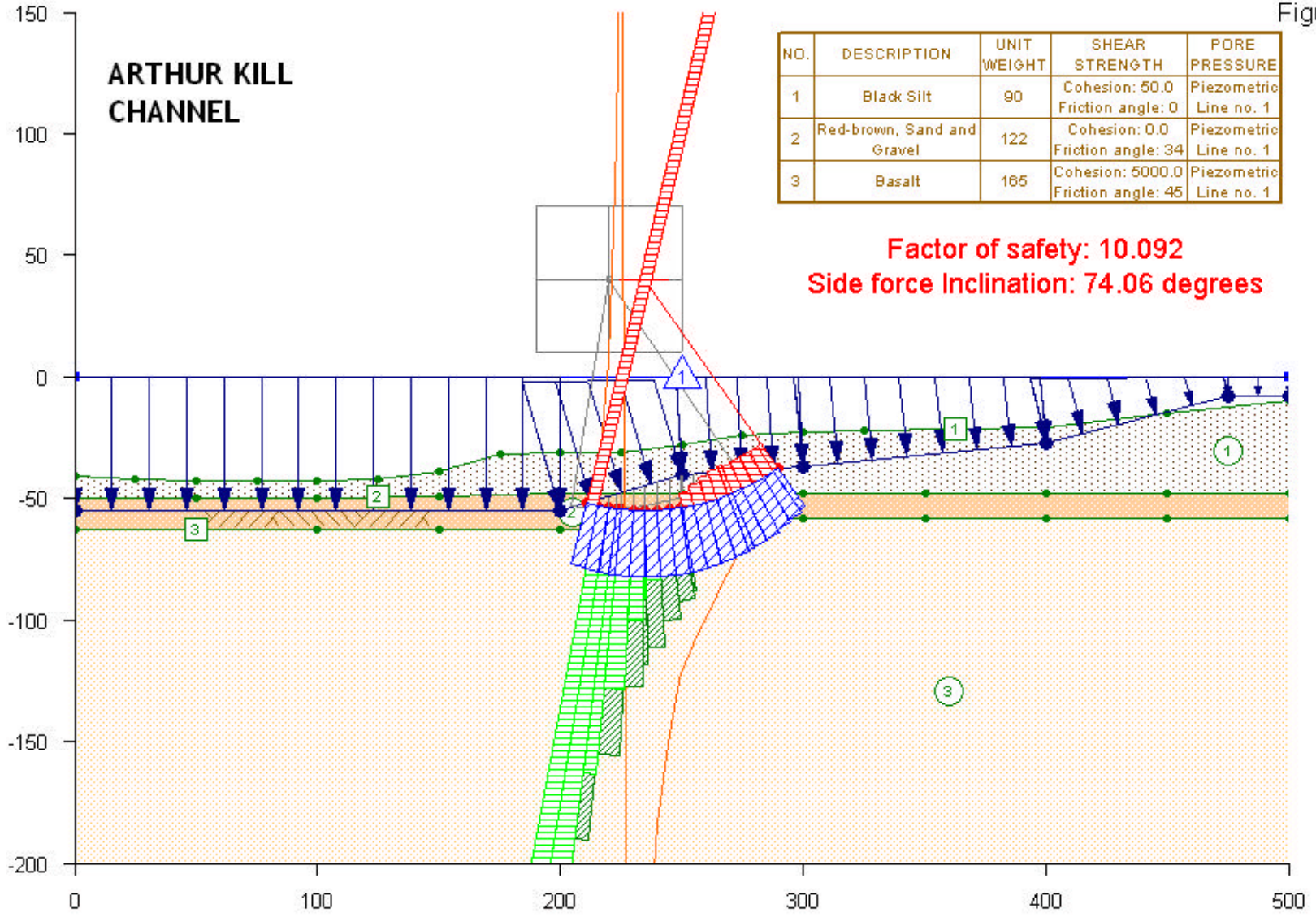

KILL VAN KULL CHANNEL
NO. | DESCRIPTION | UNIT WEIGHT | SHEAR STRENGTH | PORE PRESSURE
1 | Black SILT | 90 | Cohesion: 50.0 Friction angle: 0 | Piezometric Line no. 1
2 | RED-BROWN Sand & Gravel | 122 | Cohesion: 0.0 Friction angle: 34 | Piezometric Line no. 1
3 | Diabase | 165 | Cohesion: 5000.0 Friction angle: 40 | Piezometric Line no. 1
Factor of safety: 2.087
Side force Inclination: 1.83 degrees
160
120
80
40
0
-40
-80
-120
0
50
100
150
200
250
300
350
400

Figure 148

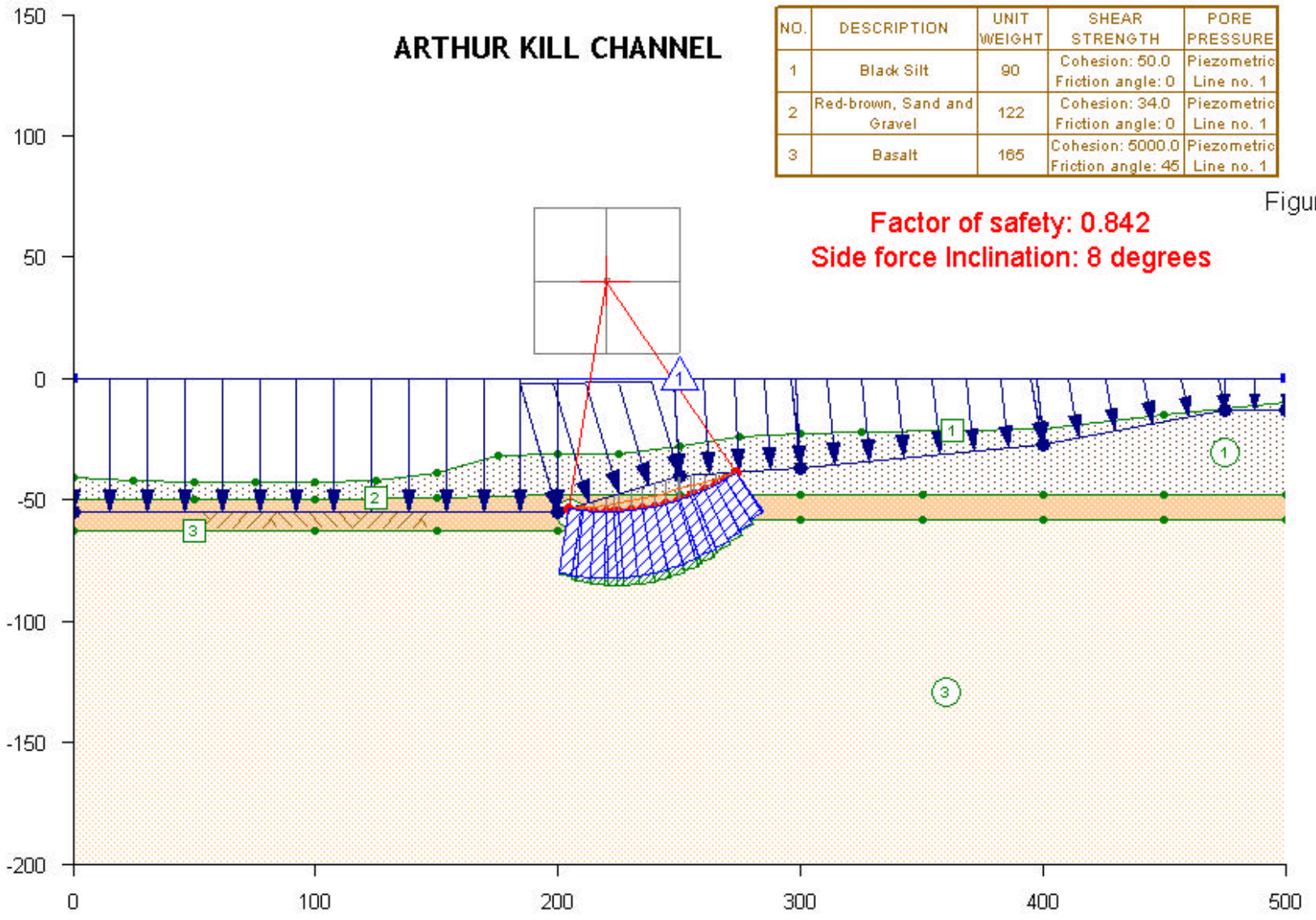


NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Black SILT	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
2	RED-BROWN Sand & Gravel	122	Cohesion: 0.0 Friction angle: 34	Piezometric Line no. 1
3	Diabase	165	Cohesion: 5000.0 Friction angle: 40	Piezometric Line no. 1

Figure 149



NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
2	Red-brown, Sand and Gravel	122	Cohesion: 0.0 Friction angle: 34	Piezometric Line no. 1
3	Basalt	165	Cohesion: 5000.0 Friction angle: 45	Piezometric Line no. 1



NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
2	Red-brown, Sand and Gravel	122	Cohesion: 34.0 Friction angle: 0	Piezometric Line no. 1
3	Basalt	165	Cohesion: 5000.0 Friction angle: 45	Piezometric Line no. 1

Figure 150

Figure 151

NAME OF BOX 17

NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Brown Sand and Fine Gravel	122	Cohesion: 0.0 Friction angle: 34	Piezometric Line no. 1
2	Red Brown to Brown Till	125	Cohesion: 300.0 Friction angle: 35	Piezometric Line no. 1

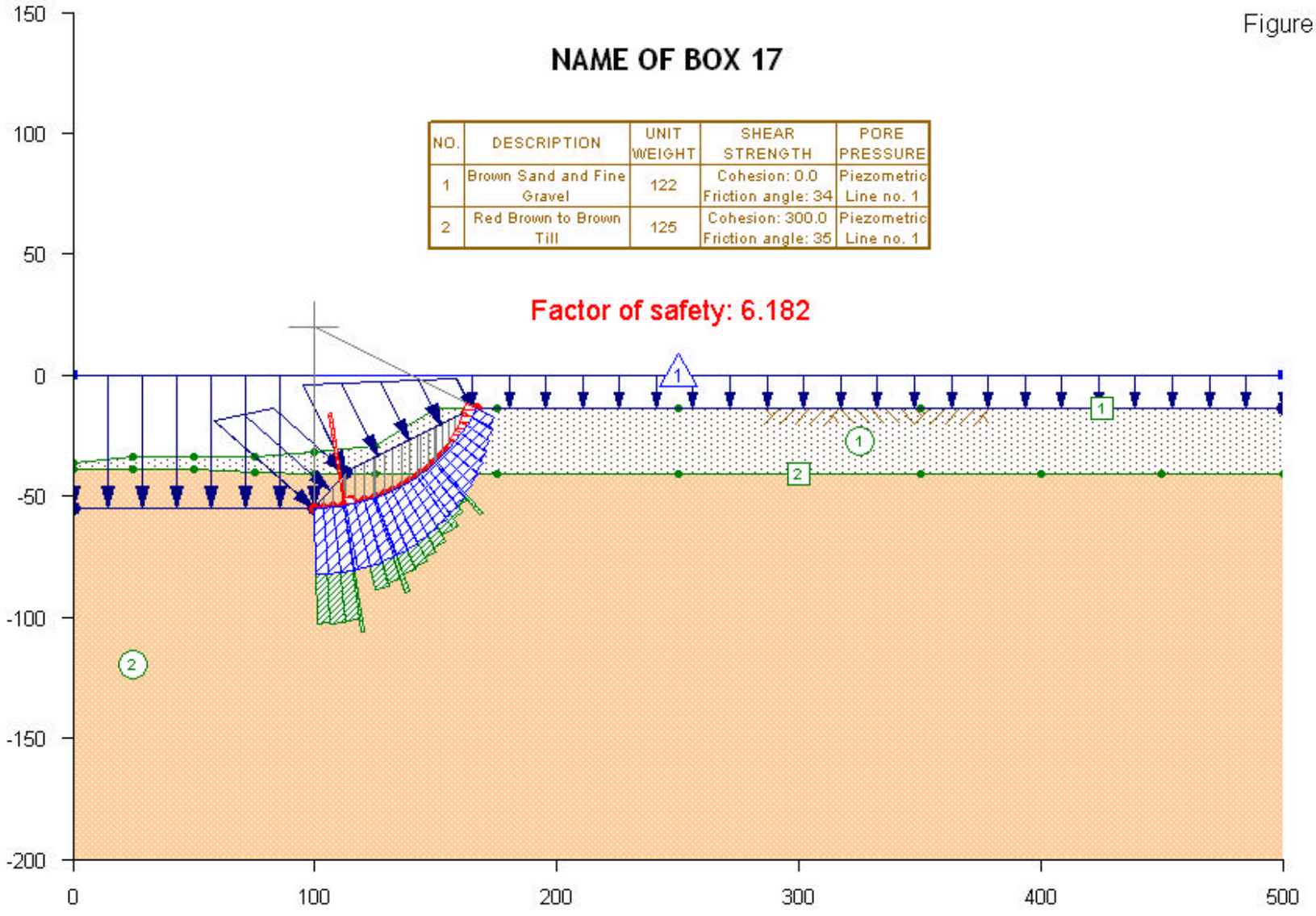


Figure 152

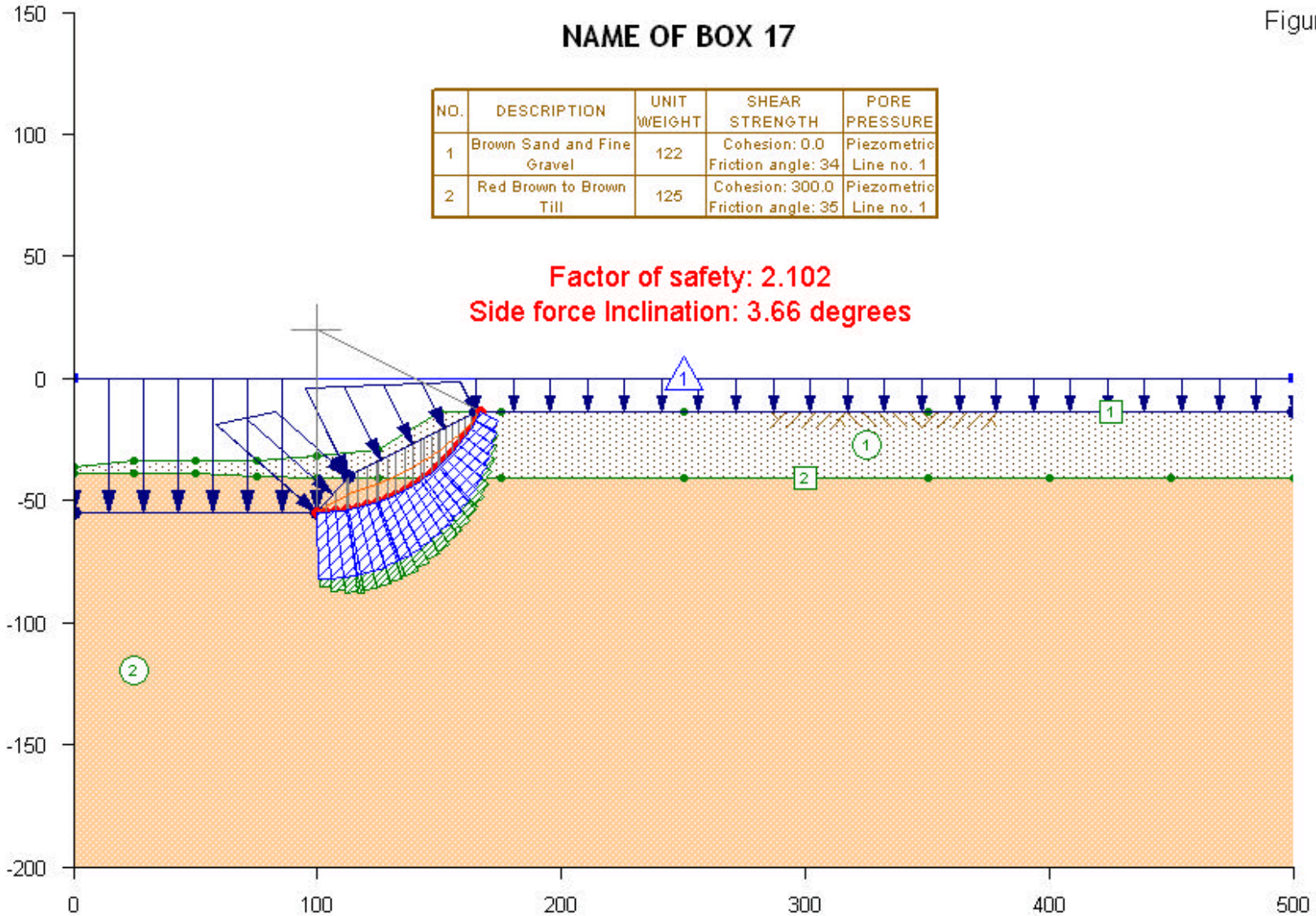
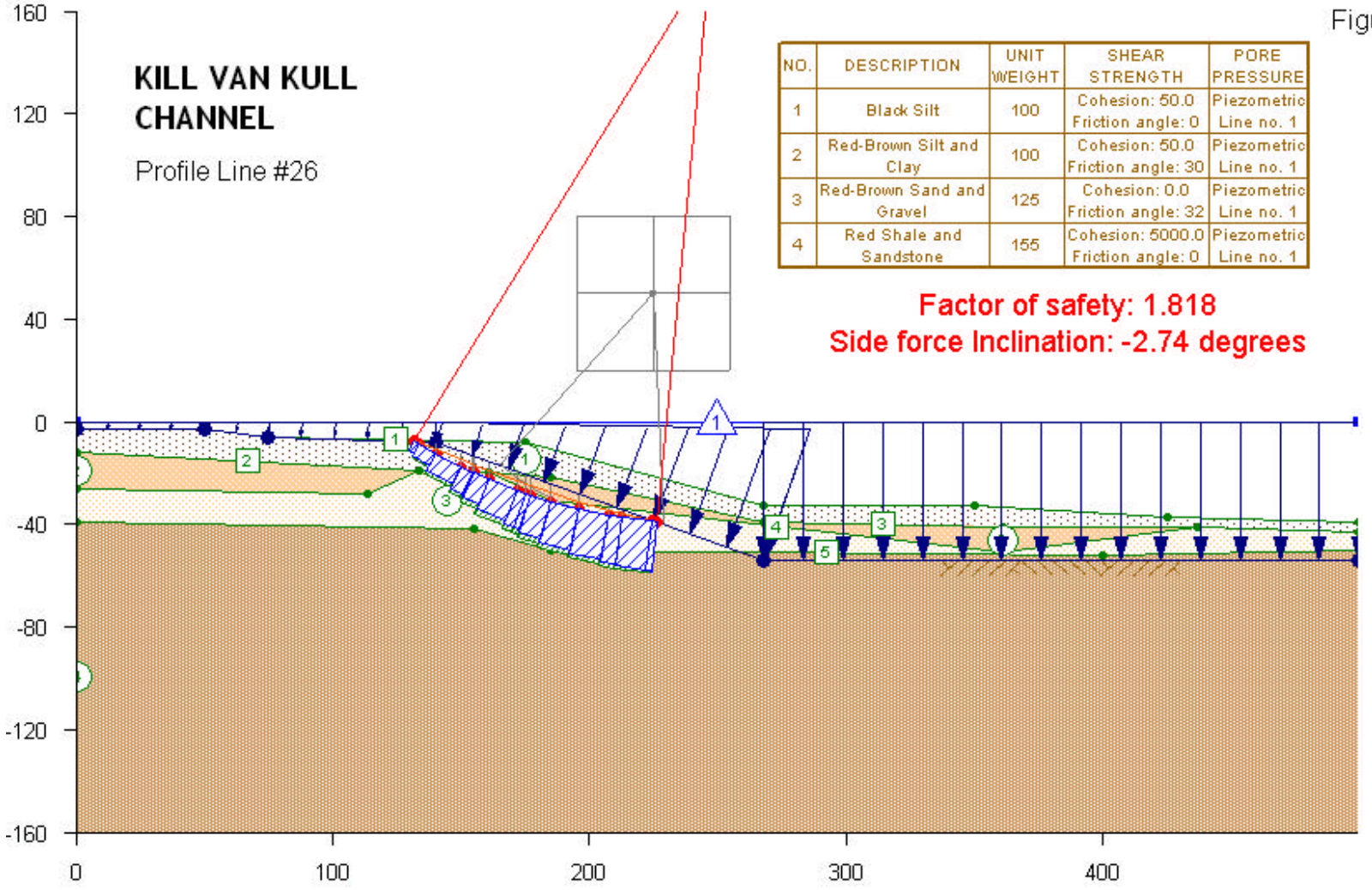
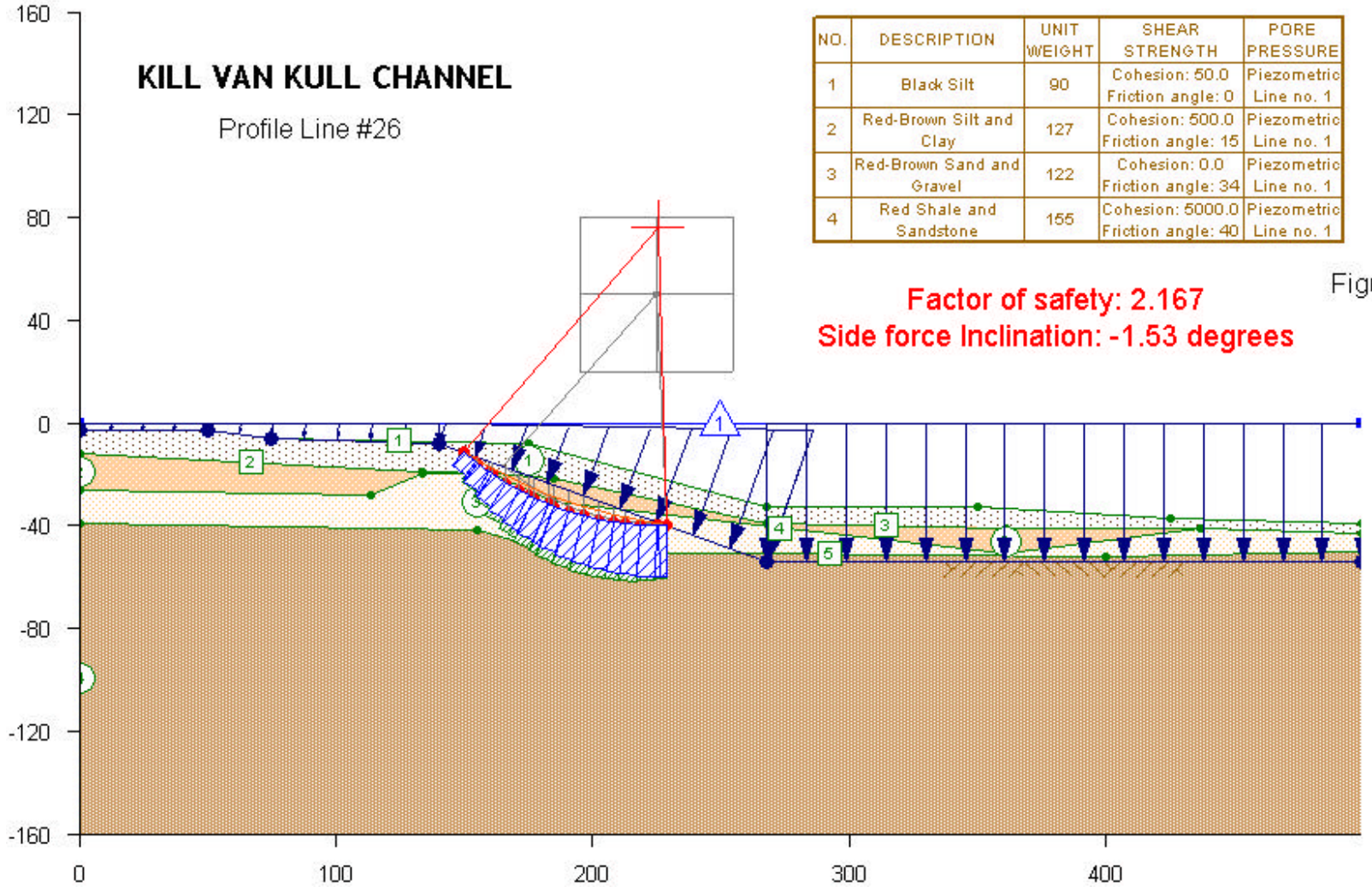

NAME OF BOX 17
NO. | DESCRIPTION | UNIT WEIGHT | SHEAR STRENGTH | PORE PRESSURE
1 | Brown Sand and Fine Gravel | 122 | Cohesion: 0.0 Friction angle: 34 | Piezometric Line no. 1
2 | Red Brown to Brown Till | 125 | Cohesion: 300.0 Friction angle: 35 | Piezometric Line no. 1
Factor of safety: 2.102
Side force Inclination: 3.66 degrees
150
100
50
0
-50
-100
-150
-200
0
100
200
300
400
500

Figure 153



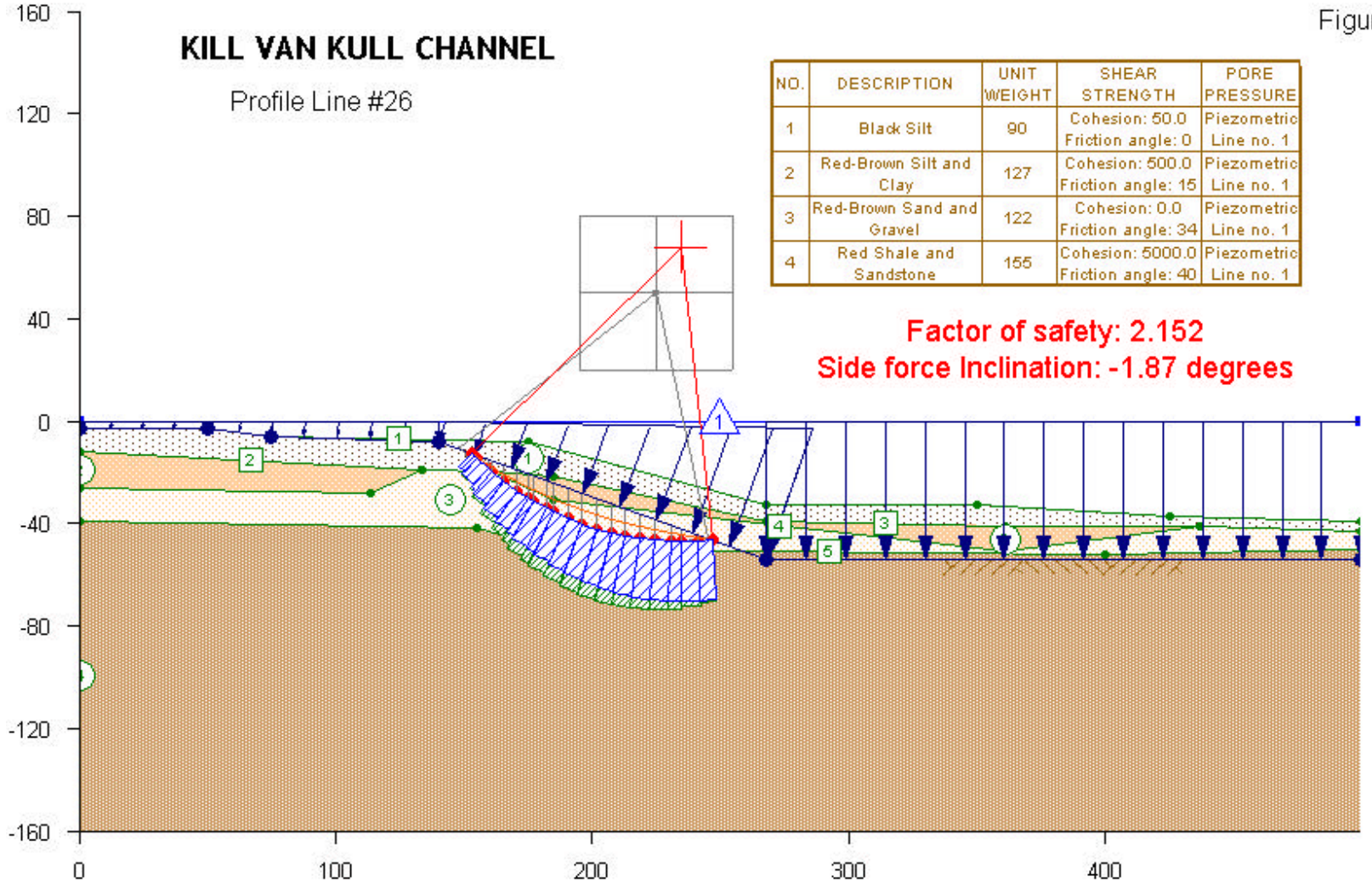
NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Black Silt	100	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
2	Red-Brown Silt and Clay	100	Cohesion: 50.0 Friction angle: 30	Piezometric Line no. 1
3	Red-Brown Sand and Gravel	125	Cohesion: 0.0 Friction angle: 32	Piezometric Line no. 1
4	Red Shale and Sandstone	155	Cohesion: 5000.0 Friction angle: 0	Piezometric Line no. 1



NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
2	Red-Brown Silt and Clay	127	Cohesion: 500.0 Friction angle: 15	Piezometric Line no. 1
3	Red-Brown Sand and Gravel	122	Cohesion: 0.0 Friction angle: 34	Piezometric Line no. 1
4	Red Shale and Sandstone	155	Cohesion: 5000.0 Friction angle: 40	Piezometric Line no. 1

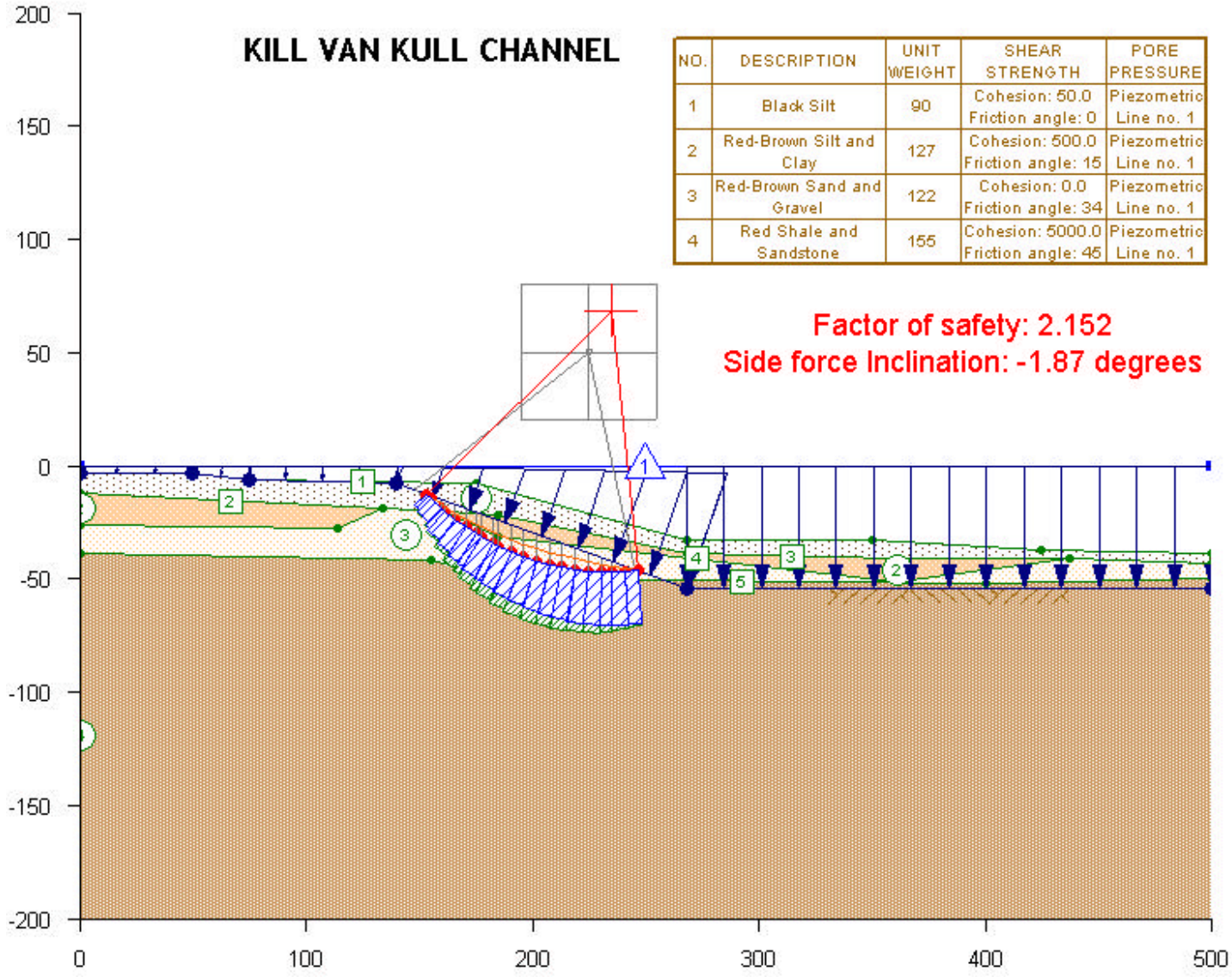
Figure 154

Figure 155



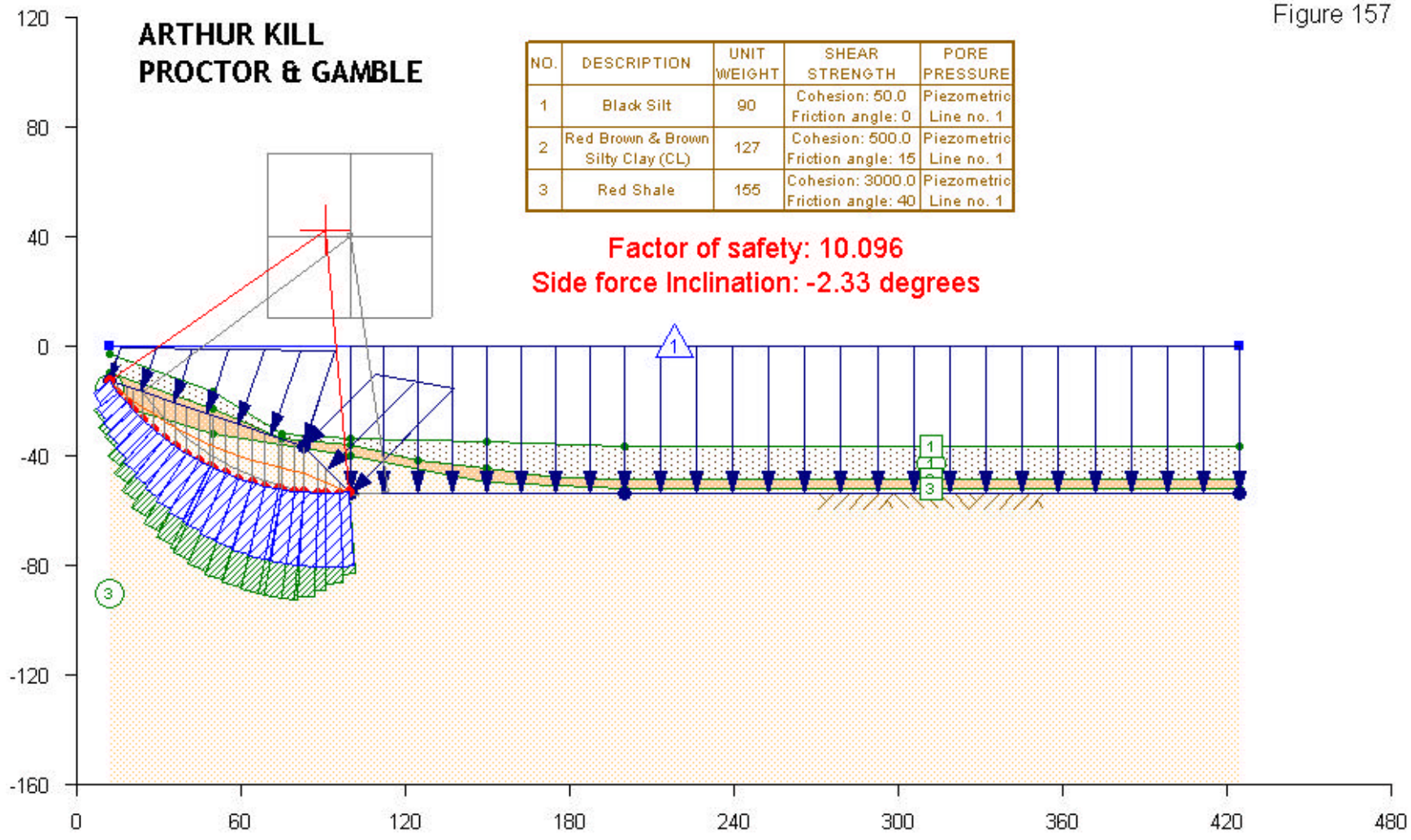
NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
2	Red-Brown Silt and Clay	127	Cohesion: 500.0 Friction angle: 15	Piezometric Line no. 1
3	Red-Brown Sand and Gravel	122	Cohesion: 0.0 Friction angle: 34	Piezometric Line no. 1
4	Red Shale and Sandstone	155	Cohesion: 5000.0 Friction angle: 40	Piezometric Line no. 1

Figure 156



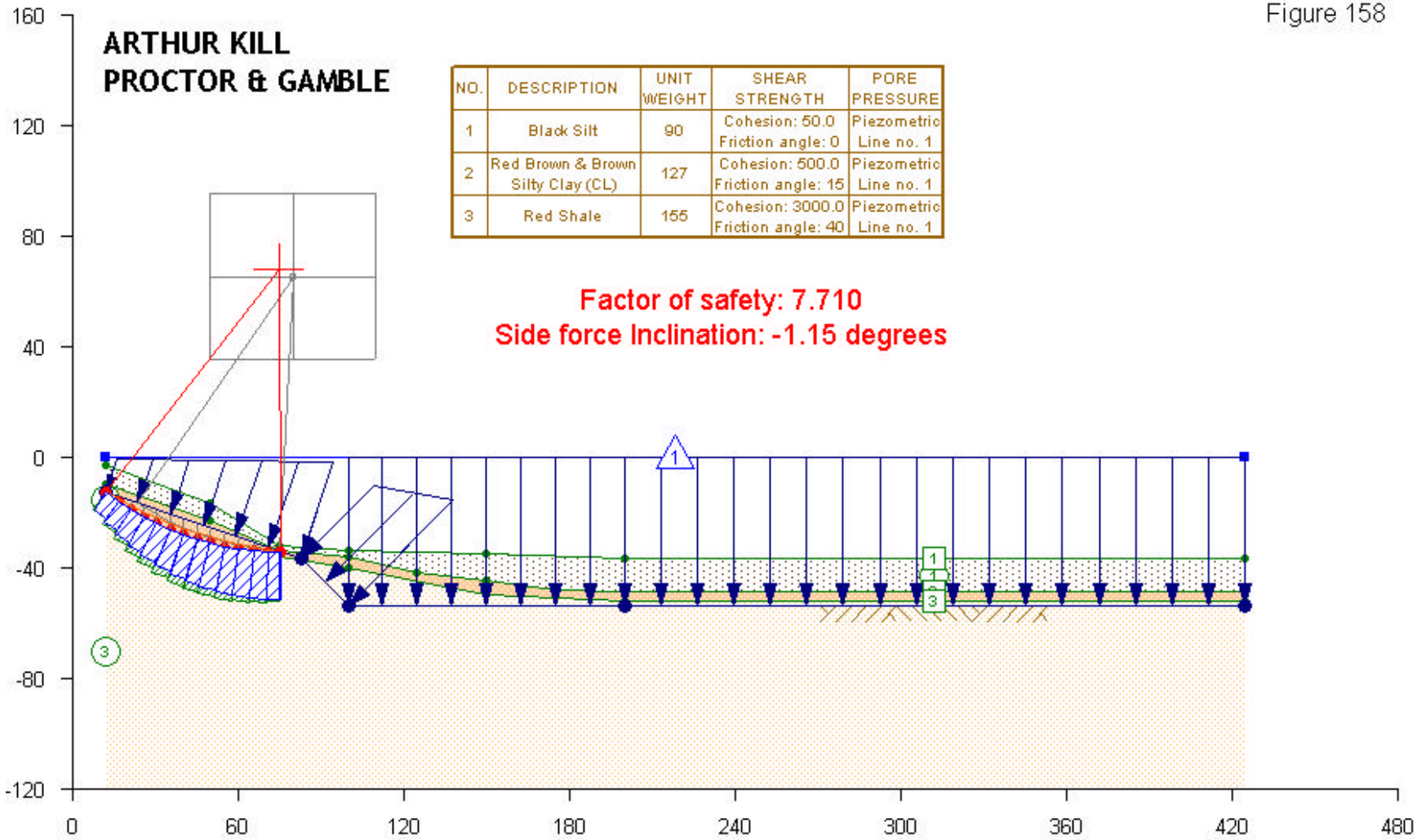
NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
2	Red-Brown Silt and Clay	127	Cohesion: 500.0 Friction angle: 15	Piezometric Line no. 1
3	Red-Brown Sand and Gravel	122	Cohesion: 0.0 Friction angle: 34	Piezometric Line no. 1
4	Red Shale and Sandstone	155	Cohesion: 5000.0 Friction angle: 45	Piezometric Line no. 1

Figure 157



NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
2	Red Brown & Brown Silty Clay (CL)	127	Cohesion: 500.0 Friction angle: 15	Piezometric Line no. 1
3	Red Shale	155	Cohesion: 3000.0 Friction angle: 40	Piezometric Line no. 1

Figure 158



NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
2	Red Brown & Brown Silty Clay (CL)	127	Cohesion: 500.0 Friction angle: 15	Piezometric Line no. 1
3	Red Shale	155	Cohesion: 3000.0 Friction angle: 40	Piezometric Line no. 1

Figure 159

KILL VAN KULL SALT STORAGE, RICHMOND TERRACE (5A)

NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Fill Material	125	Cohesion: 500.0 Friction angle: 33	Piezometric Line no. 1
2	Red-brown, Silt and Clay	127	Cohesion: 500.0 Friction angle: 15	Piezometric Line no. 1
3	Red-brown, SAND (SP)	120	Cohesion: 0.0 Friction angle: 32	Piezometric Line no. 1
4	SALT	100	Cohesion: 0.0 Friction angle: 25	Piezometric Line no. 1

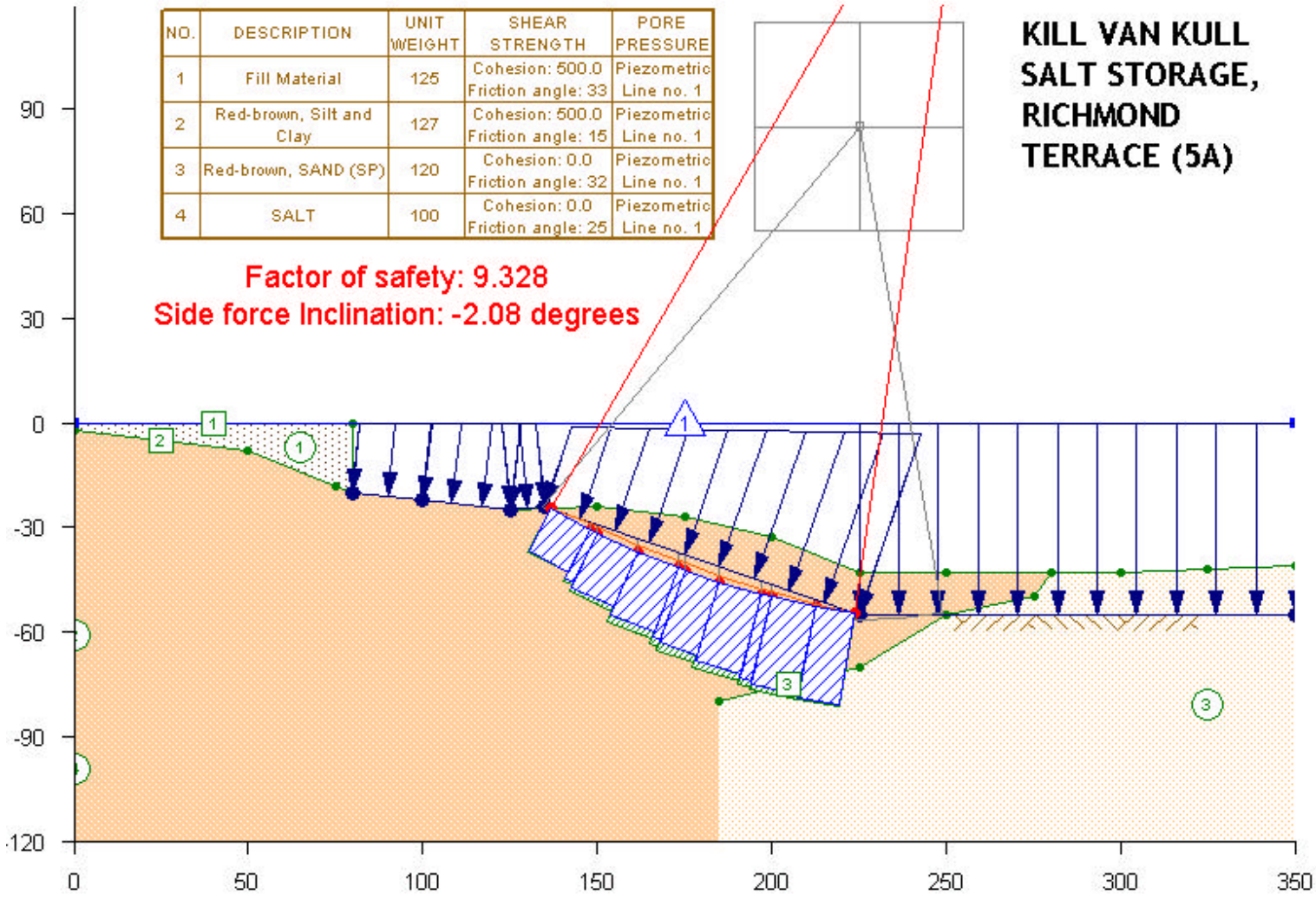


Figure 160

KILL VAN KULL SALT STORAGE, RICHMOND TERRACE (5B)

NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Fill Material	125	Cohesion: 500.0 Friction angle: 33	Piezometric Line no. 1
2	Red-brown, Silt and Clay	127	Cohesion: 500.0 Friction angle: 15	Piezometric Line no. 1
3	Red-brown, SAND (SP)	120	Cohesion: 0.0 Friction angle: 32	Piezometric Line no. 1
4	SALT	100	Cohesion: 0.0 Friction angle: 25	Piezometric Line no. 1

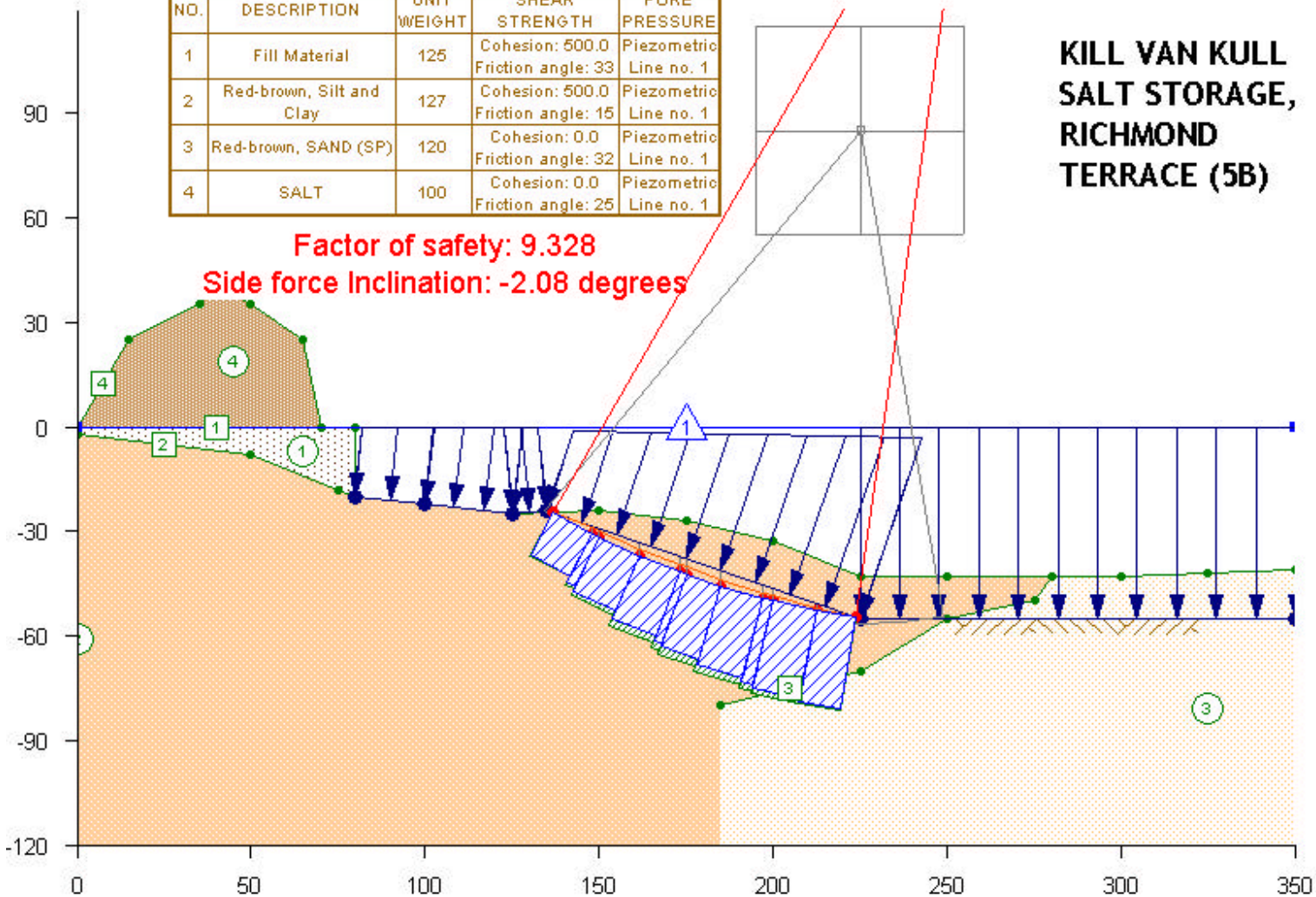
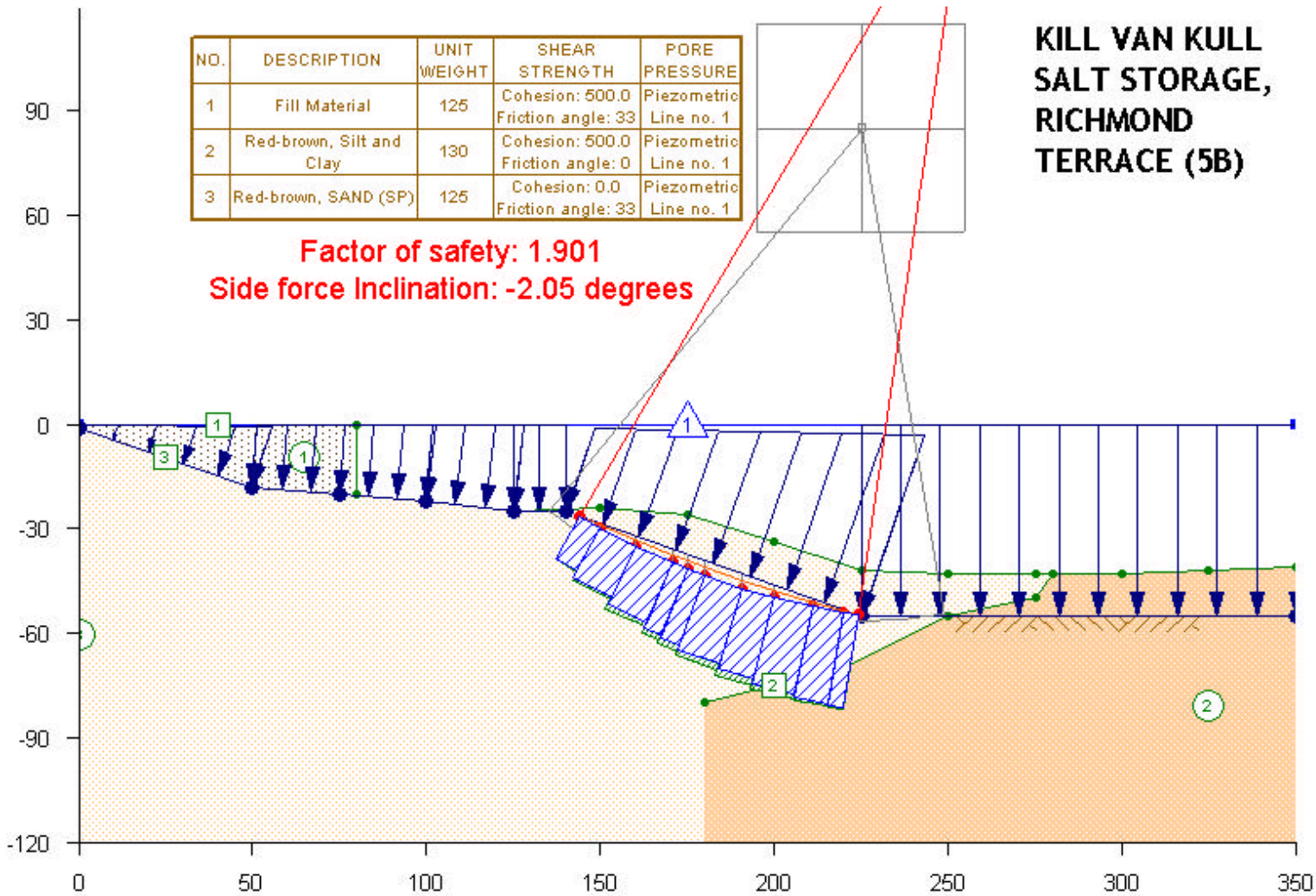


Figure 161

KILL VAN KULL SALT STORAGE, RICHMOND TERRACE (5B)

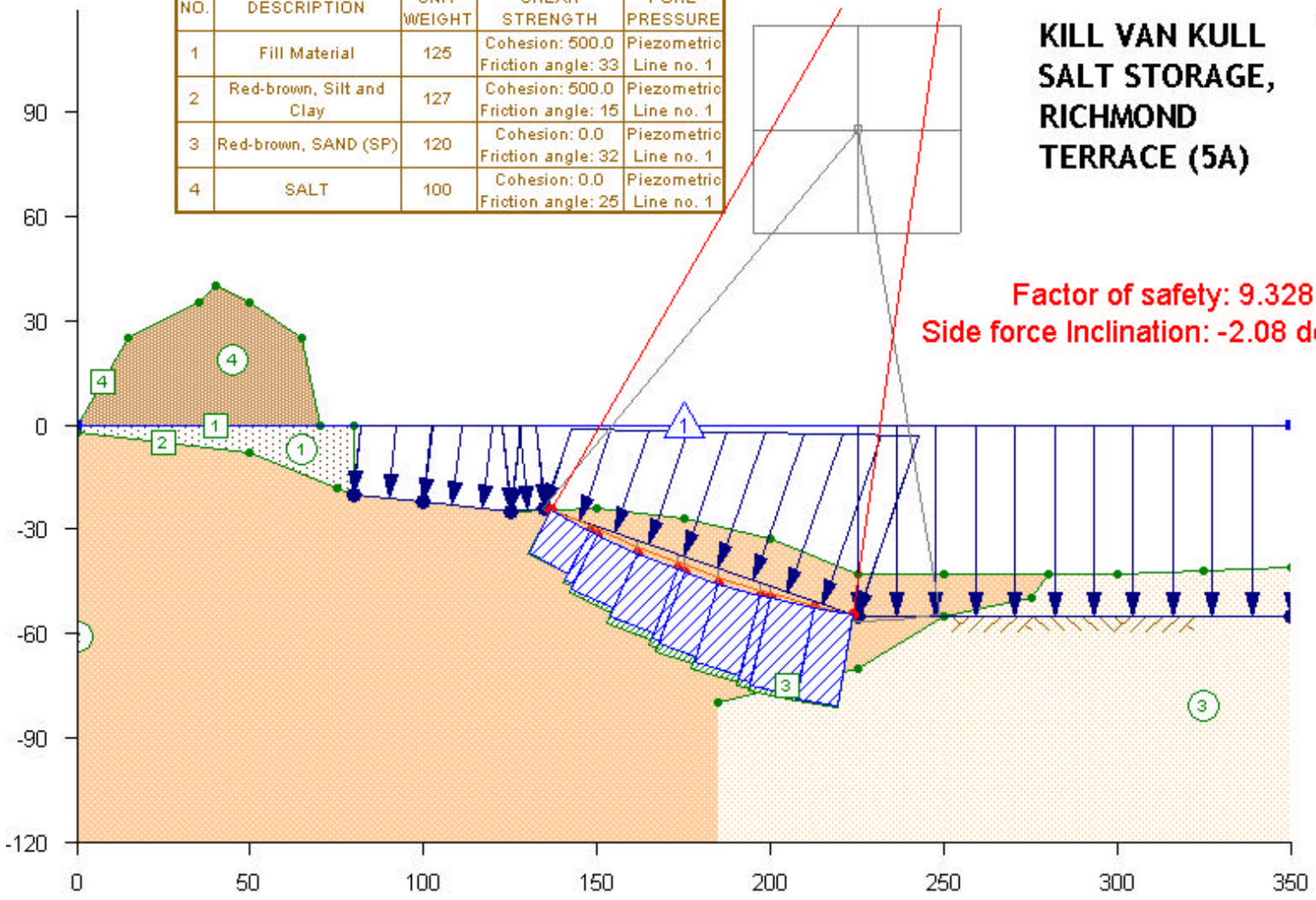


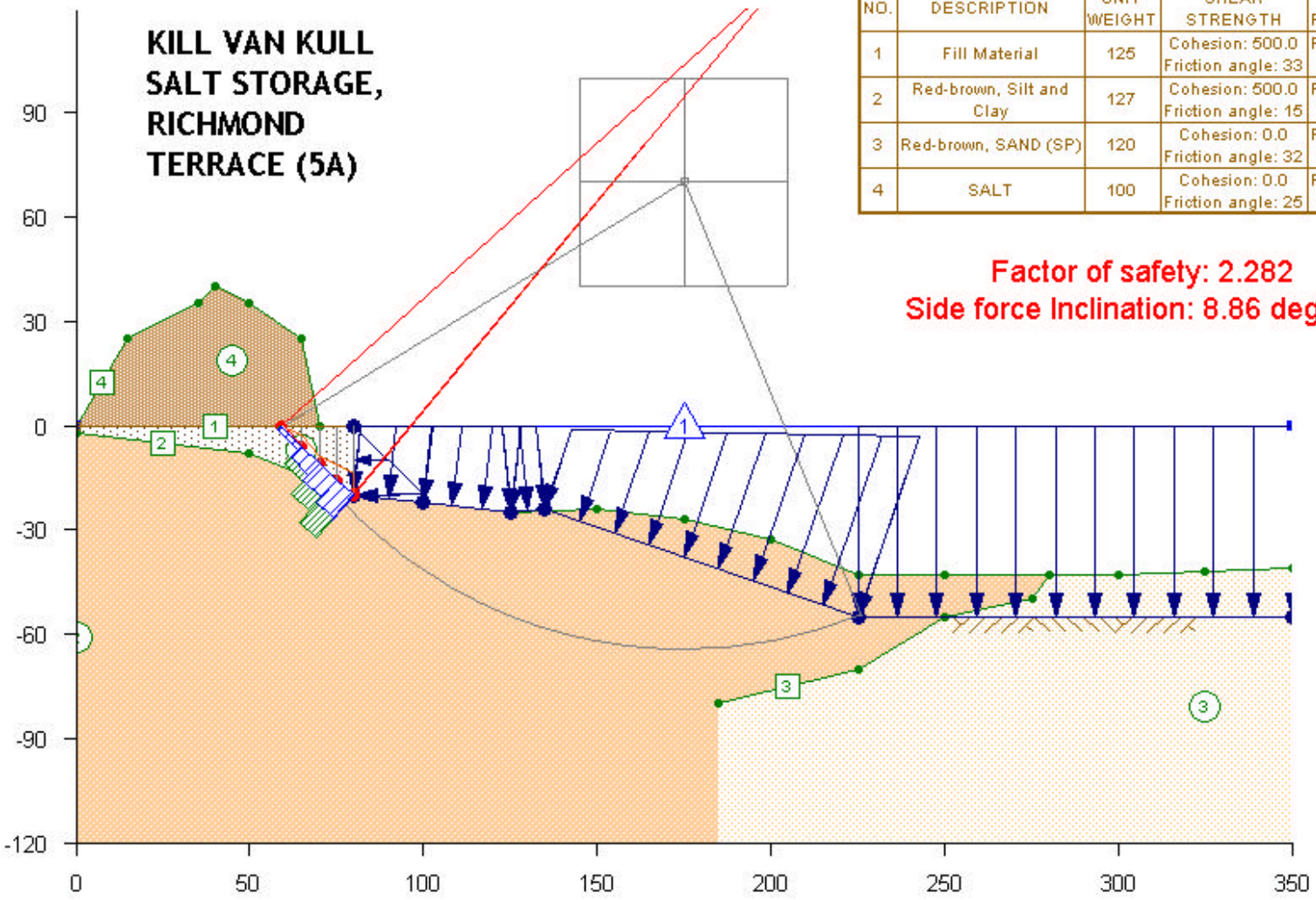
NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Fill Material	125	Cohesion: 500.0 Friction angle: 33	Piezometric Line no. 1
2	Red-brown, Silt and Clay	130	Cohesion: 500.0 Friction angle: 0	Piezometric Line no. 1
3	Red-brown, SAND (SP)	125	Cohesion: 0.0 Friction angle: 33	Piezometric Line no. 1

Figure 162

KILL VAN KULL SALT STORAGE, RICHMOND TERRACE (5A)

NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Fill Material	125	Cohesion: 500.0 Friction angle: 33	Piezometric Line no. 1
2	Red-brown, Silt and Clay	127	Cohesion: 500.0 Friction angle: 15	Piezometric Line no. 1
3	Red-brown, SAND (SP)	120	Cohesion: 0.0 Friction angle: 32	Piezometric Line no. 1
4	SALT	100	Cohesion: 0.0 Friction angle: 25	Piezometric Line no. 1

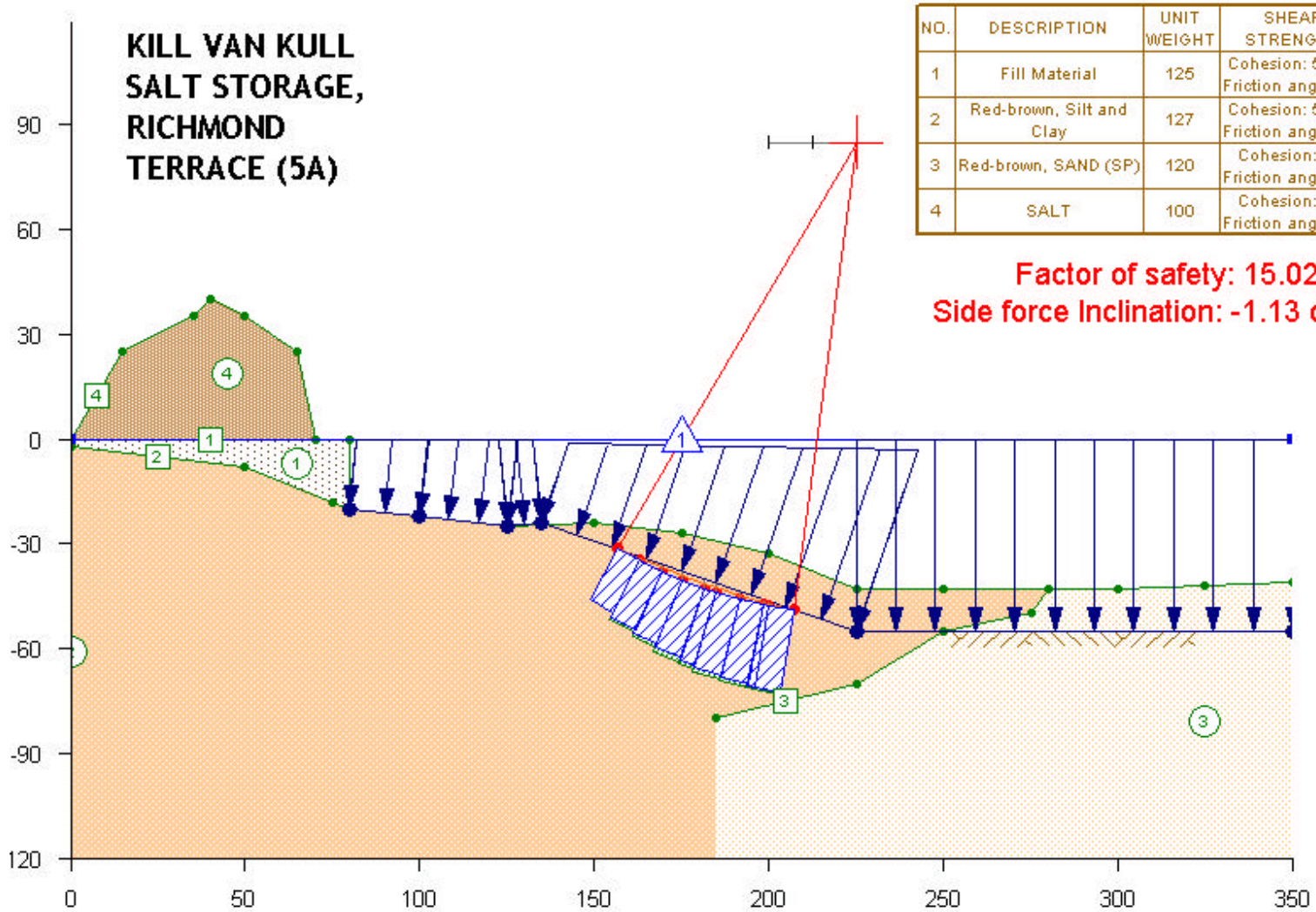




NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Fill Material	125	Cohesion: 500.0 Friction angle: 33	Piezometric Line no. 1
2	Red-brown, Silt and Clay	127	Cohesion: 500.0 Friction angle: 15	Piezometric Line no. 1
3	Red-brown, SAND (SP)	120	Cohesion: 0.0 Friction angle: 32	Piezometric Line no. 1
4	SALT	100	Cohesion: 0.0 Friction angle: 25	Piezometric Line no. 1

Figure 163

Factor of safety: 2.282
Side force Inclination: 8.86 degrees



NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Fill Material	125	Cohesion: 500.0 Friction angle: 33	Piezometric Line no. 1
2	Red-brown, Silt and Clay	127	Cohesion: 500.0 Friction angle: 15	Piezometric Line no. 1
3	Red-brown, SAND (SP)	120	Cohesion: 0.0 Friction angle: 32	Piezometric Line no. 1
4	SALT	100	Cohesion: 0.0 Friction angle: 25	Piezometric Line no. 1

Factor of safety: 15.022

Side force Inclination: -1.13 degrees

Figure 164

Figure 165

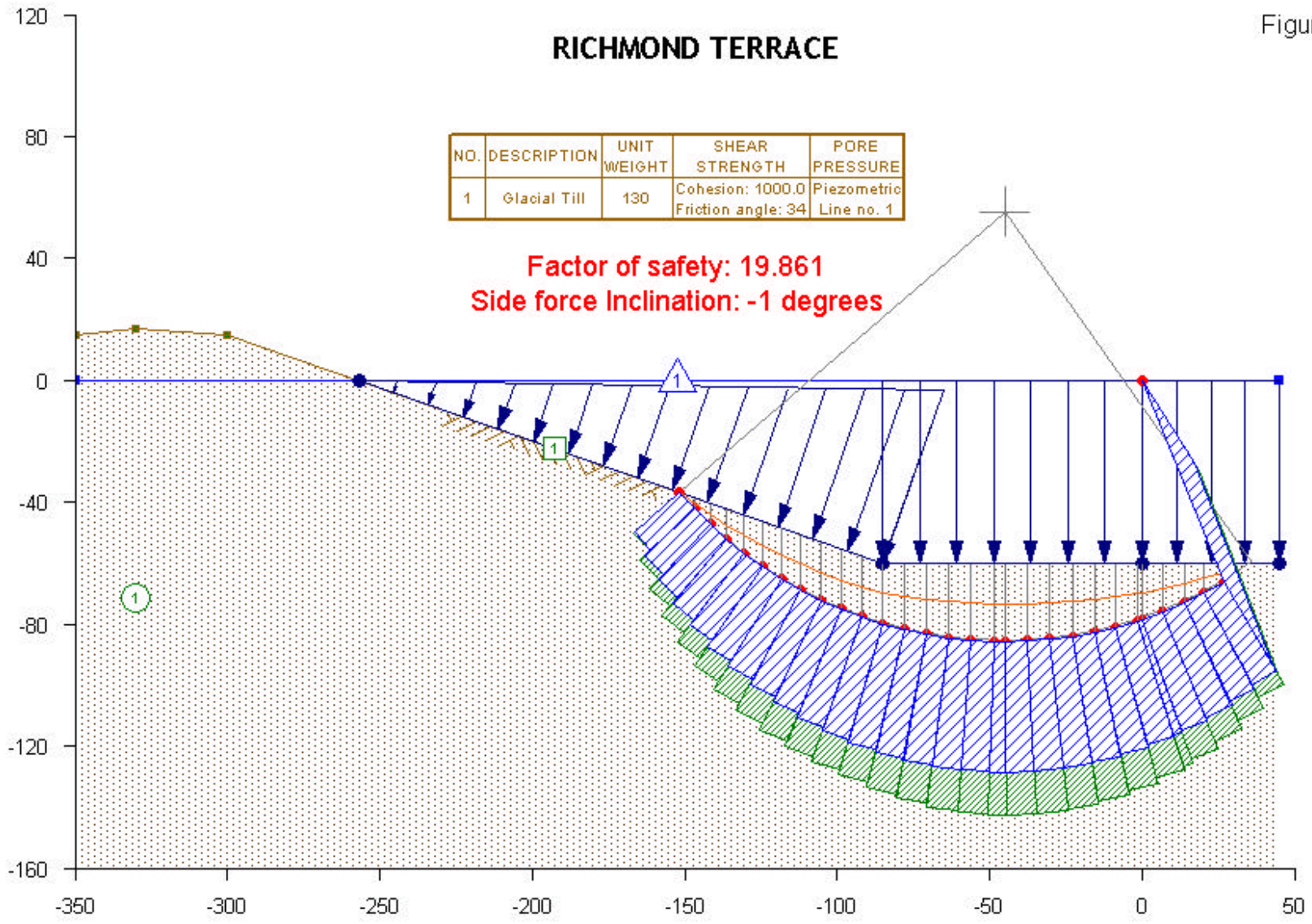

RICHMOND TERRACE
NO. | DESCRIPTION | UNIT WEIGHT | SHEAR STRENGTH | PORE PRESSURE
1 | Glacial Till | 130 | Cohesion: 1000.0 Friction angle: 34 | Piezometric Line no. 1
Factor of safety: 19.861
Side force Inclination: -1 degrees
120
80
40
0
-40
-80
-120
-160
-350
-300
-250
-200
-150
-100
-50
0
50

Figure 166

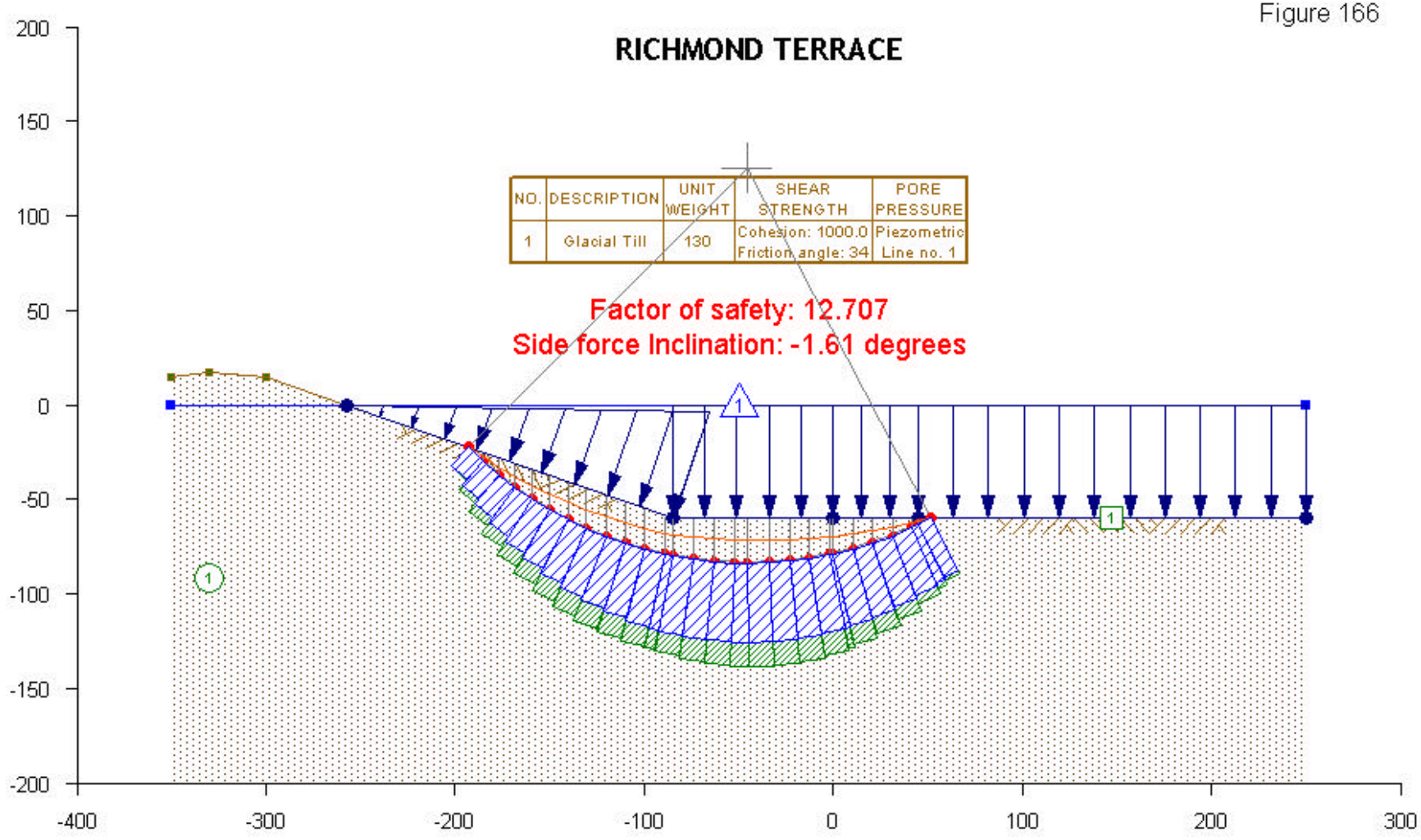

RICHMOND TERRACE
NO. | DESCRIPTION | UNIT WEIGHT | SHEAR STRENGTH | PORE PRESSURE
1 | Glacial Till | 130 | Cohesion: 1000.0 Friction angle: 34 | Piezometric Line no. 1
Factor of safety: 12.707
Side force Inclination: -1.61 degrees
200
150
100
50
0
-50
-100
-150
-200
-400
-300
-200
-100
0
100
200
300

Figure 167

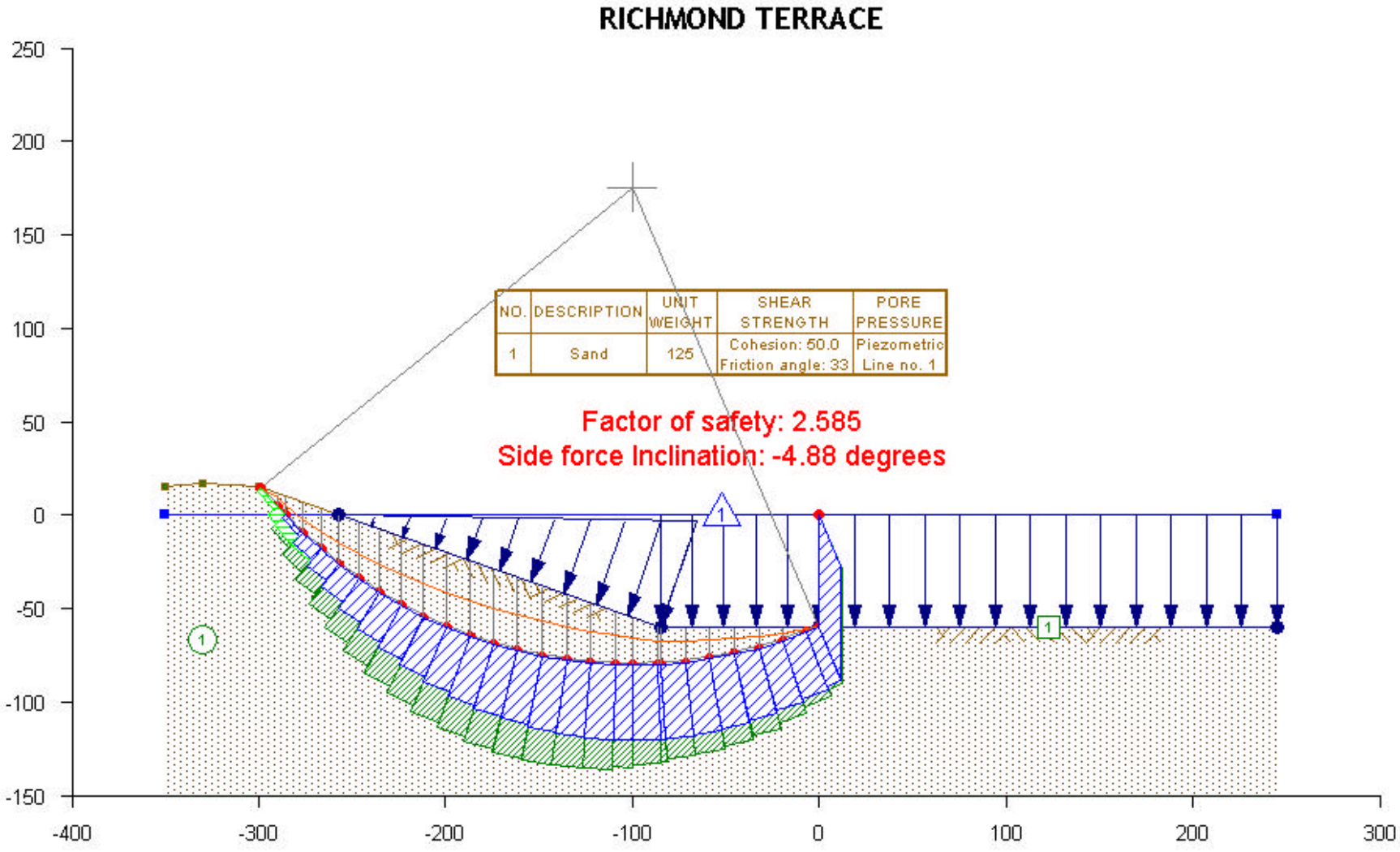

RICHMOND TERRACE
NO. | DESCRIPTION | UNIT WEIGHT | SHEAR STRENGTH | PORE PRESSURE
1 | Sand | 125 | Cohesion: 50.0 Friction angle: 33 | Piezometric Line no. 1
Factor of safety: 2.585
Side force Inclination: -4.88 degrees
250
200
150
100
50
0
-50
-100
-150
-400
-300
-200
-100
0
100
200
300

Figure 168

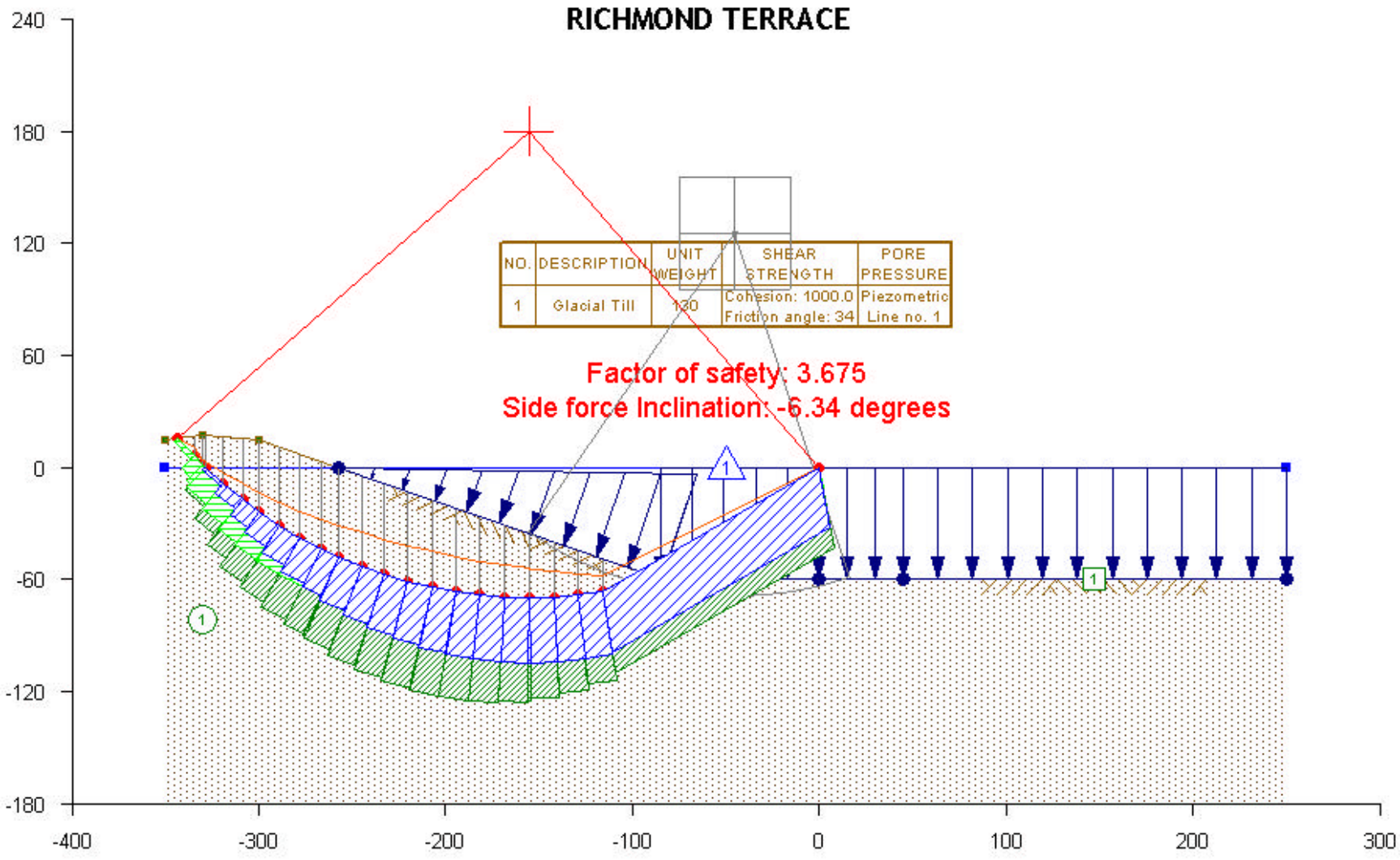
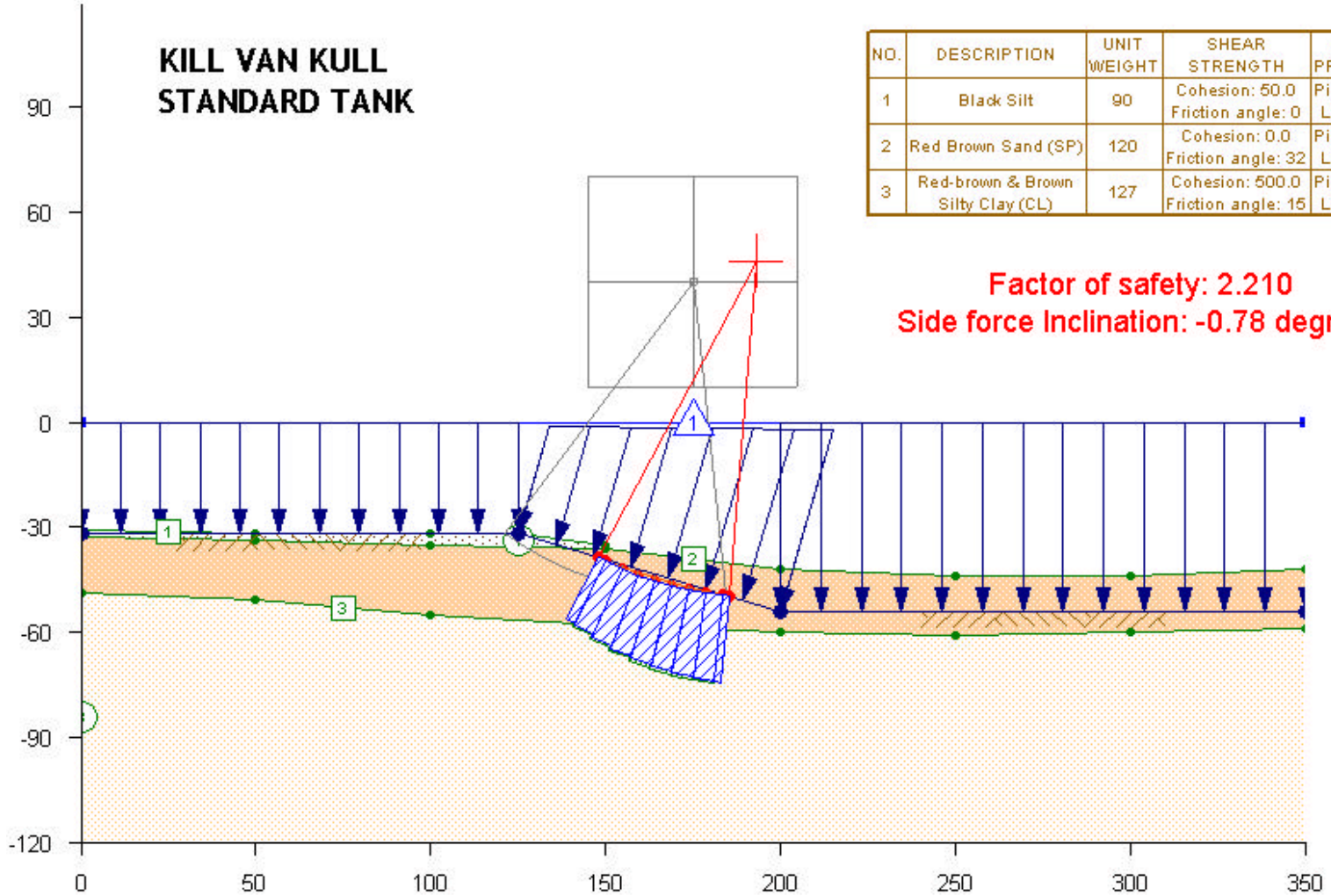
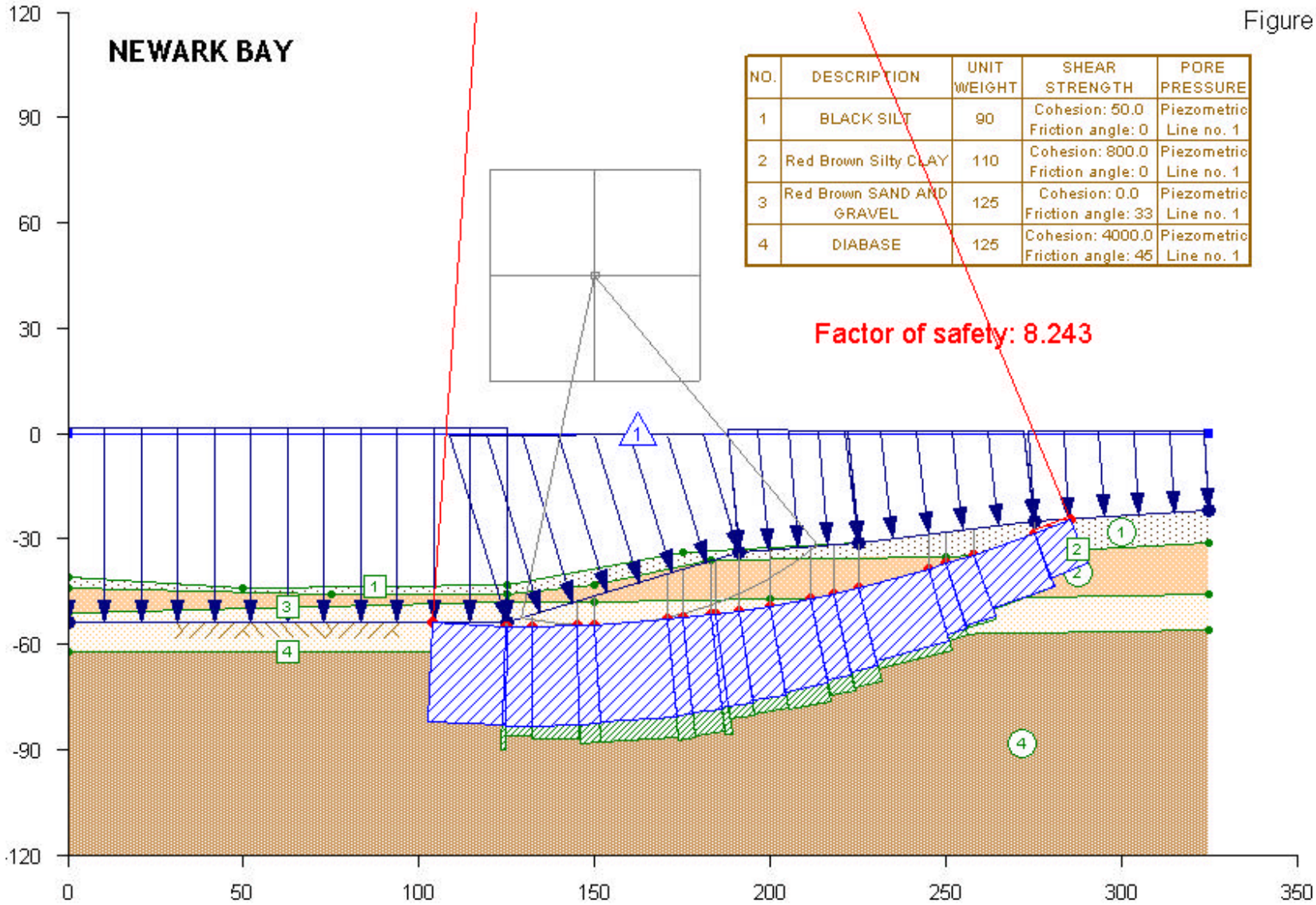

RICHMOND TERRACE
NO.
DESCRIPTION
UNIT WEIGHT
SHEAR STRENGTH
PORE PRESSURE
1
Glacial Till
130
Cohesion: 1000.0
Friction angle: 34
Piezometric Line no. 1
Factor of safety: 3.675
Side force Inclination: -6.34 degrees
240
180
120
60
0
-60
-120
-180
-400
-300
-200
-100
0
100
200
300

Figure 169



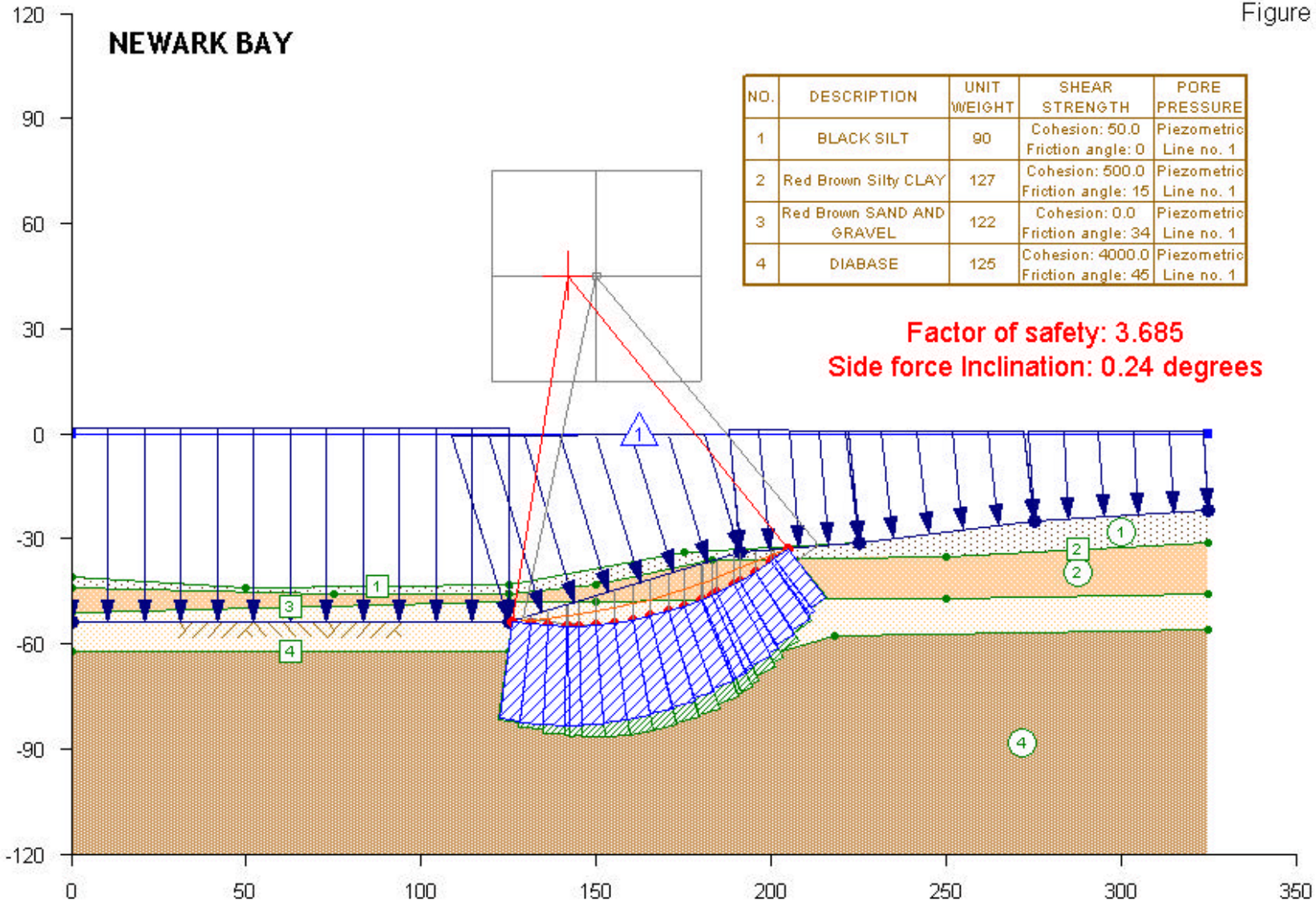
NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	Black Silt	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
2	Red Brown Sand (SP)	120	Cohesion: 0.0 Friction angle: 32	Piezometric Line no. 1
3	Red-brown & Brown Silty Clay (CL)	127	Cohesion: 500.0 Friction angle: 15	Piezometric Line no. 1

Figure 170



NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	BLACK SILT	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
2	Red Brown Silty CLAY	110	Cohesion: 800.0 Friction angle: 0	Piezometric Line no. 1
3	Red Brown SAND AND GRAVEL	125	Cohesion: 0.0 Friction angle: 33	Piezometric Line no. 1
4	DIABASE	125	Cohesion: 4000.0 Friction angle: 45	Piezometric Line no. 1

Figure 171



NO.	DESCRIPTION	UNIT WEIGHT	SHEAR STRENGTH	PORE PRESSURE
1	BLACK SILT	90	Cohesion: 50.0 Friction angle: 0	Piezometric Line no. 1
2	Red Brown Silty CLAY	127	Cohesion: 500.0 Friction angle: 15	Piezometric Line no. 1
3	Red Brown SAND AND GRAVEL	122	Cohesion: 0.0 Friction angle: 34	Piezometric Line no. 1
4	DIABASE	125	Cohesion: 4000.0 Friction angle: 45	Piezometric Line no. 1